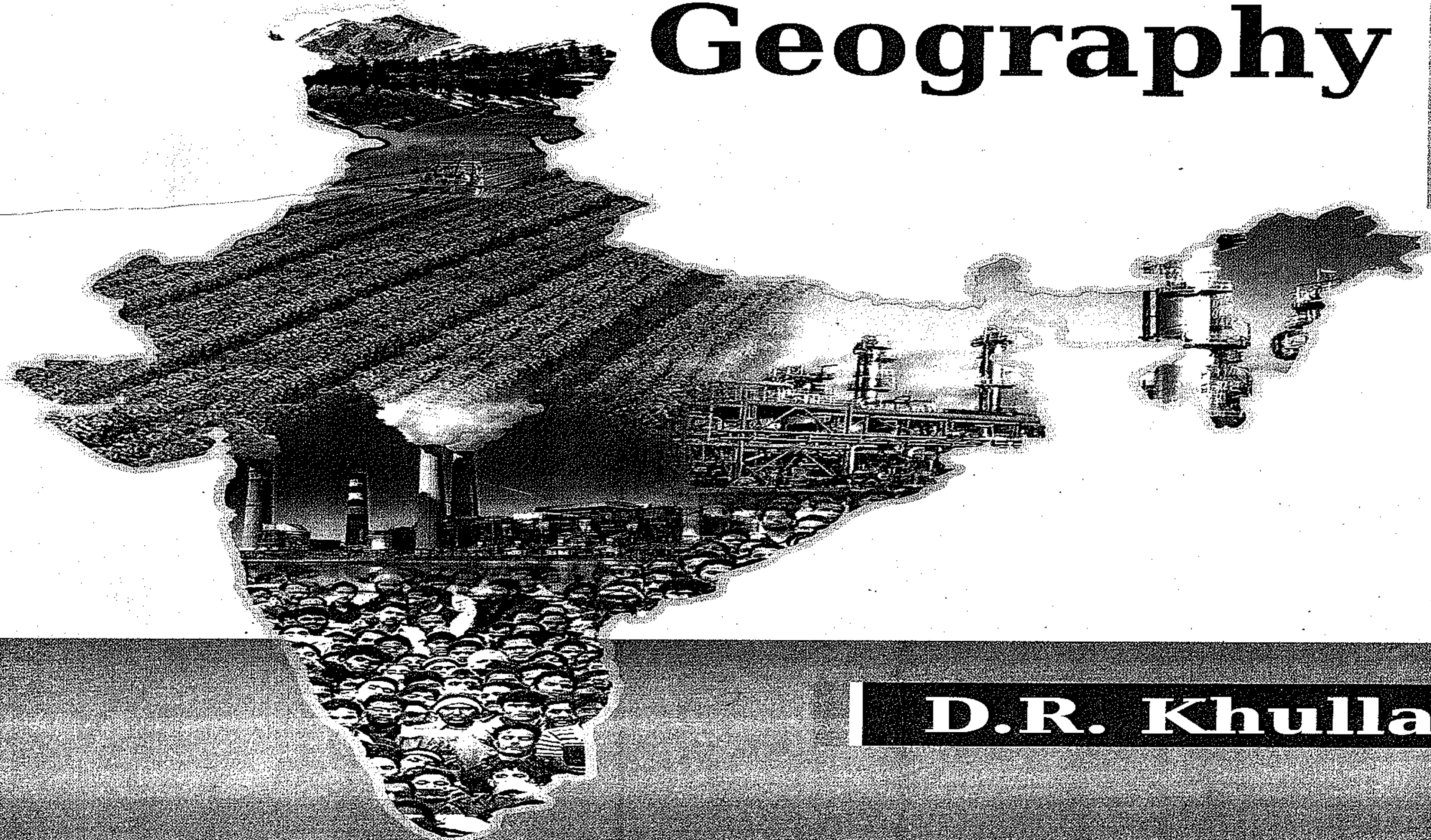
INDIA
A Comprehensive Geography



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CHAPTER 1

Introduction

INDIA AS A GEOGRAPHICAL UNIT

India is a country of great geographical extent. It sprawls from the snowy ranges of the Himalayas in the north to the shores of the Indian Ocean in the south. It belongs to Asia which is the largest continent of the world. It forms a part of south Asia and is separated by the Himalayas from the rest of the continent. It encompasses vast areas of diverse landmasses. In the north are the lofty Himalayas, parts of which are permanently ice-covered. To the south of Himalayas is the Great Indo-Gangetic Plain which is well-known for its fertile soils. The western part of this vast plain is the Thar Desert. South of this plain is the Peninsular India comprising of the uneven plateau which is surrounded by Eastern Coastal Plain in the east and Western Coastal Plain in the west. Indian landmass gets an abundance of sunshine from the tropical sun and splashing rains from the monsoons. These are two most important climatic factors for the Indian people. Due to its vastness and diversities, *India is considered to be a subcontinent* as it possesses all the characteristics of a continent.

India extends from 8° 4′ north to 37° 6′ north latitude and 68° 7′ east to 97° 25′ east longitude. Thus, its latitudinal and longitudinal extent is about thirty degrees. Away from the mainland of India, the southernmost point of the country in the Andaman and Nicobar Islands, the Pygmalion Point or Indira Point is located at 6° 45′ north latitude. Its north-south extent from Indira Col in Kashmir to Kanniyakumari is 3,214 km while its east-west width from the Rann of Kachachh to Arunachal Pradesh is 2,933 km (**Fig. 1.1**). The latitudinal extent of India is about one-third the angular distance between the Equator and the North pole and its longitudinal extent is about one-twelfth of the circumference of the Equator. The longitudinal difference between Saurashtra in the west and Arunachal Pradesh in the east is about 30°. The earth moves around its axis through 360° in 24 hours. Thus, a difference of 1° longitude will make a difference of 4 minutes in time. Therefore the difference of local time between Saurashtra and Arunachal Pradesh is $30 \times 4 = 120$ minutes or 2 hours. Since Arunachal Pradesh is towards the east, it will have sunrise about two hours before the sunrise at Saurashtra. Thus, the sun is quite high in the sky in Arunachal Pradesh while Saurashtra still waits for the first ray of the sun. Latitudinal extent also has its own impact. Rainfall, temperature and vegetation vary with latitude. The difference between the longest and the shortest day in Kerala is hardly 45 minutes whereas this difference may be as

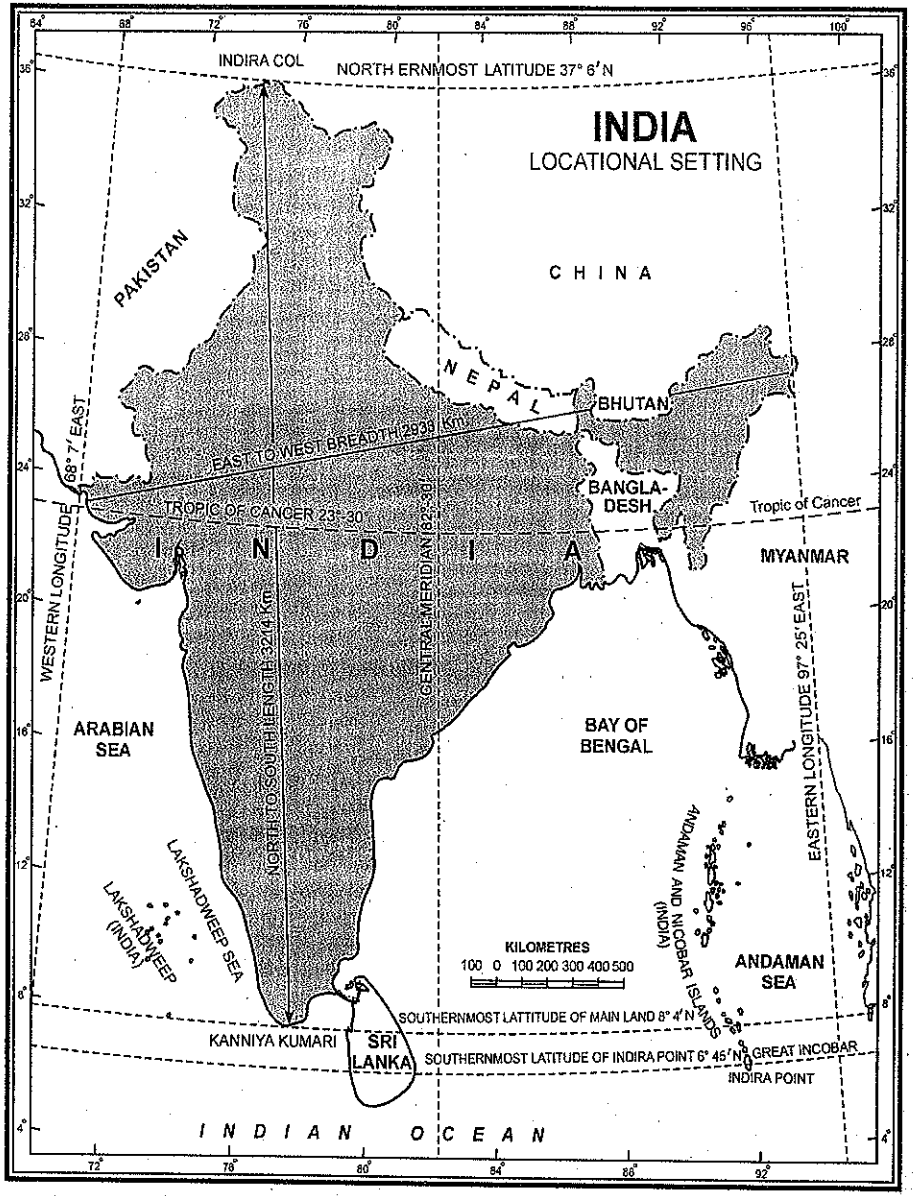

FIG. 1.1. India : Locational Setting

large as 4 hours in Leh and Ladakh. The difference between the longest and the shortest day increases with latitude.

With an area of 32,87,263 sq km, India is the seventh largest country of the world. (**Table 1.1** and **Fig. 1.2**)

TABLE 1.1. Area of seven largest countries of the world

Name of the country	Area in sq km
1. Russian Federation	17,075,200
2. Canada	9,984,670
3. U.S.A.	9,626,091
4. China	9,596,960
5. Brazil	8,511,965
6. Australia	7,686,850
7. India	3,287,263*

Source : Dorling Kindersley World Atlas, 2010, pp. 198-206

* Data for India has been taken from Statistical Abstract, India, 2007, p. 5.

Figures regarding area of India include the area under unlawful occupation of Pakistan and China. This area includes 78,114 sq km under illegal occupation of Pakistan, 5,180 sq km illegally handed over by Pakistan to China and 37,555 sq km under illegal occupation of China.

India accounts for about 2.4 per cent of the total surface area of the world. India is nearly 13 times as large as Great Britain, the country which ruled over us for about two centuries. Many of the Indian states are larger than several countries of the world.

The peninsular tableland juts into the Indian Ocean for a distance of about 1,600 km.

The Tropic of Cancer passes through the middle of the country dividing it into two latitudinal halves being about 15° from either end. But the northern portion is very broad and the area to the north of Tropic of Cancer is nearly twice the area which lies to the south of it. The enormous width of India is often forgotten, being overshadowed by the more popular fact of its length. We are habitual of expressing the dimension of the country as *'from Kashmir to Kanniyakumari'* and not from *'Rann of Kachchh to Arunachal Pradesh'*. The east-west extent of India is almost equal to the combined longitudinal extent of Spain, France, Germany, Belgium, the Netherlands and Poland. South of 22° north latitude, the country tapers off over 800 km into the Indian Ocean as a peninsula and divides this ocean into two arms—the Arabian Sea in the west and the Bay of Bengal in the east.

It is natural to look upon India as being divided into northern temperate and southern tropical lands by the Tropic of Cancer. Thus the temperate part of the country should be twice as much as its tropical part. But India has always been treated as a tropical country for two widely different reasons. The reasons are those of physical and cultural geography. The country is separated from the rest of Asia by a mountain wall forming an insulated compartment. Its climate is dominated by the tropical monsoons and the temperate air masses are restricted by the mountain chain. Further, although the night temperatures in January at several places in Punjab may come down to the level of those prevailing in temperate lands, yet clear skies and intense insolation raise the day temperatures to a tropical level, so that the entire area south of the Himalayas is essentially

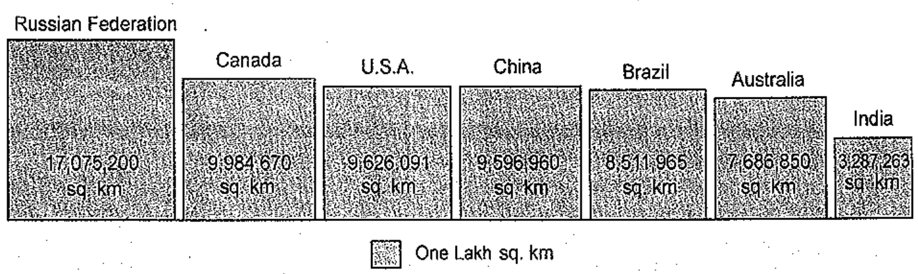

FIG. 1.2. Seven largest countries of the world

tropical from climatic point of view. Outside the Himalayas, almost everywhere agriculture is tropical in type. As per cultural geography, the culture of India is totally different from that of the temperate countries of the western civilisation.

Girdled by the rampart of the young folded mountains in north-west, north and north-east and washed by the Indian Ocean in the south, India along with its neighbouring countries, is a well defined geographical unit. South of the mountain chain, India, Pakistan, Bangladesh, Nepal and Bhutan form a definite realm of South Asia which is often referred to as the ***Indian subcontinent.*** India alone accounts for about three-fourths of the total area of the subcontinent. According to **Prof. Chisholm**, 'there is no part of the world better demarcated by nature as a region by itself than the Indian subcontinent'. **G.B. Cressey** strongly advocated that India may be termed as subcontinent because it is a distinct geographical unit with many physical and cultural units. But some Indian geographers are of the view that the use of the term subcontinent for India is a misnomer and is a legacy of the British rule which tended to divide the area on the basis of region and religion. These geographers contend that this expression has never been used for much vaster and more diverse geographical units like China and Russia. It is worth mentioning that the subcontinental theory of the Britishers worked very well in dividing the area into different nations giving credibility to their basic policy of '***divide and rule***'. Total area of the country before partition was 42,27,378 sq km. The partition of the country on 15th August, 1947 gave birth to a new country of Pakistan. This led to a loss of 7,96,095 sq km area of West Pakistan (now called Pakistan) and 1,44,020 sq km of East Pakistan (the present Bangladesh). Thus the present extent of the country is reduced to about three-fourths of its original size. Consequently, some scholars tend to replace the term Indian subcontinent by South Asia which includes, India, Pakistan, Bangladesh, Nepal, Bhutan, Sri Lanka and sometimes even Afghanistan.

Nomenclature of the Country

This country has been variously named as ***India***, ***Hindustan***, ***Bharat*** and ***Aryavarta***. The word India has its origin in the Greek literature meaning the land of '*Indoi*', the people living near the *Indos* (latin Indus). Persians and Greeks extended the name ***Sindhu***—'the river' from the Indus. Thus it was called ***Hindustan***—the land of Hindus in Persian and other West Asian languages. The term Hindu is derived from Sindhu. The Persians pronounce 'S' as 'H' and thus they called Sindhu as Hindu. The land to the east of the Sindhu was called Hindustan. In the Hindu literature the subcontinent as a whole is styled as *Bharat* or *Bharat-Varsha*, the land of the legendary King Bharata who visualised the fundamental unity of the country. However, some scholars believe that the name has been derived from the Bharath tribe, who among others inhabited the area. In the European languages it is popularly known as ***India***. The name *Aryavarta* refers to the land of the Aryan race. At present only *India* and *Bharat* are officially recognised, although *Hindustan* is also in common use.

INDIA'S FRONTIERS

Encompassed between the Himalayas in the north, north-west and north-east, the Indian Ocean in the south and marshy Rann of Kachchh, vast desert of Rajasthan and fertile plain of Punjab in the west, India has both land and water frontiers.

Land Frontiers

India shares her 15,200 long land frontier with Pakistan, in the west and north-west. Afghanistan in the north-west, China, Nepal and Bhutan in the north, and Bangladesh and Myanmar in the east. India's longest border is with Bangladesh while the shortest border is with Afghanistan as is indicated in **Table 1.2. Figure 1.2** shows land frontiers of India.

1. Border with China

India shares 3,917 km long border with China which is over one-fourth of the total land border of the country. This is the second longest border of India, next only to its border with Bangladesh. Five Indian states, namely Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh touch the Indian boundary with China. This border is the product of Manchu policy, Chinese Republican policy and the British policy. It is difficult to demarcate this boundary on the ground due to rugged terrain and harsh environment. Therefore, it was

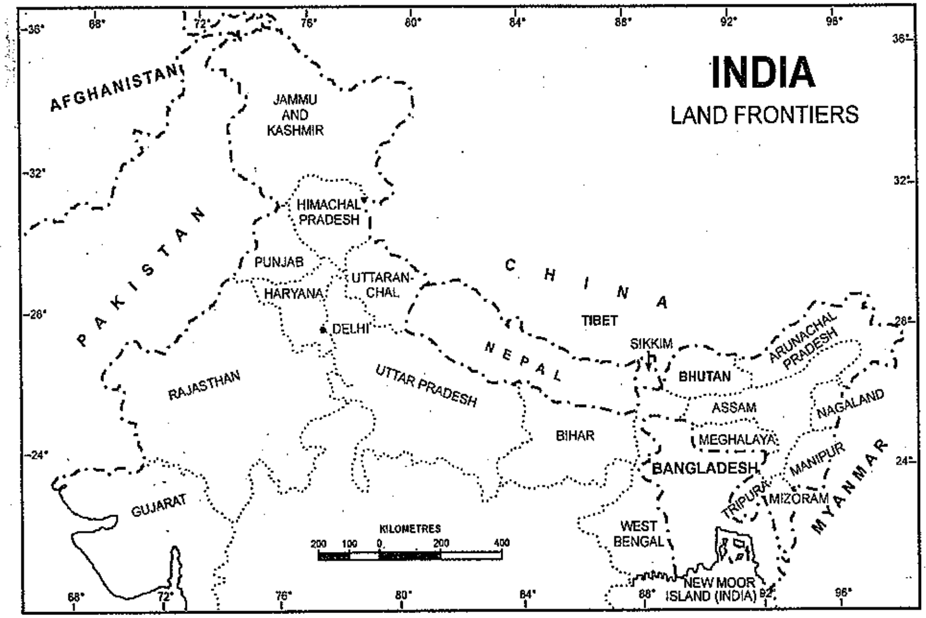

FIG. 1.3. India : Land Frontiers

delimited on the maps in a rather imprecise form, between British India and independent Tibet. China never accepted this boundary legally but ignored the issue during the British rule in India. Since Independence of India on August 15, 1947 and the Communist takeover of China on October 1, 1949, a goodwill gesture developed between these two countries and in 1954 a general agreement containing the principle *Panch Sheel* was announced. These five principles were (*i*) mutual respect for each others territorial integrity and sovereignty, (*ii*) mutual non-aggression, (*iii*) mutual non-interference in each others internal affairs, (*iv*) equality and mutual benefit, and (*v*) peaceful co-existence. In the same year, India recognised the Chinese sovereignty over Tibet and it was brought under the direct control of China. Thus, the buffer character of Tibet ceased to function and a razor-thin boundary between India and China became operative. However, China attacked India in 1962 to take revenge of the so called Indian interference in Tibetan affairs.

The Sino-Indian border is generally divided into three sectors namely : (*i*) the Western sector, (*ii*) the Middle sector, and (*iii*) the Eastern sector.

(*i*) **The Western Sector.** This 2,152 km long sector of the Sino-Indian border separates Jammu and Kashmir state of India from the Sinkiang province of China. The frontier between Sinkiang and Pakistan occupied Kashmir (PoK) is about 480 km long. The rest is boundary between Ladakh and Tibet. The boundary in the western sector runs along the Muztaghata Range and the Aghil Mountain across the

TABLE 1.2. Length of India's Border with the Neighbouring Countries

Name of the country	Length of border (in kilometres)	Percentage of total length of border
1. Bangladesh	4,096	26.95
2. China	3,917	25.77
3. Pakistan	3,310	21.78
4. Nepal	1,752	11.53
5. Myanmar	1,458	9.59
6. Bhutan	587	3.86
7. Afghanistan	80	0.52
Total	**15,200**	**100.00**

Karakoram Pass via Quara Tagh pass and along the main Kunlun Range to a point east of 80°E longitude and 40 km north of Hajit Langer. It forms a physical boundary between Gilgit area and Sinkiang following the main Karakoram watershed separating the streams flowing into the Indus basin from those flowing into the Tarim basin. Farther south-east the boundary runs along the watershed across Lanak La, Kone La and Kepsang La, then follows the Chemesang river across Pergyon Lake and the Kailash Range. Here the boundary constitutes the watershed between the Indus system in India and the Khotan system in China.

The western sector boundary is largely the outcome of the British policy towards the state of Jammu and Kashmir. These boundaries were defined by the treaties of 1665 and 1686 (known as ***Ladakh-Tibet*** agreements) and were confirmed by 1842 Dogra-Ladakh agreement among Kashmir, Tibet and China. However, this boundary was never delimited precisely on maps and has led to several boundary disputes between China and India. The Chinese claim rests mainly on ethnic grounds, and on the assertion that the wastelands of the Aksai Chin in disputed territory were always linked more with Tibet and Sinkiang. The Chinese claim that Aksai Chin is just an extension of Tibet with regard to language, religion and culture. But in Chinese documentation regarding the actual occupation of the area by Tibet is inconclusive. The Indians, on the other hand, claim that the area has been historically administered by the state of Jammu and Kashmir since 1849, and that the Indo-Tibet Treaties of 1665, 1686 and 1842 confirmed the boundary between Tibet and Ladakh. China claims the Aksai Chin district, the Changmo valley, Pangong Tso and the Sponggar Tso area of north-east Ladakh as well as a strip of about 5,000 sq km down the entire length of eastern Ladakh. China also claims a part of Huza-Gilgit area in North Kashmir (ceded to it in 1963 by Pakistan), although the whole territory has been effectively under the British sovereignty since 1895.

Since 1954, the Chinese have repeatedly violated the international border between India and China and penetrated deep into the Indian territory in the western sector. China renewed aggression in 1959 and the Line of Actual Control (LoAC) became a series of positions occupied by the Chinese forces rather than a well defined border between the two countries. In 1962, China waged a full scale war and its forces intruded far deeper into the Indian territory. Currently the Chinese occupation line runs 16 to 240 km west of traditional line. China is in actual possession of about 54,000 sq km of the Indian territory of which 37,555 sq km is in Ladakh area alone.

(ii) **The Middle Sector.** The middle sector boundary between China and India is 625 km long and runs along the watershed from Ladakh to Nepal. Two Indian states of Himachal Pradesh and Uttarakhand touch this border. The boundary of Himachal Pradesh follows the water parting between the Spiti and Para Chu rivers and continues along the watershed between the eastern and western tributaries of the Satluj. The Uttarakhand boundary is demarcated by the watershed between the Satluj on one hand and the Kali, the Alaknanda, and the Bhagirathi on the other. This boundary crosses the Satluj near the Shipki La on the Himachal-Tibet border. Thereafter, it runs along the watershed passes of Mana, Niti, Kungri-Bingri, Dharma and Lipu Ladakh. It finally joins trijunction of China, India and Nepal. This part of the border was approved by the Tibetan and the British governments under the 1890 and 1919 treaties. Although there are not much serious territorial problems between the two countries, the Chinese lay claim on nearly 2,000 sq km area in this sector.

(iii) **The Eastern Sector.** The 1,140 km long boundary between India and China runs from the eastern limit of Bhutan to a point near Talu-Pass at the trijunction of India, Tibet and Myanmar. This line is usually referred to as the Mc Mahon Line after Sir Henry Mc Mahon, then foreign secretary of British India, who negotiated the boundary agreement between Great Britain and Tibet at Shimla accord in 1913-14. This line normally runs along the crest of the Himalayas between Bhutan in the west and Myanmar in the east. India has stressed that the Mc Mahon Line is the international boundary between Tibet and India as was agreed to between the governments of India, China and Tibet. On the other hand China considers the Mc Mahon line as illegal and unacceptable, claiming that Tibet had no right to sign the 1913-14 convention held in Shimla which delineated the Mc Mahon Line on the map. India challenges such a position, maintaining that Tibet was

independent and in fact concluded several independent treaties which were considered valid by all parties, and were in operation for decades.

China declined the validity of the Mc Mahon Line as an international boundary and laid claims to areas south of this line up to the foot of the Himalayan range in the Brahmaputra valley. The whole of Arunachal Pradesh, measuring over 88 thousand sq km has been claimed by China as the Chinese territory—calling it ***"South Tibet"***. This area has been administered by India since 1947.

Chinese government never formally questioned the validity of 1913-14 Shimla convention until 1959. India has been striking at the two crucial points. First, Britain and India had been exercising jurisdiction over the area since 1914 and 1947 respectively and second China never disputed the Indian control over the area until 1959. Even in 1956 when the Chinese attention was drawn to certain maps drawn by China which showed these areas to be parts of China, the Chinese government promised to look into the 'cartographic errors' in their maps.

China's relations with India started taking a bad turn in 1950s when China started consolidating its position in Tibet and then in Ladakh. By 1956, China started intensifying its intrusions into the Indian territory. India wishfully hoped that the insurmountable barrier of the Himalayas would prevent Chinese to attack Indian territory. Indian apprehensions grew in 1956 when China built a road through Ladakh linking West Tibet with Sinkiang and quickly moved into Aksai Chin and eastern Ladakh. China also moved its forces into the North-East Frontier Agency (NEFA), the present Arunachal Pradesh. Reported small-scale armed clashes between 1959 and 1962 escalated into a full-scale war in October, 1962 when China launched a major offensive in Ladakh in the western sector and NEFA in the eastern sector. Indian armed forces were not well trained to fight a modern war in a rough and rugged mountainous terrain. They were outnumbered and outgunned by the Chinese forces.

Following lessons have been learnt from Chinese aggression over India :

(i) The myth that the Himalayas was an effective defense barrier was exploded.

(ii) India's naive confidence in China's friendliness had dulled its perception regarding effective security measures in the Indo-China borderlands.

(iii) The prompt and positive response of western countries in rushing military supplies to the war zone helped improve the image of the West in Indian eyes.

(iv) India realised that posture of "non-alignment" was no substitute for defense preparedness.

Surprisingly, Chinese forces pulled back without annexing the disputed territory in the eastern sector. In the western sector, however, they did not pull out of most of Aksai Chin. Perhaps they did so due to the fear that their advance troops would have been cut off from supply bases in Tibet in winter of 1962 when the high passes in the Himalayas would have been closed by snow. The Chinese justified their withdrawal by stating that they had no further territorial ambitions.

The primary aim of Chinese invasion was to deprive India of its moral leadership in the world especially among the Afro-Asian countries, and to put pressure on it to join the socialist camp. China's collusion with Pakistan is a clear indication of this political ambition. Perhaps China miscalculated its political power strategy. The support of the Western countries to India compelled China to rethink its strategy. India's unity in the face of Chinese aggression was another deterrent for China to achieve political mileage.

An uneasy truce had been prevailing for a long time since the October, 1962 war. Neither side made a serious effort to normalise the situation on the border. The Colombo powers, spearheaded by Ceylon (now Sri Lanka) and the erstwhile Soviet Union failed to bring about a respectable agreement between the two countries. Several countries condemned China as an aggressor. However, Cuba, Albania and Portugal supported the Chinese.

Of late, leaders of both the countries have engaged themselves in improving bilateral relations. Several meetings have been held to resolve the problem of border issues. The first important step to resolve dispute was the signing of Border Peace and Tranquillity Agreement at Beijing on September 7,

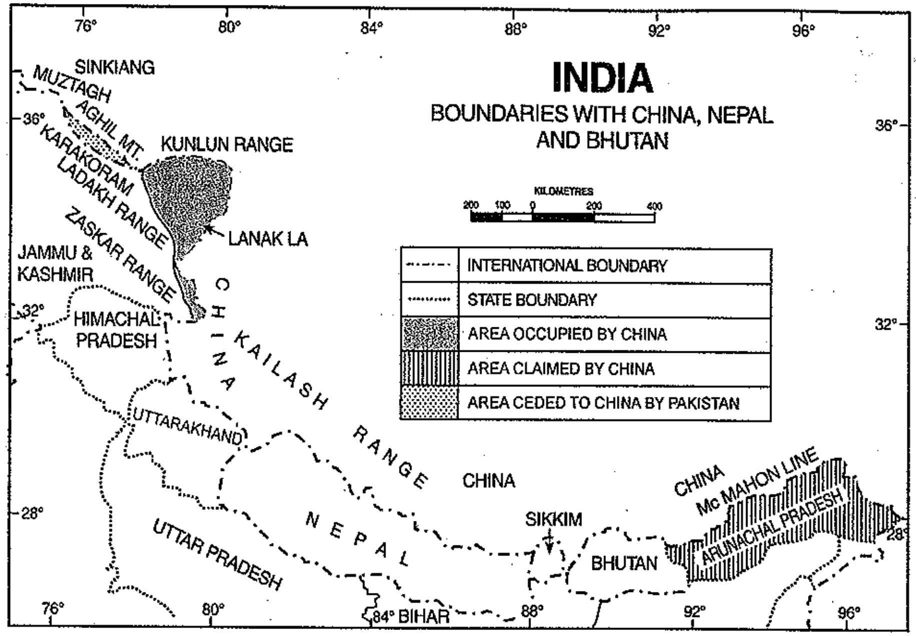

FIG. 1.4. India : Boundaries with China, Nepal and Bhutan

1993. The pact consists of confidence-building measures (CBMS). An agreement on CBMS and the military field along the line of Actual Control (LAC) was signed between the two sides on November 29, 1996. A major development took place in October, 2003 when China made a significant change in its official website. It removed the mention of Sikkim from its list of nations. In May, 2004, China recognised Sikkim as a part of India for the first time. The world map in World Affairs Year Book 2003/2004 does not show Sikkim as a separate country in Asia. It also does not mention Sikkim in its index of countries. The move was significant since it involves recognition of Sikkim-China border which is a part of the Mc Mahon Line. A protocol on modalities for implementing military CBMS was signed on April 11, 2005. If things go as planned, the two nations should be able to work out the guidelines for transforming the Line of Actual Control (LoAC) into a mutually acceptable and internationally recognised boundary. However, China still insists that Arunachal Pradesh is a disputed territory. China has also suggested a 'package deal'. It asked India to accept Chinese domination over Aksai Chin in return of China's acceptance of Mc Mahon Line as the international boundary. India, however, has advocated 'sector-by-sector' approach. Indian side is hopeful because China has settled border disputes with Russia and Vietnam.

China's Aggressive Postures

China has been adopting aggressive postures against India and some other neighbouring countries even since the Indo-China wars of 1962. With its fast growing economy, China is dreaming of becoming a super power like the U.S.A. and one of the main devices to realise this dream is to dominate over its main rivals. From this point of view, India is the main target because India is also progressing rapidly. Some of the recent developments are pointers towards the unwanted intentions of China, so far as India is concerned.

1. China Water Strategy. China has prepared an ambitious plan to harness the huge water potential of the upper Brahmaputra river course in Tibet. The plan includes construction of gigantic 38,000 MW. Motuo dam along the Brahmaputra's ***'great bend'*** when the river curves to flow south into Arunachal Pradesh of India. China considers it to be the word's biggest hydroelectric project which would supply clean energy and would save 200 million tons of carbon emissions per year. It would involve 15-25 km long tunnels attached to downstream pipes. China claims that this dam would be 1.5 times the size of Three Gorges dam—currently world's biggest. In all 28 dams are proposed to constructed across the main Brahmaputra river and its tributaries in Tibet. Of these 28 dams, ten dams have been completed, three are under construction, seven under active consideration and eight more are proposed. Some of the important dams are shown in **Fig. 1.5**. These dams are primarily motivated by Beijing's desire to develop larger hydropower projects to power resource extraction, infrastructure development and ultimately for supply to coastal Chinese cities where demands are the highest.

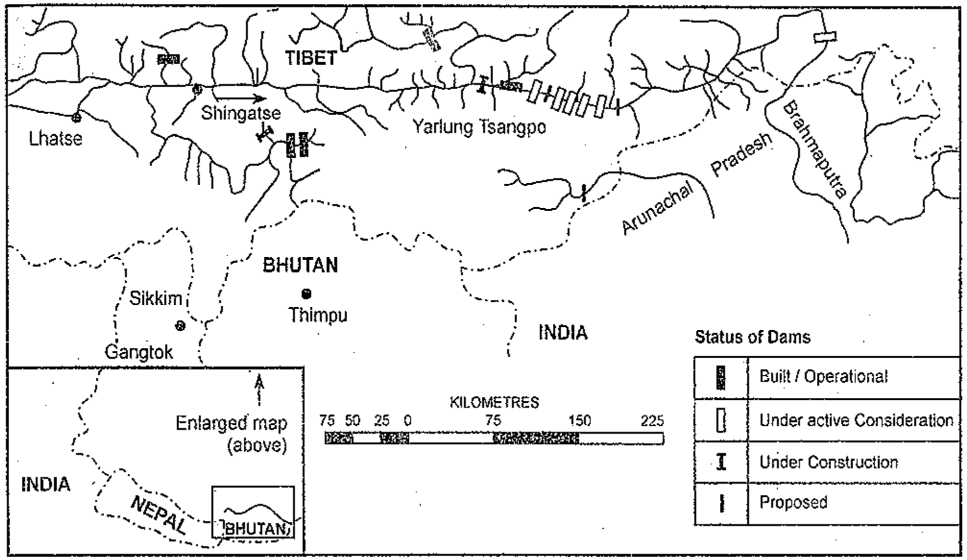

FIG. 1.5. China's water strategy includes construction of 28 Tibetan dams which will put India at a greater risk as the free flow of the Brahmaputra river water will be controlled by China.

The construction of these 28 dams will put India at a greater risk, because China will gain significant capacity to control the Brahmaputra's flow. China will be able to hold back water in the river when it is most needed in India during spring and summer, and release more water during the monsoon when there is fear of flood in large tracts of Assam and Arunachal Pradesh in the middle course of the river. Thus India will become dependent on China for flow of what is now a ***"free-flowing international river."*** Further, the proposed projects pose greatest risk for India because of seismic activity in the region. Thus water dispute has added a new dimension to the already complex relations between India and China. Limited water resources and rapidly growing demand for water resources on both sides of McMohan line is bothering our security planners. Since India is the lower riparian country, she is likely to suffer severely due to the Chinese plans and a conflict between the two giants of Asia can break at any time. Some defence experts on the Indian side have gone to the extent of calling the plan of China as ***'Chinese Water Bomb.'*** It may be pointed out that the turbulent Tibetan plateau is the source of most of China's water. According to an estimate, the existing water resources in Tibet are about 40,000 times higher than in China. Of that about 354 billion cubic metres (BCM) flows into India with 131 BCM being accounted for by the Brahmaputra alone.

According to a report published by Institute for Defence Studies and Analyses (IDSA), Beijing has plans of damming the Yarlung-Trangpo (Brahmaputra) and controlling the flow the river water to China's advantage. The IDSA report, "Water Security for India : The External Dynamics", states, "Harnessing the potential of the Yarlung-Tsangpo is critical to China's overall development" plans and is part of its grand design to divert waters from the south to the north. As a lower riparian state, India will be vulnerable to any major storage projects planned on the Yarlung-Tsangpo. The report also held that, "Given the political situation between the two countries it is hard to imagine China playing the role of a responsible upper riparian country by releasing *re-regulated* flows from power houses immediately back into the river." In fact China has advantage of using water resources as a ***military tool.*** Thus there is an urgent need for a regional basin approach by which China, India and Bangladesh decide to treat the water of the river systems of Tibet as a common resource and develop a formula to reasonably distribute it among themselves.

China's rail and road projects. Realising the strategic significances of railways and roads from the defence point of view, China has drawn a gigantic plan to construct railways and roads in the border areas. China has already completed its 3,900 km long Beijing-Lhasa rail link. This is considered as a great achievement by China because of the rough and rocky terrain and adverse climatic conditions prevailing in the Tibet plateau. China is also pushing ahead with several other railroad projects adjoining the Indian border. Two major projects are to connect Lhasa with Shigatse near Sikkim border and Nijingchi near Arunachal Pradesh border.

China has also announced plans to extend rail connectivity to its outpost at Rulli, adjoining its border with Myanmar. Proposals are also afoot to build 5,000 km of rail links, with emphasis on establishing connectivity in the Tibetan autonomous Region. Further, China has also proposed to build a rail network in Nepal.

In contrast, India is very poorly prepared so far as railway construction in border areas is concerned. There is practically no rail service in the whole of the Himalayan region except Jammu-Baramula rail link. Another plan has been drawn to construct 497 km Bilaspur-Manali-Leh rail link stretching from Himachal Pradesh to Jammu and Kashmir.

China is showing considerable interest in railway development in Pakistan also. Pakistan happens to be China's close allie so far as economic and defence ties are concerned. That country is helping Pakistan to build railway infrastructure very close to Indo-Pak border along the six km long Munabao (in Rajasthan) and Khakrapur (in Pakistan) making India vulnerable to Pakistani attack. Another 1,800 km long railway line has been planned by China. It will connect Keshgar in Xinjiang in China to Gwadar Port of Pakistan, passing through PoK, Islamabad and Karachi. Preliminary research study has already been conducted. India has objected to this project. China is also building Karakoram highway, a road of great strategic significance in the Pakistan occupied Kashmir (PoK) (**Fig. 1.8**).

All the above mentioned developments put India to a great risk because India will find herself at a great disadvantage as compared to China and Pakistan regarding the movement of men and materials in the event of a war.

Chinas Increasing Influence in the Indian Ocean. Although China has its coast on the Pacific Ocean only, that country is increasing its influence in the Indian Ocean also. As part of a new strategy called ***'far sea defence'***, the Chinese military is seeking to project naval power well beyond the Chinese coast, from the oil ports of West Asia to the shipping lanes of the Pacific. According to the Chinese admirals, Chinese warships will escort and defend tankers and other ships from as far as Persian Gulf and Gulf of Aden, sailing across the Indian Ocean to the Strait of Malacca carrying commercially important cargo. China imports most of its mineral oil requirements through this ocean router. According to the U.S. sources, China aims to have a formidable naval presence in the Indian Ocean. According Robert Kaplan of the centre for a New American security, "The rise of China as a sea power is one of the biggest development of the last one decade. China's ambition of becoming a big power in the Indian ocean is reflected in the plan to build ports at Chittagong in Bangladesh, Hambantota in Sri Lanka and Kyaukpyu in Myanmar." He further remarked that China becoming sea power across the Indian Ocean and India too, is raising and becoming a sea power—

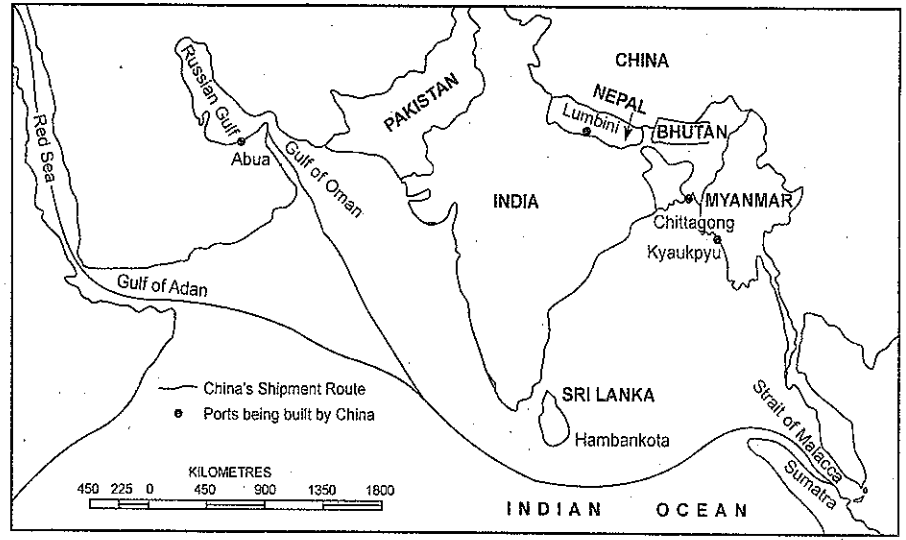

FIG. 1.6. China's increasing influence in the Indian Ocean

brings China and India into competition for the first time in their histories.

Apart from China's efforts to increase its influence in the Indian Ocean, that country is also trying to influence Nepal by providing facilitates for infrastructural development such as railways and roads and some industries. The latest venture is to develop Lumbini, the birth place of Lord Buddha as Mecca for Buddhists (**Fig. 1.6**). A Chinese government backed NGO, has signed a deal to develop Lumbini, a UN world heritage site, with funds worth $ 3 billion. The project is aimed at creating a 'special development zone' in the sleepy town by building airports, convention centres and infrastructural network. The project could be a major security concern for India due to long-term presence of Chinese personnel in the area.

2. The India-Nepal Boundary

India has common border with Nepal which stretches for 1,752 km from the trijunction of Nepal, Tibet and Uttarakhand state of India in the west to Sikkim state of India in the east. Five states of India, namely Uttarakhand, Uttar Pradesh, Bihar, West Bengal and Sikkim touch the Nepalese border with India. Major portion of Indo-Nepalese border runs in the east-west direction almost along the foothill of the Shiwalik Range. Although there had been numerous border conflicts between British India and Nepal since 1769, the present Indo-Nepal boundary is peaceful and there is no boundary dispute between the two countries.

Nepal is a landlocked country which is sandwiched between two giant countries of China and India. Consequently, Nepal has pursued its foreign policy very carefully and has allowed both India and China to construct roads linking its capital city of Kathmandu with its two big neighbours. Nepal has close contacts with India by treaties of friendship and protection from external aggression.

3. The India-Bhutan Boundary

Bhutan is a 'buffer' state between India and China and shares 587 km long border with India. Bhutan is protected from external invasion, although it became a fully sovereign nation and became a member of the United Nations in 1971. India's border with Bhutan is quite peaceful and there is no boundary dispute between the two countries.

Bhutan's border with China follows the crest of the Great Himalayas—the watershed for the north part. China rejected the watershed principle and claimed nearly 775 sq km of the northern Bhutan as its own territory. Bhutan has friendly relations with

India which are based on 1949 treaty. This treaty provides a sound framework to ensure 'perpetual peace and friendship'. Under this treaty, India has got the rights to protect Bhutan's sovereignty and defend its border. Accordingly, India formally protested in 1959 against China's claim over Bhutanese territory. China denounced India's rights of protection of Bhutan, and asserted that any border dispute with Bhutan could be settled with Bhutan without Indian interference, India maintained its right to defend Bhutanese borders as per provisions of the 1949 treaty. India has been closely helping Bhutan in its defense efforts. Indian army units are permanently stationed all along the Bhutan-China border.

4. *The Indo-Pakistan Boundary*

The Indo-Pakistan boundary is the result of partition of the country in 1947 under the Radcliffe award of which Sir Cyril Radcliffe was the chairman. This boundary runs through varied relief features and is marked by a large number of incongruities, anomalies and irrationalities. It starts from the marshy Rann of Kachchh in Gujarat, and traverses through the sandy deserts of Rajasthan, fertile plain of Punjab, hills and mountains of Jammu and Kashmir and reaches right upto the Karakoram Range in its northernmost reach (**Fig. 1.7**).

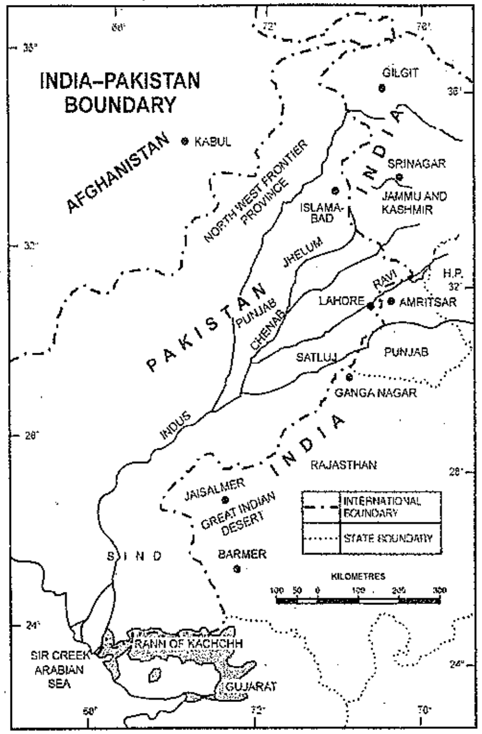

FIG. 1.7. India-Pakistan Boundary

This boundary has created several problems by dividing the fertile erstwhile Punjab, the eastern part remaining with India and the western-part going to Pakistan in the form of West Punjab. Here the boundary line cuts across the canals, roads, railways, towns, villages, fields and even the places of worship. Thus, it is a purely unnatural boundary created by man as a result of partition of the country which is based entirely on communal considerations.

Consequently boundary has been marred by a number of disputes and hostile activities from both the countries ever since it came into being. Following disputes are worth mentioning.

(*i*) **The Rann of Kachchh Dispute.** Rann of Kachchh boundary was well defined according to the Radcliffe award but Pakistan advocated that it was not properly delineated. That country argued that the Rann was not a marsh but a land-locked sea or lake and as such it should be equally divided between India and Pakistan. India countered Pakistani claim by presenting documentary proof that the Rann was a marsh which always remained a part of the Kachchh state. As this state merged with India after independence, the entire Rann of Kachchh should be given to India. Pakistan claimed about 9,065 sq km out of a total area of 20,720 sq km of the Rann of Kachchh. During the 1965 Indo-Pakistan war, the Pakistani troops invaded this area and reached inside the Indian territory. The matter was referred to a boundary tribunal constituted by the International Court of Justice which awarded 906.5 sq km area of the Kachchh to Pakistan. After a number of protests and representations both India and Pakistan accepted the award and the demarcation of the boundary was completed in June 1969.

(*ii*) **The Kashmir Problem.** The former princely state (more precisely the state of Jammu and Kashmir), is undoubtedly the most complex and serious problem between India and Pakistan and is the major stumbling block in normalising the relations between the two countries. The Kashmir problem has led to bloody wars between the two countries in 1948, 1965, 1971 and 1999. There had been large scale violations of LoC by Pakistan in 2014. From defence point of view these violations are serious and can be compared to the 1971 war. Besides there had been skirmishes adding to bitterness between the two countries. Both countries have large political, economic and strategic stakes in Kashmir and this state has become a symbol of national prestige and honour for either of the two countries.

With an area of 2,22,236 sq km Jammu and Kashmir is the sixth largest state of India and represents heterogenetic character with regard to geographic, economic, cultural and linguistic elements. The whole state of Jammu and Kashmir can be treated as conglomeration of six distinctive regions. These regions (excepting for Hunza-Gilgit and Nagar) were brought together as a united political unit by Maharaja Gulab Singh, who entered into a subsidiary alliance with the British within the Indian empire in 1849. The *first* is the beautiful **Kashmir Valley.** It is the most important centre of tourist attraction and politically the seat of central authority. Until recent time, it was accessible from India by a single road. This road remained snowbound until the introduction of snowplows in 1948. A few roads connect it with Pakistan. The nucleus of dispute in this valley is its overwhelmingly Muslim population. The minority of Kashmiri Brahmans have been holding high positions of economic, social and political significance, whereas the Muslim peasantry remained very poor. The *second* is the **Jammu** region which lies in the southern part of the state. It covers only one-seventh of the total area of the state and is predominantly a Hindu majority region. More than half of the population of this region consists of Hindus. Jammu is the winter capital of the state and home of state's former rulers—the Dogra Rajputs. The *Third* region is **Gilgit.** It lies in the northern part of the state. This region is marked by high mountains and is almost entirely inhabited by Muslims. Previously it used to be reached from Srinagar by crossing high mountains, plateaus and glaciers. Now it is well linked to Pakistan through Karakoram highway built by China-Pakistan in 1970. The *fourth* region is that of **Baltistan** which lies in the extreme northern part of the state. Like Gilgit, it contains high mountains and is not easily accessible. It is reached by road along the Indus river in Pakistan. It is an overwhelmingly Muslim area. The *fifth* region is that of **Punch** which lies to the north of the Jammu region and in the west of the Kashmir valley. It is near the Pakistan border and is inhabited by Muslims. Pakistan has easy access to this region. The *sixth* is the **Ladakh** region which is also known as 'Little Tibet'. It lies in eastern part of the state and covers about one-third territory of the state. It is a vast, barren, high plateau which resembles Tibet in many respects.

As mentioned earlier, the state was ruled by a Hindu whereas about 77 per cent of the population of the consisted of Muslims before partition of the country. It is an extremely important state from the strategic point of view because of its contiguity to Pakistan, China and Afghanistan and proximity to Tajikistan (formerly a part of the U.S.S.R.). The state was sought by Pakistan on the basis of its Muslim majority status. Moreover, major rivers of Pakistan namely Ravi, Chenab, Jhelum and Indus flow through Kashmir. Unlike most of the rulers of princely states who had acceded to either India or Pakistan before August 15, 1947, ruler of Kashmir did not make up his mind. The Maharaja thought that any decision to accede to India or Pakistan may spark off chain reactions and disturb the peace of the state. Pakistan cut off the communications and stopped the supply of essentials to coerce Kashmir to accede to Pakistan. On October 22, 1947, fully armed tribesmen, supported by Pakistani armed forces, invaded Kashmir. They indulged in large scale killing of Hindus and Muslims and committed large scale looting and arson. This forced the ruler to make a desperate appeal to the Indian government for military help. India promised to help the ruler but only after he decided to accede to the Indian Union. The ruler agreed to this condition and the instrument of accession of Kashmir was signed by Maharaja Hari Singh on October 26, 1947. The accession was accepted by the Governor General of India on October 27, 1947. Thus, Kashmir became legally and constitutionally an integral part of the Indian Union. Pakistan described the Maharaja's accession to India as based upon "fraud, deceit and violence", and maintained that it was totally against the wishes of its long oppressed Muslim subjects. Soon after, Pakistan rushed its own troops to support the invading tribesmen. India quickly moved its troops to halt the invaders and Indo-Pakistan war broke out in 1948.

India could have done much better, had it flushed out the invaders from the entire state. Instead, India took the case of aggression from Pakistan to the United Nations which immediately appointed a commission to investigate the dispute. The United Nations Commission on India and Pakistan (UNCIP) proposed a plebiscite to ascertain the wishes of the people of the state. It also called on India and Pakistan to agree on a cease-fire line. A cease-fire line was delimited with areas of high altitude left undelimited. The line was accepted by both India and Pakistan on January 1, 1949. The cease-fire line left India in possession of two-thirds of the state including the Kashmir valley, lying south-east of the line, and one-third area in the north and west of the line remained under Pakistan's control. The area is administered through the so-called ***Azad Kashmir*** government. The cease-fire line (adjusted under Shimla Agreement as Line of Actual Control) has crystallized into de facto boundary between areas controlled by India and Pakistan respectively.

Right from the beginning Pakistan has been insisting on plebiscite in the entire state in the hope that such an exercise will give clear mandate in its favour. That country argues that plebiscite has been recommended by the United Nations. India, on the other hand, held the position that Kashmir's accession had given India sovereignty over Kashmir. Initially agreeing to the proposal of plebiscite, India rejected it on the ground that Pakistan had not withdrawn its

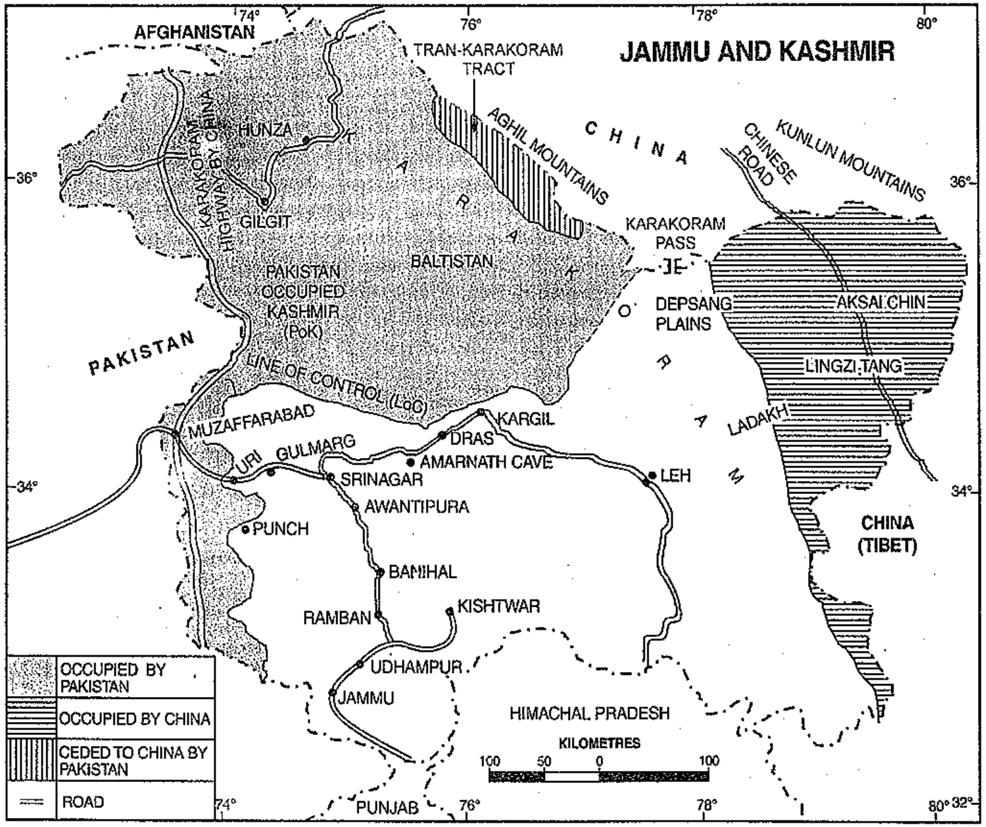

FIG. 1.8. Jammu and Kashmir

invading forces from Kashmir. This condition was stipulated by the United Nations resolution, but had never been realised on the ground. India has been regularly stressing upon the illegality of Pakistani support of the raiders and the *Azad Kashmir* government. Pakistan blames India for failing to withdraw its forces from the Indian-controlled territory, and for supporting a regime prejudicial to holding of a plebiscite. Since then the issue has been getting listed in the U.N. Security Council and the Cease Fire line or Line of Actual Control divides Kashmir between Indian and Pakistani occupied areas.

Ever since Kashmir's accession to India, the Kashmir government in Srinagar has maintained a close relationship with the Indian Union, and in 1952, negotiated a pact which has given it a special status within India. In 1956, arrangements were made for establishing an elected constituent assembly for Kashmir which voted to make it a regular state within India. Since then, India has treated Kashmir as a constituent unit of the country and the state is no longer open to a plebiscite.

Two major considerations have guided India's policy about Kashmir problem. *First*, India is secular state and surrender of Kashmir to Pakistan on religious grounds would amount to denial of the nation's essential principles. *Second*, the strategic location of Kashmir is of great importance to India. China's occupation of Tibet and part of Ladakh and building a road through Aksai Chin to serve Tibet and Sinkiang, and full scale aggression on India in 1962 further lent urgency to the strategic aspect of Kashmir's location. China helped Pakistan in building a new road across its occupied area to Sinkiang and Pakistan, in turn, ceded a large territory of 5,180 sq km to China. This move by Pakistan has been termed as illegal; because India claimed that the entire state including the territory controlled by Pakistan, annexed by China and ceded by Pakistan to China belonged to India. Thus, out of a total area of 2,22,236, a territory of 78,114 sq km is under illegal occupation of Pakistan, and 5,180 sq km illegally handed over by Pakistan to China and 37,555 sq km under illegal occupation of China in Ladakh district.

Pakistan has so far made four abortive attempts to conquer Kashmir. Its forces had to trace back in 1947-48 war when Kashmir was legally acceded to India. Pakistan again invaded in 1965 and it was badly mauled by the Indian forces. The 1971 India-Pakistan conflict led to the liberation of East Pakistan and emergence of a new country by the name of Bangladesh. This left Pakistan a truncated country and added much to the already increasing bitterness between India and Pakistan. In 1999, Pakistani troops stealthily occupied certain positions in the Kargil sector for which India had to use strong force. Unable to beat India in regular warfare, its forces are launching proxy war in Kashmir and sending foreign mercenaries and terrorists to disturb law and order in and incite communal tension in the state. Due to its link with Islamic terrorist organisations and ISI, Pakistan has become the hot-bed of international terrorism and is posing a serious threat to world peace. Even after more than six decades of Kashmir's accession to India, there seems no sign of resolving the Kashmir problem as both sides stick to their respective positions. India is taking no chance to safeguard the integrity and sovereignty of the country, particularly of Jammu and Kashmir. There are an estimated 1,00,000 Indian troops ranged along 188 km long International Border, the 788 km Line of Control (LoC) and 150 km Actual Ground Position Line (AGPL) in Jammu and Kashmir.

***(iii)* The Siachin Glacier Dispute.** Siachin glacier is about 75 km long and 2 to 8 km wide. This glacier has the distinction of being the largest glacier outside the Polar or sub-Polar regions. It covers an area of about 450 sq km at an altitude of about 5,800 metre above sea level in Ladakh region near Karakoram range. The Karakoram highway between China and Pakistan is very close which enhances its strategic value. India occupies about two-third area of the glacier in its south-eastern part. Here Nubra river emerges from Karakoram glacier and meets the Shyok river which is a tributary of the Indus river. Indian troops use the Nubra valley to reach the glacier. The glacier has four passes. Of these Gasherbrum, Saltoro and Vilafondala are in India and Gyongla is under Pak occupied Kashmir.

It is worth mentioning that LoC demarcated in 1972 after the Shimla agreement stopped dead at the grid reference N.J. 9842, with no indication as to how it would run along the 70-odd km left to the Chinese border in the north. While Pakistan decided to extend this line eastward to Karakoram Pass, thus claiming an area two-thirds the size of Sikkim, India's decision

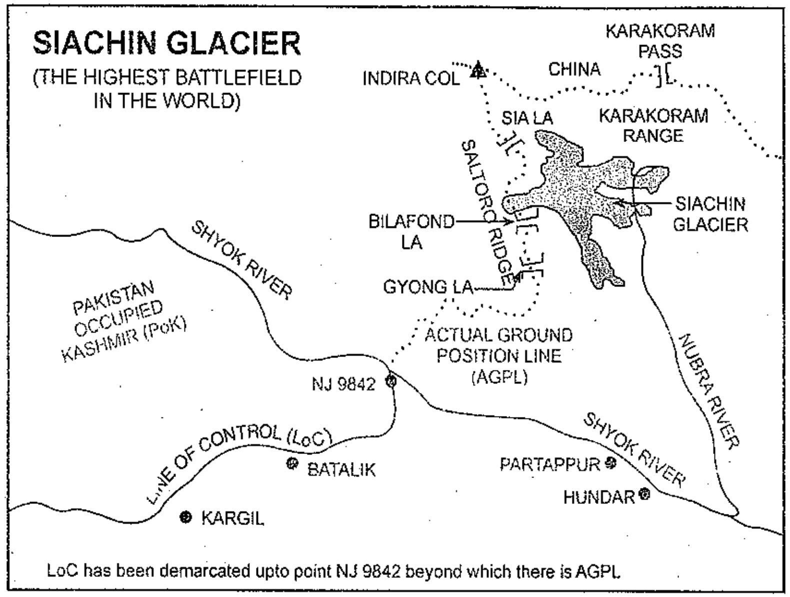

FIG. 1.9. The Siachin Glacier : The Highest Battlefield in the world.

was to go by the wording of 1949 Karachi agreement that was superseded by LoC of 1972 which spoke of line "thence northwards joining the glaciers". Further, India wants Pakistan to officially recognise the Actual Ground Position Line (AGPL) begin N.J. 9892 grid point as a pre-requisite to de-militarisation of the Siachin glacier.

Pakistani troops established an observation post on Saltoro range. To counter this, India launched Operation Meghdoot on April 13, 1984. Since then both the countries are maintaining troops in this inhospitable environment at a very high altitude. A number of skirmishes have taken place making it the highest battlefield in the world (**Fig. 1.9**). Sending men and material in such an area is a very expensive affair. On an average India spends about ₹ 5 crore per day for maintaining troops in this hostile area. Pakistan also spends about ₹ 2 crore for the same purpose. Casualties on both sides of the border are also very high. Even in normal circumstances, Indian troops suffer one casualty every second day while Pakistani troops suffer one casualty every fourth day. Besides there are psychological desorders, frostbite, high altitude pulmonary and cerebral edema and snow blindness. Such heavy losses can be avoided if both the countries start living in peace as friendly neighbouring countries.

(*iv*) **Sir Creek.** Sir Creek forms the boundary between Gujarat state of India and Sind Province of Pakistan. This creek is extremely rich in oil and marine life and both the countries desire to include it in their respective territories (**Fig. 1.10**). Sir Creek has become a contentious issue between the two countries as Pakistan has been claiming a 40 km region inside India's territory. The Sir Creek dispute goes back to pre-independence India and involves the last portion of our western land border that is in the form of a 100-km estuary that empties into the sea. Pakistan claims that the border runs along is eastern shore, while India invokes the "Thalweg principle" in international law to say that it lies in the middle of the channel.

Pakistan has responded positively to the goodwill gesture initiated by India since early 2004 to ease tension on the border. This can lead to friendly relations between the two countries if the concerned countries take necessary positive steps for normalisation of relations.

Some of the steps taken/proposed are :

- Srinagar-Muzaffrabad bus survice.
- Kargil-Skardu bus link and routes into Poonch-Rajouri sector.
- Amritsar-Lahore bus and rail link.
- Meeting points for divided families across LoC at Poonch, Mendhar, Suchetgarh, Uri, Tangdar and Kargil.
- Rail link between Munnabao (Rajasthan) and Khokrapar (Sind).
- Link between Ferozpur and Sahiwal.
- Trade across the LoC/border.
- Mechanisms to permit two-way religious pilgrims.
- Promotion of cultural interaction and cooperation.
- Joint efforts to promote tourism.

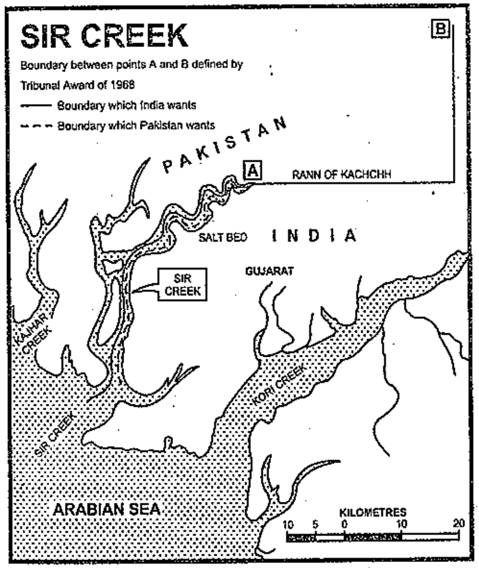

FIG. 1.10. Sir Creek

5. *The India-Bangladesh Border*

Of all the neighbouring countries, India's 4,096 km long border with Bangladesh is the longest and accounts for nearly 27 per cent of the total land border of India (**Table 1.2**). As many as five Indian states share the international boundary with Bangladesh. They are West Bengal, Assam, Maghalaya, Tripura and Mizoram. The boundary line between India and Bangladesh criss-crosses the vast Ganga-Brahmaputra delta. This boundary runs through an entirely flat country, in which there is not even a small mound or hill which could be used for demarcating the boundary between the two countries. It is, therefore, a very unsatisfactory border because it fails to separate the people living on either side of the frontier. This boundary has been determined under the Radcliffe Award which divided the erstwhile province of Bengal into two parts. The eastern part went to the then East Pakistan which became an independent country, Bangladesh in 1971, and western part remained with India as the state of West Bengal. West Bengal has 2,272 km long border with Bangladesh which is the longest border shared by any Indian state with Bangladesh. Although Indo-Bangladesh border has remained more or less peaceful and there are no serious border problems between the two countries, yet there were four overlapping claims, which were referred to the tribunal. The first was between Rajshahi district of Bangladesh and Murshidabad district of West Bengal (India). Here the channel of the Ganga fluctuates rather frequently as a result of which the boundary has shifted several times. The northern portion of the district was confirmed as the international boundary. The *second* dispute was between Karimpur district (India) and Daulatpur district (Bangladesh). In this

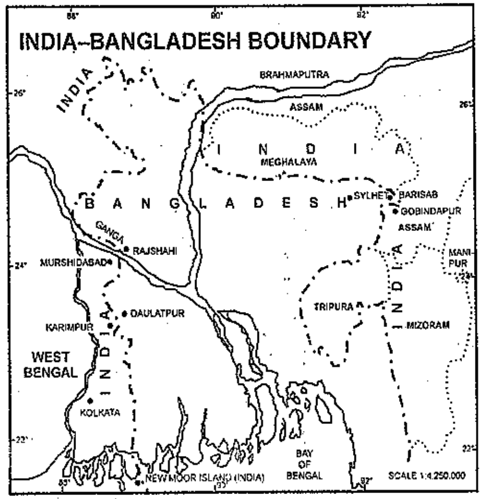

FIG. 1.11. India-Bangladesh Boundary

case, Redcliff award was amended and half way line in the Matabhanga River was treated as the international boundary. Bangladesh gained about 13 sq km as a result of this amendment. The *third* dispute was in Sylhet district of Bangladesh and Garo, Khasi, and Jaintia Hills districts of Meghalaya in India. This is a densely forested area where demarcation is difficult. Here Radcliffe Award was confirmed and India's claim was sustained. The *fourth* dispute existed between Barisari district (Bangladesh) and Gobindpur district (Assam).

Farakka barrage was another major issue between India and the then East Pakistan (now Bangladesh). Immediately after the Indus Water Treaty between India and Pakistan, a dispute arose over the use of the Ganga river water. India planned the construction of a barrage across the Ganga at Farakka. This barrage aimed at rejuvenating the river system of West Bengal, flood control, efficient distribution of water between the northern and southern parts of West Bengal and for desilting the Kolkata harbour. Pakistan feared that construction of Farakka barrage would seriously reduce water supply to East Pakistan. Negotiations failed to produce a settled agreement and the work on the construction of Farakka barrage started in mid 1960s.

During the 1980s a refugee influx of Bangladeshis in Tripura and Assam created problems for India. By 1989 more than six lakh refugees from Bangladesh had entered India. The refugee influx continues even today, creating economic, social and political problems for India. Currently, almost all the Indian states touching the Bangladesh border are infested by refugees from Bangladesh. India's plan to erect barbed-wire fence along the Bangladesh border to check the illegal migration of refugees from Bangladesh has not been welcomed by that country.

In the beginning, the emergence of an independent and generally friendly country of Bangladesh in place of the initial East Pakistan was viewed positively by India. But the recent growth of anti-India elements backed by ISI of Pakistan is likely to create problems between the two countries.

However, things have slightly changed in the positive direction as India and Bangladesh agreed on 6th September, 2011 to exchange 166 enclaves in each other's territory, settle all issues related to adverse possessions and demarcate the lost stretch of 6.5 km of the 4906 km border. According to the deal, India will get back 111 enclaves and 55 will go to Bangladesh. But there is strong resentment in Assam as that state is likely to lose 665 acres of land across Dhubri and Karimganj districts to Bangladesh. Bangladesh initially wanted 793 acres of land from India but was given only 267.5 acres according to the agreement signed by the countries on 6th September, 2011. Indian states bordering Bangladesh are also sour about the illegal Bangladeshi immigrants to their states. It is estimated that there are over 40 lakh illegal Bangladeshis in Assam alone. Sharing of waters of the river Teesla—including those of Feni, Manu, Muhuri, Khowai, Gumti, Dharla and Dudhkumar still remain the main irritant.

Another major problem between India and Bangladesh is the refusal of transit facility to India by that country. **Figure 1.12** shows that a narrow stretch of land in the northern part of West Bengal—referred to as the **Siliguri Corridor** or **Chicken's Neck**—is north east's only gateway to the rest of the country. This not only puts extraordinary pressure on this route but gave Dhaka a diplomatic edge over India due to the economic and strategic significance attached to the transit facility requested by New Delhi. India has entered into an agreement with Myanmar to execute the Kaladan Multi-Modal Transit Transport Project through which goods can be easily shipped from ports in eastern India, loaded into small vessels to be transported trough Kaladan river in Myanmar and then transhipped onto trucks that would drive through Myanmar into Mizoram state of India. India will bear the cost of upgradation of Sittiwe Port and Kaladar waterway and construction of road from Setypitpyin (Kaletwa) to Indo-Myanmar border. The plan includes construction and improvement of the 117 km road on the Indian side from the border up to National Highway 54. The Kaladan river is navigable from the Sittwe port to Setpyitpyin (Kaletwa) beyond which navigation is not possible due to shallow water and frequent rapids across the river.

SALIENT FEATURES

- Alternate route to Chicken's Neck from Kolkata to Mizoram.
- Kolkata (India) to Sittwe (Myanmar) sea route.
- 225 km journey from Sittwe post to Setpyispyin (Kaletwa) transport on River Kaladan.
- 62 km road journey from Setpyipsyin to Mizoram border.
- Mylikwa will be handling port in Myanmar.
- Hmawngbu will be the handling port in Mizoram.

BENEFITS FROM THE PROJECT

- An alternative access route from any part of India to landlocked north-eastern region.
- Net saving of time and cost involved in the movement of goods.
- The route will lead to economic development of the entire north-east region and motivate youth to stay away from insurgency.
- A strong message to Dhaka that withholding transit did not imply that India did not have alternatives.

6. India-Myanmar Boundary

The boundary between India and Myanmar is 1,458 km long and runs from India-China-Myanmar trijunction in the north to the southern tip of Mizoram. This boundary runs roughly along the watershed between the Brahmaputra and Ayeyarwady. It passes through thickly forested hill country, with Mizo Hills, Manipur and Nagaland on the Indian side and Chin Hills, Naga Hills and Kachin state on the Myanmar side. Although defined under the treaty of Yundaboo in 1926, this boundary was determined precisely by bilateral treaty signed on March 10, 1967. Barring a few minor incidents, the Indo-Myanmar-border has remained peaceful due to the goodwill gesture of give and take on both sides.

In May, 2012, India and Myanmar signed several agreements in Naypyidaw (new capital of Myanmar, over 300 km north of old capital Yaugon) to strengthen relations between two neighbouring countries. Some of the important agreements are briefly described as under :

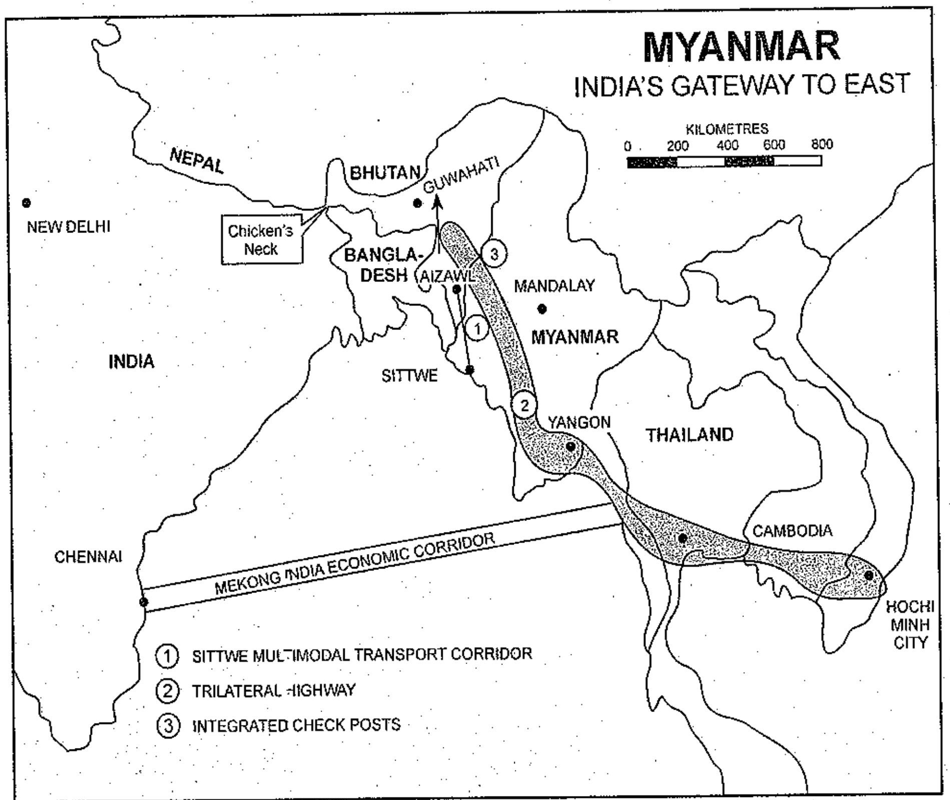

FIG. 1.12. Myanmar : India's Gateway to East

1. Sittwe Multimodal Transport Corridor. This a road and river corridor which will run from Sittwe port (Myanmar) to Aizawl in Mizoram. It will provide India an alternate access to Mizoram and Manipur in case northeast insurgents block National Highway 45 again. It will also strengthen trade between India and Myanmar.

2. Trilateral Highway. This highway from India to Vietnam is the most ambitious and geopolitically the most significant project. Concerned as a three nation project by India under the Ganga-Mekong cooperation agreement in 2004, it now includes Combodia and Vietnam. However, it is facing difficulties due to poor infrastructure in India and Myanmar.

3. Integrated Check Posts. India is building a check post on the Myanmar border in Morch like the one at Wegah with Pakistan border near Amritsar. The difficulty lies in the fact that the trade agreement covers only 40 items, compared to thousands in most such deals.

4. Mekong India Corridor. There is plan to developed Dawei port of Myanmar which will allow shipments from the Indian Ocean to find easy access to Thailand and South-east Asia avoiding much longer route via Malacca Straits.

Water Frontiers

About 6,100 km long coastline of mainland of India is washed on three sides of the country by the Indian Ocean and its two arms namely the Arabian Sea in the west and the Bay of Bengal in the east. If we add to this the coastlines of Andaman and Nicobar Islands in the Bay of Bengal and Lakshadweep Islands in the Arabian Sea, the total coastline stretches to 7,517 km. Next to the Himalayas, the Indian Ocean is the most dominant factor which has influenced the destiny of India. It is through the waters of the Indian Ocean that India could establish her trade contacts with the neighbouring countries in the historic past. One of the greatest climatological phenomena, the Monsoon winds, have their origin in the Indian Ocean. Our water frontiers had been considered to be safe in the past. But the recent technological advancements in naval warfare have made these frontiers vulnerable to attack by the enemy forces and this has necessitated greater defence preparedness. "To be secure on land, we must be secure at sea."

7. *India-Sri Lanka Boundary*

India and Sri Lanka are separated from each other by a narrow and shallow sea called Palk Strait. Dhanushkodi on the Tamil Nadu coast in India is only 32 km away from Talaimanar in Jaffna peninsula in Sri Lanka. These two points are joined by a group of islets forming Adam's Bridge. There have been close and cordial relations between the two countries in the historical times. Every phase of Peninsular Indian culture found its way into the island. Consequently more than half of the island had remained under the peninsular influences. The northern and north-eastern parts of the island have large number of Tamilians who migrated from Tamil Nadu to that country.

The maritime boundary between India and Sri Lanka passes through Palk Strait as Palk Bay touching Dhanushkodi (**Fig. 1.13**). This boundary has remained peaceful barring a few minor clashes between the fishermen of the two countries over the fishing rights. Some bitterness was created over the ownership of Kachchitevu Island (area 1.92 sq km) in the Palk Strait about 16 km from the Tamil Nadu coast. The problem was resolved with the demarcation of India, Sri Lanka boundary along the median line. This island was given to Sri Lanka as a result of agreement of 1974. The maritime boundary between India and Sri Lanka became lively in 1980s with the insurgent activity of L.T.T.E. which is demanding a separate homeland for Sri Lankan Tamils within the island.

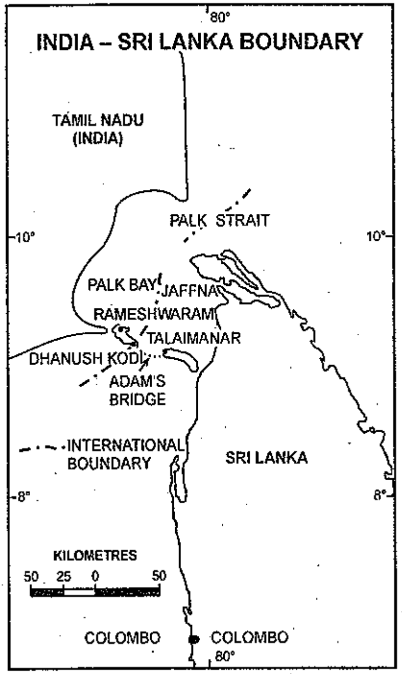

FIG. 1.13. India-Sri Lanka Boundary

GEOPOLITICS OF THE INDIAN OCEAN

With an estimated area of about 73,442,700 sq km the Indian ocean is the third largest ocean in the world after the Pacific Ocean and the Atlantic Ocean. Although the Indian Ocean is much smaller in size than the Pacific and the Atlantic Oceans, yet it is of immense importance for us because it is located to the south of India. This is the only ocean in the world to be named after the name of a country, *i.e.*, Indian Ocean after India. In a way, it is just half an ocean because it does not open out northwards in the Arctic Ocean. It is bounded by South Asia in the north, Indonesian islands and Australia in the east and by Africa in the west. The meridian of Cape of Tasmania (147°E) forms the boundary line between the Indian and the Pacific Oceans while the meridian of Cape Town (18° 22'E) forms the dividing line between the Atlantic Ocean and the Indian Ocean. In the south, it extends to the Antarctic continent from where it merges with the Atlantic and the Pacific. The International Hydrographic Organisation has recognised the coast of Antarctica as the southern extreme of the Indian Ocean. Tropic of Cancer forms its northernmost limit.

The Indian Ocean has great strategic importance for India. The "landlocked" nature of the Indian Ocean has given India a commanding position. From the eastern coast of Africa and the shores of the Persian Gulf to the Strait of Malacca, no other country rivals India's dominant location in the Indian Ocean. The strategic importance of this ocean is further enhanced by the fact that it is accessible from the west and the east through narrow straits only. The Red Sea and the Persian Gulf are the narrow outlets in the west while in the east, there are the Strait of Malacca and the Timore and Arafura sea.

The Indian Ocean has limited outlets. Before the opening of the Suez Canal in 1869, the only contact of littoral states of the Indian Ocean with the western countries was via Cape of Good Hope by circum-navigating the whole continent of Africa. On the eastern side there are two outlets—one through the islands of Indonesia and the second is to the south of Australia. The Indian Ocean can be choked any time by controlling these outlets. Since the Indian Ocean and the countries surrounding it are very rich in natural resources, such a possibility has considerably enhanced the geopolitical strategy of this ocean.

In spite of above mentioned geopolitical limitations, the Indian Ocean has never been a barrier between the countries. On the contrary it has served as a great linkage between the countries lying on its coasts and even further beyond. We can reach West Asia, Africa and Europe from the west coast and South East Asia, Far East and Oceania from the eastern coast. The Indian Ocean, thus, bridges a gap between east and west. This ocean is encircled by 46 countries (27 littoral including Australia, 7 island countries and 12 landlocked countries as recognised by the U.N.), with great diversity in almost every respect; shape, size, people, resources, economy, polity, culture, etc. (**Fig. 1.14**)

The Indian Ocean is endowed with rich variety of natural resources of which mineral and power resources as well as food resources are very important. Some of the resources are briefly described as under :

Aggregates

Marine aggregates comprise sand, gravel or shell deposits and are used primarily in construction industry. They are, at present the most important commodities mined offshore, both quantitatively and by value. They are mainly found on the continental shelves. Offshore calcareous deposits are formed by fragmentation of shells by waves and currents. These are used for manufacturing cement.

Placers

Placer deposits are concentrations of heavy, resilient, and chemically resistant minerals eroded

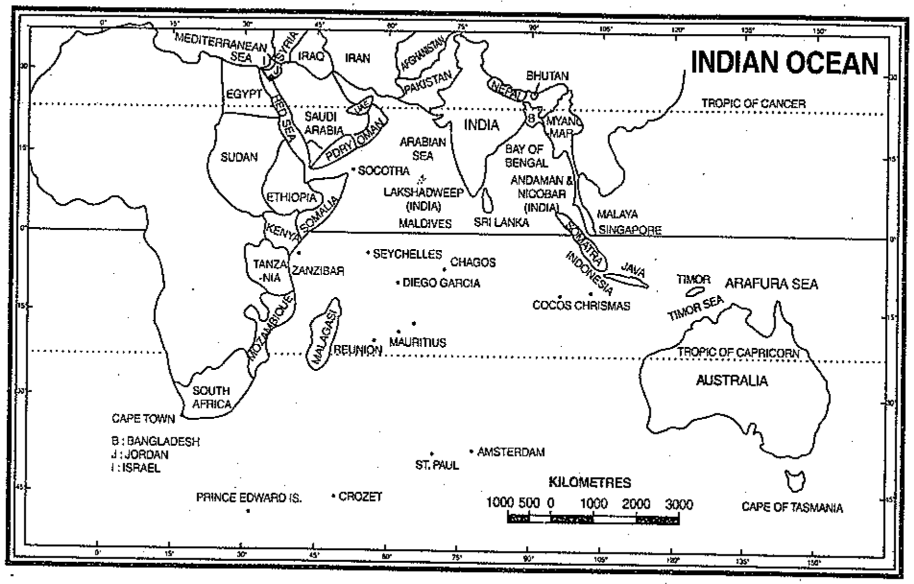

FIG. 1.14. Indian Ocean

from existing ore bodies by mechanical weathering. Such deposits include native gold, native platinum, tin, titanium, magnetite (iron), zirconium, monozite (thorium) and gemstones. In the Indian ocean, such placers are found along the coasts of Sri Lanka, India, Australia, Malaysia and Indonesia. Sri Lanka, India and Australia have titanium sands, whereas Malaysia and Indonesia have tin deposits. Indonesia is one of the main areas in the world where offshore placers are mined. Primary tin deposits occur in granitic rocks onshore and heavy minerals extend offshore.

Polymetallic Nodules

Polymetallic nodules are those which contain several metals, the important metals being manganese, copper, nickel, cobalt, etc. They occur in many shapes, sizes and forms and are generally friable.

Manganese nodules were first discovered on the 1872-76 scientific voyage of *Challenger*, but systematic exploration and detailed studies only started in late 1950s when it was realised that nodules might be a source of nickel, copper and cobalt. Several investigations in the mid 1960s reported finding enrichment of manganese and iron in the sediments of wide areas of the ocean floor on the East Pacific Rise axis, and since then similar enrichments have been found in Indian ocean also, especially along the mid-Indian rise. India has obtained the technology of exploiting these mineral nodules from the ocean beds. The United Nations has granted permission to India to exploit the polymetallic nodules over an area of 1,50,000 sq km in the Indian Ocean. India is the first country to obtain such a right. The National Insititute of Oceanography, Goa has played a leading role in the research and development of this mining technique.

Metalliferous nodules containing zinc, copper and silver have been discovered in Red Sea. *Seafloor phosphorite* contains phosphate mineral which is used for the manufacture of phosphate fertilizers and certains phosphate based chemicals. Seafloor phosphorite was first discovered as nodules in dredge samples obtained from the Agulhas Bank off South Africa during the *Challenger* Expedition of 1872-76 and have since been found elsewhere. They occur mostly on the continental margins and upper parts of the continental slopes at depths of less than 500 metres. They are normally confined to the zone between 40°N and 40°S latitudes. In the Indian ocean phosphorite deposits occur along the coast of Arabian

Peninsula, east coast of India in the Bay of Bengal, near Andaman and Nicobar Islands and in the south of Sri Lanka. Phosphorites occur widely on Agulhas Bank off South Africa. It has become one of the most intensely studied areas of the world. The total reserves are estimated at 450 million tonnes.

Estimates of reserves suggest that recoverable *nickel* and *copper* are of the same order as known land economic resources. But the current level of technology is not competent enough to exploit these resources. Specialised mining systems have to be developed to recover the nodules without lifting the underlying sediment from depths in excess of 4000 metres. The environmental conditions of potential mine sites and possibilities of mineral extraction have been ascertained.

Oil and Gas

Oil and gas are the most valuable of all the minerals extracted from the sea bed. Most of the oil and gas producing areas of the oceans are confined to the *continental shelf*, but oil wells in much deeper seas have been dug in the recent past. At present half of the world's total output of oil and gas comes from offshore wells and over 80 countries of the world are engaged in offshore drilling.

In the Indian ocean, the major players in offshore oil and gas exploration, drilling and production are India, countries surrounding the Persian Gulf and the south-east Asian countries like Indonesia and Malaysia. Coastal areas of Australia (western Australia) also have offshore oil reserves.

India has 3.2 lakh sq km offshore area of sedimentary deposits on the continental shelf upto a depth of 200 metres. The Indus cone formed by the deposition of sediments by the Indus river encompasses the Kachchh Shelf, Gulf of Khambhat and Mumbai High. Mumbai High is the largest oil producer of India. Huge gas reserves have been found in the Krishna-Godavari basin off the coast of Andhra Pradesh.

Oil and gas reserves of the Persian Gulf are simply amazing. But these reserves remained unexploitated for a pretty long time because this gulf has land based reserves also and those reserves were to be exploited first. The offshore potential is very important, especially for smaller states which have restricted land areas. The Persian Gulf has the advantage of being sheltered from the open ocean, is shallow and relatively free of hazards. It is the most rapidly developing part of the industrialising world as its onshore and offshore wealth is re-invested in industry. Kuwait, Saudi Arabia, Bahrain, Qatar, United Arab Emirates, Iran and Iraq are the likely beneficiary states.

In South-east Asian waters, offshore, oil is becoming increasingly significant for a number of countries in this vast archipelagic area. There is increasing shift from exploitation of land resources to offshore resources. This phenomena is particularly seen in Indonesia and Malaysia where the main producing areas are off southern Sumatra. The South-east Asian waters are considered as one of the most promising for immediate exploitation.

Off the coast of Western Australia there are substantial reserves of oil and gas. These reserves experienced rapid development in the 1970s.

Besides there is great scope for harnessing the non-conventional energy resources in this ocean.

The above mentioned and some other natural resources of this ocean can be a great cause of rivalry among the nations of the world.

India has used the Indian Ocean for thousands of years. This ocean had been a powerful medium of trade, defence, colonization and diffusion of Indian culture particularly in Southeast Asia. The Mauryan kings had established ports on the Bay of Bengal in the fourth century B.C. Kautilya made a mention of a separate administrative division of overseas maritime activities in his famous *Arthsastra*. Large naval kingdoms of the Cholas and Chalukyas were set up in South India. Sri Vijaya empire, set up by the Indian rulers in South-east Asia from eighth to eleven centuries, maintained strong cultural and commercial ties with south India through the Indian Ocean. The Arab explorers and traders increased their activities in the Arabian Sea from the middle of the 13th century to the beginning of the 16th century. However, they could not exercise much control on this ocean. The European influence in the Indian Ocean started after the landing of Vasco da Gama at Calicut on the western coast of India in 1498. Major European powers were eventually drawn into a long and bloody struggle for power in the Indian Ocean. Out of all the

European powers, Britain had the best naval force and gained supremacy over the Indian Ocean and the Indian subcontinent.

During the 18th and 19th centuries, sea ports like Mumbai, Kolkata and Chennai were developed to boost up sea trade and maritime activities. The British became a super power by dint of its naval superiority. According to an Indian historian and diplomat, K.M. Panikkar (1945), the history of British control in Indian Ocean illustrates the basic geopolitical principle that *the power which rules the sea eventually rules the adjoining land*. He observed that the pre-British invasions and land directed conquests of India led to the founding of political dynasties, which in a short period were Indianised. Only the British rulers could remain unassimilated as they could draw their strength from England through the naval supply lines. It is worth noting that although a large portion of north India was conquered many times by foreigners, India was never ruled by a monarch who did not have his capital in India except whom it was under the naval power of the British (Panikkar, 1951). Japanese effort to capture Singapore and Andaman Islands during the World War II also corroborated the above statement.

Most of the former British colonies became independent countries after the World War II. This resulted in shrinking of the British empire and reducing of the British influence in the Indian Ocean. By mid 1960s, it lost almost all the colonies and serious economic strains were experienced in Britain. Consequently Britain started withdrawing its military forces from the Indian Ocean region. This withdrawal created "*a power vacuum*" which gave birth to super power rivalry in the Indian Ocean region. The USA immediately jumped into the fray and made efforts to fill the '*power vacuum*' created by the withdrawal of the British forces. The USA purchased Diego Garcia island from Britain to build a military base there. The base is fully equipped with nuclear weapons and provides decisive advantage to the USA to command the areas of the Middle East, South Asia, Central Asia, Russia and China. In addition to Diego Garcia, the USA has set up military bases near Asmara (Ethiopia), Woomera and Harsld E. Holt (Australia) as well as in Bahrain and Mahe. The military bases at Vacaaos (Mauritius), Gan Island, Masirah Island, Simonstown (South Africa) and Port Louis (Seychelles) are jointly owned by the US and the UK. France has also set up bases in Diego Suareg and Reunion Island.

The Russian interest in the Indian Ocean region is as intense as that of the USA. The individuality of the ocean makes it possible for both the countries to exercise their power even though they may be far removed from the Indian Ocean. In order to counter the US influence, Russia sent its fleet in 1968. Since 1970, Russia has been steadily building trade and economic connections with India and the countries bordering the Indian Ocean. That country has entered into bilateral treaties with several countries of the region such as India, Sri Lanka, Bangladesh, Iraq, Egypt, Mauritius, Somalia, Seychelles, etc. Russia maintains military bases at Berbera, Masira, Umakas, Dahalak and Socotra islands. It constructed naval radio stations and ammunition depots too at the north of the Red Sea. It has also obtained access to port facilities in Somalia, Mauritius and Singapore. Russia is trying to gain a foothold in the oil rich countries of the Middle East also.

In the recent past, China has also shown keen interest in the Indian Ocean. With the former U.S.S.R. having lost its super-power status, China wants to take full advantage of the situation and is trying hard to fill in the vacuum, and ultimately assume the leadership of the Afro-Asian world. One of the major aims of the Russian push in the Indian Ocean is to contain Chinese influence in the African and Arab countries and in Southeast Asia. Since Indian and Australian naval capabilities are not significant, the western countries are deeply concerned over expanding influence of Russia in the Indian Ocean. India is currently preoccupied with economic development programmes. With her modest financial resources, India finds it difficult to develop a strong naval capability to deter encroachment by other major powers on India's role in the Indian Ocean.

India could establish her supremacy in the Indian Ocean in 1988 when Sri Lankan mercenaries invaded Maldives and Indian forces had come to its rescue. Maldives has been consistently turning down lucrative offers by big powers to provide facilities for establishing military bases on its soil in order to make the Indian Ocean a zone of peace.

The littoral countries encroaching the Indian

Ocean are closely associated with this ocean traditionally, culturally and economically. These countries are awfully worried about the geopolitical affairs of the ocean. The concerned countries want to keep the Indian Ocean a zone of peace rather than an area of cold war, great power rivalry, super power confrontation and a battle-field.

Maintaining the environment of peace in the Indian Ocean is very important for the littoral states because almost all the countries surrounding this ocean are at the developing stage. They are in the process of economic reconstruction and development, social change towards modernization and building the democratic political system. As such these countries cannot afford confrontation and war and they want to maintain peace in the Indian Ocean at any cost. Majority of these countries are members of the Non-aligned movement and do not want any external interference in the affairs concerning Indian Ocean. The member countries of the Non-aligned group strongly feel that the socio-economic prosperity in the region will only be possible when there is an atmosphere of economic co-operation and co-ordination among the richly endowed littoral states. This can happen only if the external powers are not allowed to show their presence in the Indian Ocean and are deterred from influencing the littoral states. The conference of the Heads of Non-aligned nations held at Lusaka in 1970 called upon all states to identify the Indian Ocean as a zone of peace and should also be free of nuclear weapons. The UN General Assembly has also passed a resolution to keep the Indian Ocean zone as a '*zone of peace*.'

However, there are several obstacles in maintaining peace in the Indian Ocean. A large number of the littoral states are small, economically poor and politically immature. Some of the littoral states such as India, Australia, Republic of South Africa, Iran and Indonesia are strong enough to influence the political events at the regional and international levels. Environment of politically strained relations between some of the neighbouring countries is also a great hindrance in the way of peaceful co-existence. The situation has become rather complicated with the growing interference of China and Japan. China wants to establish itself as a major power in the Afro-Asian region. Similarly, Japan wants to increase its influence because nearly 50 per cent of the Japanese international trade is carried through the Indian Ocean. The Gulf War made the Indian Ocean the focal point of the world geopolitics. The growing terrorism in the Muslim world has also assumed dangerous posture for the world in general and for the Indian Ocean in particular.

Thus, peace in the Indian Ocean is very fragile and it can be maintained only by the cooperation of the littoral states. Only such cooperation can save this ocean from exploitation by the developed countries and the erstwhile colonial powers.

ROUTES INTO INDIA

It has already been mentioned that India is separated from the rest of Asia by a broad *no-man's land* of mountains, from the north, north-west and north-east. Most of the Himalayan ranges are either ice bound or covered by thick vegetation and offer an almost an impenetrable wall. This makes India an intelligible isolate. However, there are a few passes which provide routes into India.

Three high passes *viz. Muztagh* (Snowy mountain), the *Karakoram* and the *Changchemo* are all over 6,000 metres above sea level and offer little scope for interaction between the two sides of the mountain ranges. Some passes in the high Himalayas such as *Burzil* and *Zoji La* in Jammu and Kashmir; *Bara Lacha La* and *Shipki La* in Himachal Pradesh; *Thagla La*, *K-Lang*, *Niti and Lipu Lekh* in Uttarakhand; *Nathu La* and *Jelep La* in Sikkim are used for crossing the main Himalayan range.

Towards the north-west, the frontier formed by the Himalayas is continued by the *Karakoram* range and the *Hindukush*. Further south lie the *Safed Koh*, *Sulaiman* range and the *Kirthar range*, which separate India from Afghanistan and Baluchistan. Thus the real natural frontier of India lies far away from the present man-made and artificial frontier between India and Pakistan which is the creation of partition of the country in 1947. The mountain ranges here become shallow and narrow down to less than 500 km between Turkestan and the Punjab (undivided) Plains. The *Hindukush* is pierced by numerous passes which are snow covered in winter but can easily be crossed in other seasons. There are a few passes which are less than 1,600 metres above sea level and offer easy access into India. The passes of *Khyber*, *Malakand*, *Tochi*, *Gomal* and *Kohat* have their base in *Badakhshan* province of Afghanistan and provide passage from Afghanistan to the Indian subcontinent. Towards the south, the highways of *Herat* and *Seistan* converge at Quetta. It is worth noting that Quetta lies at the head of the *Bolan pass* and provides one of the most significant gateways into the Indian subcontinent. History reveals that the barrier was at no time an insuperable one, and at all periods, invaders, settlers and traders have found their way over the high and desolate passes into India, while Indians have carried their commerce and culture beyond her frontiers by the same routes. India's isolation has never been complete, and the effect of the mountain wall in developing her unique civilisation has been over emphasised. People after people, literally nations have pressed into the Indian subcontinent through these passes and changed the fate of various dynasties in India. Hordes of invaders have attacked and conquered India through these passes.

Perhaps the earliest immigrants of civilised man into India were the *Dravidians* about whom little evidence is available. It is believed that they migrated into India from the *Tigris Valley* along the *Makran Coast* of present Pakistan. This was followed by many others in the pre-historic times, the most prominent being the *Aryans* who migrated by the Kabul approaches. Later in the historic times, several other people such as *Greeks*, *Parsees*, *Huns*, *Mughals* and *Mohammadans* entered India mostly through these passes.

In the east, the hills forming the boundary between India and Myanmar are comparatively low and rarely exceed 3,000 metres in elevation. But the dense forests, heavy rainfall for half the year, difficult terrain and a large number of swift flowing rivers have acted as effective barriers between the two countries. The only passages are along the courses of rivers Brahmaputra, Mekong, Salween and Ayeyarwadi—the main gaps being the *Ann*, *Teju*, *Manipur*, *Tulu*, *Tongap*, etc. Therefore, not many foreigners have crossed through this frontier into India. In fact, reaching Ayeyarwadi valley in Myanmar from India is much easier by sea than by land. The opening of a new trade route in 1995 connecting *More* in Manipur with *Tamu* in *Myanmar* may help in developing trade and cultural relations between the two countries. The bus service proposed in June 2014 between Imphal (Manipur) and Mandalay covering a distance of 579 km may further strengthen ties between India and Myanmar.

It is surprising that until the coming of European seamen, no considerable power was founded in India from the sea; but some were from India. Initiative to the east really came from India. Hindu traders and colonisers took their civilisation by sea to the south-east Asian countries. Buddhism originated in India and spread to the whole of eastern Asia. The Cholas had an empire in the East Indies. Several other Hindu cultural traits are still found in large parts of the Far East.

LAND OF DIVERSITIES

India is a land of great diversities and contrasts. It is but natural that an area as vast as the Indian subcontinent should have considerable physical diversity. *The extremes of physical and human geography of India are extreme indeed.* In the south is the Plateau which is one of the oldest and least disturbed land masses on the earth's surface. Its rocks have never been extensively covered by sea since their formation in the pre-cambrian period over 3,000 million years ago. In contrast to this, the Himalayan mountain ranges and the Great Plains represent the most recent formations. The denudational processes have made these contrasts still sharper. While the mountain ranges in the north have very youthful topography with sharp peaks and steep-sided valleys, the Peninsular plateau shows old and senile topography with gently rising ridges and wide valleys. The Aravalis and the Himalayas are perhaps the oldest and the youngest ranges on the earth's surface. The differences are most striking even in the landforms of recent origin. Within a distance of a few hundred kilometres from north to south, one can reach from the highest peak of the world to the flat, featureless and monotonous plain.

Even the rivers of the Himalayan and the Peninsular regions have contrasting characteristics. The Himalayan rivers have their origin in the snow covered areas. As such, they receive water even in dry season due to snow melt and are perennial. On the other hand, rivers of the Peninsular plateau carry only

rain water and the quantity of water carried by them decreases considerably in dry season. They are, therefore, termed as seasonal rivers. Moreover, the rivers of the Peninsular plateau have reached maturity whereas the Himalayan rivers are still in their youthful stage. Most of the Himalayan region is made of sedimentary rocks while the Peninsular plateau has mostly igneous and metamorphic rocks. Hemmed between the Himalayas in the north and the Peninsular plateau in the south, lies one of the largest alluvial plains of the world. This vast plain stretching in a great curve from Arabian Sea to the Bay of Bengal, consists of extremely fertile soils washed down by the streams and rivers for thousands of years.

Climatic contrasts are no less pronounced than the physiographic contrasts. Although a typical monsoonal realm, Indian climate exhibits a wide range of climatic variations. While the mercury may dip to (–) 40°C during winter nights at Dras or Kargil in Jammu and Kashmir, the temperature may stand at a fairly high level of 20°C to 25°C at Chennai. In summer, the day temperature at Barmer in Rajasthan may soar to 48°C–50°C while the higher reaches of the Himalayas may still remain snow covered. The differences are equally striking in rainfall patterns also. Mawsynram near Cherrapunji receives an annual rainfall of over 1,221 cm as compared to only 12 cm received at Jaisalmer. Several places in Garo hills receive more rainfall in a single day than received by Jaisalmer in a long span of ten years. The people of Mumbai experiencing maritime climate may not have any idea of extremes of climate. But Delhiites living in continental climate have to pass through the entire cycle of seasonal changes. As a result of climatic extremes, the natural vegetation varies from dense tropical evergreen forests of the Western Ghats, North-Eastern states and Andaman and Nicobar islands to the scanty shrub bush vegetation of the Thar Desert and its adjoining areas.

Extremes and diversities of the physical features and climatic conditions have produced cultured heterogeneity of a high order. On one end of the scale are the vast uninhabited areas of Ladakh and the Thar desert and on the other end are the river valleys and deltas accounting for some of the highest population densities in the world and that too based on purely agrarian economy. The length and breadth of the country comprises a rich mosaic of religions, languages, cultures and races and is, thus, heterogeneous in character and spirit. All levels of economic development from that of the *stone age* to the *satellite* and *computer* age are seen in the country. In large parts of the country, purely tribal, agricultural, industrial and commercial economies exist simultaneously. Considering its physical and cultural diversities India is often called the *'epitome of the world'*.

UNITY IN DIVERSITY

It must not be forgotten that the above mentioned diversity of India is based on its underlying unity. India has been able to project itself as a single territorial unit in the face of physical, political, social and economic contrasts. The unifying role of the Great Plains between the Himalayan ranges on one hand and the Peninsular India on the other can hardly be ignored. Climatically, the monsoonal rhythm of seasons provides a strong element of uniformity. The concentration of monsoonal rainfall to a few months in a year and the associated agricultural activities are an all India phenomena. Many of our cultural traditions are strongly tied to the monsoons. Our saints have spread the message of universal brotherhood which has helped a great deal in uniting different sections of society in India and making the country a united nation. The *Ramayana* and the *Mahabharata* have provided themes even for tribal dances and music for thousands of years and still continue to do so. Although *Hinduism* is the way of life for majority of Indians, *Hinduism* and *Islam* are intertwined into a composite matrix on the Indian land. It is in this composite matrix that integration of India is strongly rooted. In fact there are almost as many Muslims in India as in Pakistan. Centuries of foreign rule failed to disrupt our cultural ties.

On economic front, the development of inter-regional linkage and the emergence of a national home market have played a significant role in uniting the country. For example, tea from Assam, wheat from Punjab and Haryana, minerals from Chotanagpur plateau and spices from the hill areas of the southern states are used all over the country and in turn these areas obtain items required by them from other areas. This process has been accelerated by rapid development of transportation and communication.

LAND OF POTENTIALITIES

India is blessed with a large variety of natural resources in huge quantities. Many of these still await exploitation. Whereas nature has been bountiful to India, the inhabitants of this country have not been able to develop requisite technology, in the modern context, to harness these resources. India is, therefore, often referred to as '*poorly developed rich country*' or '*a rich country inhabited by poor people*'. Sometimes it is also called the '*land of the future*' or '*land of potentialities*'.

India's huge mineral wealth encompasses a wide range which is supposed to be sufficient enough for developing a modern industrial base. India is particularly rich in the deposits of high grade iron ore, manganese and chromite. Her reserves are said to be adequate with respect to limestone, bauxite, coal and strategic minerals.

Although India's forest resources are not very large and there is urgent need to increase the area under forests to meet the growing demand for forest products and to maintain the ecological balance, yet they are able to feed many forest based industries like paper, plywood, match box, furniture, resins, lac, etc.

India has vast resources of both surface and ground water which can be used for irrigation, power generation, industries and for drinking purposes. Only a small proportion of this natural resource has actually been utilised offering us enormous potentialities. It is estimated that about 42% of the cropped area is presently irrigated whereas about three-fourths of the cropped area can be irrigated by making optimum use of the water resources available to us. Similarly only one-fourth of the total water power potential in the country is actually used. Indian rivers offer numerous sites suitable for generating hydroelectricity.

India is one of the leading agricultural countries of the world and agriculture is the most important occupation of Indians. But the overall production and the yields per hectare are very low as compared to that in the advanced countries. The total production can be increased only by increasing the yields as all the cultivable land has already been brought under plough. This requires intensive use of high yielding varieties of seeds, fertilisers and irrigation facilities.

Of course, the greatest asset of India is its population which is second only to that of China. The poverty stricken, much cursed and ever growing vast ocean of humanity, if properly channelized, could be converted into huge manpower resource and could prove to be a boon, rather than a bane, for national development. The only problem is that not many avenues are open due to backward state of economy in the present day context.

INDIA AND THE ORIENTAL WORLD

The Oriental world includes into its fold the countries of East Africa, South West Asia, South Asia and South East Asia. These countries surround the Indian Ocean which unites them through sea routes. Economically and culturally, India's major contacts with outside world for the last two millennia have been by sea, earning India, the title of ***'Mistress of the Eastern Seas'***. The opening of the Suez Canal has brought the countries of Southern Europe and North Africa very close to India. In ancient days, the boats of the Babylonians, the Egyptians and the Phoenicians used to sail in the Arabian Sea. Hindu and Buddhist cultures and religions spread to far off areas towards south and east Asia. There are a number of temples in Thailand with *slokas* from *Ramayana* engraved on the walls. Bali in Indonesia was the seat of Hindu Kingdom. Mauritius in the Indian Ocean is a '*miniature India*'.

Our relationship through land frontiers are much older than our maritime contacts. Passes, gorges and valleys in the mountain chains offered passages to travellers in the ancient times. Waves of settlers from the north-west were lured by the riches of India in general and that of the Great Plains in particular. Mongols, Turks, Arabs and Iranians entered India as conquerors and settled down here. These settlers got assimilated in the national mainstream with the passage of time which led to a mixture of races, cultures, people and ethnic groups. Some of the invaders brought architectural excellence to India and took back to their homeland the Indian numerals, the decimal system and the ideas of *Upnishads*. *Buddhism* travelled from India to Tibet through land routes and further crossed over to China, Korea and even Japan. Thus, India is an integral part of the oriental world and holds a significant position in the region.

STRATEGIC SIGNIFICANCE OF INDIA

India stands at the head of the Indian Ocean at the very centre of the *Eastern Hemisphere* commanding trade routes running in all directions. Its location, size and economic resources have made it the most dominating country among the *littoral states*. Indian Ocean is the only ocean in the world which has been named after a country *i.e.* India. This only proves the great prominence enjoyed by India in early days when these oceans were given their names. The trans-Indian Ocean routes connecting the developed countries of Europe in the west and the developing countries of Asia in the east must skirt the shores of India. No other country has such a long coastline on this ocean as India has. Therefore, *the Indian Ocean is truly Indian Ocean*. Most of the air routes between Europe, West Asia and Africa in the west and East Asia, South East Asia, Japan and Australia in the east also pass through India.

The centrality and the consequent significance of India to broader Indian Ocean geopolitics and economics has been proved beyond doubt. It was India's status as the principal entrepot in a highly profitable oceanic trade structure which attracted the West Asian Muslims, and the European colonial powers towards India. India became the '*jewel in the crown*' of the vast British empire due to its wealth and because of its role as a fulcrum upon which the imperial and commercial system in Asia was balanced.

India thus commands an important strategic position on the globe with respect to trade as well as social and cultural interaction. India is a concept. India is an experiment through ages. India is unique, India is India—no parallel example exists.

INDIA'S POLITICAL DIVISIONS

About two centuries of British rule left India fragmented into nine British provinces and 562 small

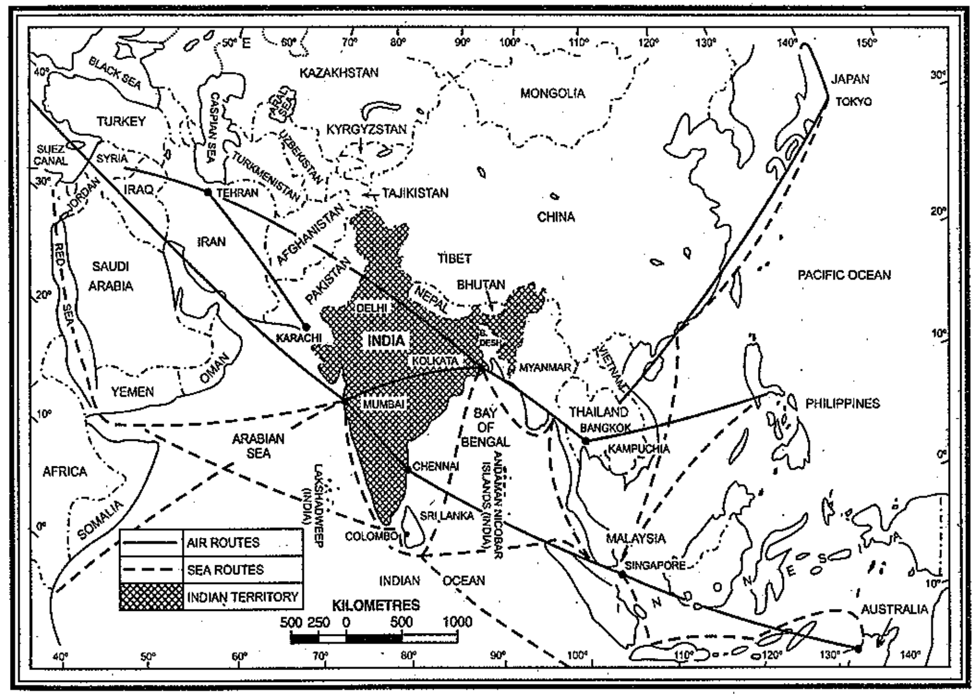

FIG. 1.15. Location of India at the head of Indian Ocean in the Oriental World on the International Highway of Trade and Commerce

princely states at the time of independence in 1947. The constitution of India was adopted with the establishment of Democratic Republic of India on 26th Jan., 1950 and India became a Union of States.

After Independence, the country was reorganised by merging various princely states and other states. During the first phase of reorganisation of Independent India, there were four categories of states :

(*i*) **States of 'A' category** which included Uttar Pradesh, Bihar, West Bengal, Assam, Odisha, Madhya Pradesh, Madras (present Tamil Nadu, Andhra Pradesh and Telangana), Bombay (present Maharashtra and Gujarat). These were governed by a governor.

(*ii*) **States of category 'B'** including PEPSU, Central India, Mysore (present Karnataka), Saurashtra, Rajasthan, Hyderabad and Travancore-Cochin. These were governed by the chief of the states.

(*iii*) **The states of 'C'** category included Ajmer, Kutch, Coorg, Delhi, Bilaspur, Bhopal, Tripura, Himachal Pradesh, Manipur and Vindhya Pradesh, governed by the Lieutenant Governors.

(*iv*) **States of 'D'** category included Andaman and Nicobar Island, governed by the central government.

States Reorganisation Commission

The above classification lacked economic viability or a sustainable administrative machinery and did not represent the unity of the nation. The Indian government devised a mechanism based on such considerations as distinctive regional, linguistic, cultural and economic characteristics. With this background and with growing demand for creation of linguistic states, the first linguistically, based Andhra state was created by separating Telugu speaking areas from the composite Madras state on October 1, 1953. Telangana area was added to Andhra state and Andhra Pradesh was formed on November 1, 1956. The formation of Andhra state in 1953, quickly sparked renewed demand of political recognition by other linguistic and cultural groups. This led to the appointment of States Reorganisation Commission in December, 1953. The commission submitted its report on 30th September, 1955, recommending reorganisation of India into 16 states and 3 territories. The government accepted the major part of the report but proposed the reorganisation of India into 15 states and 7 territories. Finally the Parliament passed the States Reorganisation Act, 1956 reorganising India into 14 states and 6 union territories as on 1st November, 1956.

Post-Reorganisation Changes

The Reorganisation of the states as per recommendations of the States Reorganisation Commission could not meet the aspirations of the people living in different parts of the country and pressing demands have been made from time to time for readjustment of politico—territorial units on linguistic, ethnic and cultural grounds. The trend had been towards creating more states thereby leading to division and fragmentation of the existing states. The influence of underlying centrifugal forces in the unity of India is conspicuous in these changes.

Within a short span of five years after the recommendations of the States Reorganisation Commission were implemented with slight modifications, the erstwhile bilingual province of Bombay was bifurcated into Gujarati speaking Gujarat and Marathi speaking Maharashtra on 1st May, 1961. The Portuguese colonies of Goa, Daman and Diu were the last remnants of the European occupation in India. These were liberated from the foreign yoke and they became part of India on 16th December, 1961. This completed the territorial integration of the Indian Union.

Several new states have been carved out in the north-eastern region of the country in response to demands by the tribals. In 1957 the north eastern part of Assam was separated and was designated as North-East Frontier Agency (N.E.F.A.). The Naga hills territory was a centrally administered area and was known as the Naga Hills Tuensang Area. It was renamed as Nagaland in 1961 and was given the status of a state on 1st December, 1963. Manipur became a Union Territory under States Reorganisation Act 1956 and was made a full fledged state of Union in 1972. Meghalaya was created as an autonomous state within the state of Assam on 2nd April, 1970. The full-fledged state of Meghalaya came into existence on January 21, 1972. Tripura was annexed to the

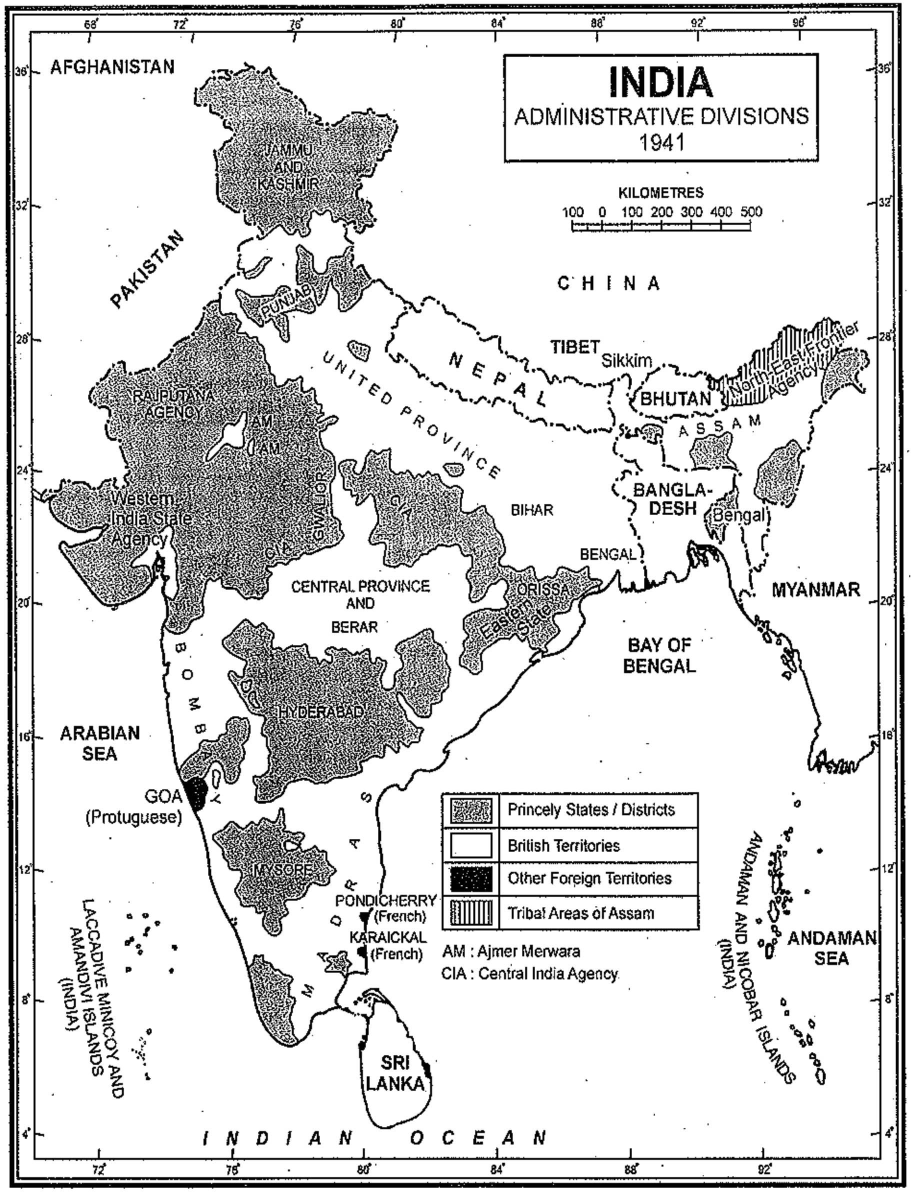

FIG. 1.16. India : Administrative Division, 1941

Indian Union in 1947 and became centrally administered territory in 1956. It was granted statehood in 1972. Thus three states in the north-eastern region came into existence in 1972. Sikkim ceased as a protectorate of India in 1974 and became an Associate State of India thereafter. It became an integral part of India as a result of referendum held on April 14, 1975. The North-East Frontier Agency (N.E.F.A.)

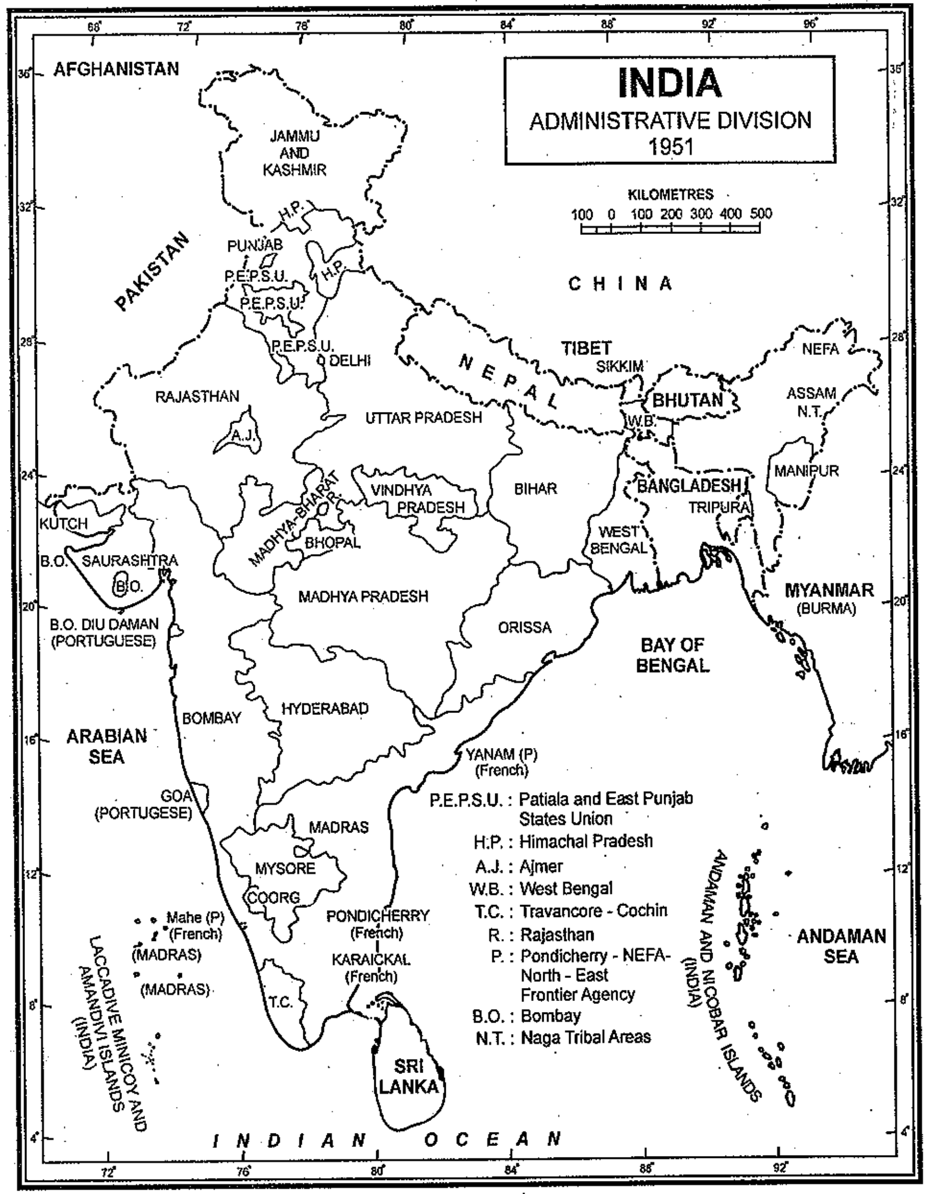

FIG. 1.17. India : Administrative Division, 1951

was given the new name of Arunachal Pradesh and was granted full statehood on February 20, 1987. Mizoram was one of the districts of Assam till 1972 when it became a union territory with the implementation of the North-Eastern Reorganisation Act. It was granted full statehood on February 20, 1987.

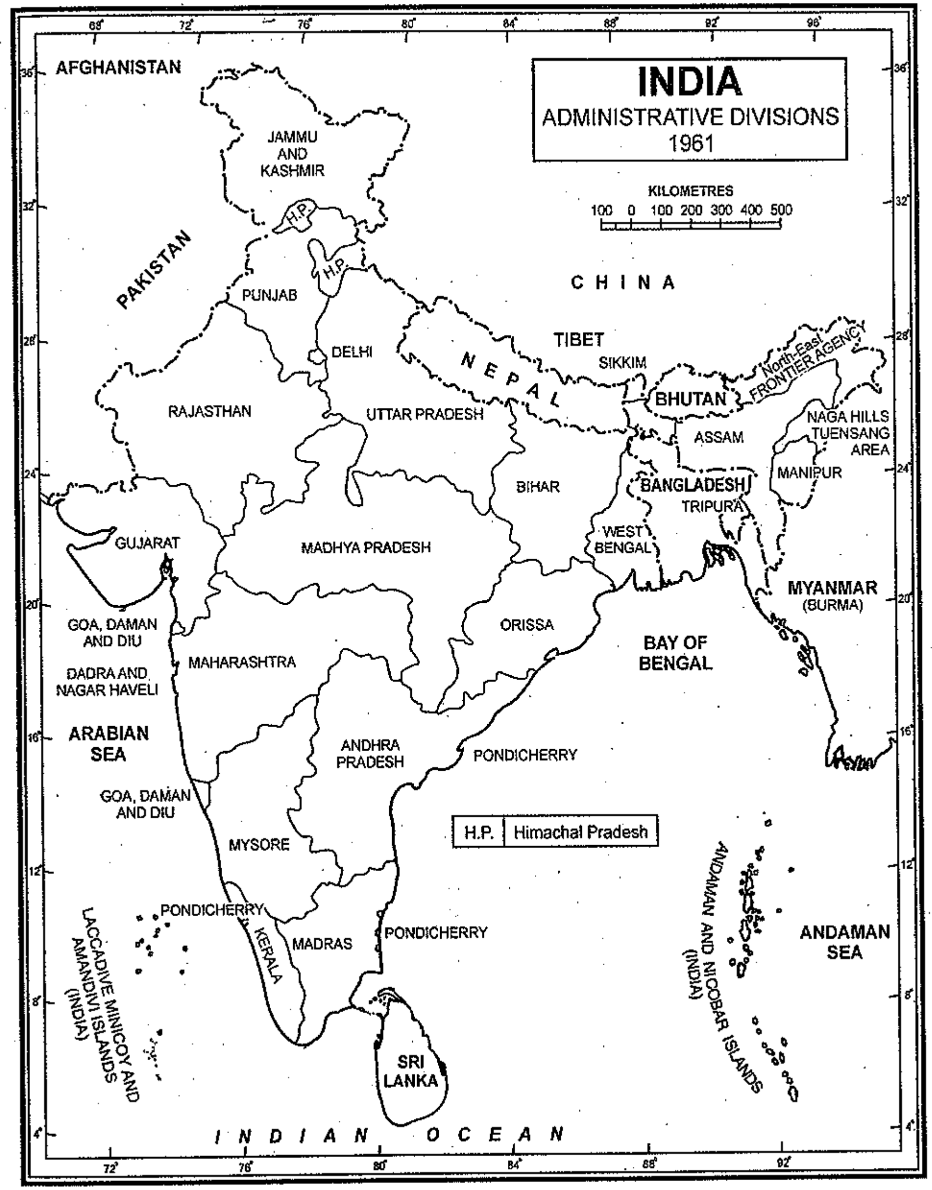

FIG. 1.18. India : Administrative Division, 1961

Turning again to the south, it is worth mentioning that the Mysore State, created in 1956, was renamed as Karnataka in 1973 on the demand of Kannada speaking majority of the area. Goa which was liberated in 1961 was conferred statehood on May 30, 1987 although Daman & Diu still remain as union territory.

FIG. 1.19. India : Political Divisions at Present

In the north-western part of the country, the bilingual state of Punjab was divided into Punjabi speaking Punjab and Hindi speaking Haryana on 1st November, 1966. Thus the new state of Haryana was born on this date. Certain hill areas of erstwhile Punjab were transferred to Himachal Pradesh. It was granted full statehood on January 25, 1971.

Three new states came into being in November 2000. Chhattisgarh was carved out of Madhya Pradesh on November 1, 2000 as the 26th state of the union to fulfill the long cherished demand of the tribal people. The hill areas of Uttar Pradesh were separated to form a new state of Uttarakhand on November 9, 2000. This is the 27th state of India which shares its

TABLE 1.3. Political Divisions of India (2011)

Sl. No.	States	Area in sq km	Capital	Principal languages	No. of districts at 2011 census
1.	Andhra Pradesh	1,60,229	Hyderabad	Telugu	13
2.	Arunachal Pradesh	83,743	Itanagar	Monpa, Miji, Aka, Sherdukpen, Nyishi, Apatani, Tagin, Hill Miri, Adi, Digaru-Mismi, Idu-Mishmi, Khamtli, Miju—Mishmi, Nocte, Tangsa and Wancho	16
3.	Assam	78,438	Dispur	Assamese	27
4.	Bihar	94,163	Patna	Hindi	38
5.	Chhattisgarh	1,36,034	Raipur	Hindi	18
6.	Goa	3,702	Panaji	Konkani and Marathi	2
7.	Gujarat	1,96,024	Gandhinagar	Gujarati	26
8.	Haryana	44,212	Chandigarh	Hindi	21
9.	Himachal Pradesh	55,673	Shimla	Hindi and Pahari	12
10.	Jammu & Kashmir	2,22,236*	Srinagar	Urdu, Kashmiri, Dogri, Pahari, Balti, Ladakhi, Punjabi, Gujri & Dadri	22
11.	Jharkhand	79,714	Ranchi	Hindi	24
12.	Karnataka	1,91,791	Bengaluru	Kannada	30
13.	Kerala	38,863	Thiruvananthapuram	Malayalam	14
14.	Madhya Pradesh	3,08,000	Bhopal	Hindi	50
15.	Maharashtra	3,07,713	Mumbai	Marathi	35
16.	Manipur	22,327	Imphal	Manipuri	9
17.	Meghalaya	22,429	Shillong	Khasi, Garo and English	7
18.	Mizoram	21,081	Aizawl	Mizo and English	8
19.	Nagaland	16,579	Kohima	Angami, Ao, Chang, Konyak, Lotha, Sangtam, Sema and Chakhesang	11
20.	Odisha	1,55,707	Bhubaneshwar	Oriya	30
21.	Punjab	50,362	Chandigarh	Punjabi	20
22.	Rajasthan	3,42,239	Jaipur	Hindi and Rajasthani	33
23.	Sikkim	7,096	Gangtok	Lepcha, Bhutia, Nepali and Limbu	4
24.	Tamil Nadu	1,30,058	Chennai	Tamil	31
25.	Tripura	10,492	Agartala	Bengali and Kokborak	4
26.	Uttar Pradesh	2,38,566	Lucknow	Hindi and Urdu	71
27.	Uttarakhand	53,484	Dehra Dun	Hindi, Garhwali, Kumaoni	13
28.	West Bengal	88,752	Kolkata	Bengali	19
29.	Telengana	1,14,840	Hyderabad	Telugu, Urdu	10

Union Territories					
1.	Andaman & Nicobar Islands	8,249	Port Blair	Hindi, Nicobarese, Bengali, Malayalam, Tamil and Telugu	3
2.	Chandigarh	114	Chandigarh	Hindi, Punjabi, English	1
3.	Dadra and Nagar Haveli	491	Silvassa	Gujarati, Hindi	1
4.	Daman & Diu	112	Daman	Gujarati	2
5.	Delhi	1,483	Delhi	Hindi, Punjabi, Urdu and English	9
6.	Lakshadweep	32	Kavaratti	Jesery (Dweep Bhasha) and Mahal	1
7.	Puducherry	492	Pondicherry	Tamil, Telugu, Malayalam, English and French	4
	India	32,87,263	New Delhi	—	640

*Includes 78,114 sq km under illegal occupation of Pakistan, 5,180 sq km illegally handed over by Pakistan to China and 37,555 sq km under illegal occupation of China.

The number of districts are as per Administrative Atlas of India, Census of India, 2011.

Source : (*i*) India 2011, A Reference Annual,
(*ii*) Census of India 2011, Provisional Population Totals, Paper 1, p. 32.

international boundaries with China (Tibet) in the north and Nepal in the east. Jharkhand, the 28th state of India was carved out of Bihar on November 15, 2000. This tribal state largely comprises forest tracts of Chotanagpur plateau and Santhal Pargana and has distinct cultural traditions. 29th state of Telangana was carved out of Andhra Pradesh on 2nd June, 2014 thus meeting the long standing demand of people belonging to Telangana region of Andhra Pradesh. So far this is the youngest state of the Indian Union.

There are some small scattered areas in the Union of India which are centrally administered and are known as Union Territories. As the things stand today the Indian Union comprises 29 states and 7 union territories (See **Fig. 1.19**). Their details are given in **Table 1.3**.

It is clear from **Table 1.3** that Rajasthan with an area of 3,42,239 sq km is the largest state of the Indian Union. In fact Rajasthan, Madhya Pradesh and Maharashtra have area more than three lakh sq km each and these three states account for about thirty per cent of the total area of the country. On the other end, Goa is the smallest state with an area of 3,702 sq km only. With the exception of Arunachal Pradesh and Assam, most of the north-eastern states are of small size. From administrative point of view, Uttar Pradesh has the largest number of 71 districts while Goa has only two districts. Bihar, Chhattisgarh, Haryana, Himachal Pradesh, Jharkhand, Madhya Pradesh, Uttar Pradesh, Uttarakhand, Rajasthan and NCT of Delhi have Hindi as their main language.

Demand for New States

Carving of Telangana out of Andhra Pradesh on 02-06-2014 has opened a pandora's box of demands for creating new states in different parts of the country. Demands for creating new states is very old and remained dormant for some time. But formation of new state Telengana has reinforced the old demands and generated more new demands for creating new states. Supporters of demand for new states argue that the existing states are very large and cannot be easily administered. For example Uttar Pradesh with a total population of 19,95,81,477 (Census 2011) spread over 71 districts is the most populous state of India and smooth and fair administration of such a big state is almost impossible. Most of the political parties support the concept of smaller states due to their compulsion of vote bank politics. However, there are some political parties which are opposed to the idea of dividing the present states and creation of new smaller states. They argue that such a trend will gain momentum, the lead to strengthening of centrifugal forces and even may

result in disintegration of the country as happened to erstwhile U.S.S.R. in 1990s. At present, demand for creating new states is gaining strength in several parts of the country and many more demands may spring up in future. Some of the major flash points where demands for creating new and smaller states are becoming louder, are briefly described as under :

1. Vidarbha. Vidarbha region consists of 11 districts of eastern part of Maharasthra with Nagpur as its centre. This region is very rich in mineral and forest resources and is part of cotton growing belt of Maharashtra. However, this region is plogued by poverty and malnutrition. About 70% of the farmer suicides in Maharashtra in 2010s have taken place in this region. The demand for a separate state of Vidarbha was first raised in 1956. The States Reorganisation Commission recommended a separate state of Vidarbha in mid 1950s.

2. Harit Pradesh. Not only the people, but sometimes even the government in power pleads for division of its own state. This is true in case of Uttar Pradesh where the political party in power suggested the division of the state into four states *viz.* Harit Pradesh (Western U.P.), Awadh Pradesh (Central. U.P.), Purvanchal (Eastern U.P.) and Bundelkhand in the year 2010. However, the initial demand for carving Harit Pradesh out of U.P. was made by Rashtriya Lok Dal (RLD). The issue of Harit Pradesh comprising about 24 agriculturally rich districts with its proposed capital at Meerut come-up for discussion at the National Reorganisation Commission in 1953. Thereafter the demand was raised in 1960. It was only in 1990s that serious movement for Harit Pradesh was launched by RLD, but the movement never gained much strength.

3. Awadh Pradesh. Consisting of about 21 districts, Awadh Pradesh lies in the centre of the present state of Uttar Pradesh. It forms a transitional zone between the proposed Harit Pradesh in the west and Purvanchal in the east. If formed, it will have its capital as Lucknow.

4. Purvanchal. If constituted, the state will comprise of eastern part of Uttar Pradesh with 27 districts including Gorakhpur, Allahabad and Varanasi. Movement for a separate state of Purvanchal began in 1996 which went on till 2002. No serious movement had taken place after that. If formed, this state would like have Allahabad as its capital.

5. Bundelkhand. It is a dry and under-developed zone comprising seven districts of Uttar Pradesh and five districts of Madhya Pradesh. Surprisingly Bundelkhand was a separate state at the time of independence. It was split into two and merged with Uttar Pradesh and Central Provinces (Madhya Pradesh). Bundelkhand is a distinct agro-climatic zone and needs a region-specific agricultural policy like irrigation and other agricultural inputs. Demand for a separate state of Bundelkhand was first raised by Bundelkhand Mukti Morcha (BMM) in 1989. This demand has gathered momentum following repeated droughts and crop failures during the last 15 years. If formed, this state would most popularity have Banda as its capital.

6. Gorkhaland. Gorkhaland comprises mainly Darjeeling and its adjoining areas in the northern part of West Bengal. Demand for separate state of Gorkhaland is surprisingly over 100 years old. Agitation for Gorkhaland turned violent in 1980s when 28 month long agitation spearheaded by the Gorkha National Liberation Front resulted in the loss of over 1200 lives. Since 2007, Gorkha Janmukti Morch (GJM) has been leading the demand for statehood. An autonomous set up within West Bengal for hills, as offered by the central government, has failed to satisfy the sentiments of majority of Gorkhas. The demand for a separate state of Gorkhaland is primarily for safeguarding the identity of the Gorkhas and for the overall development of the region.

7. Badoland. Badoland People's Front is demanding the creation of Bodoland out of Assam state. It is a narrow strip extending in an east-west direction just to the south of Assam-Butan boundary. Northern parts of districts of Kokrajhar, Barpeta, Nathari and Darang are included in this region.

8. Garoland. Garoland is situated in the western part of Meghalaya comprising three districts of South Garo Hills, East Garo Hills and West Garo Hills. Garos is one of the three major tribes of Meghalaya which has been demanding a separate Garoland comprising in western half of Meghalaya. The other two tribes are Khasi and Janlia.

9. Greater Cooch Behar. It consists of the present districts of Darjeeling, Jalpaiguri, Cooch

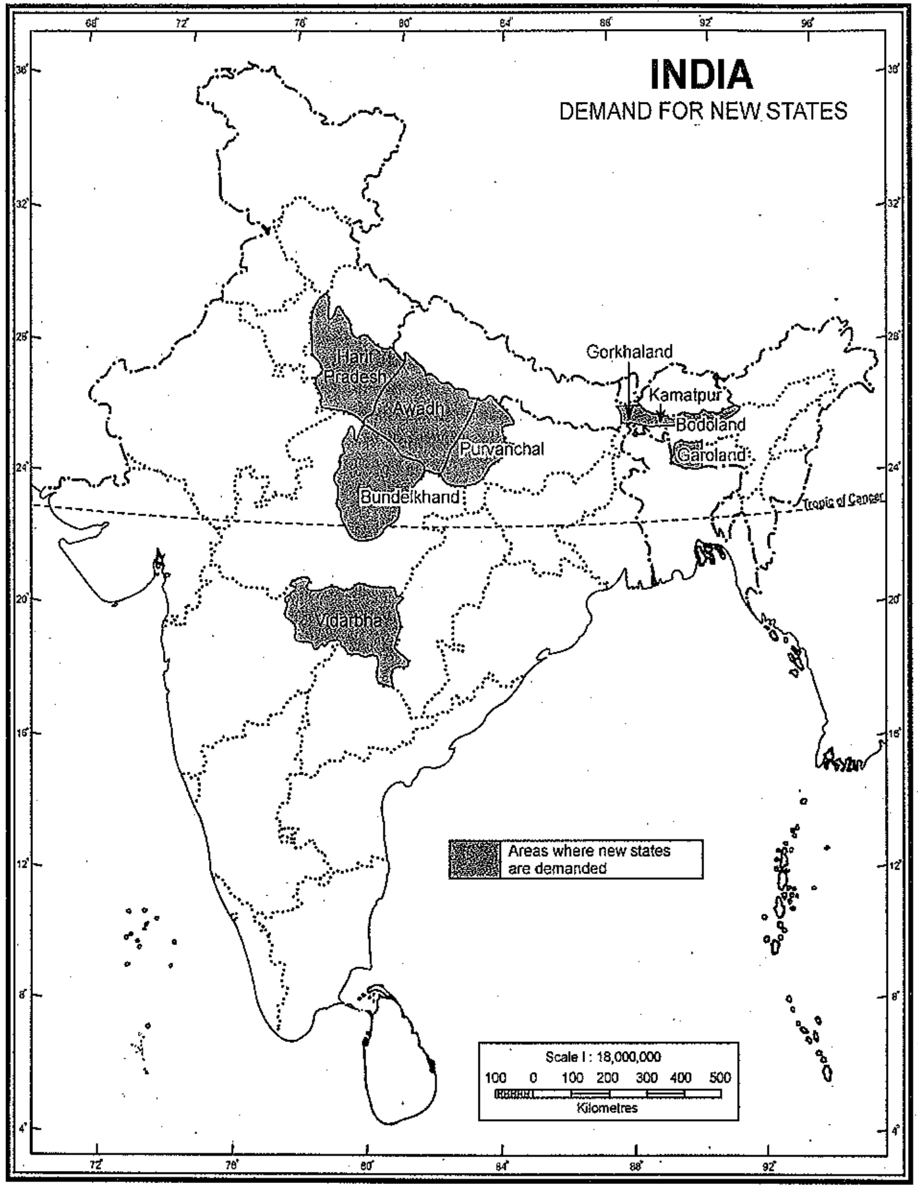

FIG. 1.20. Demand for new states

Behar, and North and South districts of Bengal and undivided district of Goalpara in Assam that included today's Bongaigoan, Dhubri and Kokrajhar districts. The British government took charge of the Cooch Behar kingdom through various treaties during 1773-1902 and returned the land to the royals 27 days before independence. On August 28, 1949, the kingdom was finally merged with India. Demand for

separate state began in 1998 but gradually dried up by 2006. However, demand for creation of this state has again gained strength after the central government created Telangana as a separate state.

10. Kamatpur. It consists of 17 districts of northern part of the present West Bengal and contiguous parts of the present Assam. People of this region are demanding a separate state on the lines of Gorkhaland and Greater Cooch Behar. There are some areas which are being claimed by the supporters of all the three states *viz.* Gorkhaland, Greater Cooch Behar and Kamatpur.

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Geological Structure

INTRODUCTION

The geological structure, which includes the arrangement and deposition of rocks in the earth's crust, plays a dominant role in determining the relief of land and nature of soil. It also helps in knowing about the vast mineral wealth buried beneath the earth's surface. As such, study of geological structure plays a vital role in agricultural and industrial growth and in the economic prosperity of the country. For example, the vast alluvial Indo-Gangetic plain has very fertile soils and is extremely useful for agriculture. But it is almost completely devoid of any mineral deposits worth the name. On the other hand, igneous and metamorphic rocks of the peninsular plateau, especially those of the Chotanagpur plateau are very rich in mineral resources. Similarly the study of geological structure helps in land use planning, development of transport and communication lines, increasing potentials for irrigation, determining the quality and quantity of ground water resources and understanding disasters like earthquakes, volcanoes, landslides, floods, etc. Therefore, it is necessary for us to study the geology of India before we proceed to learn more about the geography of the country.

GEOLOGICAL REGIONS OF INDIA

Geologically, India is divided into three regions, *viz*., (1) *the Peninsular region*, including the Meghalaya plateau in the north-east and the Kuchchh-Kathiawar region in the west; (2) *the extra-peninsular region*—the Himalayas and their eastern extensions including Andaman and Nicobar Islands and (3) *the Indo-Gangetic plain*, between Peninsular and exra-peninsular region.

Although the *triple tectonic division* of India, as mentioned above, is generally held valid and is readily accepted by majority of geologists, some scholars recognise only two geological divisions of India *i.e.* the *Peninsular* block and the *Extra-Peninsular* region comprising the Himalayan ranges and the Indo-Gangetic plain. These macro-regions present most striking geological contrasts. The Peninsula is one of the oldest land-masses of the earth and is dominated by open senile topography. The Extra-Peninsula, on the other hand, presents the most youthful relief of the earth in the form of the Himalayas. The alluvium filled Indo-Gangetic plain presents flat, featurless and monotonous topography. The Indian Peninsula has not undergone marine

submergence since the *Cambrian period* and is not much affected by the tectonic forces. In contrast, the extra-peninuslar region has its origin in the Tethys Sea and is prone to tectonic forces resulting in devastating earthquakes. It is a weak and flexible portion of the earth's crust which has been folded, faulted and overthrust.

GEOLOGICAL HISTORY OF INDIA

Geologically India represents a monumental assemblage of rocks of different character belonging to different ages, ranging from pre-Cambrian (prior to 600 million years) to the recent times. **Sir T. Holland** of the *Geological Survey* of India has classified the rock systems of the country into following four major divisions :

1. The Archaean Rock System.
2. The Purana Rock System.
3. The Dravidian Rock System.
4. The Aryan Rock System.

The major geological systems of India are shown in **Fig. 2.1**.

1. THE ARCHAEAN ROCK SYSTEM

The word 'Archaean' was first used by **J.D. Dana** for rock structure prior to the Cambrian system. Obviously the Archaean rocks are the oldest in the world. The Archaean rock system includes the following rock groups :

(a)* The Archaean System-Gneisses and Schists.** These are the oldest rocks and were the first to be formed at the time of cooling and solidification of the upper crust of the earth's surface in the pre-Cambrian era (about 4000 million years ago). Although their broad characteristics are well known, the details of their origin continue to arouse considerable speculation. They are all azoic, thoroughly crystalline, extremely contorted and faulted, often formed as plutonic intrusions and generally have a well defined foliated structure. They often underlie strata formed subsequently and the system is generally known by names of the ***'Fundamental Complex' or the ***'Basement Complex'***. Their details are complex but recent advances in geochemistry are likely to enhance our understanding of their formation.

The most common Archaean rock covering about two-thirds of the Peninsular surface is gneiss. This is the rock which, in mineral composition, may vary from granite to gabro, possesses a constant, more or less foliated or banded structure. The schists, mostly crystalline, include mica, talc, hornblende, chlorite, epidote sillimanite and graphite schists.

The crystalline metamorphosed sediments and gneissic rocks cover large parts of India. The central and the southern parts of the Peninsula are occupied by this rock system. To the north-east of the Peninsula, they occupy wide areas in Odisha, Meghalaya, Madhya Pradesh, Chhatisgarh and Chotanagpur plateau of Jharkhand. They also cover the whole of Bundelkhand in the north and to the north-west, they are found in a number of isolated outcrops, extending from north of Vadodara to a long distance along the Aravalis. In the extra-peninsula, these rocks are exposed all along the Himalayas, forming the bulk of the high ranges and the backbone of the mountain system (**Fig. 2.2**).

***(b)* The Dharwar System.** This system derives its name from the rocks first studied in the Dharwar district of Karnataka where such rocks are found in abundance. The Dharwars include some of the highly metamorphosed rocks of both sedimentary and igneous origin. According to **Wadia**, the Dharwar System is the most ancient metamorphosed sedimentary rock-system of India, as old as, and in some cases older than, the basement gneisses and schists. He further adds that the weathering of the pristine Archaean gneisses and schists yielded the earliest sediments which were deposited on the bed of the sea, and formed the oldest sedimentary strata, known in the geology of India as the Dharwar system. Some of the metamorphosed rocks of the igneous origin are also included in this system. Most rocks of the Dharwar system are so metamorphosed that they are practically indistinguishable from their primitive formations. The major rocks of the Dharwar system are hornblende, schists, quartzites, phyllites, slates, crystalline limestones and dolomites. These rocks were deposited in three major cycles, the earliest one is over 3,100 million years old and the latest one about 2,300 million years. They were metamorphosed around 1,000 million years ago.

The Dharwar system is very well developed in the Dharwar-Bellary-Mysore belt of Karnataka. It also

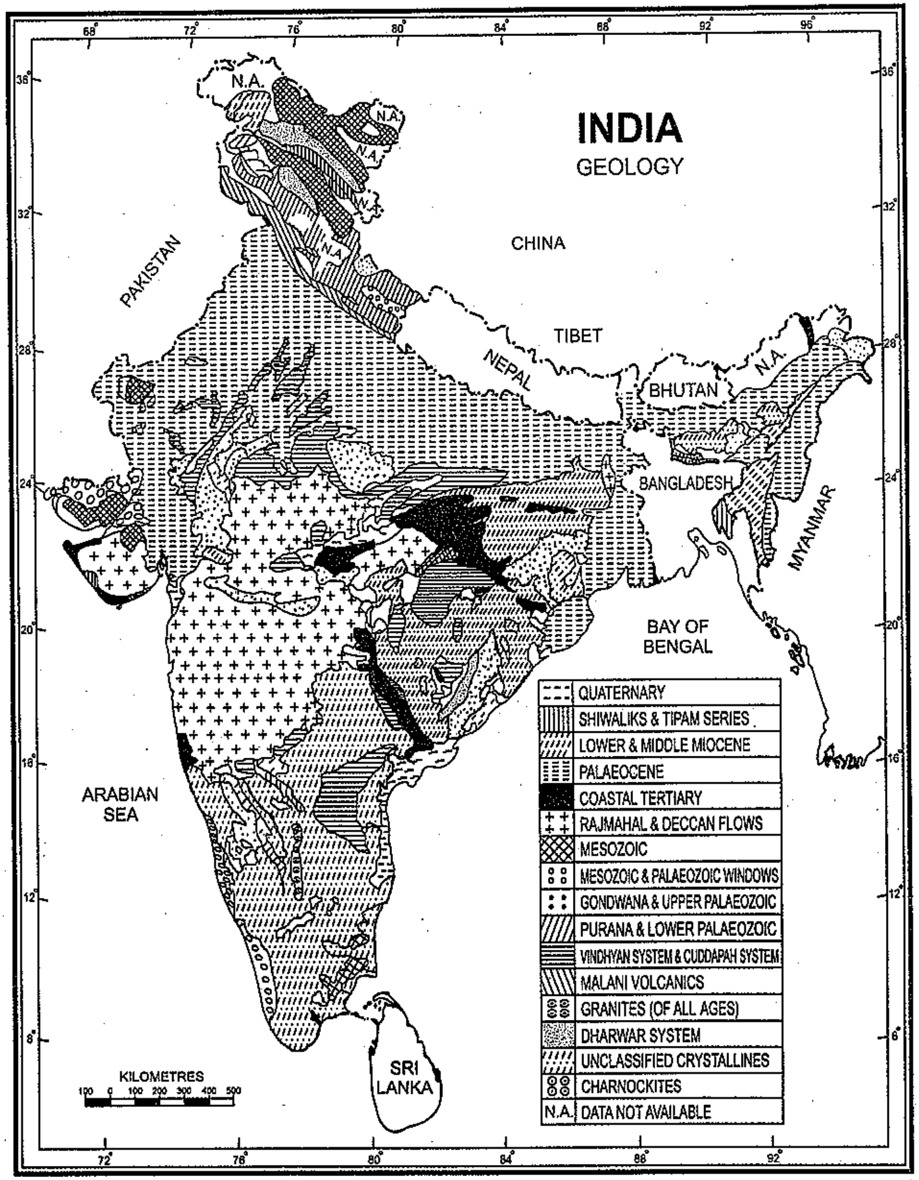

FIG. 2.1. India : Geology

occurs in Jharkhand (Ranchi, Hazaribagh), Madhya Pradesh (Balaghat, Rewa), Chhatisgarh (Bastar, Dantewara, Kanker), Odisha (Sundergarh, Keonjhar) and in the Aravalis between Jaipur and Palanpur. In the extra-Peninsular region, the Dharwar system is well represented in the Himalayas both in the central and northern zones as well as in the Meghalaya plateau (**Fig. 2.3**).

The Dharwars are economieally the most important rocks because they possess valuable minerals like high grade iron-ore, manganese, copper, lead, gold, quartzites, slates, mica, etc.

2. THE PURANA ROCK SYSTEM (1400–600 MILLION YEARS)

In india, the word purana has been used in place of Proterozoic and includes two divisions : the Cuddapah System and the Vindhyas.

The Cuddapah System. A long interval of time elapsed before the rock system next to the Dharwars and Peninsular gneisses began to be deposited. A great thickness of unfossiliferous clay, slates, quartzites, sandstones and limestones was deposited presumably in great synclinal basins. This formation is known as the Cuddapah system, from the occurrence of the most typical and first-studied, outcrops of these rocks in Cuddapah district of Andhra Pradesh. Naturally the Cuddapah system is separated from the Dharwar system by a great unconformity. In some parts of southern India, we have the Cuddapah system amounting to 6,100 metres in thickness with several unconformities.

The most extensive occurrence of this system is in Cuddapah district followed by Kurnool district of Andhra Pradesh. The outcrop is of an irregular crescent shape concave towards the coast covering an area of about 45,000 sq km. The crescent shaped outcrops of the Cuddapah rocks suggest that the rocks were subjected to compressive forces directed from the concave side near which stood high mountains that supplied materials forming the rocks of the basin. Another large development of this system is in the southern parts of Chhattisgarh covering the districts of Dantewara, Bastar, Kanker, Dhamtari, Raipur, Durg and Rajnandgaon. A few isolated exposures occur in Singhbhum district of Jharkhand, Kalahandi and Keonjhar districts of Odisha and along the main axis of the Aravalli range from Delhi to Idar in Gujarat aggregating 5,200 metres in thickness at certain places. Some deposits of Cuddapah rock system are found in Karnataka also (**Fig. 2.4**).

The economic significance of the Cuddapah system lies in the fact that these rocks contain ores of iron, manganese, copper, cobalt, nickel, barytes, jasper, asbestos, steatite and cherts. They also contain large deposits of building purpose quartzites and cement grade limestones.

The Vindhyan System (1300-600 million years). This system derives its name from the great Vindhyan mountains although *Spate* has tried to distinguish between the Vindhyan rocks and the Vindhyan hills. The system comprises of ancient sedimentary rocks superimposed on the Archaean base. It is a vast stratified formation of sandstones, shales and limestones, often over 4000 m thick. Except a few traces of animal and vegetable life, this group is devoid of any recognisable fossils. Occupying a large area of over 1,00,000 sq km, the Vindhyan system stretches from Sasaram and Rohtas in western Bihar to Chittaurgarh in Rajasthan with the exception of a central tract in Bundelkhand which makes a gap in this belt. Large area of this belt is covered by the Deccan trap. The outcrop has the maximum breadth between Agra and Neemuch. These rocks are also found in Chhattisgarh, Bhima Valley of Karnataka and Kurnool district of Andhra Pradesh. The Vindhyan system has been found to continue to the north under the Gangetic alluvium and they are perhaps buckled down underneath the Himalaya. The rocks of the Vindhyan system comprise two distinct but unequal sets of deposits. The *Lower Vindhyan* (1,300-1,100 million years) is marine in origin, mostly calcareous in nature and shows tectonic deformation by folding movements. This system is well placed in the Son valley, in Chhattisgarh, in the valley of the Bhima and in a separate basin in Mewar. *The upper Vindhayan system* (1000-600 million years), on the other hand, is fluviatile in origin and is gently lying in undisturbed horizontal strata. The Lower and the Upper Vindhyans are separated by an unconformity which is quite prominent in the north but almost disappears in southern areas of Mewar, Chittaurgarh and the Son valley.

The Upper Vindhayan beds enclose two diamond bearing horizons, from which Panna and Golconda diamonds have been mined. The Vindhyan system, on the whole, is devoid of metalliferous minerals but provides large quantities of excellent and durable stones, flagstones, ornamental stones, limestone, pure glass making sand and some coal.

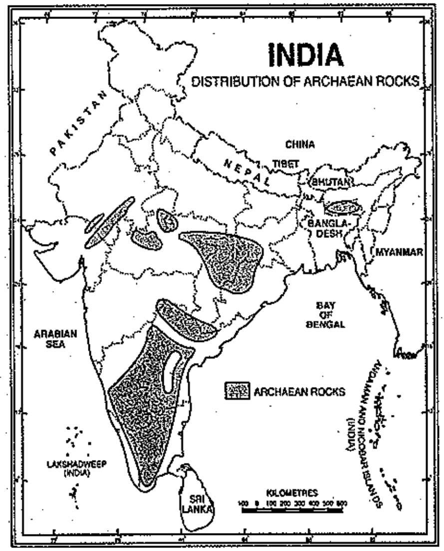

FIG. 2.2. India : Distribution of Archaeon Rocks

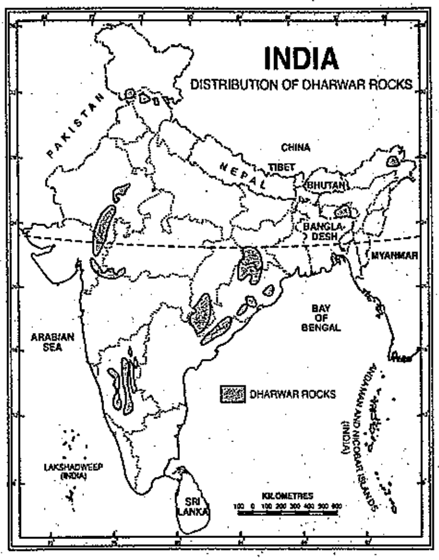

FIG. 2.3. India : Distribution of Dharwar Rocks

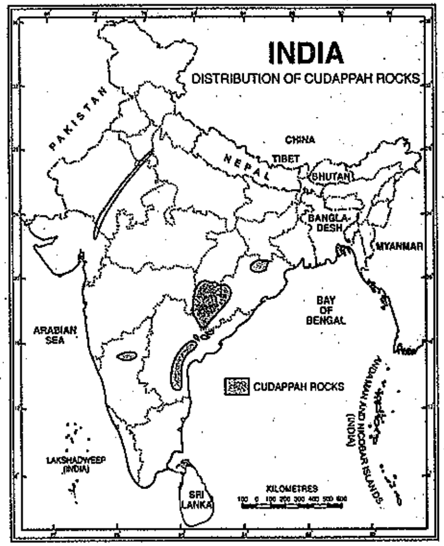

FIG. 2.4. India : Distribution of Cuddapah Rocks

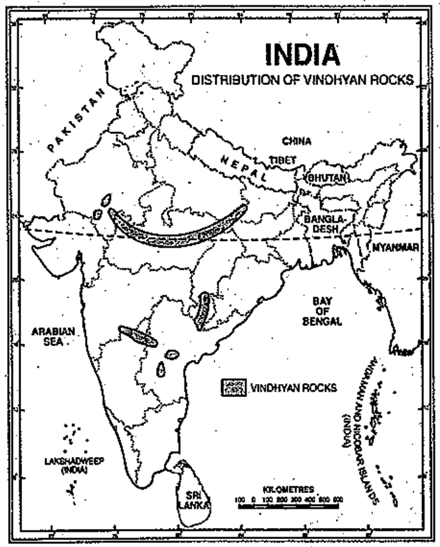

FIG. 2.5. India : Distribution of Vindhyan Rocks

3. THE DRAVIDIAN ROCK SYSTEM (PALAEOZOIC)

The rocks of the Dravidian system came into being about 600-300 million years ago. Most rocks of this system are found in the Extra Peninsular region and they are conspicuous by their absence in the Peninsular India except for one or two small patches of lower Permian age near Umaria. The Cambrian and Devonian rocks containing recognisable fossils are unknown in the Peninsula. The rocks belonging to the

Dravidian System contain abundant fossils which help in determining correctly the age of the rocks and make correlation of rocks possible over distant areas. The rocks of Cambrian, Ordovician, Silurian, Devonian and Carboniferous periods are included in the Dravidian system.

The Cambrian rocks (600 million years) named after Cambria, the Latin name for Wales in Great Britain, include slates, clays, quartzites and limestones. They are best developed in the north west Himalayan region. In the Spiti valley of Himachal Pradesh, there is an extensive fauna known as the ***Haimanta System.*** This 1600 metre thick deposit consists of slates, quartzites and dolomites. Similar formations are found north of Kullu and Lahul in Himachal Pradesh as well as in the Baramula district of Jammu and Kashmir. In Kumaon, some slaty and sandy rocks of the Cambrian period are found. In the salt range on the Indo-Pak border, the Cambrian rocks are represented by 900 metres of fossiliferous sandstones, shales and dolomites underlain by salt marl (clayey salt) known as the ***saline series.***

The Ordovician rocks (500 million years) after the Ordovices, former inhabitants of Wales include quartzites, grits, sandstones and limestones. They overlie the Haimanta system in all parts of the Spiti in the form of a thick series underlain by conglomerates. They are also present in the Lidar valley of Kashmir and in the Kumaon region.

The Silurian rocks (440 million years) after the Silures, former inhabitants on the borders of Wales and England. In the Spiti valley, the Silurian rocks are in continuation with the Ordovicians. Round the core of the Lidar anticline there runs a thin but continuous band of Silurian strata. The Lahul and the Kullu valleys of Himachal Pradesh also have some Silurian deposits. The limes and shales of the Kumaon region belong to the Silurian period.

The Devonian rocks after Devonshire in England (400 million years) are a great thickness of massive white quartzite reaching a thickness of 900 m at certain places. They are devoid of any fossil remains. These rocks have definitely been identified in the Muth quartzite of Spiti and Kumaon, on the flanks of Lidar anticline and in the Haridwar district of Uttarakhand.

The Carboniferous rocks (350 million years) comprise mainly of limestone, shale and quartzite. These rocks are generally divided into the *Upper Carboniferous, Middle Carboniferous* and *Lower Carboniferous* systems. *The Upper Carboniferous* rocks are made of limestone and dolomite. *Mount Everest* is composed of Upper Carboniferous limestones. *The Middle Carboniferous* has been the age of great upheavels. The rocks of this group are mainly found in the Spiti valley, Kashmir, Shimla and in the eastern Himalayas. In the Lower *Carboniferous group* are included slates of different types, Pir Panjal trap, and some rocks of the Kumaon region. Coal formation started in the Carboniferous age. Carboniferous in geology means *coal bearing*.

4. THE ARYAN ROCK SYSTEM

The Aryan System comprises the rock formations ranging from the *Upper Carboniferous* to the *Recent.* They are fairly preserved in the Peninsular India and are found in a perfect sequence in the Himalayan region along the entire northern border.

The Gondwana System derives its name from the Kingdom of the Gonds, the most primitive people living in Telangana and Andhra Pradesh. It has relevance with the Gond region of Madhya Pradesh also where these rocks were first discovered. The Gondwanas consist of sandstones with some shales and clays. They are of continental origin, fluviatile and lacustrine deposits laid down in geosynclinal troughs on ancient plateau surface. As the sediments accumulated, the loaded troughs subsided which led to thick deposits of fresh water and subaerial sediments into which were embedded the terrestrial plants and animals. These flat sedimentary strata, some 6,000 m thick, were laid down from the start of the Permian period some 250 million years ago. The system shows several climatic changes during its deposition.

The main areas of Gondwana rocks in the Peninsula are along the Damodar Valley in Jharkhand, along the Mahanadi river valley in Chhattisgarh and Odisha, in the southern part of Madhya Pradesh and a series of troughs along the Godavari from Nagpur to the delta (**Fig. 2.6**). In the extra-peninsular region these rocks are found in Kashmir, Darjeeling and Sikkim. Here they are so much deformed that they have lost their original identity and are entirely different from the peninsular rocks.

Economically, the Gondwana rocks are the most important in India containing about 98 per cent of her coal reserves. They have rich deposits of iron ore, copper, uranium and antimony also. Sandstones, slates and conglomerates are used as building materials.

The Triassic System meaning three fold (280-225 million years) is almost unknown in the Peninsula but is found over extensive areas from Hazara to Nepal. Impressive sections of the system are exposed on the south flank of the Great Himalaya range from Kashmir to Byans in Eastern Kumaon. The trias are generally divided into lower, middle and upper divisions. *The Lower Trias* is over 100 m thick in Kashmir, 50 m in Byans and only 12 m in Spiti. *The Middle Trias* is 275 m thick in Kashmir. *The Upper Trias* of Kashmir is 1200-1800 m thick well bedded limestones. In the Spiti both these stages are represented by about 1,000 m thick dominantly calcareous strata.

The Jurassic System, after Jura mountains on the borders of France and Switzerland (180 million years) overlies the Triassic, covering wide areas in Tibet, South Ladakh, Spiti, Nepal and Bhutan, where limestone occurs to a depth of 600-900 m. The marine transgression in the latter part of the Jurassic gave rise to thick series of shallow water deposits in Rajasthan and in Kachchh. There is 190 km long and 64 km wide area in Kuchchh which is covered by rocks of the Jurassic system. Córal limestone, oolitic limestone, sandstone, conglomerates and shales occur in Kuchchh. The Jaisalmer area of Rajasthan also has some Jurassic rocks. Another transgression on the east coast of the Peninsula between Guntur and Rajahmundry has resulted in the development of marine Upper Jurassic strata interbedded with the upper Gondwana formation.

The Cretaceous System, from Creta, the Latin name for chalk (135-70 million years), is one of the best developed marine systems of India showing a variety of faces and represented by a wide variety of rocks, deposited on the land, sea estuaries and lakes. No other system is so widely distributed in India as the Cretaceous System is, both in the Peninsular and the Extra-peninsular parts.

The Cretaceous rocks of the Spiti area include sandstones, quartzites, limestones and shales. In the Kumoun region, the important rocks are sandstones and shales. Cretaceous limestones are also found in Rupshu and Burzil areas of Kashmir. The plateau of Meghalaya has sandstones. The upper Cretaceous system occurs in the Pondicherry-Tiruchchirapalli belt. Some detached outcrops of marine Cretaceous, known as Bagh Beds in Gwalior are found along the Narmada Valley where they underlie the Deccan Trap. In the Central parts of the Peninsula occur estuarine and lacustrine deposits called the ***Lemetas***.

The Deccan Trap. From the end of the Cretaceous till the beginning of the Eocene, stupendous volcanic outburst overwhelmed a vast area of the Peninsular India, like the one which is seldom known anywhere else in the world geological history. A vast area of about ten lakh sq km was flooded by the outpourings of extremely mobile basalt lava from fissures and cracks covering fully the pre-existing topography. These volcanic deposits have flat top and steep sides so that they appear as gigantic steps from a distance, and therefore called ***'trap'***, the name derived from the Swedish word meaning a ***'stair'*** or ***'step'***. However, **Spate** feels that the term Deccan Trap is used in old literature and he prefers to use the term ***'Deccan Lava'*** instead. The individual lava flows that make up the Deccan Trap plateau vary greatly from a fraction of a metre to 36 metres in thickness. The hills formed by them are in some places over 1200 metre high.

The process of denudation over a long period has reduced the Deccan Trap to almost half of its original size and the present Deccan Trap covers about 5 lakh sq km mainly in parts of Kachchh, Saurashtra, Maharashtra, the Malwa plateau and northern Karnataka (**Fig. 2.7**). Parts of Telangana, Tamil Nadu, Jharkhand and Uttar Pradesh also have some outliers of the Deccan Trap. Thickness of the Deccan Traps is not uniform everywhere. It is as much as 3,000 metres along the coast of Mumbai which is reduced to 600-800 metres towards the southern limit, 800 metres in Kachchh and only 150 metres at Amarkantak near its eastern limit. The Deccan Trap has been divided into following groups :

(*a*) **The Upper Trap**, found in Maharashtra and Saurashtra has numerous inter-trappean beds and

layers of volcanic ash and has an average thickness of about 450 m.

(*b*) **The Middle Trap** is about 1200 m thick and is spread over Central India and Malwa. It has numerous ash-beds in the upper portion and is practically devoid of inter-trappeans.

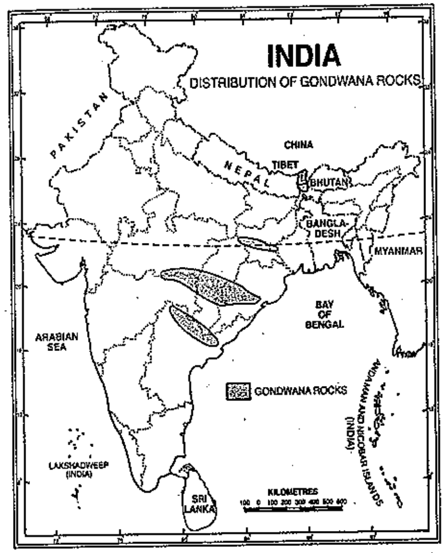

FIG. 2.6. India : Distribution of Gondwana Rocks

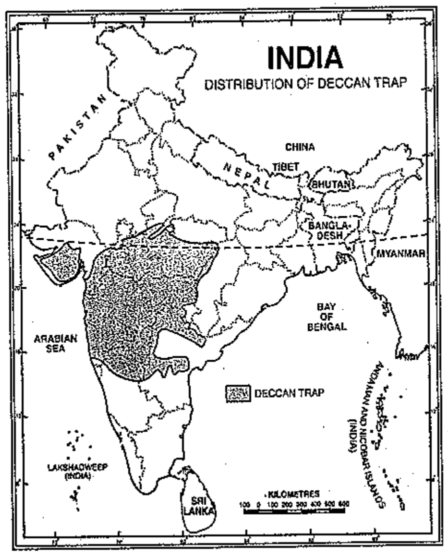

FIG. 2.7. India : Deccan Trap.

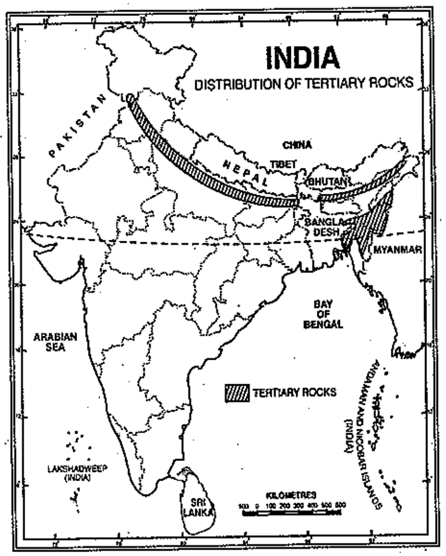

FIG. 2.8. India : Distribution of Tertiary Rocks.

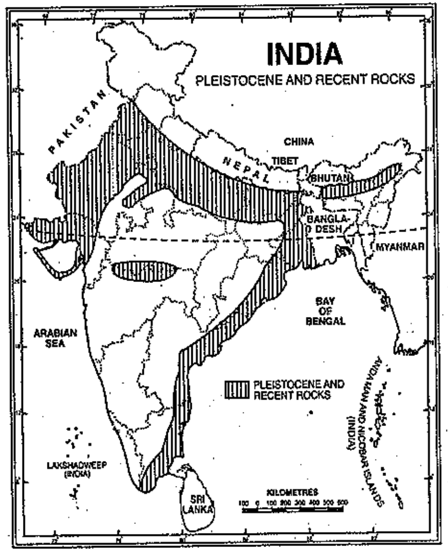

FIG. 2.9. India : Pleistocene and Recent Rocks

(*c*) **The Lower Trap** is only 150 m thick with inter trappean beds but rare ash beds. It is found in Central India and Tamil Nadu.

Basalt is the main rock but dolorite, rhyolite, gabro and many other rocks are also found. These rocks are a great source of quartz, agate, calcite, building stones and road building material. The weathering of these rocks for a long time has given birth to black cotton soil known as ***'regur'***.

The Tertiary System. The rocks of the Tertiary System were formed from Eocene to Pliocene about 60 to 7 million years ago. The tertiary is the most significant period in India's geological history because the Himalayas were born and India's present form came into being in this period. The Tertiary has been called the ***Age of the Mammals*** because of the abundance of the fossil remains of these animals in the deposits of this period. The Tertiary System is generally divided into the following three systems.

(*a*) **The Eocene System** (60 million years ago) is mainly found in Jammu and Kashmir, Himachal Pradesh, Rajasthan, Gujarat and in the north-eastern part of India. The Eocene belt of Jammu goes upto Shimla and further east upto Mussoorie. Such deposits also occur in the southern flank of the Pir Panjal. In Rajasthan, the lignite deposits belong to the Eocene System. The Kuchchh, Surat and Broach areas of Gujarat have deposits of the Eocene System. In the north eastern part of the country, the Eocene is represented by limestones and coal-bearing sandstones in Jaintia series in the southern and eastern parts of the Meghalaya plateau. The Barail series has a wide distribution in Surma Valley and in the Naga Hills. The Tertiary coal deposits of Upper Assam are worth noting. Some Eocene deposits have recently been noticed in Puducherry.

(*b*) **Oligocene and Lower Miocene System** (40-25 million years) is very poorly developed in India. It is estimated that during a part of this period the Tertiary outcrops suffered considerable denudation which resulted in the removal of rocks belonging to this system. Rocks of the Oligocene age are found in the greater part of the Barail series of Assam where they are overlain with a marked unconformity by Lower Miocene rocks.

Unlike the Oligocene, the Miocene system is fully developed in India and is found in all the Tertiary areas of the extra-Peninsula. The outcrop of the Murree series in Jammu hills, forming a belt 25-40 km wide from the Indus to the Chenab, narrows towards the east and merges into the typical Dagshai-Kasauli band (Sirmur series) is of Shimla area. The thickness of the deposits in Dagshai-Kasauli band is about 2600 m and is dominated by red clay and sandstone. No major fossils are seen in Dagshai and Kasauli group. The coal measures of Assam, belonging to the Barail series are overlain by the Surma series. It is composed of sandstones and sandy shales, mudstones and conglomerates. The deposits of Garo Hills have large number of marine fossils. Besides some rocks of Kachchh in Gujarat, Mayurbhanj in Odisha, Durgapur in West Bengal, and Kollam in Kerala also belong to this group.

The Shiwalik System—Middle Miocene to Lower Pleistocene (14 to 0.2 million years ago) takes its name from Shiwalik hills between rivers Ganga and Yamuna, where they were first known to science. It is from here the first palaeontological treasures were obtained which have made this system extremely famous with the geologists all over the world. The Shiwalik strata are found all along the length of the Shiwalik hills. Sandstones, grits, conglomerates, clays, and silts comprise the rocks of this system. They have been deposited in lagoons and fresh water lakes by the rivers of that time upto a thickness of about 5000 m. The great bulk of the Shiwalik formation is nonfossiliferous, but in certain areas some formations are highly fossiliferous. The fauna records the sedimentation from Middle Miocene to Lower Pleistocene and has yielded a variety of fossils showing wide range of environment—from humid forest conditions to aridity. The mammalian fossils were first discovered from the Shiwaliks near Haridwar in 1839.

TABLE 2.1. Division of Shiwalik Strata

Upper Shiwaliks 1800-2750 m	Boulder Conglomerate beds, Sandstones, thick earthy clays. Richly fossiliferous in Shiwalik hills	Lower Pleistocene to Upper and Lower Pliocene
Middle Shiwaliks 1800-2500 m	Gravels, sandstones, shales and clays	Upper to Middle Miocene
Lower Shiwaliks 1200-1500 m	Bright red shales and sandstones	Middle Miocene

The Shiwalik strata are divided into the following three sections, the passage from one into the other division being quite gradual and transitional.

In Assam the Shiwalik system is almost equivalent to the Tipam, Dupi Tila and Dihing series. In the southern part of Assam, the lower part of the Tipam series consists of coarse ferruginous sandstones and sandy shales, and has some marine fossils. Above the Tipam series lies the Dupi Tila series which consists of sandstone and conglomerates. Its lower beds contain the oil fields of Lakhimpur and Digboi. The Dihing beds overlie the Dupi Tila and correspond to the Upper Shiwaliks.

The Shiwalik rocks are also found in Kachchh and Saurashtra areas of Gujarat. Highly fossiliferous beds have been struck in a well at Karikal on the Thanjavur coast (Tamil Nadu). In Mayurbhanj area of Odisha there are rocks of Miocene age. Some rocks of Middle Miocene and Lower Pleistocene age are seen in Varkala (Kerala) as well as in the sandstones of Cuddalore and Rajahmundry.

The Shiwalik system is famous for its oil resources, lignite, bauxite and clays of different varieties.

The Pleistocene and the Recent (Quaternary) is a brief period of nearly one million years and is said to have just begun. It has two divisions without a clear-cut boundary between them. The older is the Pleistocene which is marked by cold climate and glaciation. The younger division is called ***Recent***. It started about 12,000 years ago since the withdrawal of the last glaciation. The Pleistocene age has been marked by several advances and retreats of the glaciers. This age is divided into four glacial and three inter-glacial periods by ***de Terra*** and ***Paterson***. During the glacial periods, sea level was lowered by about 100 metres than it is now and this resulted in much larger extension of land.

The Himalayan glaciers were much larger during the glacial period than their present size. They have left indelible impression on the Himalayan topography. The First Glacial and Inter-glacial periods belong to the lower Pleistocene in Kashmir. The Second Glacial and Inter-glacial periods embrace Middle Pleistocene. Heavy deposition of sediment consisting of boulder fans and thick fluvo-glacial material took place in this period. The *Karewas* of Kashmir are supposed to be of the second inter-glacial period. The flat-topped terraces of the Kashmir valley, and on the flanks of the Pir Panjal consisting of clays, sands, silts together with lenticles of conglomerate from old deltaic fans are known as ***Karewas*** in Kashmiri language. The alluvial deposits of the Narmada are also of the same period. The Upper Pleistocene includes the Third and the Fourth glaciations and the intervening Third Inter-Glacial period. Pir Panjal experienced uplift during the First and the Third Glacial periods, and the terrace deposits of Kashmir occurred at the end of the Fourth Glaciation.

The fossiferous clays, sands and gravels of the Upper Satluj and the alluvial deposits in the valleys of Tapi, Godavari and Krishna are also of the Pleistocene age.

The most important, extensive and recent deposits in India are the Indo-Gangetic alluviums filling the great depression between the foot of the Himalayas and the northern edge of the Peninsula. The older alluvium called ***bhangar*** is of the Middle or Upper Pleistocene age. The newer alluvium occupies the lower areas of the river valleys prone to annual floods is called ***khadar*** and belongs to the Upper Pleistocene age.

THE COASTLINE OF INDIA

India has about 6100 km long coast most of which is more or less uniform and regular with a few creeks, inlets, back waters and promonotories here and there. ***Suess*** has opined that the straight and regular coastline of India is the result of disruption and faulting of the Gondwanaland during the Cretaceous period. As such the coast of India does not offer many sites for good natural harbours. The peninsular shape of South India has divided the entire coast into western and eastern parts with Kanniyakumari at the southernmost tip as the dividing point. The Bay of Bengal and the Arabian Sea came into being during the Cretaceous or early Tertiary period after the disintegration of *Gondwanaland*.

The east coast of India extends from the Ganga delta to Kanniyakumari facing the Bay of Bengal. It is marked by deltas of great rivers like the Mahanadi, the Godavari, the Krishna and the Cauvery. There are several lagoons of which the Chilka lake and the Pulicut lagoon are outstanding.

The West Coast runs almost straight in the north-south direction right from the Gujarat plains to Kanniyakumari. However, it is dotted with a large number of coves, creeks and a few estuaries. The estuaries, of the Narmada and the Tapi are well known. The Malabar coast in the south has some lakes, lagoons and backwaters, the largest being the Vembanad Lake.

There are evidences to show that large parts of Indian coast have undergone submergence and emergence during the geological times and even during the historical times. The most outstanding example of submergence of the sea coast is the existence of a submerged forest on the eastern side of the island of Mumbai. It is located at depths of 6-12 m below the present sea level where a number of tree-stumps are seen with their roots *in situ* embedded in the old soil. The submergence is further proved by the raised terraces formed of coral reefs or loosely cemented fragmentary shell limestone rocks. A similar submerged forest or old land surface, about half an acre, is seen on the Tinnevelli coast. A thick bed of lignite found at Puducherry 73 m below ground level also provides proof of submergence. Such vegetable debris is also found in the Ganga delta. Sudden increase in the depth of sea about 30 km from the coast of Makran is due to the submergence of a cliff lying at the coast. Marine archaeologists have recently discovered the ancient city of Dwarka lying under shallow waters off the coast of Saurashtra.

Examples of both submergence and emergence have been found in the Rann of Kachchh. As a result of the great earthquake in 1819, an area of 5180 sq km on the western border of the Rann of Kachchh was suddenly submerged under the sea upto a depth of 3.6 to 4.5 m. The fort of Sindree on the sea coast was completely submerged excepting a single turret which remained above the water level. Simultaneously another area of about 1550 sq km was elevated by several metres. In fact there have been repeated falls in sea level in the Rann of Kachchh area which is evident from the presence of coastal dunes, sea cliffs in the islands of the Gulf, sea caves within the plains and raised beaches of littoral concrete on the fringes of the islands. The total fall in the sea level has been estimated at 26 m. Even during historic times the Rann of Kachchh was a gulf which was silted up by the rivers falling into it. This process was supplemented by the slow elevation of the floor of the gulf and the entire area was converted into a low-lying tract. Before the Rann became dry, the Luni river used to enter the Arabian Sea through the Kori estuary crossing the entire length of the great Rann, and the Western Banas flowed over the Little Rann into the Gulf of Kachchh. Some islands off the Arabian Sea coast came into existence due to submergence of low-lying areas around them. The coral archipelago of the Lakshadweep islands probably marks the site of submerged land.

Several evidences of uplift of the western coast have been given by the geologists. Raised beaches are found at altitudes ranging between 30-45 metres at many places, while marine shells are found at many places on land at a height far above the level of tides. The steep face of the Sahyadri parallel to the west coast of India, suggests that the escarpment is the result of a recent elevation of the Ghats from the sea.

Proofs of uplift of the coastal plain of Kerala are numerous and decisive. The occurrence of coral reefs below the alluvium several kilometres from the present coast and the presence of a number of lakes, lagoons, backwaters and spits are a few of them. At least two phases of uplift have been noticed.

Away from the coast in the Bay of Bengal the Andaman and Nicobar Islands were once connected with the Arakan Yoma. They have come into being as a result of submergence of the surrounding low-lying areas in the geological times. However, the shape and size of some of the islands near the Ganga delta change with the change in sea level. Old islands disappear and some new islands emerge above the sea level. The recent emergence of New Moore Island in the Ganga delta is an outstanding example of such changes.

Sri Lanka was a part of India in the geological times, and the two landmasses were connected with each other by Adam's Bridge. This link was drowned in the Quarternary times and is now represented by

Pamban Island on Indian side and the Mannar Island on the Sri Lankan side along with several other small islands lying between these two islands.

Ice Ages in India

Following three ice ages are generally recognised in India.

1. The Dharwar Ice Age. Ice age of Dharwar is reflected by conglomerates near Kaldurg in South India.

2. The Gondwana Ice Age. The Talcher series of the Gondwana system in Odisha provide proof of the glaciation during that period. Boulders found here are similar to those existing in Shimla, Hazara and Salt Range.

3. The Pleistocene Ice Age. During the Pleistocene period the effect of ice age was noticed in the Himalayas. This period was not a continuous frigid spell, rather it was marked by cold and warm spells in succession. In the Himalayas, evidences of extensive glaciation are found upto height of 1800 m while glacial drifts and terminal moraines covered hill sides and valley floors down to 1,400 m. In Kashmir region, four or five periods of glaciation with inter-glacial periods have been noticed by de **Terra** and **Peterson.** Large blocks and boulders are normally seen in different parts of the Himalayas. Rock polishing and grooving on lower steps of the Himalayas, the buff coloured sands and luminated clays inter-stratified among the Karewa deposits of Kashmir, accumulations of marine debris found on the tops and sides of many ranges of the middle Himalayas which do not have any glaciers now, ancient moraines found before the snouts of existing glacier at an elevation of about 1,650 m amply prove that this part of India experienced a glacial age in the Pleistocene period. Glaciation also led to the formation of a number of glacial lakes in different parts of the Himalayas. Kailash kund, the Sanasar basin near Batoti, the Gulmarg basin, the Sheshnag, the Kaunsarmag, etc. are some of the examples of this type of lakes. The impact of glaciation also led to sudden and large scale reduction of the Shiwalik mammals. The Peninsular part of India has no evidence of glaciation during the Pleistocene period.

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CHAPTER

Physiography

INTRODUCTION

Physiography is that branch of geography which studies the present relief features of the earth's surface or of natural features in their causal relationships. As described in the previous chapter, the present surface features of India owe their formation to various geological events which took place in different geological periods. Both endogenetic and exogenetic forces have been consistently working to shape the present land forms on the surface of the earth. India has a unique personality with regard to physiography. The great diversity of relief features encompassed in the vast dimansions of the country is simply amazing. The physiographic diversity of India embraces lofty young fold mountains, flat plains and one of the oldest plateaus of the world. The Indian islands have their own unique personality. A rough estimate made by the Census Commission in 1951, shows that of the total land area, 10.7 per cent is more than 2135 m above sea level and is mountanious, 18.6 per cent is hilly area (305 to 2135 m), 27.7 per cent is plateau (305 to 915 m) and the remaining 43 per cent is plain area.

Due to geological complexities and geomorphological diversities, division of India into physiographic regions is a difficult task. The views expressed by geographers in this regard are as diverse as the diversities of landforms in India. Some scholars follow the *triple tectonic division* viz. (*i*) the Himalayan Mountains (*ii*) the Indo-Gangetic plains and (*iii*) the Indian Peninsula. There are some scholars who feel that the coastal plains have a separate identity and should be treated as such. More recently, it has been felt that the distant islands in the Bay of Bengal and the Arabian Sea should also be treated separately. Thus, to be more realistic and for the sake of convenience, it is preferred to divide India into following five physiographic divisions (**Fig. 3.1**).

1. The Himalayan Mountains.
2. The Great Plain of North India.
3. The Peninsular Plateau.
4. The Coastal Plains.
5. The Islands.

1. THE HIMALAYAN MOUNTAINS

The Himalayan mountains are also known as the ***Himadri***, ***Himavan*** or ***Himachal***. The Himalayas consist of the youngest and the loftiest mountain chains in the world. The magnitude of their size can be estimated from the fact that the central axial range of the main Himalayas alone stretches for a distance of over 2,400 km (over 22° longitude) from the Indus gorge in the west to the Brahmaputra gorge in the east.

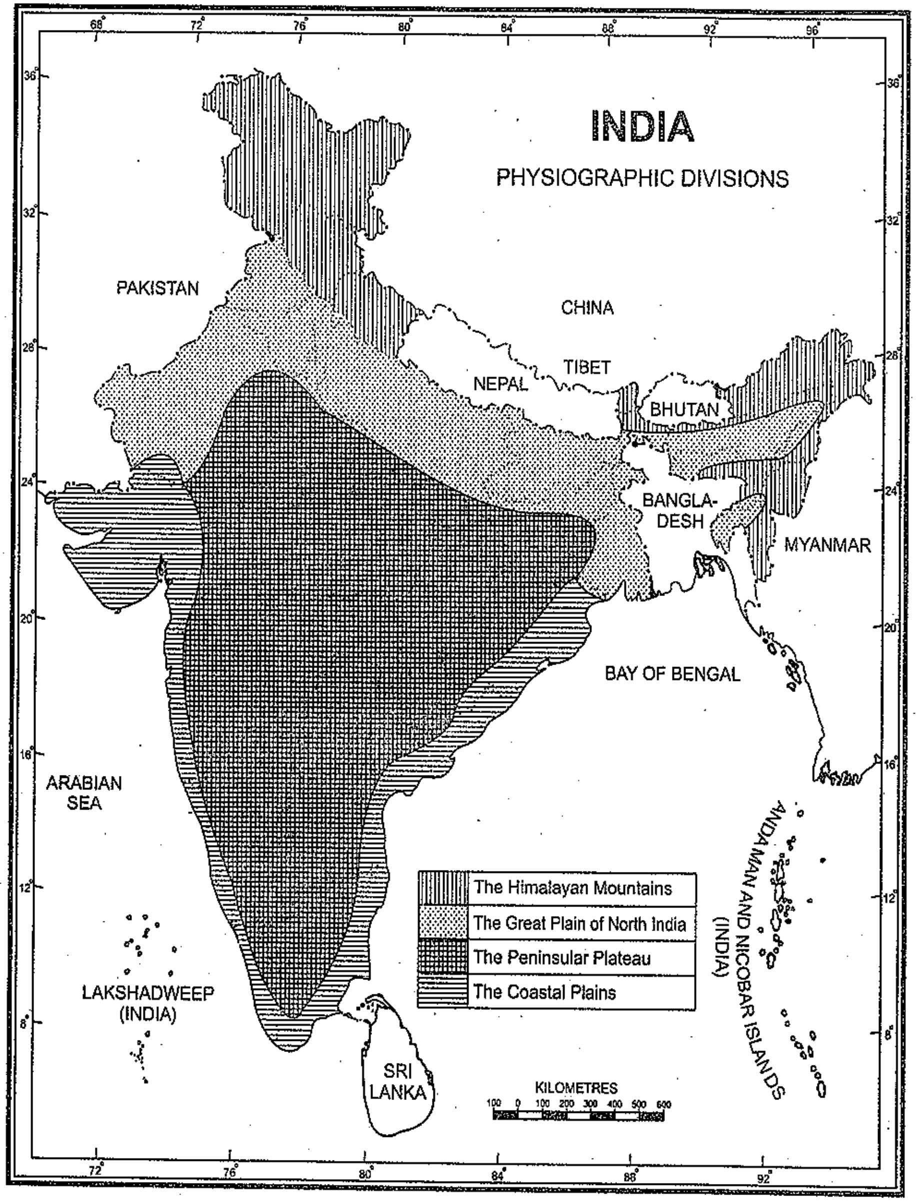


FIG. 3.1. India : Physiographic Divisions

The width of the Himalayas varies from 500 km in Kashmir to 200 km in Arunachal Pradesh. The total area of the Himalayan mountain region is nearly five lakh sq km. The Pamir, popularly known as the ***roof of the world*** is the connecting link between the Himalayas and the high ranges of Central Asia. From the Pamir, the Himalayas extend eastward in the form of an arcuate curve which is convex to the south. The southern boundary of the Himalayas is well defined by the foothills (300 m contour line) but the northern boundary is rather obscure and merges with the edge of the Tibet Plateau.

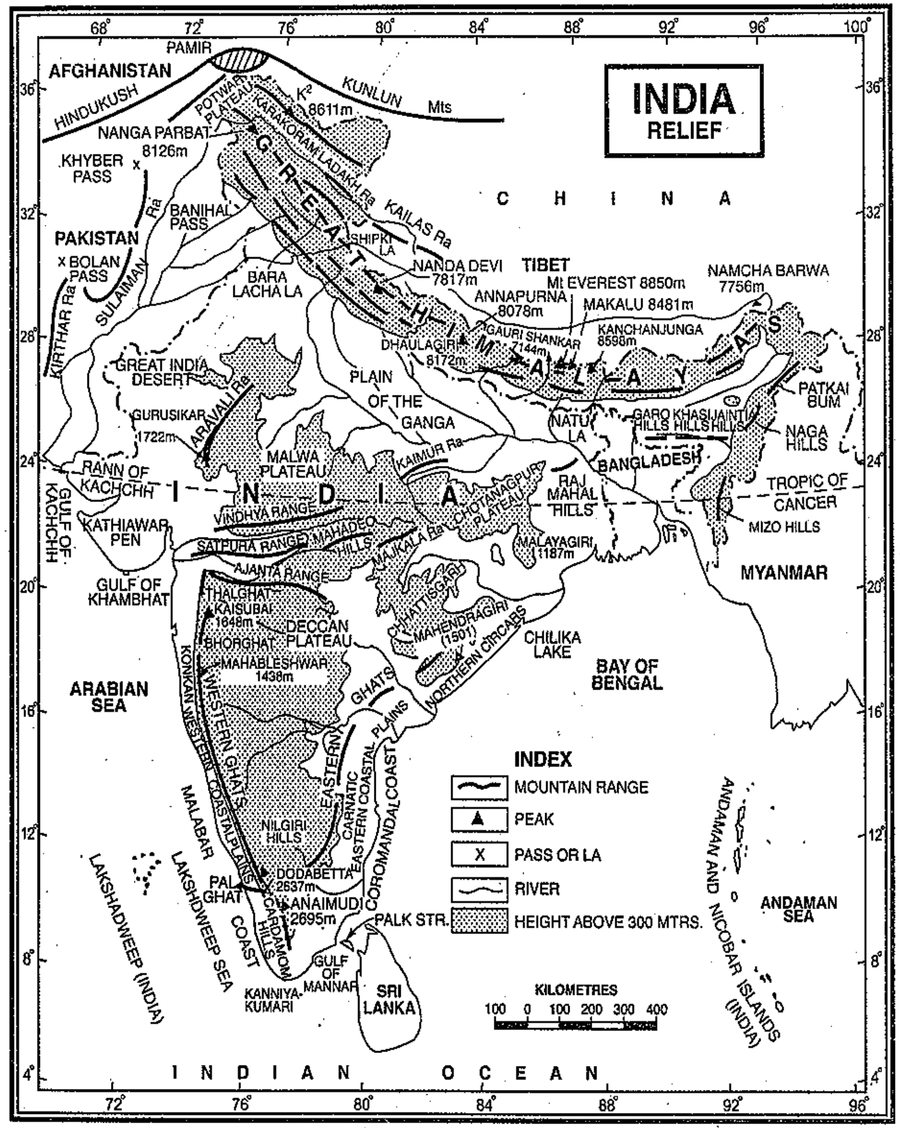


FIG. 3.2. India : Relief

The Himalayas have attained a unique personality owing to their high altitude, steep gradient, snow capped summits, deeply dissected topography, youthful drainage, complex geological structure and rich temperate flora in the subtropical latitudes.

The Himalayan mountain chains have the loftiest peaks of the world. The number of peaks higher than 8,000 metre is 14 and those over 7,500 metre total 20. Of the 94 Asian peaks which exceed 7,300 metre, all but two are in the Himalaya and Karakoram ranges. The number of peaks over 7,000 metre runs into hundreds and several peaks above 6000 metre have not been adequately counted and mapped. Many of them have not been even given their names till now.

Origin of the Himalayas

Several scholars have expressed their views regarding the origin of the Himalayas. Prominent among them are O.H.K. Spate, D.N. Wadia, M.S. Krishnan, S. Burrard, E.H. Pasco, G.E. Pilgrim, de Terra, T.T. Paterson, T. Hagen, Auden, A. Heim and A. Gansser, Wagner and a host of others. There is almost a complete unanimity that the Himalayan mountains have come out of a great geosynchine called the ***Tethys Sea*** and that the uplift has taken place in different phases. But divergent views have been expressed regarding the process and time of uplift as well as the forces responsible for uplift on such a vast scale. The consensus which has emerged from the views of different scholars is reproduced as under :

About 120 million years ago, the arrangement of continents and oceans was quite different from what it is today. There was a super continent known as ***Pangaea***. Its northern part consisted of the present North America and Eurasia (Europe and Asia) which was called ***Laurasia*** or ***Angaraland***. The southern part of Pangaea consisted of South America, Africa, South India, Australia and Antarctica. This landmass was called ***Gondwanaland***. In between Laurasia and Gondwanaland, there was a long, narrow and shallow sea known as the ***Tethys Sea***. Sediments were brought by rivers from these landmasses and deposited on the bed of this sea. These sediments were subjected to powerful compression, either because of the southward movement of the Angaraland or due to the northward movement of the Gondwanaland. Majority of the scientists believe that it is the northward movement of the Gondwanaland which caused compression in the sediments at the floor of the Tethys Sea. In any case, whether Angaraland moved southwards or Gondwanaland moved northwards or both moved towards each other, the net result would be the same; the sediment in the Tethys Sea was squeezed and crushed, and a series of folds were formed one behind the other giving birth to the highest relief features on the earth—the Himalayas. The curved shape of the Himalayas convex to the south, is attributed to the maximum push offered at two ends of the Indian Peninsula during its northward drift. In the northwest it was done by the Aravalis and in the north-east by the Assam ranges, both acting as two extended arms pushing out the extremities, while the central area sagged giving the arcuate shape to the Himalayas. Recent studies have shown that India is moving northwards at the rate of about five cm per year and crashing into rest of the Asia, buckling the Himalayas between Angaraland and Gondwanaland.

It is important to note that the Himalayas do not comprise a single range but a series of at least three ranges running more or less parallel to one another. Therefore, the Himalayas are supposed to have emerged out of the *Himalayan Geosyncline i.e.* the Tethys Sea in three different phases following one after the other. The first phase commenced about 120 million years ago, when the Great Himalayas were formed. Some geologists are of the opinion that the formation of the Great Himalayas was completed about 70 million years ago. The second phase took place about 25 to 30 million years ago when the Middle Himalayas were formed. The Shiwaliks were formed in the last phase of the Himalayan orogeny—say about two million to twenty million years ago (**Fig. 3.3**).

The diastrophic movements which helped in the formation of the Himalayas started in the late Cretaceous times and continued through the Eocene, Middle Miocene, Pliocene to the lower Pliocene and finally into the upper Pleistocene to sub-Recent times. There are evidences to show that the process of uplift of the Himalayas is not yet complete and they are still rising. The heights of various places as determined by trigonometrical methods indicate that the Himalayas continue to rise till date. According to the estimates made by Godwin Austen, the average elevation of the Himalayas was 2,440 m above the sea level about a

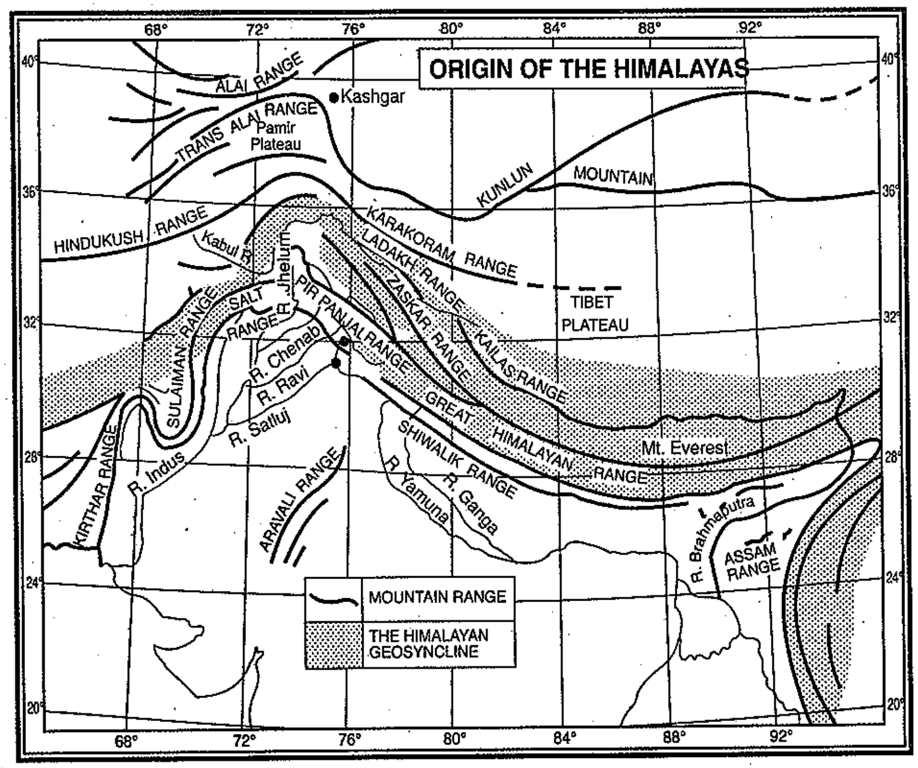


FIG. 3.3. Origin of the Himalayas

million years ago which has now risen to 3,050 m. The Mahabharat range is still in a state of rigorous uplift. Following evidences are cited to prove that the Himalayas are still rising :

(*i*) Some of the fossil formations found in the Shiwalik hills are also available in the Tibet plateau. It indicates that the past climate of the Tibet plateau was somewhat similar to the climate of the Shiwalik hills and that the elevation of Tibet plateau was almost the same as that of the present Shiwalik hills and the plateau has since risen to its present elevation.

(*ii*) Desiccation of lakes of Tibet has been observed within the recent or even in historical times. Surrounding these lakes, the sand and gravel terraces at higher levels, sometimes 60-100 metres above the present water level, are seen which prove that the water stood at a much higher level till recent times. This could be possible only in the event of uplift of the region.

(*iii*) The frequent occurrence of earthquakes in the Himalayan region shows that the Himalayas have not yet attained *isostatic equilibrium* and they still continue to rise further.

(*iv*) The Himalayan rivers are still in their youthful stage and have been rejuvenated in recent times. This is another proof of rising trend in the Himalayas. Terraces found at the valley sides suggest rejuvenation of the valley region due to uplift.

The present rate of uplift of the Himalayas has been calculated at 5 to 10 cm per year.

Plate Tectonics

Plate tectonics is the most recent and widely acclaimed theory which gives most satisfactory answers to intricate and puzzling questions regarding origin of continents and oceans, formation of mountains, occurrence of earthquakes and eruption of volcanoes. The credit for introducing this theory goes to Harry Hess (1960), R.S. Dietz (Global Tectonics, 1961), W.J. Morgan and Le Pichon (Sea Floor Spreading and Continental Drift, 1968). Plate tectonics is a theory of global dynamics in which the lithosphere is believed to be broken into a series of separate plates that move in response to convection in the upper mantle. *Plate is a broad segment of lithosphere (including rigid upper mantle plus oceanic and continental crust) that is about 100 km thick and floats on the underlying asthenosphere and moves independently of other plates.* The margins of the plates are sites of considerable geological activity such as sea-floor spreading, volcanic eruptions, earthquakes, crustial deformation, mountain building and continental drift. There are three types of plate boundaries, *viz*., (*a*) constructive, (*b*) destructive, and (*c*) conservative. *Constructive boundaries* represented zones of 'diverging margins'. In this case, two plates move away from each other. *Destructive boundaries* are also known as '*converging margins*'. In this case, two plates move towards each other, converge and in the process one plate overrides the other. The overridden plate is subducted and goes under the asthenosphere and is lost or consumed. Where two plates slide past along transform faults neither creating nor destroying earth crust it is called ***conservative zone***.

It is the converging boundary of the plates where folded mountains like the Himalayas build up. When two convergent plates composed of continental crusts collide against each other, the denser plate is subducted under the lighter plate. The resultant lateral compression squeezes and folds the sediments deposited on either side of the continental plate margins or sediments of the geosynclines lying between the two.

The Himalayas are the product of such a process on the convergence zone of the Asiatic plate in the north and the Indian plate in the south. Some 70 million years ago, the Indian plate started moving towards the Asian plate and the Tethys sea began to contract due to the movement of Indian and Asian plates towards each other. Since the Indian plate was made up of denser material than the Asian plate, the former began to subduct under the latter causing lateral compression of the marine sediment in the bed of the Tethys (**Fig. 3.4**). Geologists believe that the sediment got folded in three successive phases giving rise to three important ranges of the Himalayas. Although the process of the Indian plate moving towards the Asian plate and formation of the Himalayan ranges was more or less completed about 10 million years ago, it is believed that the Indian plate is still moving northwards and the Himalayas continue to rise further. Evidences regarding rise in the Himalayas have already been mentioned in the foregoing paragraphs.

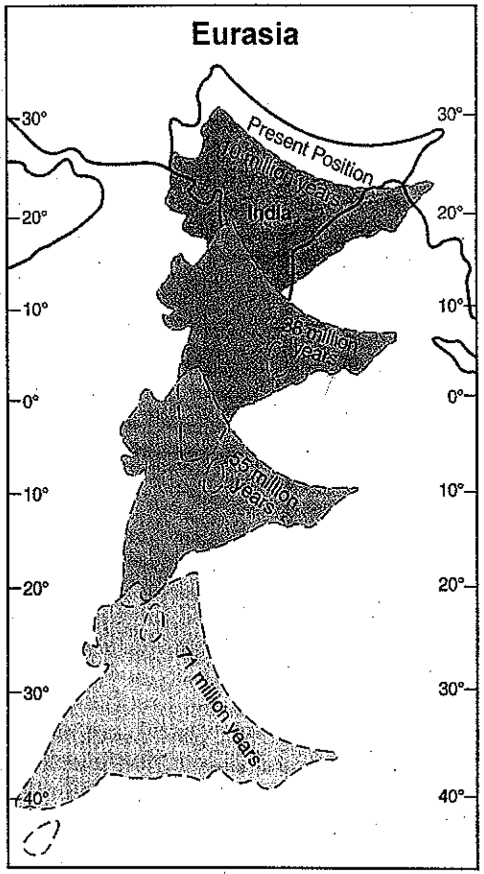


FIG. 3.4. The northerly drift of Indian plate and its collision with Asian plate

Different stages of movement of the Indian plate and the evolution of the Himalayas is illustrated in Fig. 3.5.

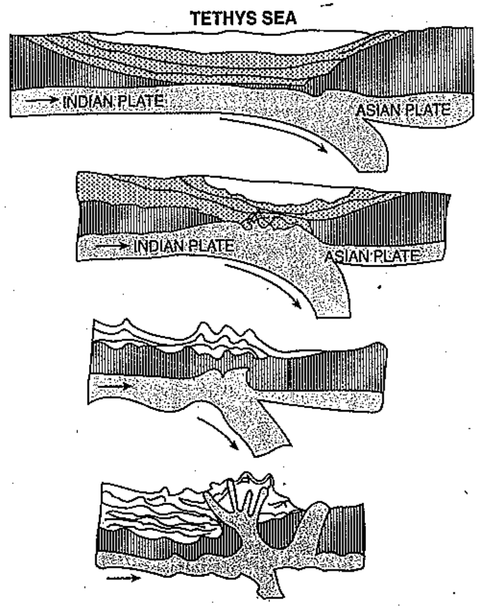


FIG. 3.5. Plate Tectonics and Evolution of the Himalayas

Recent studies have shown that convergence of the Indian plate and the Asian plate has caused a crustal shortening of about 500 km in the Himalayan region. This shortening has been compensated by sea floor spreading along the oceanic ridge in the Indian Ocean. Since the northward movement of the Indian plate is still continuing the height of the Himalayan ranges is increasing with the passage of time. It has been estimated that the Indian plate is still moving northward at a rate of about 5 cm per year. As a result of this movement, one more fracture has appeared in the outer fringes of the Shiwalik Hills which demarcates these hills from the Ganga Plain. Geologists postulate that a new mountain chain would be formed in the Ganga basin forcing the rivers of this region to migrate further south. This clearly indicates that the process of upheaval of the Himalayas is not yet over and will continue for a pretty long period in the times to come.

Division of the Himalayas

Geographers generally tend to divide the Himalayas on geographical, regional and geological bases. Geographically the entire Himalayan region can be divided into: (*i*) The Himalayan Ranges; (*ii*) The Trans-Himalayas and (*iii*) The Eastern Hills.

(*i*) *The Himalayan Ranges*

The Himalayas are not a single chain or range of mountains, but a series of several, more or less parallel or converging ranges. These ranges are separated by deep valleys. As in all young fold mountains, we find a densely dissected "*ridge-and-valley-topography*" in the Himalayas. The most outstanding valleys in the Himalayan region are the vale of Kashmir and the Karewas, the Kangra and Kulu valley in Himachal Pradesh; the Dun valley; the Bhagirathi valley (near Gangotri) and the Mandakini valley (near Kedarnath) in Uttarakhand and the Kathmandu valley in Nepal. The individual ranges have very steep gradient towards the south but they present a much gentler slope towards the north. In the eastern section the Himalayas rise abruptly from the plains of Bengal and Oudh and suddenly attain great elevations within a short distance from the foot of the mountains. Thus the peaks of Kanchenjunga and Everest are only a few kilometres from the plains and are clearly visible from there. In contrast, the western Himalayas rise gradually from the plains through a series of ranges. Their peaks of perpetual snow are 150 to 200 km away from the plain areas. Most of the Himalayan ranges fall in India, Nepal and Bhutan, but the northern slopes are partly situated in Tibet while the western extremity lies in Pakistan, Afghanistan and Central Asia. A succession of at least three parallel ranges from the Indo-Gangetic plain to the Tibet plateau may be recognised in the Himalayas.

(*a*) **The Shiwalik Range.** The Shiwalik comprises the outermost range of the Himalayas and is also known as the ***Outer Himalayas***. With its southern steep slopes, it assumes a ***hogback*** appearance. Flat scarps, anticlinal crests and synclinal valleys are the chief characteristic features of this range. Overlooking the Great Plain, this chain of hills runs almost parallel to the lesser Himalayas for a distance of about 2,400 km from the Potwar Plateau to the Brahmaputra valley. The width of the Shiwaliks varies from 50 km in Himachal Pradesh to less than 15 km in Arunachal Pradesh. It is an almost unbroken succession of low hills except for a gap of 80-90 km which is occupied by the valley of the Tista River. The gorges of the Tista and the Raidak have jointly formed a gap 80-90 km wide in the Shiwalik range. The altitude varies from 600 to 1500 metres. The Shiwaliks are formed of great thickness of Mio-Pleistocene sands, gravels and conglomerates which have been brought by the rivers flowing from the higher ranges of the Himalayas. These have been folded, faulted and indurated by the earth movements from the Middle Miocene to the lower Pliestocene ages. Obviously the Shiwaliks were formed last of all the ranges. The Shiwaliks are known by different names in different areas. They are called Jammu Hills in Jammu and Dafla, Miri, Abor and Mishmi Hills in Arunachal Pradesh. The Dhang Range, Dundwa Range (Uttarakhand) and the Churia Ghat Hills of Nepal also form part of the Shiwalik range.

As the Shiwalik Hills were formed after the formation of the Himalayas, they obstructed the courses of the rivers draining from the higher reaches of the Himalayas and formed temporary lakes. The debris brought by those rivers were deposited in these lakes. After the rivers had cut their courses through the Shiwalik Range, the lakes were drained away leaving behind plains called ***'duns'*** or ***'doons'*** in the west and ***'duars'*** in the east. Dehra Dun in Uttarakhand is the best example of such a plain which is 75 km long and 15-20 km wide. It is covered with boulder and clay deposits. Kotah, Patli Kothri, Chumbi, Kyarda and Chaukhamba are other duns. In the Jammu hills the extensive picturesque duns of Udhampur and Kotli are quite typical.

The eastern part of the Shiwalik range upto Nepal is covered with thick forests but the forest cover becomes thin in the west. The southern slopes of this range are almost completely devoid of forest cover in Punjab and Himachal Pradesh and are highly dissected by several seasonal streams locally called ***Chos***.

(*b*) The Middle or the Lesser Himalaya. In between the Shiwaliks in the south and the Great Himalayas in the north is the Middle Himalaya running almost parallel to both the ranges. It is also called the ***Himachal*** or ***Lower Himalaya***. It has an intricate system of ranges which are 60-80 km wide having elevations varying from 3,500 to 4,500 m above sea level. Locally linear longitudinal ranges have also developed, with steep, bare southern slopes and more gentle, forest covered northern slopes, they give these ranges typical *hogback* look, more pronounced here than in the Shiwalik. Many peaks are more than 5,050 m above sea level and are snow covered throughout the year. The important ranges included are the Pir Panjal, the Dhaola Dhar, the Mussoorie Range, the Nag Tiba and the Mahabharat Lekh. The Pir Panjal range in Kashmir is the longest and the most important range. It extends from the Jhelum river to the upper Beas river for 300-400 km and is separated from the Zaskar Range by the valley of Kashmir. It rises to 5,000 metres and more in elevation and contains mostly volcanic rocks. The best known passes of the Pir Panjal range are the Pir Panjal Pass (3,480 m), the Bidil (4,270 m), Golabghar Pass (3,812 m) and Banihal Pass (2,835 m). The Banihal Pass is used by the Jammu-Srinagar highway and Jammu-Baramula railway. The Kishanganga, the Jhelum and the Chenab cut through this range. South-east of the Ravi, the Pir Panjal continues as Dhaola Dhar range, passing through Dalhousie, Dharmshala, and Shimla. This is the southernmost range of the Middle Himalayas and rarely attains elevations higher than 4,000 metres.

Between the Pir Panjal and the Zaskar Range of the main Himalayas, lies the famous valley of Kashmir running over a distance of about 135 km in a south-east to north-west direction. This valley is about 40 km broad in its middle. Its total area is 4921 sq km and its average elevation is 1,585 m above mean sea level. Geographers and geologists have divergent views regarding the origin of this valley. **Wadia** thinks that the valley of Kashmir is the synclical basin enclosed between the Pir Panjal to the south and an offshoot of the central axial range to the north while **de Terra** feels that it is a recently depressed intermont basin pointing to evidence of faulting on the Himalayan flank. However, it is generally believed that this basin was occupied by a lake in the Pleistocene age. This was filled with sediment and uplifted to form the Kashmir valley. The synclinal basin of the valley is floored with a variety of alluvial deposits, lacustrine, fluvial and fluvioglacial, through which the Jehlum River meanders majestically before entering the deep gorge it has cut through the Pir Panjal. In Himachal Pradesh there is *Kangra Valley*. It is a strike valley and extends from the foot of the Dhaola Dhar Range to the south of Beas. On the other hand, the *Kulu Valley* in the upper course of the Ravi is transverse valley.

Further east, the Middle Himalayas are marked by the Mussoorie and the Nag Tibba ranges. The Mussoorie range has an average elevation of 2,000-2,600 m and runs over a distance of 120 km from Mussoorie to Lansdowne. Mussoorie, Nainital, Chakrata and Ranikhet are important hill stations situated between 1,500 to 2,000 metres above sea level. The Mahabharat Lekh, in southern Nepal is a continuation of the Mussoorie Range. Its summits rise to 3000 m and its average elevation varies from 1,500 to 2,000 m above sea level. The Kathmandu valley to its north is a very important feature of this area. East of the Sun Kosi River, the Sapt Kosi, Sikkim, Bhutan, Miri, Abor and Mishmi hills represent the lower Himalayas.

On the whole, the Middle Himalayan ranges are less hostile and more friendly to human contact. Majority of the Himalayan hill resorts like Shimla, Mussoorie, Ranikhet, Nainital, Almora and Darjeeling, etc. are located here.

(*c*) The Great Himalaya. This is also known as ***Inner Himalaya***, ***Central Himalaya*** or ***Himadri***. This is the northernmost or the innermost of all the Himalayan ranges. With an average elevation of 6,100 m above sea level and an average width of about 25 km, this is the loftiest and the most continuous mountain range of the world. It is about 150 km away from the northern edge of the plains of Northern India. It is mainly formed of the central crystallines (granites and gneisses) overlain by metamorphosed sediments. The folds in this range are asymmetrical with steep south slope and gentle north slope giving ***'hog back'*** topography. This mountain arc, convex to the south, terminates abruptly in the Nanga Parbat in north-west and in the Namcha Barwa in the north-east.

This mountain range boasts of the tallest peaks of the world, most of which remain under perpetual snow. There are several peaks over 8,000 m in altitude. The highest is the Mount Everest which is 8,850 m* above sea level. Its Nepalese name is ***Sagarmatha*** which means ***The Goddess of the Sky***. The Tibetans call it ***Chomlungma***. Located at 27° 59′ 16″ N latitude and 86° 55′ 46″ E longitude this sky touching peak was first located by George Everest, the then Surveyor General of India in 1841 and in 1852 it was established as the highest peak of the world by the Great Trigonometrical Survey of India. In 1865 it was named as Mount Everest as a tribute to Sir George Everest. Before that, it was known as Peak XV. However, Chinese want the peak to be named as Qomolangma, meaning the "Mother of the World". China claims that this peak was mapped by Qing dynasty officials in 1717. The other important peaks in descending order of altitude are, Kanchenjunga, Lhotse, Makalu, Dhaulagiri, Manaslu, Cho Oyu, Nanga Parbat, Annapurna, Gosainthan or Shisha Pangma. The number of known peaks rising over 7,000 m in elevation exceeds forty. Some of the important peaks between 7,100 and 8,000 m elevation are Nanda Devi, Kamet, Namcha Barwa, Gurla Mandhata, Badri Nath, Trisul, etc. (*see* **Table 3.1** and **Fig. 3.6** and **3.8**).

This range is so formidable that it cannot be easily crossed even through the passes because they are generally higher than 4,570 m above sea level and are snowbound for most of the year. The Burzil Pass and the Zoji La in Jammu and Kashmir, the Bara Lacha La and the Shipki La in Himachal Pradesh, the Thaga La, the Niti Pass and the Lipu Lekh pass in Uttarakhand and the Nathu La and the Jelep La in Sikkim are the important passes through the Great Himalaya. The Hindustan-Tibet Road connecting Shimla with Gartok in Western Tibet passes through the Shipki La. Another important trade route connecting Kalimpong (near Darjeeling) with Lhasa in Tibet, passes through Jelep La (4,386 m).

* Earier the height of the Mount Everest was considered to be 8848 metres. But according to the measurements made by the National Geographic Society (Washington) using Global Positioning System (GPS) satellite equipment on May 5, 2000, the height of the peak is 8850 metres.

On the basis of a new survey conducted recently, the Chinese on 9th October, 2005, reported that the height of Mount Everest had been calculated at 8,844.43 m above sea level with an error margin of 0.21 m. Chen Bangzhu, Director General of the State Bureau of Surveying and Mapping, however, added, "We cannot arrive at the conclusion that the Everest has become shorter, because there have been problems with surveying technology." According to surveyors of China and Nepal, confusion about the exact height of the Mt. Everest is primarily due to different technologies used for the purpose. Moreover, Philip's Geography Dictionary in its 2000 edition has mentioned the height of the peak as 8,850 on page 138. Therefore, it sounds logical to retain the height of the peak at 8,850 m above sea level.

TABLE 3.1. Some Important Peaks and their Heights of the Great Himalayas

Name of the Peak	Height above sea level (in metres)
1. Mount Everest	8,850*
2. Kanchenjunga	8,598
3. Lhotse I	8,501
4. Makalu	8,481
5. Dhaulagiri	8,172
6. Manaslu	8,156
7. Cho Oyu	8,153
8. Annapurna	8,078
9. Gosainthan or Shisha Pangma	8,013
10. Nanda Devi	7,817
11. Kamet	7,756
12. Namcha Barwa	7,756
13. Gurla Mandhata	7,728
14. Trisul	7,140
15. Badarinath	7,138

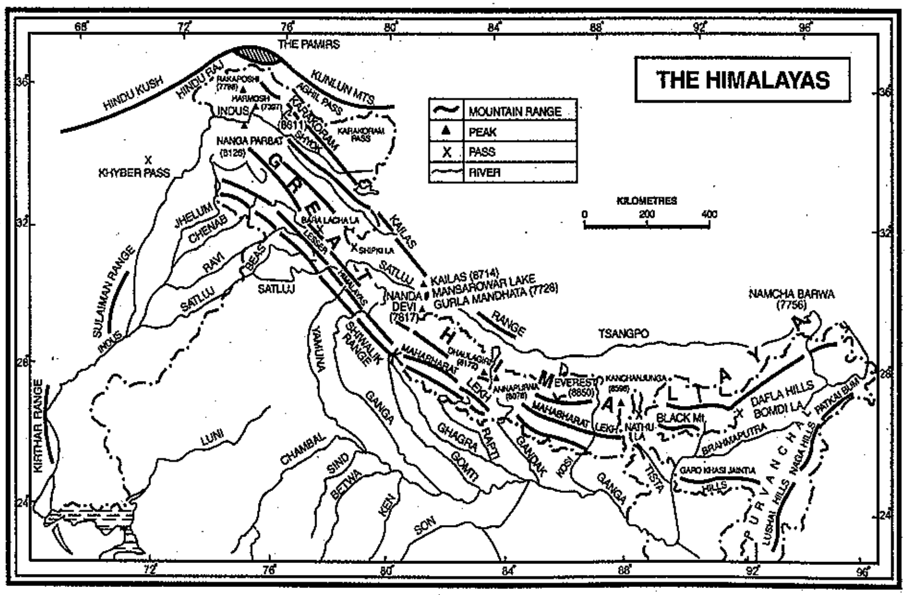


FIG. 3.6. The Himalayas

(ii) The Trans Himalayas

The Himalayan ranges immediately north of the Great Himalayan range are called the trans-Himalayas. This part of the Himalayan ranges is also called the ***Tibetan Himalaya*** because most of it lies in Tibet. The Zaskar, the Ladakh, the Kailas and the Karakoram are the main ranges of the Trans-Himalayan system. It stretches for a distance of about 1,000 km in east-west direction and its average elevation is 3000 m above mean sea level. The average width of this region is 40 km at the eastern and western extremities and about 225 km in the central part.

The *Zaskar Range* branches off from the great Himalayan Range near 80° E longitude and runs more or less parallel to it. The Nanga Parbat (8126 m) forms its culmination in the north-west but the adjoining Deosai Mountain may also be included in it. North of the Zaskar Range and running parallel to it is the *Ladakh Range*. It is about 300 km long and its average elevation is 5800 metre above the sea level. Only a few peaks of this range attain heights of over 6000 metres. The Rakaposhi-Haramosh Ranges beyond the Indus may be treated as extensions of the Ladakh Range to the northwest. The Kailas Range (*Gangdise in Chinese*) in western Tibet is an offshoot of the Ladakh Range. Its average elevation is 5,500-6,000 m above sea level and its average width is 30 km. The highest peak is Mount Kailas (6714 m). River Indus originates from the northern slopes of the Kailas range. The northern-most range of the Trans-Himalayan Ranges in India is the Great Karakoram Range also known as the Krishnagiri range. It forms India's frontier with Afghanistan and China and acts as the watershed between India and Turkistan. It extends eastwards from the Pamir for about 800 km. The average width of this range is 120-140 km. It is a range with lofty peaks and its elevation hardly ever falls below 5,500 m. It is the abode of some of the greatest glaciers of the world outside the polar regions. Some of the peaks are more than 8,000 metre above sea level. K^2 (8,611 m) is the second highest peak in the world and the highest peak in the Indian Union and rises majestically like a cone. It has been named as ***Godwin Austen*** by the Britishers and ***Qogir*** by the Chinese. The other peaks located in its neighbourhood and rising more than 8,000 m above sea level are the Gasherbrum I or Hidden Peak (8,068 m), Broad Peak (8,047 m) and Gasherbrum II (8,035 m). Another 19 peaks in Korakoram cross the 7,600 m elevation mark and those over 7,000 m have not yet been fully enumerated.

The Ladakh Plateau lies to the north-east of the Karakoram Range. With an average elevation of over five thousand metres above sea level, it is the highest plateau of the Indian Union. It has been dissected into a number of plains and mountains, the most outstanding among them being Soda Plains, Aksai Chin, Lingzi Tang, Depsang Plains and Chang Chenmo.

(iii) The Eastern Hills or The Purvanchal

After crossing the Dihang gorge, the Himalayas take a sudden southward turn and form a series of comparatively low hills running in the shape of a crescent with its convex side pointing towards the west. These hills are collectively called the ***Purvanchal*** because they are located in the eastern part of India. Extending from Arunachal Pradesh in the north to Mizoram in the south, they form India's boundary with Myanmar. Differing markedly from the Himalaya in the scale of their relief and in their morphology, these hill ranges none-the-less stem from the same orogeny.

In the north is the Patkai Bum which forms the international boundary between Arunachal Pradesh and Myanmar. It is made up of strong sandstone and rises to elevation varying from 2,000 m to 3,000 m. After running for some distance southwards, it merges into Naga Hills where Saramati (3,826 m) is the highest peak. Patkai Bum and Naga Hills form the watershed between India and Myanmar. The Kohima hills to the west are made up of sandstone and slate and have a very rough topography. South of Naga Hills are the Manipur hills which are generally less than 2,500 metres in elevation. They form the boundary between Manipur and Myanmar. The Barail range separates Naga Hills from Manipur Hills. Further south the Barail Range swings to south-west and then west into Jaintia, Khasi and Garo hills which are an eastward continuation of the Indian peninsular block and has been separated by the Bengal Basin. South of the Manipur Hills are the Mizo Hills (previously known as the Lushai hills) which have an elevation of less than 1,500 metres. The highest point is the Blue Mountain (2,157 m) in the south. It is obvious that the elevation of the eastern hills decreases as we move from north to south. Although comparatively low, these hill ranges are rather forbidding because of the rough terrain, dense forests and swift streams.

Regional Division of the Himalayas

Sir Sidney Burrard divided the entire length of the Himalayas into the following four divisions on the basis of the river valleys :

(i) The Punjab Himalayas

The 560 km long stretch of the Himalayas between the Indus and the Satluj rivers is known as the ***Punjab Himalayas***. A large portion of this sector lies in Jammu and Kashmir and Himachal Pradesh as a result of which it is also called the ***Kashmir and Himachal Himalaya***. Karakoram, Ladakh, Pir Panjal, Zaskar and Dhaola Dhar are the main ranges of this section. The 3,444 metre high Zoji La pass provides an easy passage. In between the main ranges, there are valleys, duns, and lakes. The general elevation falls westwards.

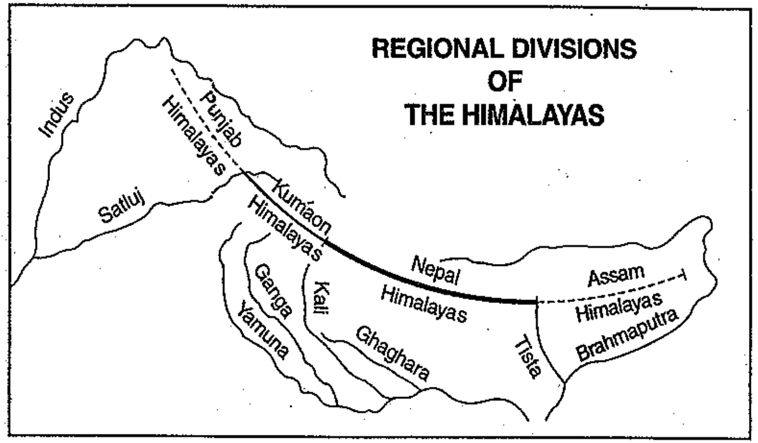


FIG. 3.7. Regional Divisions of the Himalayas

(ii) The Kumaon Himalayas

Between the Satluj and the Kali rivers is the 320 km long Kumaon Himalayas. Its western part is called **Garhwal Himalaya** while the eastern part is known as **Kumaon Himalaya** proper. The general elevation is higher as compared to Panjab Himalayas. Nanda Devi (7,817 m), Kamet (7,756 m), Trisul (7,140 m), Badrinath (7,138 m), Kedarnath (6,968 m), Gangotri (6,510 m) are important peaks. The sources of sacred rivers like the Ganga and the Yamuna are located in the Kumaon Himalayas. There are several *duns* between the Middle Himalayas and the Shiwalik Hills. Nainital and Bhimtal are important lakes.

(iii) The Nepal Himalayas

This section of the Himalayas stretches for a distance of 800 km between the Kali and the Tista rivers. Most of it lies in Nepal as a result of which it is called the ***Nepal Himalayas***. This is the tallest section of the Himalayas and is crowned by several peaks of perpetual snow. The Mount Everest (8,850 m) is the tallest peak of the world. The other major peaks are Kanchenjunga (8,598 m), Lhotse I (8,501 m), Makalu (8,481 m), Dhaula Giri (8,172 m), Cho Oyu (8,153 m) and Annapurna (8,078 m). Kathmandu is a famous valley in this region.

(iv) The Assam Himalayas

The Himalayan ranges from Tista to Brahmputra rivers covering a distance of 750 km are called the ***Assam Himalayas***. This part of the Himalayas spreads over large parts of Sikkim, Assam and Arunachal Pradesh and has elevation much lesser than that of the Nepal Himalayas. The southern slopes are very steep but the northern slopes are gentle. The Lesser Himalayas are very narrow and are very close to the Great Himalayas. The improtant peaks of this region are Namcha Barwa (7,756 m), Kula Kangri (7,554 m) and Chomo Lhari (7,327 m).

Apart from Sir Sydney Burrard, some other scholars have also divided the Himalayas in their own way. For example, **Prof. S.P. Chatterjee** (1,964) divided the Himalayan region into three meso physiographic regions. Their names are (1) Western Himalayas (Kashmir, Punjab and Kumaon Himalayas), (2) Central Himalayas (Nepal Himalayas) and (3) Eastern Himalaya—besides the Purvanchal consisting of the north-eastern ranges. **R.L. Singh** (1971) also made three fold subdivision of the Himalayas. His division was slightly different from that made by **S.P. Chatterjee. Prof. R.L. Singh's** division comprises (*i*) Western Himalaya (1. Kashmir Himalaya and 2. Himachal Himalaya), (*ii*) Central Himalaya (3. U.P. Himalaya—now Uttarakhand Himalaya, 4. Nepal Himalaya), and (*iii*) Eastern Himalaya (5. Darjeeling—Bhutan—Assam Himalaya and 6. Purvanchal).

From the above discussion, it sounds more logical to divide the Himalayas into the following three broad divisions :

1. The Western Himalayas. Stretching for 880 km between the Indus in the west and the Kali river in the east, the Western Himalayas spread in three states of Jammu and Kashmir, Himachal Pradesh and Uttarakhand. It encompasses three physiographic provinces namely Kashmir Himalaya, Himachal Himalaya and Kumaon Himalaya.

The *Kashmir Himalaya* lies almost entirely in the state of Jammu and Kashmir. The average height of this region is nearly 3,000 m above sea level. This province is marked by a number of glaciated troughs. The Indus is the most important river which traverses this area diagonally for about 650 km. North of this river lies the imposing Karakoram range. This range has lofty peaks and a large number of big glaciers. The second highest peak of the world K_2 (8,611 m) lies in this range. The Ladakh plateau and the Kashmir valley are two important areas of this region. The chief characteristic features of the Kashmir Himalaya are high snow covered peaks, deep valleys, interlocked spurs and high mountain passes.

The *Himachal Himalayas* are mainly confined to Himachal Pradesh. All the three ranges of the Himalaya are represented in this area. The Greater Himalaya is represented by the Zaskar range, lesser Himalaya by Pir Panjal and Dhauladhar ranges and the Outer Himalaya by the Shiwalik range. The main range has some peaks which rise above 6,000 m. The southern slopes are rugged and forested while the northern slopes are bare and show plains with lakes. Zojila La, Rohtang, Bara Lacha La and Shipki La are important passes. This area has beautiful valleys of Kullu, Kangra and Lahul and Spiti.

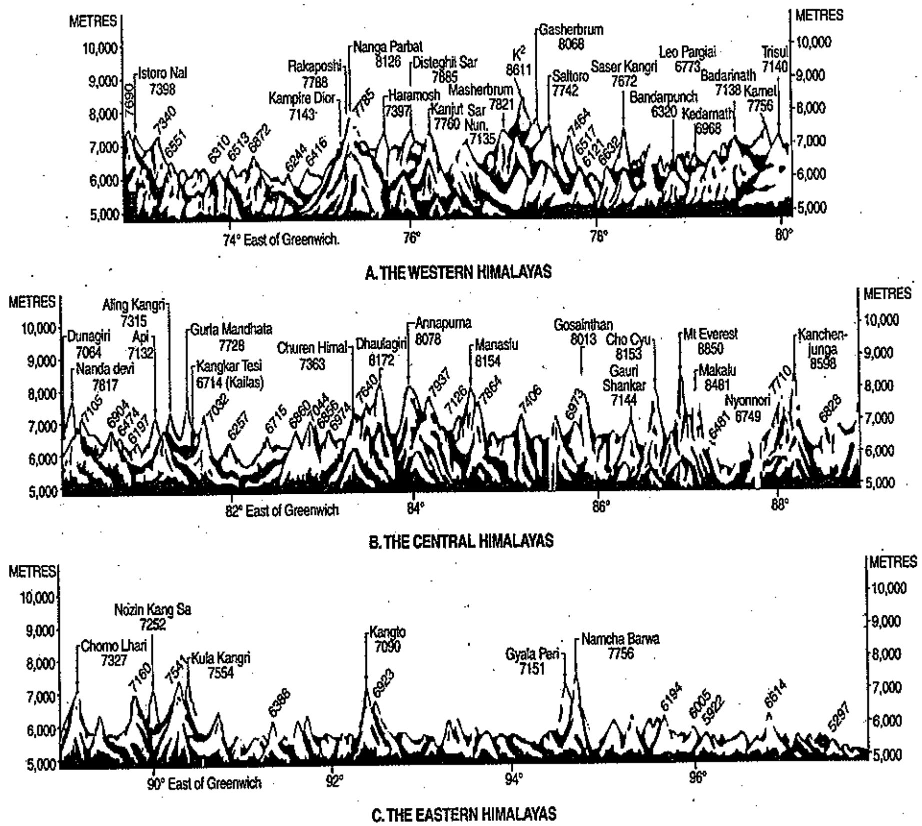


FIG. 3.8. Longitudinal cross section of the Himalayas showing important peaks

The *Kumaon Himalayas* lie in Uttarakhand and extend from the Satluj to the Kali river. Its main peaks are Nanda Devi (7,817 m), Kamet (7,756 m), Mana (7,273 m), Trisul (7,140 m), Badrinath (7,138 m), Kedarnath (6,968 m), Jauli or Shivling (6,638 m) and Gayatri (6,515 m). The Gangotri glacier is the source of the sacred Ganga. The region is dotted by about 36 lakes. The Lesser Himalayas in Kumaon Himalaya is represented by the Mussoorie and Nag Tiba ranges. The area has the famous Nainital lake. The Shiwalik in this region is about 900-1000 m high and runs south of the Mussoori range between the Ganga and the Yamuna rivers for a length of about 75 km. The flat valleys between the Lesser Himalaya and the Shiwalik range are called ***'Doons'*** or ***'Duns'*** of which ***Dehra Dun*** is the most famous. The Kumaon Himalaya is connected to Tibet by a number of mountain passes of which Thaya La, Muling La (5,669 m), Mana (5,611 m), Niti (5,068), Marhi La (4,953 m), Kungribingri, Darma and Lipin Laot are important.

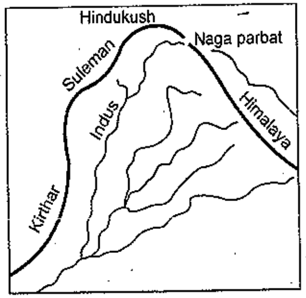
2. The Central Himalayas. The Central Himalayas stretch for a distance of about 800 km between river Kali in the west and river Tista in the east. All the three ranges of the Himalayas are present here. The Great Himalaya range attains maximum height in this portion. Some of the world famous peaks Mt. Everest, Kanchenjunga, Makalu, Annapurna, Gosainthan and Dhaulagiri are located here (**Fig. 3.8**). The Lesser Himalaya is known as ***Mahabharat Lekh*** in this region. The range is crossed by rivers like Ghaghara, Gandak, Kosi, etc. In between the Great and the Lesser Himalayas, there are Kathmandu and Pokhra valleys which represent lacustrine deposits. The Shiwalik range come very close to the lesser Himalaya towards the east and is almost non-existent beyond Narayani (Gandak).

3. The Eastern Himalayas. This part of the Himalayas lies between the Tista river in the west and the mighty Brahmaputra river in the east and stretches for a distance of about 720 km. Also known as the ***Assam Himalayas***, the Eastern Himalayas occupy mainly the areas of Arunachal Pradesh and Bhutan. This part of the Himalayas is known by a number of different names according to the names of the tribal people living in different areas. The prominent peaks of this area are Namcha Barwa (7,756 m), Kula Kangri (7,554 m), Chamo Lhari (7,327 m), Hozin Kang Sa (7,252 m), Gyalaperi (7,151 m) and Kangto (7,090). A number of mountain passes are found in the Eastern Himalayas. The important passes are Jalep La (4,535 m), Bum La (4,331 m), Tse La (4,740 m), Tunga (5,044 m), Yonggyap (3,962 m), and Kangri Karpo La (5,636 m). The Jelep La in the Chumbi valley of Sikkim and Bum La in Arunachal Pradesh provide passage to the Tibetan Capital Lhasa. The Assam Himalayas show a marked dominance of fluvial erosion due to heavy rainfall.

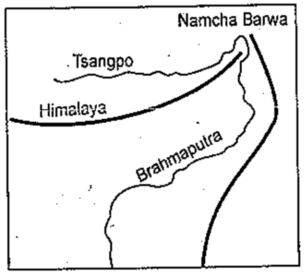
The Himalayas take a sudden southward turn after the Dihang gorge and the hill ranges running in more or less north-south direction along India's border with Myanmar are collectively known as the ***Purvanchal***. These are known by various local names such as *Patkai Bum*, *Naga hills*, *Kohima hills*, *Manipur hills*, *Mizo hills* (previously known as the Lushai hills), Tripura hills and Barail range. The extension of the Purvanchal Himalaya continues southwards upto Andaman and Nicobar Islands through the Myanmar range and even upto the Indonesian archipelago.

Syntaxial Bends of the Himalayas

It has already been mentioned that the Himalayas extend in the east-west direction from the Indus gorge in the west to the Brahmaputra gorge in the east. This east-west trend of the Himalayas is suddenly terminated at its western and eastern extremities and the Himalayan ranges take sharp southward bends. These bends are called ***syntaxial bends*** of the Himalayas. The bend on the western extremity is called the ***western syntaxial bend*** and that on the eastern extremity is known as the ***eastern syntaxial bend***. The ***western syntaxial bend*** occurs near the Naga Parbat where the Indus river has cut a deep gorge. It forms a great knee-bend some 500 km deep and effects the strike of the ranges probably as far as the foot of the Pamirs. The geological formations take a sharp hairpin bend as if they were bent round pivotal points. The ***eastern syntaxial bend*** occurs at the eastern extremity of the Himalayas where the Himalayan range takes a sharp bend in the southern direction and the eastern trend of the ranges terminates here. The bend is conspicuous in Arunachal Pradesh where the mountain ranges turn southward after crossing the Brahmaputra. The strike of the ranges also has a deep knee-bend towards the south.



(a) Western Syntaxial Bend



(b) Eastern Syntaxial Bend

FIG. 3.9. Syntaxial Bends of the Himalayas

Glaciers of the Himalayas

As the name implies, the Himalayas are the *abode of snow* and are called the ***storehouse of snow***. Out of a total area of five lakh square kilometres of the Himalayas, about 33,000 sq km area is covered by snow. Evidences of large snow areas in the past are available in abundance. The active glaciers and the associated landscape provide an ideal platform for investigation of historic glacial variation. Obviously the Pleistocene ice was far more extensive than that of today. There are about 15,000 glaciers in the Himalayas lying between the two syntaxial bends in the east and west. The ***snow line, the lowest level of perpetual snow***, varies to a great extent in different parts of the Himalayas depending upon latitude, amount of precipitation and local topography. While the glaciers of Kanchenjunga in Sikkim portion hardly move below 3,965 m, and those of Kumaon and Lahul to 3,660 m, the glaciers of the Kashmir Himalayas may descend to 2,500 m above sea level. **T.D. La Touche** while elaborating the cause of these variations, has suggested that in part it is due to the increase in latitude from 28° N in Kanchenjunga to 36° N in the Karakoram, and in part because of the fact that the eastern Himalayas rise abruptly from the plains without the intervention of high ranges. Though the total precipitation is much less in the western Himalayas it all takes place in the form of snow. In the Great Himalayan ranges, the snow line is at lower elevation on the southern slopes than on the northern slopes because the southern slopes are steeper and receive more precipitation as compared to the northern slopes.

Glaciers of the Karakoram Range

Maximum development of glaciers occurs in the Karakoram range. This range accounts for about 16,000 sq km or about half of the snow bound area of the Himalayan region. Some of the largest glaciers outside the polar and sub-polar regions are found in this range. The southern side of this range nourishes a number of gigantic glaciers, some of which are exceeded in size by the great Humboldt of Greenland only. The 75 km long *Siachen Glacier* in Nubra valley has the distinction of being the largest glacier outside the polar and the sub-polar regions. Lolofond and Teram Shehr are its main tributaries. The second largest is the 74 km long *Fedchenko Glacier*. It covers an area of 450 sq km in the north-western Pamir and has a depth of nearly 550 m of ice. Third comes the *Hispar Glacier*. It is 62 km long and occupies a tributary of the Hunza River. It combines with 59 km long *Biafo Glacier* occupying about 65 sq km area of Braldoh valley. Kunyong or Lak (24 km) is an important tributary of the Hispar Glacier. The west flowing *Baltoro Glacier* also flows in the Braldoh valley. The depth of solid ice at the end of the Baltoro Glacier is about 120 m; the thickness in the middle of the glacier could be much greater. The great *Godwin Austen Glacier* drains three sides of K_2 and joins the Baltoro Glacier. The *Punmah Glacier* also flows in the Braldoh valley. This 27 km long glacier has a complex system of branches in its upper reaches. The *Batura Glacier* draining the Hunza is 58 km long and is considered to be the fifth longest glacier, along with Baltoro, outside the polar and sub-polar regions. The sixth largest glacier outside the polar and sub-polar regions is the 50 km long *Chogo Lungma* glacier in the Rakaposhi Range. It terminates at an altitude of 2075 m, the lowest recorded in the Himalayas. The other two glaciers draining into the

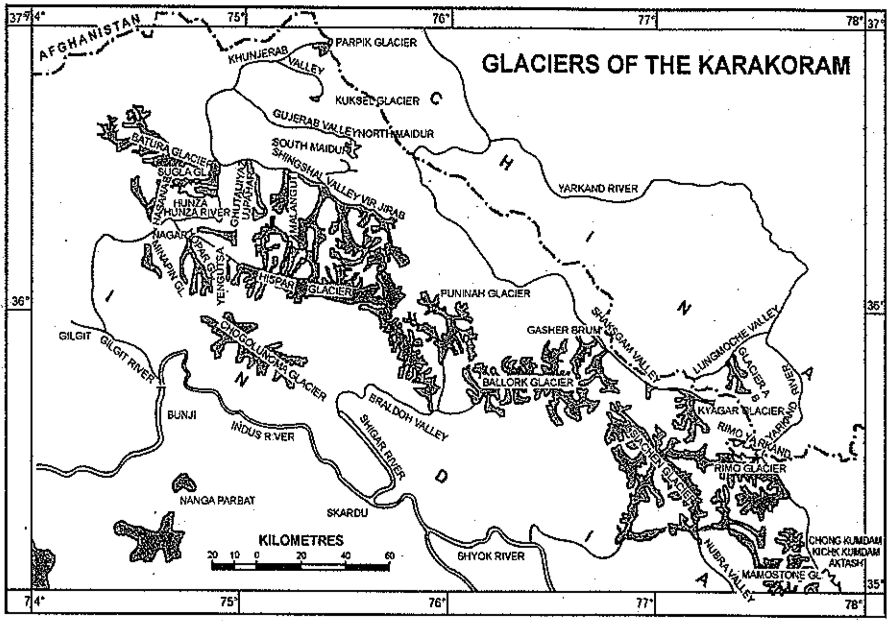


FIG. 3.10. Glaciers of the Karakoram

Hunza Valley are the *Pasu* (25 km) and *Sasaini* or *Ghulkin* (18 km). The *Rimo Glacier* occupying the Shyok valley is about 40 km long. It is joined by the 20 km long *Yarkand Rimo* from the north. The other Glaciers in the Shyok valley are the *Chong Kumdan* (21 km), *Kichik Kumdan* (11 km) and *Aktash* (8 km). The *Khurdopla Glacier* in Shingshal valley is 47 km long. The other glaciers of this valley are the *Virjerab Glacier* (40 km), the *Mombil Yaz* (32 km), *Yazghil* (31 km) and the *Malangutti Yaz* (23 km) The *Gasherbrum* and the *Kyagar* in the Shaksgam valley are 21 km long each. The *Urdok Glacier* lying below these two glaciers is nearly 23 km long.

Glaciers of the Pir Panjal Range

The glaciers of the Pir Panjal Range are less numerous and smaller in size as compared to those of the Karakoram Range. The longest *Sonapani Glacier* in the Chandra Valley of Lahul and Spiti region is only 15 km long. Rising at about 4000 m near the Rohtang Pass and flowing in south west direction it has developed a dry lake basin about 2.5 km long and 1.5 km wide, just below the ice cliff. The *Bara Shigri Glacier* also occupies the Chandra Valley. The rough estimates put its length varying from 10 to 20 km. The largest glacier in the Nun Kun massif is the *Gangri Glacier* which is 13 km long. The glaciers of the Nanga Parbat massif are small in size and are moving fast due to steep slope. The *Chungphar*, *Rakhiot*, *Buzhi* and *Tashan* are important glaciers.

Glaciers of the Kumaon-Garhwal Region

In the Kumaon-Garhwal region of the Himalayas, the largest is the 30 km long *Gangotri Glacier* which is the source of the holy Ganga. It is fed by five tributary glaciers, the largest of which is 24 km long. The second largest glacier of this region is the *Milam Glacier* which occupies the valley of the Gori Ganga River. It is 20 km long and is formed by the union of nine tributary glaciers. The other glaciers of this region are the *Mana Glacier* (18 km), the *Bhagirath-Kharak Glacier* (18 km), the *Satopanch* (16 km) the *Sankalpa Glacier* (12 km) and the *Raikane Glacier* (9 km).

Glaciers of Central Nepal

Central Nepal comprises the mountain ranges between Cho Oyu and Dhaulagiri. Little known glaciers of this region are confined to the surroundings of Gosainthan, Manaslu, Annapurna and Dhaulagiri mountains. The 13.5 km long *Yepokangara* glacier is in the Gosainthan mountain. Two 11 km long ones are the *Lidanda* and *Chhuling* glaciers, both on the south-eastern side of the Manaslu. The *Annapurna* glacier is in the Annapurna mountain. Another 11 km long Mayondi glacier is in the north of the Dhaulagiri.

TABLE 3.2. Important Glaciers of the Himalayan Mountains

Name of the Glacier	Length (km)	Location
The Karakoram Range		
1. Siachen	75	Nubra Valley
2. Fedchenko	74	South-Western Pamir
3. Hispar	62	Tributary of Hunza River
4. Biafo	59	Brabloh Valley
5. Batura	58	Hunza
6. Baltoro	58	Braldoh Valley
7. Chogo Lungma	50	Rakaposhi Range
8. Khurdopla	47	Shingshal Valley
9. Lolofond	40	West of Siachen
10. Yarkand Rimo	40	Shyok Valley
11. Mohil Yaz	32	Shingshal Valley
12. Yazhit	31	Shingshal Valley
13. Godwin Austen	30	K_2
14. Pasu	25	Hunza
15. Kunyang	24	Muztagh, Karakoram
16. Chong Kumdon	21	Shyok
17. Gasherbrum	16	Gasherbrum
The Pir Panjal Range		
18. Sonapani	15	Chandra Valley of Lahul and Spiti
19. Bara Shigri	10-20	Chandra Valley
20. Rakhiot	15	Nanga Parbat
21. Gangri	13	Nun Kun Massif
22. Chungphar	13	Nanga Parbat
The Kumaon-Garhwal Region		
23. Gangotri	30	Source of the Ganga
24. Milam	20	Gori Ganga
25. Bhagirath Kharak	18	Near Badrinath
26. Mana	18	Mana Valley north of the Gangotri
27. Satopanch	16	Near Badrinath
The Central Nepal Region		
28. Yepokangara	13.5	Gosainthan
29. Lidanda	11	Manaslu
30. Chhuling	11	Manaslu
31. Mayondi	11	Dhaulagiri Himal
The Kanchenjunga-Everest Region		
32. Rongbuk	52	Northern (Tibetan) side of the Mount Everest
33. Zemu	25	Zemu Valley (Forms headwaters of the Tista River)
34. Kanchanjunga	21	North of Kanchanjunga, occupies head of Kangchen river.
35. Khumbu	20	South of Mt. Everest
36. Kangshung	19	East of the Mt. Everest
37. Tolam Bau	19	South-west of the Mt. Everest
38. Barun	15	North-east of Baruntse peak
39. Rambang	10	Kanchanjunga

Glaciers of the Kanchenjunga-Everest Region

In the Kanchenjunga-Everest region, there is *Rongbuk Glacier* on the northern side of the Mount Everest. This is 52 km long and is considered to be the largest outside the Karakoram. Another important glacier of the Everest group is the *Khumbu Glacier*, (20 km) lying to the south of the Everest. The 25 km long *Zemu Glacier* flows in the easterly direction at the head of the Zemu River. It is about one kilometre wide with 180 metre thick ice. The 21 km long *Kanchenjunga Glacier* descends from the peak of the same name and occupies the head of Kangchen river. Both the Zemu and the Kanchenjunga glaciers are formed as a result of the union of several branches coming down from the peaks. The *Yalung Glacier* is 16 km long and flows in a south-west direction from the Kanchenjunga peak. The *Talung Glacier* (13 km) also flow southwest wards. This glacier is separated from the *Alukthang Glacier* by a ridge. Though only 5 km long the Alukthang glacier is unique because it is clearly visible from Darjeeling at the foot of the Kanchenjunga in clear weather. The *Knagshung Glacier* is 19 km long and flows east of the Everest. The *Barun Glacier* flowing down the Baruntse peak is about 15 km long.

Main Passes of the Himalayas

Although the mighty Himalayas rise abruptly from the Indus-Ganga-Brahmaputra plain and stand like a great wall providing little opportunity to cross. Yet there are some passes across this mountain wall which offer passes to cross. Some of the important passes are briefly described below :

A. Passes of the Western Himalayas

The Western Himalayas are dotted with a number of passes which offer passages through them. States of Jammu and Kashmir, Himachal Pradesh and Uttarakhand are included in this part of the Himalayas.

I. Jammu and Kashmir

1. Mintaka Pass. It lies near the trijunction of India-China and Afghanistan border and joins north Kashmir with China.

2. Parpik Pass. It lies to the east of Mintaka pass on the Indo-China border and joins north Kashmir with China.

3. Khunjerab Pass. This pass lies at an altitude of 4934 m on the Indo-China border and gives access between Kashmir and China.

4. Aghil Pass. Lying in the north of K_2 Peak (the highest peak in India and the second highest peak in the world). This pass is situated at the elevation of about 5000 m above sea level and join the Ladakh region of India with the Xinjiang (Sinkiang) Province of China. Being located at a high altitude and surrounded by lofty mountains, it remains snow covered during the winter season and is closed from November to May.

5. Banihal Pass. It is situated at an elevation of 2832 m across the Pir-Panjal Range. It remains snow covered during winter season and cannot be used as a transport route in that season. To provide round-the-year transport facilities between Jammu in south and Srinagar in the north, a tunnel named as ***The Jawahar Tunnel*** (after Pandit Jawaharlal Nehru, the first prime minister of India) was inaugurated in December, 1956. Another 11 km long tunnel provides railway link between Banihal and Kazigund. It was thrown open to railway transport in July, 2013.

6. Chang-La. Located at the border between India and China at an altitude of 5360 m, this pass joins Ladakh with Tibet. Road after Chang La is very steep. This has a temple dedicated to Chang-La Baba after whom the temple has been named. This pass remains closed to traffic during the winter season because of heavy snowfall.

7. Khardung La. This pass is situated at an altitude of 5602 m near Leh in the Ladakh range. The world's highest motorable road passes through this pass. However, this road remains closed in winter due to heavy snowfall.

8. Lanak La. Located near the border between India and China at an altitude exceeding five thousand metres in the Akasai-Chin area of Jammu and Kashmir, this pass provides passage between Ladak and Lhasa. A road to connect Xinjiang Province with Tibet has been constructed by the Chinese.

9. Pir-Panjal. Lying across the Pir Panjal range, it had been a traditional pass on the Mughal Road and provides the shortest and the easiest metal road between Jammu and Kashmir Valley. But this route had to be closed down as a result of partition of the subcontinent.

10. Qara Tag La. It is situated on the Indo-China borer across the Karakoram Range. It remains snow bound and closed to traffic during winters because it is located at an elevation of over six thousand metres. It was an offshoot of the Great Silk Route.

11. Imis La. Situated at the Indo-China border at an altitude of over 4500 m, this pass provides passage between Ladakh region of India and Tibet in China. However, the access is not very easy due to difficult terrain and steep slopes. It remains snowbound and closed during the winter season.

12. Pensi La. Situated to the east of the famous Zoji La in the Greater Himalayas at an elevation of over five thousand metres, this pass provides a vital link between the Kashmir Valley and Kargil. It remains closed to traffic from November to mid-May due to heavy snowfall.

13. Zoji La. It is located at an altitude of 3850 m above sea level and provides an important road link between Srinagar on one side and Kargil and Leh on the other side. The road passing through this pass has been designated at the National Highway (NH-1D). Border Road Organisation (BRO) is responsible for maintaining the road and cleaning it off snow during winter. In spite of all these efforts, the road through this pass remains closed from December to mid-May.

II. Himachal Pradesh

14. Bara Lacha La. This mountain pass is situated at an altitude of 4883 m and provides passage between Himachal Pradesh and Jammu and Kashmir. National highway connecting Mandi in Himachal Pradesh with Leh in Jammu and Kashmir passes through this pass. Being situated at high altitude, it remains snow covered in winter and is not used as a transport route.

15. Debsa Pass. Situated at an elevation of 5270 m above sea level in the Greater Himalayas, it provides a link between Kullu and Spiti districts. It offers a much easier and shorter alternative route to traditional Pin-Parbati Pass route between Kullu and Spiti.

16. Rohtang Pass. It is located at an altitude of 3979 m and provides road link between Kullu, Lahul and Spiti Valleys. Border Road Organisation (BRO) is responsible for constructing and maintaining roads in this area. Rohtang pass is a great tourist attraction and traffic jams are very common because this route is widely used by military, public and private vehicles.

17. Shipki La. It is located at the Indo-China border at an altitude of over 6000 m through the Jhalum Gorge and provides a road connection between Himachal Pradesh and Tibet. It remains snow bound for most of the winter season and is not available for transport.

III. Uttarakhand

18. Lipu Lekh. Situated near the trijunction of Uttarakhand (India), Tibet (China) and Nepal borders, in Pithoragarh district, it provides a link between Uttarakhand and Tibet. This pass is used by pilgrims to Kailash-Mansarowar. Use of this pass becomes difficult due to landslides in the rainy season and avalanches in the winter season.

19. Mana Pass. Situated a little north of the holy place of Badrinath at an elevation of 5610 m near the Indo-China border in the Greater Himalayas, this pass connects Uttarakhand with Tibet. It remains closed for six winter months in the year due to heavy snowfall.

20. Mangsha Dhura. Situated at an altitude of over five thousand metres at the Indo-China border in the Greater Himalayas in Pithoragarh district, this pass connects Uttarakhand with Tibet. It is used by pilgrims going to Kailash-Mansarowar. Landslides during the rainy season and avalanches during the winter season pose great threat to pilgrims using of this route.

21. Niti Pass. Located at an altitude of 5068 m at the Indo-China border across the Greater Himalayas, this pass joins Uttarakhand with Tibet. It remains snow covered and hence closed to traffic from November to mid-May.

22. Muling La. It is situated in the north of Gangotri at an elevation of 5669 m in the Great Himalayas. It provides passage between Uttarakhand and Tibet but remains closed during winter season due to heavy snowfall.

B. Passes of the Eastern Himalayas

This part of the Himalayas includes states of Sikkim and Arunachal Pradesh.

IV. Sikkim

23. Nathu La. Situated at an altitude of 4310 m on the Indo-China border, it forms part of an offshoot of the ancient Silk Route. It connects Sikkim with Tibet and is an important trade route between India and China. It was closed after the Chinese aggression on India in 1962 but was reopened in 2006 as the governments of the two countries decided to enhance their trade through land routes.

24. Jelep La. It lies at the Sikkim-Bhutan border at an altitude of 4538 m and passes through Chumbi Valley. This pass provides an important link between Sikkim and Lhasa.

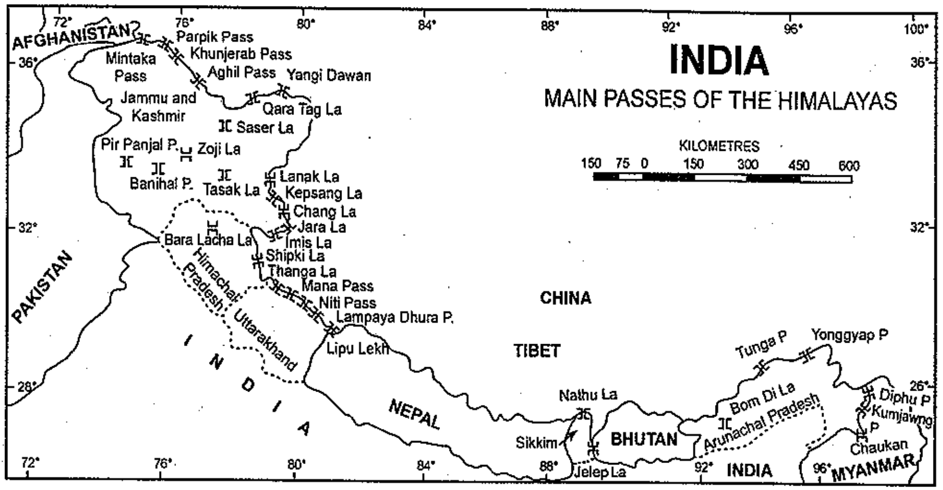


FIG. 3.11. India : Main pass of the Himalayas

V. Arunachal Pradesh

25. Bom Di La. Situated at an altitude of 4331 m near the western boundary of Bhutan in the Greater Himalayas, this pass connects Arunachal Pradesh with Lhasa. It is snowbound in winter and remains closed for traffic.

26. Dihang Pass. Situated at an elevation of more than 4000 m it provides passage between Arunachal Pradesh and Myanmar.

27. Yonggyap Pass. It lies at an altitude of 3962 m on the Indo-China border and joins Arunachal Pradesh with Tibet.

28. Dipher Pass. Lying at the trijunction of India, China and Myanmar border at an altitude of 4353 m, it provides an easy access between Arunachal Pradesh and Mandalay in Myanmar. It is an important land trade route between India and Myanmar and remains open throughout the year.

29. Kumjawng Pass. It lies on the Indo-Myanmar border at an altitude of 2929 m and joins Arunachal Pradesh with Myanmar.

30. Hpungan Pass. Lying at an altitude of 3072 m on the Indo-Myanmar border, it provides an important link between India and Myanmar.

31. Chankan Pass. This pass also lies on the Indo-Myanmar border at an elevation of 2432 m and joins Arunachal Pradesh with Myanmar.

The Significance of the Himalayas

The Himalayas comprise the most dominating geographical feature of India. No other mountain range anywhere in world has affected the life of people and shaped the destiny of a nation as the Himalayas have in respect of India. *The Himalayas are the body and soul of India.* In a very special measure, the Himalayas constitute India's national mountain system. The following few points will bring out the significance of the Himalayan mountains to India.

1. Climatic Influence. The Himalayas play a very significant role in influencing the climate of India. By virtue of their high altitude, length and direction, they effectively intercept the summer monsoons coming from the Bay of Bengal and Arabian Sea and cause precipitation in the form of rain or snow. Besides, they prevent the cold continental air masses of central Asia from entering into India. Had there been no Himalayas, the whole of India would have been a desert in the absence of precipitation and its winters would have been very severe under the influence of cold airmasses coming from Central Asia. According to the latest meteorological studies, the Himalayas are responsible for splitting the jet stream into two branches and these in turn play an extremely important role in bring monsoons in India.

2. Defence. The Himalayas have been protecting India from outside invaders since the early times thus serving as a defence barrier. But the Chinese aggression on India in October, 1962 has reduced the defence significance of the Himalayas to a considerable extent. In spite of advancement in modern warfare technology, the defence significance of the Himalayas cannot be ignored altogether.

3. Source of Rivers. Almost all the great rivers of India have their sources in the Himalayan ranges. Abundant rainfall and vast snow-fields as well as large glaciers are the feeding grounds of the mighty rivers of India. Snow melt in summer provides water to these rivers even during dry season and these are perennial rivers. The Himalayan rivers, along with hundreds of their tributaries, form the very basis of life in the whole of north India.

4. Fertile Soil. The great rivers and their tributaries carry enormous quantities of alluvium while descending from the Himalayas. This is deposited in the Great Plain of North India in the form of fertile soil, making the plain one of the most fertile lands of the world. It has been estimated that the Ganga and the Indus carry 19 and 10 lakh tonnes of silt, per day respectively and the silt carried by the Brahmaputra is even more. It is, therefore, often said that *the great plain of north India is a Gift of the Himalayas.*

5. Hydroelectricity. The Himalayan region offers several sites which can be used for producing hydroelectricity. There are natural waterfalls at certain places while dams can be constructed across rivers at some other places. The vast power potential of the Himalayan rivers still awaits proper utilisation.

6. Forest Wealth. The Himalayan ranges are very rich in forest resources. In their altitude, the Himalayan ranges show a succession of vegetal cover from the tropical to the Alpine. The Himalayan forests provide fuel wood and a large variety of raw materials for forest based industries. Besides many medicinal plants grow in the Himalayan region. Several patches are covered with grass offering rich pastures for grazing animals.

7. Agriculture. The Himalayas do not offer extensive flat lands for agriculture but some of the slopes are terraced for cultivation. Rice is the main crop on the terraced slopes. The other crops are wheat, maize, potatoes, tobacco and ginger. Tea is a unique crop which can be grown on the hill slopes only. A wide variety of fruits such as apples, pears, grapes, mulberry, walnut, cherries, peaches, apricot, etc. are also grown in the Himalayan region.

8. Tourism. By virtue of their scenic beauty and healthy environment, the Himalayan ranges have developed a large number of tourist spots. The hilly areas in the Himalayas offer cool and comfortable climate when the neighbouring plains are reeling under the scorching heat of the summer season. Millions of tourists from different parts of the country as well as from abroad throng the Himalayan tourist centres to enjoy their natural beauty and to escape from the summer heat of the plains. The increasing popularity of winter sports and the craze to enjoy snowfall has increased the rush of tourists in winters also. Srinagar, Dalhousie, Dharamshala, Chamba, Shimla, Kulu, Manali, Mussoorie, Nainital, Ranikhet, Almora, Darjeeling, Mirik, Gangtok, etc. are important tourist centres in the Himalayas.

9. Pilgrimage. Apart from places of tourists interest, the Himalayas are proud of being studded with sanctified shrines which are considered to be the abodes of the Gods. Large number of pilgrims trek through difficult terrain to pay their reverence to these sacred shrines. Kailas, Amarnath, Badrinath, Kedarnath, Vaishnu Devi, Jwalaji, Uttarkashi, Gangotri, Yamunotri, etc. are important places of pilgrimage.

10. Minerals. The Himalayan region contains many valuable minerals. There are vast potentialities of mineral oil in the tertiary rocks. Coal is found in Kashmir. Copper, lead, zinc, nickel, cobalt, antimony, tungsten, gold, silver, limestone, semi-precious and precious stones, gypsum and magnesite are known to occur at more than 100 localities in the Himalayas. Unfortunately, many of the mineral resources cannot be exploited at the present level of technological advancement due to adverse geographical conditions. Further advancements in modern technology may help in exploiting these resources. So the future possibilities of mineral exploitation in the Himalayas are great.

2. THE GREAT PLAIN OF NORTH INDIA

To the south of the Himalayas and to the north of the Peninsula lies the Great Plain of North India. It is an aggradational plain formed by the depositional work of three major river systems *viz.*, the Indus, the Ganga and the Brahmaputra. This arcuate plain is also known as Indo-Gangetic-Brahmaputra Plain. This is the largest alluvial tract of the world extending for a length of 3,200 km from the mouth of the Indus to the mouth of the Ganga, of which the Indian sector alone accounts for 2,400 km in length. Its average width varies from 150 to 300 km. It is widest in the west where it stretches for about 500 km. Its width decreases in the east. It is about 280 km wide near Allahabad and 160 km near Rajmahal Hills. It widens to about 460 km in West Bengal but narrows down in Assam where it is only 60-100 km wide. It covers a total area of 7.8 lakh sq km. The northern boundary of this plain is well defined by the foothills of the Shiwaliks but its southern boundary is a wavy irregular line along the northern edge of the Peninsular India.

Rivers flowing through this plain, especially those originating in the Himalayas have deposited a thick layer of alluvium throughout the length and breadth of this plain. Thus it is a classical example of an aggradational plain. However, the thickness of the alluvium deposit varies from place to place and different estimates have been made about it. According to **Oldham**, the maximum depth of the alluvium is about 5,000 m near its southern edge. It has probably maximum depth between Delhi and Rajmahal Hills and is shallow in Rajasthan and Assam. According to recent computations of seismic soundings, the maximum depth of the alluvium upto the basement rocks is about 6,100 m. The depth of alluvial deposits at some important locations are Meerut (1066.8 m), Kalyan (2286.0 m), and Siliguri (5577.8 m). The variation in thickness of the alluvium largely depends upon the morphological processes. The cones of Kosi in the north and those of Son in the south exhibit greater alluvial thickness while the intra-cone areas have relatively shallower deposits.

Extreme horizontality of this monotonous plain is its chief characteristic. Whereas its average elevation is about 200 m above mean sea level, its highest elevation is 291 m above mean sea level between Ambala and Saharanpur. The comparatively higher area near Ambala forms the watershed which divides the drainage system of the Ganga from that of the Indus. It is, in fact, a low land and is hardly perceptible as one enters Panjab-Haryana plain from the Uttar Pradesh plains. Its average gradient for about 1500 km from Saharanpur to Kolkata is 20 cm per km and it decreases to 15 cm per km from Varanasi to the Ganga delta.

Origin of the Plain

It is almost universally accepted that this vast plain has been formed as a result of filling of a deep depression lying between the Peninsular and the Himalayan regions by the depositional work of the rivers coming from these two landmasses. However, divergent views have been expressed regarding the origin of this great depression and the process of filling it. **Wadia** postulates that these plains were originally a deep depression or furrow lying between the Peninsula and the mountain region. The great Austrian geologist **Edward Suess** has suggested that a *"foredeep"* was formed in front of high crust-waves of the Himalayas as they were checked in their southward advance by inflexible solid landmass of the Peninsula. This foredeep was like a large syncline in which alluvium brought by the Himalayan and the Peninsular rivers was deposited. In due course of time, this was filled with alluvium and the Great Plain of North India was formed. It rests on the hard and crystalline rocks through which the region is connected to the Himalayan and the Peninsular blocks **(Fig. 3.12)**. **Sir Sydney Burrard**, on the other hand, thinks that the Indo-Gangetic alluvium conceals a great deep rift, or fracture, in the earth's sub-crust, several thousand metres deep, the hollow being subsequently filled up by detrital. He ascribes to such sub-crustal cracks or rifts a fundamental importance in geotectonics and detritus the elevation of the Himalayan chain to an incidental bending or curbing movement of the northern wall to the fissure. Such sunken tracts between parallel, vertical dislocations are called ***'Rift Valleys'***. The rift valley between the Himalayan ranges and the Peninsula which gave birth to this plain was about 2,400 km long and hundreds of metres deep. His findings were based on some anomalies in the observations of the deflections of the plumb line and other geodetic considerations. He described some other rift valleys of the Himalayan region as well as the rift valleys of Narmada and Tapi in the Peninsular India. Scholars like **Hayden** and **R.D. Oldham** as well as other geologists of the

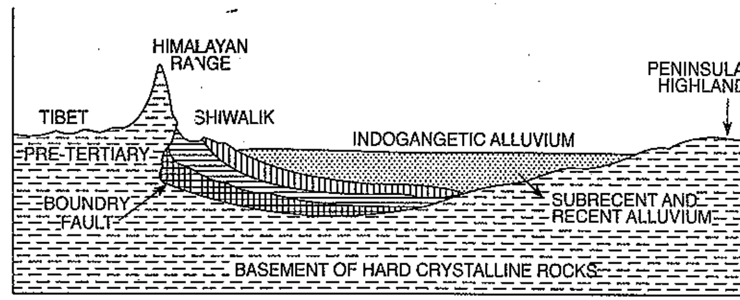


FIG. 3.12. Deposition of alluvium in the Indo-Gangetic trough and formation of the Indo-Gangetic Plain

Geological Survey of India have not accepted Burrard's view of the Indo-Gangetic depression. The main objection to Burrard's views is that there is no trace of a rift valley at the northern edge of the Peninsula and that such a vast rift valley is not possible.

According to the recent views expressed by many geologists and geographers, sediment deposited at the bed of the Tethys Sea was folded and warped due to northward drift of the Peninsula. Consequently the Himalayas and a trough to the south were formed. The origin of this depression or trough, lying at the foot of the mountain, is doubtless intimately connected with the latter. The Great plain represents the infilling of the foredeep warped down between the advancing Peninsular Block and the Himalayas. The infilling has been done by the deposition of the detritus of the mountain brought by the numerous rivers emerging from them during the period of great gradational activity. Geologically most parts of this plain are of the Pleistocene and Recent formations. Thus, the surface deposits of this tract belong to the last chapter of the earth's history and conceal beneath them the older peninsular and other formations.

Geomorphology of the Plain

There is a tendency amongst geographers to treat the Great Plain of North India as a monotonous, flat and featureless plain; but it has its own geomorphological varieties which have their own significance. The following geomorphological features may be noticed depending upon the nature of relief and soil structure.

The Bhabar is a narrow belt about 8-16 km wide running in east-west direction along the foot of the Shiwaliks with a remarkable continuity from the Indus to the Tista. Rivers descending from the Himalayas deposit their load along the foothills in the form of alluvial fans. These fans, consisting of gravel and unassorted sediments, have merged together to build up the bhabar belt which forms the northern boundary of the Great Plain. The porosity of the pebble studded rock beds is so high that most of the streams sink and flow underground. Therefore, the area is marked by dry river courses except in the rainy season. The Bhabar belt is comparatively narrow in the east and extensive in the western and north-western hilly region. The area is not suitable for agriculture and only big trees with large roots thrive in this belt.

The Tarai (Hindi : '*Tar'-wet*) is a 15-30 km wide marshy tract in the south of Bhabar running parallel to it. It is marked by the re-emergence of the underground streams of the Bhabar belt. The re-emerged water converts large areas along the rivers into ill-drained marshy lands of excessive dampness covered with thick forests giving shelter to a variety of wild life. The Tarai is more marked in the eastern part than in the west because the eastern parts of the plain receive higher amount of rainfall than their western counterparts. Most of the Tarai land, especially in Punjab, Uttar Pradesh and Uttarakhand, has been reclaimed and turned into agricultural land which gives good crops of sugarcane, rice and wheat.

The Bhangar (or Bangar) is composed of old alluvium of the Middle Pleistocene age and forms the alluvial terrace above the level of flood plains. It is often impregnated with colcareous concretions known as *kankar*. Remnants of the *bhangar* are eroded by every change in the direction of river channels, and are being levelled down by their meandering tendencies. It mostly occupies the Pleistocene terrace dating back to Middle and Upper Pleistocene periods. It also contains fossils of animals like rhinoceros, hippopotamus, elephants, etc.

The Khadar is composed of newer alluvium and forms the flood plains along the river banks. A new layer of alluvium is deposited by river flood almost every year. These deposits are normally confined to the vicinity of the present river channels. The clays have less kankar, and the organic remains entombed in them belong to still living species. The *khadar* imperceptibly merges into the deltaic and other accumulations of prehistoric times.

Reh or *Kallar* comprises barren saline efflorescences of drier areas in Uttar Pradesh and Haryana. Reh areas have spread in recent times with increase in irrigation.

Bhur denotes an elevated piece of land situated along the banks of the Ganga river especially in the upper Ganga-Yamuna Doab. This has been formed due to accumulation of wind-blown sands during the hot dry months of the year.

Regional Divisions of the Great Plain of India

Although the Great Plain of North India is treated as a geographical unit with low elevation and gentle slope, this vast area exhibits distinctive fluvial patterns, directions of flow and geomorphology in different parts allowing it to be divided into the following four major regions : **(Fig. 3.13)**

1. The Rajasthan Plain.
2. The Punjab-Haryana Plain.
3. The Ganga Plain.
4. The Brahmaputra Plain.

1. The Rajasthan Plain

The western extremity of the Great Plain of India consists of the *Thar* or the *Great Indian Desert* which covers western Rajasthan and the adjoining parts of Pakistan. The desert is about 650 km long and 250-300 km wide. Its total area is about 2.0 lakh sq km out of which 1.75 lakh sq km lies in India. About two-thirds of the Indian desert lies in Rajasthan, west of the Aravali Range, and the remaining one-third is in the neighbouring states of Haryana, Punjab and Gujarat. Recently, some geomorphic studies by using remote sensing techniques in conjunction with ground truth were undertaken by the Central Arid Zone Research Institute, Jodhpur. This vast desert is an undulating plain whose average elevation is about 325 m above mean sea level. It descends to about 150 m above mean sea level near the Indo-Pak border as well as towards the Indus Valley and the Rann of Kachchh. The desert proper is called ***Marusthali*** and accounts for greater part of the *Marwar* plain. The average elevation of the Marusthali is 200-250 m above sea mean level. It has a vast stretch of sand with a few outcrops of bedrock of gneisses, schists and granites which proves that geologically it is a part of the Peninsular Plateau and it is only at the surface that it looks like an aggradational plain. In general, the eastern part of the Marusthali is rocky while its western part is covered by shifting sand dunes locally known as ***dhrian***.

The eastern part of the Thar Desert, upto the Aravali Range is a semi-arid plain which is known as the ***Rajasthan Bagar***. It runs in a north-east to south-west direction from the edge of the Aravalli in the east to the 25 cm *isohyet* (line joining places of equal rainfall) in the west. It is drained by a number of short seasonal streams originating from the Aravali and supports agriculture in some patches of fertile tracts called ***rohi***. Even the important river, the Luni, is a seasonal stream which flows towards the south-west to the Rann of Kachchh. The tract north of the Luni is known as ***thali*** or sandy plain.

The LANDSAT imageries have been used to study the geomorphological characteristics of this Great Desert including its sand dunes. Based on the morphological, spatial and spectral characteristics, six types of sand dunes, *viz*. obstacle, parabolic, longitudinal, transverse, barchan and shrub-coppice have been identified in this desert. The mean height of the dunes varies from 8 m in Jaipur and Sikar districts to 30 m in Barmer district. The length of the dunes also varies greatly and some may be 5-10 km long.

North of the Luni basin, there is a large area of inland drainage on the eastern edge of the Thar Desert having several saline lakes. They are a great source of common salt and many other salts. The *Sambhar*, the *Didwana*, the *Degana*, the *Kuchaman*, the *Sargol* and

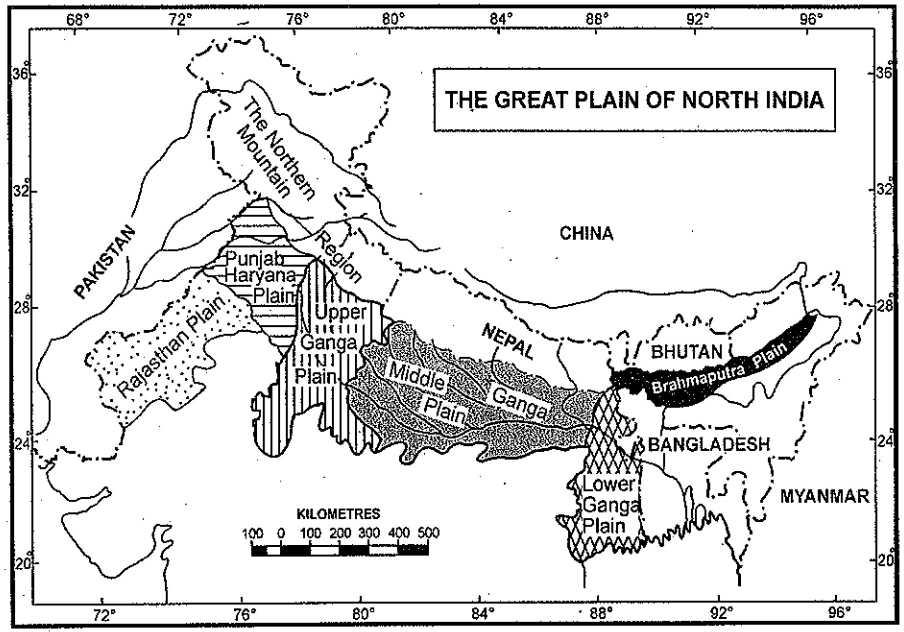


FIG. 3.13. Regional Divisions of the great Plain of North India

the *Khatu* are some of the important lakes. The largest and the most outstanding is the Sambhar lake about 65 km west of Jaipur. Situated at an altitude of about 360 m in the Aravali terrain, this lake is about 30 km long with an average width of 3-8 km. It occupies an area of about 225 sq km during the rainy season but shrinks considerably in dry season.

2. The Punjab-Haryana Plain

The Great Indian Desert imperceptibly gives way to the fertile plains of the Punjab and Haryana towards the east and north east. The entire plain extends for a length of 640 km in north-west to south-east direction and is about 300 km wide in east-west direction. The total area of this plain is about 1.75 lakh sq km. Its eastern boundary in Haryana is formed by the Yamuna river. The average elevation of the plain is about 250 m above mean sea level. Its northern part is nearly 300 m above mean sea level and it drops to about 200 m in the south-east. Part of the plain shows a flat to slightly convex planation controlled by subsurface Delhi-Aravali ridge.

The part of the plain, formed as a result of alluvial deposts by five rivers, *viz*., the Satluj, the Beas, the Ravi, the Chenab and the Jhelum, is known as the Punjab Plain—***the land of five rivers***. It is primarily made up of '***doabs***'—*the land between two rivers*. From east to west these doabs are as under :

(*a*) Bist-Jalandhar Doab, lying between the Beas and the Sutluj;

(*b*) Bari Doab, between the Beas and the Ravi;

(*c*) Rachna Doab, between the Ravi and the Chenab;

(*d*) Chaj Doab, between the Chenab and the Jhelum; and

(*e*) Sind Sagar Doab, between the Jhelum-Chenab and the Indus.

The depositional process by the rivers, continuing since long, has united these doabs and has given a homogenous geomorphological entity to the entire area. However, the mass of alluvium has been broken by the river courses which have carved for themselves broad flood plains of khadar flanked by bluffs, locally known as ***dhayas***. These bluffs, as high as 3 metres or more, have been heavily gullied. The *khadar* belt, known as ***bet lands***, though liable to flooding, is agriculturally valuable.

The northern part of this plain adjoining the Shiwalik hills has been intensively eroded by numerous streams called ***Chos***. This has led to enormous gullying. The erosion by the Chos is particularly noticed in Hoshiarpur district of Punjab. In a short stretch of about 130 km nearly a hundred Chos debouch on the plains. To the south of the Satluj river there is *Malwa* plain of Punjab.

The area between the Ghaggar and the Yamuna rivers lies in Haryana and is often termed as ***'Haryana Tract'***. It acts as water-divide between the Yamuna and the Satluj rivers. The only river between the Yamuna and the Satluj is the Ghaggar which is considered to be the present day successor of the legendary **Saraswati River**.

3. The Ganga Plain

This is the largest unit of the Great Plain of India stretching from Delhi to Kolkata in the states of Uttar Pradesh, Bihar and West Bengal covering an area of about 3.75 lakh sq km. The Ganga is the master river after whose name this plain is named. The Ganga along with its large number of tributaries originating in the Himalayan ranges *viz*., the Yamuna, the Gomati, the Ghaghara, the Gandak, the Kosi, etc. have brought large quantities of alluvium from the mountains and deposited it here to build this extensive plain. The peninsular rivers such as Chambal, Betwa, Ken, Son, etc. joining the Ganga river system have also contributed to the formation of this plain. The general slope of the entire plain is to the east and south east. Depending upon its geographical variations, this plain can be further subdivided into the following three divisions :

(*a*) The Upper Ganga Plain.

(*b*) The Middle Ganga Plain.

(*c*) The Lower Ganga Plain.

(*a*) **The Upper Ganga Plain.** Comprising the upper part of the Ganga Plain, this plain is delimited by the 300 m contour in Shiwaliks in the north, the Peninsular boundary in the south and the course of the Yamuna river in the west. Its eastern boundary is rather obscure and has become a controversial topic among geographers. The limit drawn by **L.D. Stamp** and later adopted by **O.H.K. Spate**, roughly corresponding with 100 cm *isohyet* seems to be far from being practical. Physiographically, the 100 m contour (line joining places of equal height) has been accepted by the geographers as the most effective line of demarcation. This plain is about 550 km long in the east-west direction and nearly 380 km wide in north-south direction, covering an approximate area of 1.49 lakh sq km. Its elevation varies from 100 to 300 m above mean sea level. The plain is drained by the Ganga and its tributaries like the Yamuna, the Ram Ganga, the Sarda, the Gomati and the Ghaghara rivers. Almost all the rivers follow NW-SE course concomitant with the lie of the land. The average gradient of the land is about 25 cm per km. The gradient is comparatively steep in the northern part. The rivers flow sluggishly in the plain as the gradient decreases. The monotony of this flat and featureless plain is broken by the *tarai-bhabar* submontane belt and on micro level by the river bluffs, river meanders and oxbow lakes, levees, abandoned river courses, sandy stretches (Bhurs) and the river channels themselves. The western part of this plain consists of comparatively higher Ganga-Yamuna Doab. East of this doab are the low lying Rohilkhand plains which merge into the Avadh plains further east. The Ghaghara is the main stream of the Avadh Plains. The khadar of this river is very wide because the river meanders through this area. Moreover it often changes its course. At places this khadar is 55 km wide. Consequently, there is a constant fear of devastating floods.

(*b*) **The Middle Ganga Plain.** To the east of the Upper Ganga plain is Middle Ganga plain occupying eastern part of Uttar Pradesh and Bihar. It measures about 600 km in east-west and nearly 330 km in north-south direction accounting for a total area of about 1.44 lakh sq km. Its northern and southern boundaries are well defined by the Himalayan foothills and the Peninsular edge respectively. Its western and eastern boundaries are rather ill defined and the region is wide open on both the sides giving it the personality of the *east-west continuum* of the vast isotropic Ganga Plain. There is no physical boundary worth the name and the plain imperceptibly opens up in the west from out of the upper Ganga Plain and so invisibly dies out into the lower Ganga Plain in the east. As such, it is a *transitional region par excellence*, interposed in the enormity of the Ganga Valley. However, several efforts have been made to demarcate the western and the eastern boundaries of

this transitional zone. The most accepted boundaries are those made by 100 m contour in the west, 75 m contour in the north-east and by 30 m contour in the south-east. Obviously this is a very low plain, no part of which exceeds 150 m in elevation.

This plain is drained by the Ghaghara, the Gandak and the Kosi rivers, all tributaries of the Ganga coming from the Himalayas. These rivers are responsible for filling up with alluvial deposits of 2,000 metre deep trough at the foot of the Nepal Himalayas. They flow sluggishly in this flat land as a result of which the area is marked by local prominences such as levees, bluffs, oxbow lakes, marshes, *tals*, ravines, etc. The *kankar* formation is comparatively less due to the preponderance of the *khadar*. Almost all the rivers keep on shifting their courses making this area prone to frequent floods. The Kosi river is very notorious in this respect. It used to flow near Purnea in 1736 and now its course is about 110 km west of it. At occasions its water level has risen by 10 metres in a short span of 24 hours. It has long been called the ***'Sorrow of Bihar'***. Strenuous efforts both by India and Nepal are being made to tame this river. The major units of this plain are Ganga-Ghaghara doab, Ghaghara-Gandak doab and Gandak-Kosi doab (Mithila Plain).

Some rivers join the Ganga from the south also, the Son being the most important. Here the gradient is a bit steeper, 45 cm per km, as compared to 9-10 cm per km in east Uttar Pradesh and only 6 cm per km in the Mithila Plain. East of Son river is the Magadh Plain.

(*c*) **The Lower Ganga Plain.** This plain includes the Kishanganj tehsil of Purnea district in Bihar, the whole of West Bengal (excluding the Purulia district and the mountainous parts of Darjeeling district) and most parts of Bangladesh. It measures about 580 km from the foot of the Darjeeling Himalaya in the north to Bay of Bengal in the south and nearly 200 km from the Chotanagpur Highlands in the West to the Bangladesh border in the east. The total area of this plain is about 81 thousand sq km. Its width varies greatly and it narrows down to a mere 16 km between the Rajmahal Hills and the Bangladesh border. The 50 m contour roughly corresponds with its western boundary. The northern part of this plain has been formed by the sediment deposited by the Tista, Jaldhaka and Torsa. Besides, this area is marked by the Duars (Darjeeling *Tarai*) and the Barind plain, a tract of old alluvium between the Kosi-Mahananda corridor in the west and the river Sankosh in the east. The delta formation accounts for about two-thirds of this plain. This is the largest delta in the world. The Ganga river divides itself into several channels in the delta area. The slope of the land here is a mere 2 cm per km. Two thirds of the area is below 30 m above mean sea level. The entire land upto Kolkata would be completely submerged if the sea level rose by only 7 metres. The seaward face of the delta is studded with a large number of estuaries, mud flats, mangrove swamps, sandbanks, islands and forelands. Large part of the coastal delta is covered by thick impenetrable tidal forests. These are called the ***Sunderbans*** because of the predominance of *Sundri* tree here.

4. The Brahmaputra Plain

This is also known as the Brahmaputra valley or Assam Valley or Assam Plain as most of the Brahmaputra valley is situated in Assam. Though often treated as the eastern continuation of the Great Plain of India, it is a well-demarcated physical unit girdled by the Eastern Himalaya of Arunachal Pradesh in the north, Patkai and Naga Hills in the east and the Garo-Khasi-Jaintia and Mikir Hills in the south. Its western boundary is formed by the Indo-Bangladesh border as well as the boundary of the lower Ganga Plain. Extending from the easternmost end of Assam near the syntaxial bend of the Eastern Himalayas to the west of Dhubri near the Bangladesh border this plain is about 720 km long and its average width is 60-100 km. The entire plain covers an area of about 56 thousand sq km. It is an aggradational plain built up by the depositional work of the Brahmaputra and its tributaries. The Brahmaputra river enters this plain near Sadiya and flows farther to Bangladesh after turning southwards near Dhubri. The general level of the plain varies from 130 m in the east to 30 m in the west. The average gradient of the land is 12 cm per km in the N.E. to S.W. direction. The area is well demarcated by 150 m contour beyond which the surrounding hill terrain dominates the scene. The northern margin has steep slope from the foothills of Arunachal Pradesh but the southern margin is marked by gradual fall from the hill ranges. The innumerable tributaries of the Brahmaputra river coming from the north debouch abruptly upon the main valley and form a number of alluvial fans. Consequently, the tributaries branch out in many channels giving birth to river mendering leading to formation of *bill* and ox-bow lakes. There are large marshy tracts in this area. The alluvial fans formed by the coarse alluvial debris have led to the formation of tarai or semi-tarai conditions. Some southern tributaries also have meandering courses and there are a good number of *bills* and ox-bow lakes.

Significance of the Plain

With its fertile alluvial soils, flat surface, slow moving perennial rivers and favourable climate, the Great Plain of North India is of great significance. It is the home of about half of the Indian population although it accounts for less than one fourth of the total area of the country. The plain supports some of the highest population densities depending purely upon agro-based economy in some of these areas. The extensive use of irrigation has made some parts of this plain, especially Punjab, Haryana and western part of Uttar Pradesh the *granary* of *India*. The entire plain except the Thar Desert, has a close network of roads and railways which has led to large scale industrialisation and urbanization. The development of trade and commerce in this plain is a natural sequel of industrialization and urbanization. There are many religious places along the banks of the sacred rivers like the Ganga and the Yamuna which are very dear to Hindus. Here flourished the religions of Budha and Mahavira and the movements of Bhakti and Sufism. In short, this vast plain is the hearthrob of India and constitutes its very soul.

3. THE PENINSULAR PLATEAU

The Peninsular Plateau of India is roughly triangular in shape with base coinciding with the southern edge of the great plain of North India and its apex is formed by Kanniyakumari in the southern extremity. The northern boundary of the Peninsular block is an irregular line running from Kachchh along the western flank of the Aravali range to near Delhi, and thence roughly parallel to the Yamuna and the Ganga as far as the Rajmahal Hills and the Ganga Delta. It is surrounded by the hill ranges on all the three sides. To its north are the Aravali Range, the Vindhya, the Satpura, the Bharmer and the Rajmahal Hills. To the south of about 22° N latitude, the Western Ghats (The Sahyadris) and the Eastern Ghats form its western and eastern boundaries respectively (**Fig. 3.14**). The entire plateau measures about 1,600 km in north-south and 1,400 km in east-west direction. It covers a total area of about 16 lakh sq km which is about half of the total land area of the country. It is thus the largest physiogrpahic unit of India. The average height of the plateau is 600-900 m above sea level although many parts are well over 1000 m. The general slope of the palteau is from west to east with the exception of Narmada-Tapi rift which slopes westwards.

The Peninsular Plateau is an ancient tabular block composed mostly of the Archaean gneisses and schists. It has been a stable shield which has gone through little structural changes since its formation. Ever since the dawn of geological history the Peninsula has been a land area and has never been submerged beneath the sea except in a few places where marine transgressions have been made and that too locally and temporarily. Undoubtedly, the entire Peninsular Plateau is an aggregation of several smaller plateaus and hill ranges interspersed with river basins and valleys. A brief description of these plateaus, hill ranges and the intervening river valleys will be of great help in describing the relief of this great plateau.

The Plateaus of the Peninsular India

1. The Marwar Upland. This is also called the Upland of eastern Rajasthan as it lies in the east of the Aravali Range. The average elevation of this area is 250-500 m above sea level and it slopes down eastwards. It is made up of sandstone, shales and limestones of the Vindhayan period. The Banas river originates in the Aravali Range and flows for about 400 km before joining the Chambal river. The area has been carved into a rolling plain by the erosional work of the Banas river and its tributaries.

2. The Central Highland. Also called the ***Madhya Bharat Pathar*** is in the east of the Marwar Upland. Most of it comprises of the basin of the Chambal river which flows in a rift valley. The *Sindh* and the *Parbati* are its main tributaries. It is an open rolling plateau made of old rocks which is interspersed with rounded hills composed of sandstone. Thick forests grow here. To the north are the *ravines* or *badlands* of the Chambal river.

3. The Bundelkhand Upland. To the south of the Yamuna river between the Madhya Bharat Pathar

and the Vindhyan Scarplands is the old dissected upland of the 'Bundelkhand gneiss' comprising of granite and gneiss. This is called Bundelkhand upland. Covering an area of about 54,560 sq km this upland spreads over five districts of Uttar Pradesh (Jalaun, Jhansi, Lalitpur, Hamirpur and Banda) and four districts of Madhya Pradesh (Datia, Tikamgarh, Chhatarpur, and Panna). With an average elevation of 300-600 m above sea level, this area slopes down from the Vindhyan Scarp toward the Yamuna River. The area is recognised by a mass of rounded hummocky hills made of granite and sandstone. In the north-west and north-east, the system is covered by the Ganga-Yamuna alluvium and in the south-west by the Deccan Trap. The erosional work of the rivers flowing here has converted it into an undulating area and rendered it unfit for cultivation. The region is characterised by senile topography. About 67.7 per cent of the area is under 300 m and only 3.6 per cent is above 450 m in altitude. Streams like Betwa, Dhasan and Ken have carved out steep gorges, precipitous rocky banks and waterfalls.

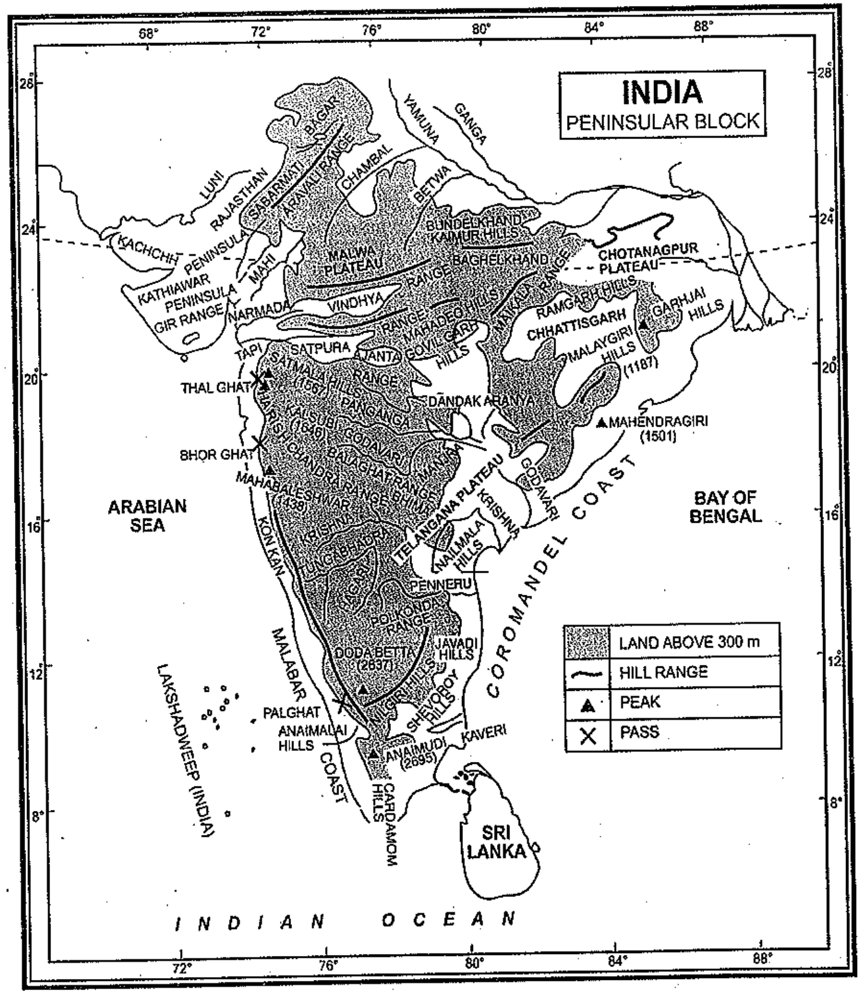


FIG. 3.14. India : Peninsular Block

4. The Malwa Plateau. The Malwa Plateau roughly forms a triangle based on the Vindhyan Hills, bounded by the Aravali Range in the west and sharply defined scarp overlooking Bundelkhand in the east. The plateau inherits a complex geology; scarcely any one of the peninsular groups is unrepresented here. This plateau has two systems of drainage; one towards the Arabian sea (The Narmada, the Tapi and the Mahi), and the other towards the Bay of Bengal (Chambal and Betwa, joining the Yamuna). With a length of 530 km and a width of 390 km, it spreads over an area of 1,50,000 sq km. In the north it is drained by the Chambal and many of its right bank tributaries like the Kali, the Sindh and the Parbati. It also includes the upper courses of the Sindh, the Ken and the Betwa. It is composed of extensive lava flow and is covered with black soils. The general height decreases from 600 m in the south to less than 500 m in the north. There are rolling surfaces and flat-topped hills dissected by rivers flowing through the area. In the north, the plateau is marked by the *Chambal ravines*.

5. The Baghelkhand. East of the Maikal Range is the Baghelkhand made of limestones and sandstones on the west and granite in the east. It covers an area of about 1.4 lakh sq km. It is bounded by the Son river on the north, and to its south occur anticlinal highlands and synclinal valleys of sandstones and limestones. The central part of the plateau acts as a water divide between the Son drainage system in the north and the Mahanadi river system in the south. The region has a general elevation of 150 m to 1,200 m and has uneven relief. The main elements of physiography are scarps of the Vindhyan sandstones between the Ganga plain and the Narmada-Son trough. The Bhanrer and Kaimur are located close to the trough-axis. The general horizontality of the strata shows that this area has not undergone any major disturbance.

6. The Chotanagpur Plateau. East of Baghelkhand, the Chotanagpur plateau represents the north-eastern projection of the Indian Peninsula. It covers an area of over 87 thousand sq km mostly in Jharkhand, northern part of Chhatisgarh and Purulia district of West Bengal. The Son river flows in the north-west of the plateau and joins the Ganga. The average elevation of the plateau is 700 m above sea level. This plateau is composed mainly of Gondwana rocks with patches of Archaean granite and gneisses and Deccan Lavas. The Chotanagpur plateau virtually consists of a series of plateaus standing at different levels of elevation. The highest general elevation of about 1,100 m is in the mid-western portion known as the *Pat* lands (high level laterite plateau). From here, the land descends in all directions in a series of steps which are marked by waterfalls across the rivers. The plateau is drained by numerous rivers and streams in different directions and presents a *radial drainage* pattern. Rivers like the Damodar, the Subarnrekaha, the North Koel, the South Koel and the Barkar have developed extensive drainage basins. The Damodar river flows through the middle of this region in a rift valley from west to east. Here are found the Gondwana coal fields which provide bulk of coal in India.

North of the Damodar river is the **Hazaribagh plateau** with an average elevation of 600 m above mean sea level. This plateau has isolated hills; Parasnath in the east rises to 1,366 m. The area is made of granites and gneisses while the hills have quartz rocks. It looks like a peneplain due to large scale erosion.

The **Ranchi Plateau** to the south of the Damodar Valley rises to about 600 m above mean sea level. The maximum height is found in western part where *pats* of high *mesas* capped with laterite steeply rise to an altitude of about 1100 m. The *Netarhat Pat* and *Goru* rise to 1,119 and 1,142 m above sea level respectively. Most of the surface is rolling where the city of Ranchi (661 m) is located. At places it is interruped by monadnocks and conical hills.

The **Rajmahal Hills** forming the north eastern edge of the Chotanagpur Plateau are mostly made of basalt and are covered by lava flows. They run in north-south direction and rise to average elevation of 400 m (highest mount is 567 m). These hills have been dissected into separate plateaus.

7. The Meghalaya Plateau. The rocks of the peninsular plateau of India extend further north-east beyond the Rajmahal hills and form a rectangular block known as the Meghalaya or the Shillong plateau. This plateau has been separated from the main block of the peninsular plateau by a wide gap known as the ***Garo-Rajmahal Gap***. This gap was formed by down-faulting and was later on filled by

sediments deposited by the Ganga. Extending over an area of about 35 thousand sq km, this plateau is largely formed by Archaean (Dharwarian) quartzites, shales and schists with granite intrusions and some basic silts. The plateau slopes down to Brahmaputra valley in the north and the Surma and Meghna valleys in the south. Its western boundary more or less coincides with the Bangladesh border. The western, central and the eastern parts of the plateau are known as the ***Garo Hills*** (900 m), the ***Khasi-Jaintia Hills*** (1,500 m) and the ***Mikir Hills*** (700 m). Shillong (1,961 m) is the highest point of the plateau.

8. The Deccan Plateau. This is the largest unit of the Peninsular Plateau of India covering an area of about five lakh sq km. This triangular plateau is bounded by the Satpura and the Vindhya in the north-west, the Mahadev and the Maikal in the north, the Western Ghats in the west and the Eastern Ghats in the east. With an average elevation of 600 m it rises to 1000 m in the south but dips to 500 m in the north. Its general slope is from west to east which is indicated by the flow of its major rivers like the Mahanadi, the Godavari, the Krishna and the Cauvery. These rivers have further subdivided this plateau into a numbmer of smaller plateaus described as under :

(a) ***The Maharashtra Plateau*** lies in Maharashtra and forms the northern part of the Deccan Plateau. Much of the region is underlain by basaltic rocks of lava origin. The area looks like a rolling plain due to weathering. The horizontal lava sheets have led to the formation of typical *Deccan Trap* topography. The broad and shallow valleys of the Godavari, the Bhima and the Krishna are flanked by flat-topped steep sided hills and ridges. The Ajanta range lies to the south of the Tapi river. The entire area is covered by black cotton soil known as ***regur***.

(b) ***The Karnataka Plateau*** also known as the Mysore plateau lies to the south of the Maharashtra plateau. Made up primarily of the Archaean formations, it is a rolling country with an average elevation of 600-900 m. It is highly dissected by numerous rivers rising from the Western Ghats. It contains the heads of the *Tungabhadra* and the *Cauvery rivers*. The general trend of the hills is either parallel to the Western Ghats or athwart it. The highest peak (1913 m) is at Mulangiri in *Baba Budan Hills* in Chikmaglur district. The plateau is divided into two parts called ***Malnad*** and ***Maidan***. The *Malnad* in Kannada means hill country. It is dissected into deep valleys covered with dense forests. The *Maidan* on the other hand is formed of rolling plain with low granite hills. The plateau tapers between the Western Ghats and the Eastern Ghats in the south and merges with the Niligiri hills there.

(c) ***The Telangana plateau*** consists of Archaean gneisses at an average elevation of 500-600 m. The southern part is higher than its northern counterpart. The region is drained by three river systems, the Godavari, the Krishna and the Penneru. The entire plateau is divided into two major physiographic regions, namely, the *Ghats* and the *Peneplains*.

9. The Chhattisgarh Plain. The Chhattisgarh plain is the only plain worth the name in the vast stretch of plateaus and hill ranges of the Peninsular plateau. It is a saucer shaped depression drained by the upper Mahanadi. The whole basin lies between the Maikala Range and the Odisha hills. The region was once ruled by *Haithaivanshi Rajputs* from whose thirty six forts (*Chhattisgarh*) it derives its name. The basin is laid with nearly horizontal beds of limestone and shales deposited during the Cuddapah age. The general elevation of the plain ranges from 250 m in the east to 330 m in the west.

Hill Ranges of the Peninsular Plateau

The above mentioned plateaus of the Peninsula are separated from one another by hill ranges and river valleys. The hills of the Peninsular India are much lower than the Himalayan ranges. Most of these hills are of the relict type, being remnants of the originally higher hills but some typical horsts are also seen. Some of the important hill ranges are described as under :

1. The Aravali Range. One of the major physiographic elements of the Peninsular India is the Aravali range running in a north-east to south-west direction for 800 km between Delhi and Palanpur (near Ahmedabad) in Gujarat. The Aravalis represent the relict of the world's oldest mountain formed as a result of folding at the close of the Archaean era. Obviously, their dimensions were much larger and probably even higher than the present Himalayas. Although its north-eastern end is marked by the Delhi ridge, it is supposed to continue upto Haridwar buried under the allivium of the Great Plains.

M.S. Krishnan, has expressed the view that one Branch of the Aravalis extends to the Lakshadweep Archipelago through the Gulf of Khambhat and the other into Andhra Pradesh and Karnataka. According to **D.N. Wadia**, the Aravalis were a prominent feature in the old Palaeozoic and Mesozoic periods and extended as a continuous chain of lofty mountains from Deccan to possibly beyond Garhwal. What we at present see of them are the eroded remnants of these mountains; their mere stumps laid bare by repeated cycles of erosion.

Prof. S.P. Chatterjee has brought out some interesting features of the Aravali Range. According to the conclusion drawn by him, the Aravali, which occupies the site of an ancient geosyncline and was uplifted and folded in synclinorium for the first time during the *Algonkian* age, 600 to 700 million years ago. The present Aravali has lost its range character in many parts and is now a relic of what it was in the past when it formed India's main watershed, extending from Kumaon Himalaya to the farthest end of the Peninsular plateau on the south, and perhaps one of its arms reaching eastwards across Central India. In that remote age several of its summits rose above the snow-line and nourished glaciers of stupendous magnitude, which in their turn fed many rivers. This range was later reduced by long continuous erosion almost to sea level. There is evidence to suggest that in the late Mesozoic times, perhaps about 100 million years ago, the peneplaned Aravali was uplifted for the second time by at least 1200 m near Udaipur, and 200 m at its two ends near Delhi and Ahmedabad.

Although its general elevation is only 400-600 m, parts of this range rise well above 1,000 m. The Aravali range has a lower elevation between Delhi and Ajmer where it is characterised by a chain of detached and discontinuous ridges. However, it becomes a continuous range south of Ajmer where it rises to 900 m. At the south-west extremity the range rises to over 1,000 m. Here Mt. Abu (1,158 m), a small hilly block, is separated from the main range by the valley of the Banas. Guru Sikhar (1,722 m), the highest peak, is situated in Mt. Abu. Barr, Pipli Ghat, Dewair and Desuri passes allow movement by roads and railways.

2. The Vindhyan Range. The Vindhaya Range rises as an escarpment flanking the northern edge of the Narmada-Son Trough overlooking the Narmada valley. It runs more or less parallel to the Narmada Valley in an east-west direction from Jobat in Gujarat to Sasaram in Bihar for a distance of over 1,200 km. The general elevation of the Vindhyan Range is 300 to 650 m and it rarely goes above 700 m. The northern slope of this range is rather gentle and there are no well marked spurs, steep falls and valleys. Most parts of the Vindhayan Range are composed of horizontally bedded sedimentary rocks of ancient age. The western part of this range is covered with lava. The Vindhayas are continued eastwards as the *Bharner* and *Kaimur* hills. The Vindhya-Kaimur scarp exceeds 610 m at a few places only. This range acts as a watershed between the Ganga system and the river systems of south India and forms the northern boundary of the Deccan. The rivers Chambal, Betwa and Ken rise within 30 km of the Narmada.

3. The Satpura Range. '*Sat*' in Sanskrit means seven and '*pura*' means mountains. Therefore, the Satpura range is a series of seven mountains. It runs in an east-west direction south of the Vindhyas and in between the Narmada and the Tapi, roughly parallel to these rivers. Commencing from the Rajpipla Hills in the west, through the Mahadev Hills to the Maikala Range, it stretches for a distance of about 900 km. These hills appear to be affected by tectonic disturbances. There are evidences that parts of the Satpuras have been folded and upheaved. They are regarded as structural uplift or 'horst'.

No other east-west tectonic mountain of Peninuslar India is as high as the Satpura. Most of the hills rise to elevation of 900 to 1,000 m. Dhupgarh (1,350 m) near Pachmarhi on Mahadev Hills is the highest peak. The other peaks are the Astamba Dongar (1,325 m) and Amarkantak (1,127 m).

4. The Western Ghats (or The Sahyadris). Forming the western edge of the Deccan tableland, the Western Ghats run in north-south direction, parallel and close to the Arabian Sea coast, from the Tapi valley (21° N latitude) to a little north of Kanniyakumari (11° N latitude) for a distance of 1,600 km. As the name implies, the Western Ghats are, down to Malabar, steep-sided, terraced, flat-topped hills or cliffs presenting the mesa-like stepped topography facing the Arabian Sea coast. This is due to the horizontally bedded lavas, which on weathering, have given a characteristic '*landing stair*

aspect' to the relief of this mountain chain. South of Malabar, the Nilgiris, Anamalai, etc. present quite different landscape due to the difference in geological structure. The Western Ghats abruptly rise as a sheer wall to an average elevation of 1,000 m from the Western Coastal Plain and appear to be an imposing mountain. But they slope gently on their eastern flank and hardly appear to be a mountain when viewed from the Deccan tableland.

The northern section of the ghats from 21° N to 16° N latitudes *i.e.* from Tapi valley to a little north of Goa is made of horizontal sheets of Deccan lavas forming a formidable wall looking over the West Coastal Plain. The average height of this section of the Ghats is 1,200 m above mean sea level, but some peaks attain more heights. Kalasubai (1,646 m) near Igatpuri, Salher (1,567 m) about 90 km north of Nashik, Mahabaleshwar (1,438 m) and Harishchandragarh (1,424 m) are important peaks. Thalghat and Bhorghat are important passes which provide passage by road and rail between the Konkan Plains in the west and the Deccan Plateau in the east. LANDSAT imagery shows a large density of faults along the trend of the Ghats.

The Middle Sahyadri runs from 16°N latitude upto Nilgiri hills. This part is made of granites and gneisses and presents rougher topography. Lying at a stone's throw from the Arabian Sea coast, this area is covered with dense forests. The western scarp is considerably dissected by headward erosion of the west flowing streams. The average height is 1200 m but many peaks exceed 1500 m. The Vavul Mala (2,339 m.), the Kudremukh (1,892 m) and Pashpagiri (1,714 m) are important peaks. The Nilgiri Hills which join the Sahyadris near Gudalur rise abruptly to over 2,000 m and mark the junction of the Western Ghats with Eastern Ghats. Doda Betta (2,637 m) and Makurti (2,554 m) are important peaks of this area.

The southern part of the Western Ghats is separated from the main Sahyadri range by Palghat Gap which presents a sudden break in the continuity of this mountain range. The high ranges terminate abruptly on either side of this gap. This 24-30 km wide gap has an elevation ranging from 75 to 300 m while the bordering hills rise to 1500-2000 m above mean sea level. In all probability, it is a rift valley which has been formed by subsidence of the land between two parallel fault lines. This gap is used by a number of roads and railway lines to connect the plains of Tamil Nadu with the coastal plain of Kerala. It is through this gap that moist-bearing clouds of the south-west monsoon can penetrate some distance inland, bringing rain to parched Mysore region. South of the Palghat Gap there is an intricate system of steep and rugged slopes on both the eastern and western sides of the Ghats. Anai Mudi (2,695 m) is the highest peak in the whole of southern India. This is a nodal point from which three ranges radiate in different directions. These ranges are the Anaimalai (1800-2000 m) to the north, the Palni (900-1,200 m) to the north-east and the Cardamom Hills or the *Ealaimalai* to the south.

5. The Eastern Ghats. Bordering the eastern edge of the Deccan Plateau, the Eastern Ghats run almost parallel to the east coast of India leaving broad plains between their base and the coast. In striking contrast to the continuous eminence of the Western Ghats, it is a chain of highly broken and detached hills starting from the Mahanadi in Odisha to the Vagai in Tamil Nadu. The hills constituting the Eastern Ghats have neither structural unity nor physiographic continuity. In fact, they almost disappear between the Godavari and the Krishna. The name Eastern Ghats is, therefore, something of a misnomer and various mountains and hill groups are generally treated as independent units. In view of the heterogenous character, **Spate** has preferred to use the terms ***Eastern Hills*** for the northern, ***Cuddapah Ranges*** for the central, and ***Tamilnad Hills*** for the southern group in place of the collective term of Eastern Ghats. Still many geographers tend to use the term Eastern Ghats to this discontinuous linear assemblage of hills, each group of hills having its separate identity.

Depending upon the relief and structure, the Eastern Ghats can be divided into northern and southern parts, the dividing boundary lying somewhere south of the Godavari valley. It is only in the northern part, between the Mahanadi and the Godavari, that the Eastern Ghats exhibit true mountain character with a width of 200 km in the north and 100 km in the south. This part comprises the Maliya and the Madugula Konda ranges. The peaks and ridges of the Maliya range have a general elevation of 900-1,200 m and Mahendra Giri (1,501 m) is the tallest peak here. The Madugula

Konda range has higher elevations ranging from 1,100 m and 1,400 m with several peaks exceeding 1,600 m. Arma Konda (1,680 m), Gali Konda (1,643 m) and Sinkram Gutta (1,620 m) are important peaks.

Between the Godavari and the Krishna rivers, the Eastern Ghats lose their hilly character and the saddle between these two rivers is occupied by Gondwana formations. The Eastern Ghats reappear as more or less a continuous hill range in Cuddapah and Kurnool districts of Andhra Pradesh. Here, the arcuate Nallamalai Range with general elevation of 600-850 m is the most prominent. It is composed of quartz and slate. The southern part of this range is called the Palkodna range. To the south, the hills and plateaus attain very low altitudes; only Javadi Hills and the Shevroy-Kalrayan Hills form two distinct features of 1,000 m elevation. The Biligiri Rangan Hills in Coimbatore district attain a height of 1,279 m. These hills have steep slope and bold relief because they are made of charnockites. Further south, the Eastern Ghats merge with the Western Ghats.

Significance of the Peninsular Plateau

The Peninsular Plateau of India is the oldest and the most stable landmass of the Indian sub-continent. It contains a rich variety of minerals which occur in large quantities. There are huge deposits of iron, manganese, copper, bauxite, chromium, mica, gold, etc. Above all, 98 per cent of the Gondwana coal deposits of India are found in the Peninsular Plateau. Besides, there are large reserves of slate, shale, sandstones, marbles, etc. A large part of north-west plateau is covered with fertile black lava soil which is extremely useful for growing cotton. Some other areas of the Peninsular Plateau are suitable for the cultivation of tea, coffee, rubber, millets, spices, tobacco and oilseeds. Some low lying areas of the plateau are suitable for growing rice. A variety of tropical fruits is also grown here. The highlands of the plateau are covered with different types of forests which provide a large variety of forest products. The rivers originating in the Western Ghats offer great opportunity for developing hydroelectricity and providing irrigation facilities to the agricultural crops. The plateau is also known for its hill resorts such as Udagamangalam (Ooty), Panchmarhi, Kodaikanal, Mahabaleshwar, Khandala, Matheron, Mount Abu, etc.

4. THE COASTAL PLAINS

The narrow coastal strip between the edges of the Peninsular Plateau and the coastline of India running for a distance of about six thousand kilometres from the Rann of Kachchh in the west to the Ganga-Brahmaputra delta in the east is called the coastal plains. The area between the Western Ghats and the Arabian Sea coast is known as the ***West Coastal Plain*** and that between the Eastern Ghats and the Coast of the Bay of Bengal is called the ***East Coastal Plain.*** The two coastal plains meet each other at the southernmost tip *i.e.* Kanniyakumari.

The West Coastal Plains

Stretching from Rann of Kachchh in the north to Kanniyakumari in the South, there are narrow west coastal plains with an average width of about 65 km. It is quite narrow in the middle and a bit broader in the northern and southern parts. Depending upon relief and structure, it can be divided into following subdivisions.

The Kachchh Peninsula was an island surrounded by seas and lagoons. These seas and lagoons were later filled by sediment brought by the Indus river which used to flow through this area. Thus, the island became a part of the mainland and comparatively broad plain was formed. Some scholars do not consider it as part of the west coastal plain and treat it as a separate identity. There are other geographers who consider Kachchh and Kathiawar as part of the Peninsular plateau because Kathiawar is made of the Deccan Lava and there are tertiary rocks in the Kachchh area. The true west coastal plain, according to them, lies between Surat and Kanniyakumari for a distance of 1600 km. But the ground reality is that it is, more or less, a plain area and lies near the west coast of India. Hence it should be treated as an integral part of the West Coastal Plain.

Due to scarcity of rain and flowing surface water, the work of wind is felt everywhere and this has given rise to arid and semi-arid landscape. Coastal sand dunes, sandy plains, interrupted with bare rocky hills are the chief characteristic physiographic features.

All along the north of Kachchh there lies a broad level salt-soaked plain. This is the ***Great Rann.*** Its southern continuation, known as the ***Little Rann*** lies on the coast and south-east of Kachchh. The flat and unbroken Great Rann is about 320 km long with a maximum width of 160 km, covering an area of about 21,500 sq km. It rises only a few metres above the sea level and is flooded by the Banas and the Luni rivers during the rainy season. Some places are actually below sea level and are inundated during high tides. Most of the area is formed of sun-baked dark silt encrusted with salt. A few patches of high ground are covered with grass and break the monotony of the otherwise flat plain.

The Kathiawar Peninsula lies to the south of the Kachchh. It is encircled on the east and north-east by the Little Rann and the Nal Basin. The average elevation is less than 200 m. The central part is a highland of Mandav Hills from which small streams radiate in all directions. Mt. Girnar (1,117 m), the highest point, is supposed to be of volcanic origin. The Gir Range is located in the southern part of the Kathiawar peninsula. It is covered with dense forests and is famous as home of the Gir lion.

The Gujarat Plain lies east of Kachchh and Kathiawar and slopes towards the west and south west. It may almost be described as an intrusion of Indo-Gangetic conditions into the Peninsula. Formed by the rivers *Narmada*, *Tapi*, *Mahi* and *Sabarmati*, the plain includes the southern part of Gujarat and the coastal areas of the Gulf of Khambhat. This is a low plain no part of which exceeds 150 m in elevation. The eastern part of this plain is made of sediments and is fertile enough to support agriculture, but the greater part near the coast is covered by wind blown loess which has given rise to semi-arid landscape. A chain of saline marshes near the coast is prone to floods during high tide.

The Konkan Plain south of the Gujarat plain extends from Daman to Goa for a distance of about 500 km with its width varying from 50 to 80 km. It has some features of marine erosion including cliffs, shoals, reefs and islands in the Arabian Sea. Mumbai was an island but parts of the sea lying between the mainland and the island have been reclaimed in recent years to connect it with the mainland. The Thane creek of the Ulhas around Mumbai is an important embayment which provides an excellent natural harbour on the southern side of the island. South of Mumbai, the Konkan coast has a series of small bays and coves lying between jutting head-lands containing beaches of sand. Behind the alluvial coastal belt, there is a series of parallel ridges reaching 450-600 m in which rivers like the Vaitarni, Ulhas and Amba have lower courses more or less parallel to the coast before reaching it transversely. Some lateritic hillocks rise to 100 m above mean sea level.

The Karnataka Coastal Plain from Goa to Mangalore is about 225 km long. It is a narrow plain with an average width of 30-50 km, the maximum being 70 km near Mangalore. The central part of this plain is crossed by numerous spurs projecting from the Ghats. These spurs approach so close to the coast that the breadth of the lowland is reduced to 5-7 km at 14°N latitude where the Ghat's crest is only 13 km away from the sea. Running like ridges, the spurs attain heights of more than 600 m near the Ghats. At some places the streams originating in the Western Ghats descend along steep slopes and make waterfalls. The Sharavati while descending over such a steep slope makes an impressive waterfall known as ***Gersoppa (Jog) Falls*** which is 271 m high. Marine topography is quite marked on the coast.

The Kerala Plain also known as the ***Malabar Plain***, between Mangalore and Kanniyakumari is about 500 km long. This is much wider than the Karnataka plain and at places it is 96 km wide. It is a low lying plain and at no place its height exceeds 30 m. The existence of lakes, lagoons, backwaters, spits, etc. is a significant characteristic of the Kerala coast. The backwaters, locally known as ***kayals*** are the shallow lagoons or inlets of the sea, lying parallel to the coastline. The largest among these is the Vembanad lake which is about 75 km long and 5-10 km wide and gives rise to a 55 km long spit. Kochi is situated on its opening into the sea. This and several other lagoons have been joined together by canals to provide excellent inland waterways from the mouth of the Ponnani in the north to Thiruvananthapuram in the south.

The East Coastal Plains

Between the Eastern Ghats and the east coast of India are located the East Coastal Plains extending from the Subarnarekha river along the West Bengal-Odisha border to Kanniyakumari. A major part of the plains is formed as a result of the alluvial fillings of the littoral zone by the rivers Mahanadi, Godavari, Krishna and Cauvery comprising some of the largest deltas. Its western boundary is a discontinuous line of the Eastern Ghats, more precisely by the contours of 75 m in Odisha, 100 m in Andhra Pradesh and 150 m in Tamil Nadu. In contrast to the West Coastal Plains, these are extensive plains with an average width of 120 km although it may be as wide as 200 km in the deltaic regions and as narrow as 35 km in-between the deltas. This plain is known as the ***Northern Circars*** between the Mahanadi and the Krishna rivers and ***Carnatic*** between the Krishna and the Cauvery rivers. Depending upon physiographic variations, the entire plain is divided into three regions.

The Utkal Plain comprising coastal areas of Odisha is about 400 km long. It includes the Mahanadi delta with Cuttack at its head. There is thick layer of alluvium covering this delta. The most prominent physiographic feature of this plain is the **Chilka Lake** in the south of the Mahanadi delta. This lagoon on the Odisha coast is about 70 km long and its maximum width on the north-east is nearly 22 km narrowing to about 7 km on its south-western end. It is the biggest lake in the country and its area varies between 780 sq km in winter to 1,144 sq km in the monsoon months. South of Chilka Lake, low hills dot the plain.

The Andhra Plain lies south of the Utkal Plain and extends upto *Pulicat Lake*, some 40 km north of Chennai. This lake has been barred by a long sand spit known as Sriharikota Island, on which is located the satellite launching station of the Indian Space Research Organisation. The lagoon is about 60 km long and about 16 km wide in its widest part. The most significant feature of this plain is the delta formation by the rivers Godavari and Krishna. In fact, the two deltas have merged with each other and formed a single physiographic unit. The combined delta has advanced by about 35 km towards the sea during the recent years. This is clear from the present location of the Kolleru lake which was once a lagoon at the shore but now lies far inland. This part of the Andhra plain is quite wide. Andhra plain has a straight coast and badly lacks good harbours with the exception of Vishakhapatnam and Machilipatnam.

The Tamil Nadu Plain stretches for 675 km from Pulicat lake to Kanniyakumari along the coast of Tamil Nadu. Its average width is 100 km. The most important feature of this plain is the Cauvery delta where the plain is 130 km wide. The fertile soil and large scale irrigation facilities have made the Cauvery delta the **granary of South India**.

Significance of the Coastal Plains

Large parts of the coastal plains of India are covered by fertile soils on which different crops are grown. Rice is the main crop of these areas. Coconut trees grow all along the coast. The entire length of the coast is dotted with big and small ports which help in carrying out trade. About 98% of our international trade is carried through these ports. The sedimentary rocks of these plains are said to contain large deposits of mineral oil. The sands of Kerala coast have large quantity of monazite which is used for nuclear power. Fishing is an important occupation of the people living in the coastal areas. Low lying areas of Gujarat are famous for producing salt.

5. THE INDIAN ISLANDS

Apart from the large number of islands in the near proximity of the Indian coast, there are two main groups of islands in the Indian Ocean far away from the coast. One of these is the Andaman and Nicobar Archipelago in the Bay of Bengal and the other is a group of tiny islands known as the Lakshadweep Islands in the Arabian Sea. These islands have gained much importance and their study has become almost indispensable in view of the increasing interest of super powers in the geopolitics of the Indian ocean.

The Andaman and Nicobar group of islands form an arcuate chain, convex to the west, extending from 6° 45′ N to 13° 45′ N and from 92° 10′ E to 94° 15′ E for a distance of about 590 km with a maximum width of about 58 km. This archipelago is composed of 265 big and small islands covering a cumulative area of about 8249 sq km. The entire chain consists of two distinct groups of islands. The Great Andaman group of islands in the north is separated by the *Ten Degree Channel* from the Nicobar group in the south. The Andaman is a closely knit group of about 203 islands. It is 260 km long and 30 km wide with a total area of 6596 sq km. This group of islands is divided into three major groups *viz*. North Andaman, Middle Andaman and South Andaman. Little Andaman is separated from the Great Anadmans by 50 km wide Duncan Passage.

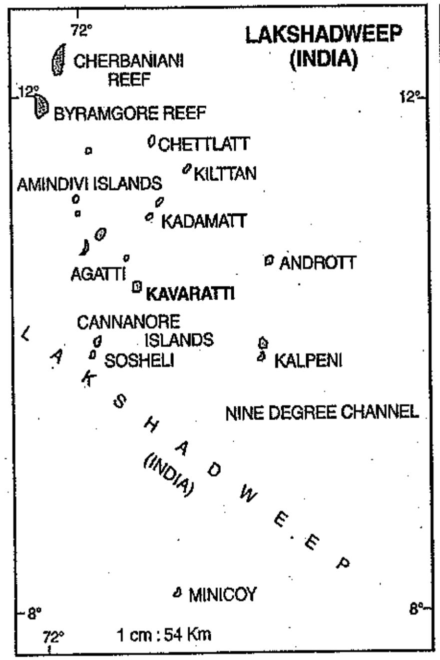
The Nicobar group of islands consists of 7 big and 12 small islands together with several tiny islands. They are scattered over a length of 262 km with maximum width of 58 km covering an area of 1,653 sq km. The Great Nicobar, as its name suggests, is the largest island measuring 50 × 25 km. It is the southernmost island and is only 147 km away from Sumatra island of Indonesia.

Most of these islands are made of tertiary sandstone, limestone and shale resting on basic and ultrabasic volcanoes. The Barren and Narcondam islands, north of Port Blair, are volcanic islands. Some of the islands are fringed with coral reefs. Many of them are covered with thick forests and some are highly dissected. Most of the islands are mountainous and reach considerable heights. Saddle peak (737 m) in North Andaman is the highest peak.

The Lakshadweep Islands in the Arabian Sea, though literally mean one lakh islands is only a group of 25 small islands. They are widely scattered over an area of 108.78 sq kms extending from 8° N to 12° 20′ N and 71° 45′ E to 74 °E about 200-500 km south-west of the Kerala coast. The islands north of 11° N are known as *Amendivi Islands* while those south of this latitude are called *Cannanore Islands*. In the extreme south is the Minicoy island. All are tiny islands of coral origin and are surrounded by fringing reefs. The largest and the most advanced is the Minicoy island with an area of 4.53 sq km. Betra has an area of only 0.12 sq km. Most of the islands have low elevation and do not rise more than five metre above sea level. Their topography is flat and relief features such as hills, streams, valleys, etc. are conspicuous by their absence. Shallow lagoons are seen on their western side, while on the eastern seaboard the slopes are steeper.

PHYSIOGRAPHIC REGIONS OF INDIA

The term physiography was conceived as 'a description of nature' or 'of natural features' in their causal relationships. After some time, the term became almost synonymous with physical geography. Gradually, it became limited to the study of landforms,



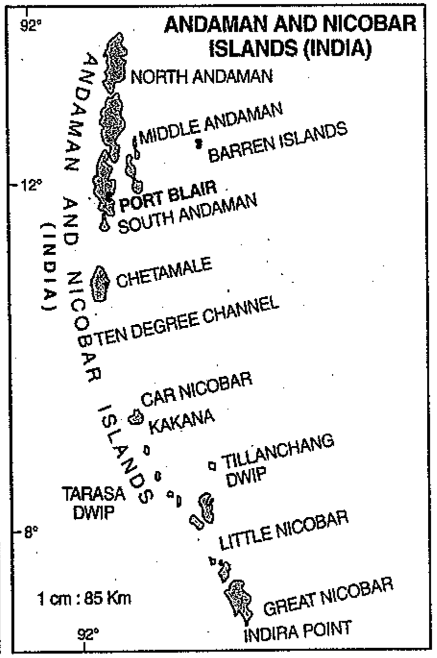


FIG. 3.15. Andaman and Nicobar Islands and Lakshadweep

especially in the U.S.A. By some authorities the term has now been superseded by more scientific term geomorphology. However, other authorities still regard it in wider terms as an integration of geomorphology, plant geography and pedology. We will confine ourselves to the study of land features of India in this context.

L.D. Stamp was the first scholar who made an attempt to classify natural regions or physiographic regions of India in 1922. His scheme was based on the homogeneity of physiography, structure and climate. He divided India into 3 major natural regions and 22 sub-regions. Another attempt was made by **J.N.L. Baker** in 1928. His scheme was based on the work of Wood and was in close agreement with the work of L.D. Stamp. Following the empirical approach adopted by Stamp and Baker, **O.H.K. Spate** presented a detailed scheme of physiographic regions of India in 1954 and slightly revised it at a later stage. In the third edition of his book entitled "India and Pakistan : A General and Regional Geography" published in 1967, he divided India into 3 macro regions which were further divided into 34 regions of first order (excluding islands), 74 regions of second order and 225 subdivisions of these regions. Three macro regions, as suggested by Spate are (*i*) the mountain rim, (*ii*) the Indo-Gangetic plain and (*iii*) the Peninsula.

S.P. Chatterjee presented his detailed study of physiographic divisions of India in The Gazetteer of India Vol. I published by Publication Division of India in 1965. He divided India into seven major physiographic divisions on the basis of topography. They are (1) Northern Mountains which include the Himalayas and mountain ranges in the north-east, (2) Great Plains, (3) Central Highlands, (4) Peninsular Plateaus, (5) East Coast, (6) West Coast and (7) Bordering Seas and Islands. Further divisions and subdivisions of these major regions are briefly described as under :

1. The Northern Mountains. This chain of mountains include the mighty Himalayas and the mountain ranges which extend in the north-east. The Himalaya extent almost uninterruptedly for a distance of 2500 kms and cover an area of about 5,00,000 sq km. This mountain range is divided into the Western Himalaya and the Eastern Himalaya. Between these two is the Himalayan country of Nepal. The **Western Himalaya** are further divided into four regions *viz.* (*a*) the North Kashmir Himalayas, (*b*) the South Kashmir Himalayas, (*c*) the Punjab Himalayas and (*d*) the Kumaon Himalayas. The **Kashmir Himalaya** is the broadest part which is 700 km from west to east and 500 km from north to south. It spreads over an area of about 3,50,000 sq km. The Great Himalayan Range acts as the dividing line between the North Kashmir Himalayas and the South Kashmir Himalayas. Kashmir Valley lying between Pir Punjab in the south and Zaskar Range in the north is the most density populated part of the Western Himalayas. Srinagar, the summer capital of Jammu and Kashmir lies in the heart of this valley. It is situated at an elevation of 1893 m above sea level. The **Punjab Himalaya** includes the portion of the Himalaya lying in Himachal Pradesh and Punjab. It covers an area of about 45,000 sq km and is drained by four important rivers namely the Satluj, the Beas, the Ravi and the Chenab. These rivers have their sources in the upper reaches of the Himalayas. The **Kumaon region** lies in the mountain region of Uttar Pradesh (now forming a separate state of Uttarakhand) and stretches over an area of about 30,000 sq km. The most important rivers, the Ganga and the Yamuna, originate in the Kumaon Himalayas. The religious places like Hardwar, Rishikesh, Kedarnath and Badrinath as well important places of tourist interest like Mussorie, Nainital, Almora and Ranikhet are located in this part of the Himalayas.

The **Eastern Himalaya** can be divided into (*a*) the Sikkim Himalaya, (*b*) the Darjeeling Himalaya, (*c*) the Bhutan Himalaya and (*d*) The Assam Himalaya.

The **Sikkim Himalaya** is an 'anticlinal valley' and this area is drained by the Tista river (a tributary of the Brahmaputra river). The **Darjeeling Himalaya** mainly consists of two north-south ranges. The Darjeeling Range is known all over the world for its tea gardens and Darjeeling tea is considered to be the best tea available anywhere in the world. The **Bhutan Himalaya** consists of high ranges and deep valleys and covers an area of about 22,500 sq km. The **Assam Himalaya** lies in NEFA (North-East Frontier Agency) of Assam which is now separate state of Arunachal Pradesh. It spreads over an area of about 67,500 sq km.

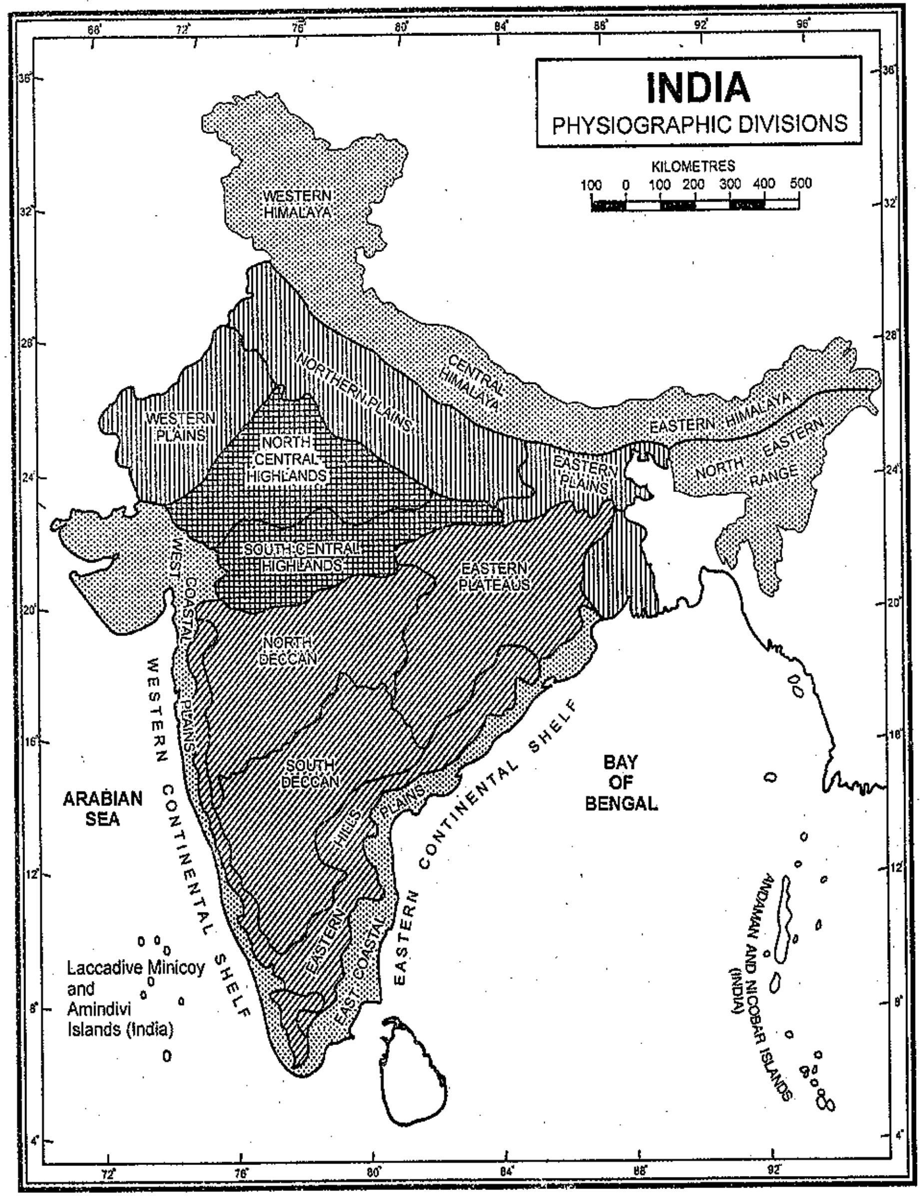


FIG. 3.16. Physiographic Divisions

The north-eastern mountains are subdivided into three physiographic provinces namely (*a*) Purvanchal, (*b*) the Meghalaya or Shillong Plateau and (*c*) the Assam valley. The **Purvanchal** includes lofty 'mountain ranges' which border India in the north-east, hills and plains in Manipur, Tripura and adjoining districts of Assam. The Purvanchal may be further sub-divided into six sub-divisions. Purva

NEFA, the Nagaland, the Manipur Hills, the North Cachar Hills, the Mizo Hills and the Tripura Hills. The Meghalaya Plateau contains Chirrapunji, the Khasi, the Jaintia, the Goro and the Makir Hills. The **Assam Valley** can be divided into two physiographic parts *viz.* the Upper Assam and the Lower Assam. Each is about 75 km wide with low relief, easy accessibility and extremely fertile land.

2. The Great Plains. In between the Himalayan mountain ranges in the north and the peninsular plateau region in the south, lies the Great Plain of India which stretches from the Indus delta in the west to the Ganga delta in the east. A part of it lies in Pakistan but major part is in India. This Great Plain can be divided into three broad divisions—Western Plains, Northern Plains and Punjab Plains.

The **Western plain** consists of arid land of Rajasthan. It has a well defined boundary in the east marked by the Aravalli range. This is a sandy desert with distinct aeolian topography. The eastern part is less sandy, comparatively more humid and is clothed with steppe vegetation. The **Punjab plains** are flat and the general elevation is 200 to 240 (except the Hoshiarpur plains). To the south of the Punjab plains lies the Haryana tract.

To the east of the Punjab plains is the **Ganga** plain which occupies about 55% of the total area of the Great Plains and stretches over the states of Uttar Pradesh, Bihar and West Bengal. The region between Ganga and its main tributary Yamuna is known as **Ganga-Yamuna Doab** which can be divided into Upper, Middle and Lower sections depending on elevation, rainfall and character of older flood plains. The **Upper Doab** extends from Hardwar in the north to Aligarh in the south. This region is irrigated by East Yamuna and Upper Ganga canals and is one of the most fertile areas giving bumper crops. It also receives more rainfall than the Middle and the Lower Doabs. The **Lower doab** is a flat area which ends at Allahabad at the confluence of Ganga and Yamuna. East of the Ganga-Yamuna Doab, lies the vast stretch of the alluvial plains, from the foot of the Himalayas to the Ganga. These are known as the **Rohilkhand** plains. These plains lie in UP and cover an area of about 35,000 sq km. The **Avadh plains** are other plains of Uttar Pradesh. To the east of the Rohilkhand and the Avadh plains, lie in **Bihar plains** covering an approximate area of 88,000 sq km. These plains are divided into the North Bihar Plains and the South Bihar Plains. The North Bihar Plains are drained by the rivers Ganga, Ghaghara, Gandak and Kosi accompanied by a large number of mountain streams passing through these plains. "The combined work of these streams has resulted in a 2000 m deep trough at the foot of the Nepal Himalaya being filled up with alluvial deposits. One of the most extensive alluvial plains of the world, 54,000 sq km in North Bihar was formed." The portion of the Great Plains coming under North Bengal covers an approximate area of 23,000 sq km and extends from the foot of the Eastern Himalayas to the northern limit of the Bengal basin. "This region has evolved from an extensive sheet of waste materials brought down from the Eastern Himalaya by a number of powerful streams like the Tista, Jaldhaka and Torsa." Its eastern part is drained by the rivers joining the Brahmaputra while its western part is drained by the tributaries of the Ganga. The Bengal basin embraces most of the alluvial plains of West Bengal and Bangladesh and the Ganga delta occupies the major portion of this basin.

3. Central Highlands. Lying in the central part of India, the Central Highlands separate the Great Plains in the north from the plateaus and coastal plains of the Deccan. "It forms a compact block of mountains, hills, and plateaus, interspersed with valleys and basins, covering about one sixth of the total area of India." It covers about half of Madhya Pradesh one-third of Rajasthan and a small part of Uttar Pradesh.

The Central Highlands can be divided into North Central Highlands and South Central Highlands. The **North Central Highlands** can further be subdivided into four divisions namely (*a*) the Aravalli Range, (*b*) Eastern Rajasthan upland, (*c*) Madhya Bharat Pathar and (*d*) Bundelkhand upland. Similarly, the **South Central** Highland can be divided into four divisions *viz.* (*a*) Malwa Plateau, (*b*) Vindhya Scarplands, (*c*) Vindhya Range and (*d*) Narmada Valley.

The **Aravalli range** runs for a distance of 800 km from Delhi to Ahmedabad. To the east of the Aravalli range lies **East Rajasthan Upland.** It's elevation varies from 250 to 500 m. It is drained by the Chambal river which enters Rajasthan near the northern end of the Gandhi Sagar and flows in this state for a distance of 360 km. The **Madhya Bharat Pathar** lies to the east of the Chambal river. It is a

rocky surface with dense forests. The **Bundelkhand** lies between the Yamuna and the northern Aravali scarp of the Vindhyan plateau.

The southern part of the Central Highlands consists of the Malwa Plateau, the Vindhya Scarplands, the Vindhya range and the Narmada Valley. The **Malwa Plateau** forms a great triangle based on the Vindhyan Hills and bounded on the north-west by the Great Boundary Fault of Aravallis, on the east by the sharply-defined scarp overlooking Bundelkhand. Most part of this plateau lies in Madhya Pradesh. It has general northward slope, good drainage and black soil. **The Vindhyan** range is really an escarpment which varies in character and height depending on the structure and lithology of the underlying sector. For the first 100 km from its western terminus, Gomanpur peak (554 m) in the Dhar district of Madhya Pradesh, the Vindhya range runs in curve, its convex side facing the Narmada valley and following a 300 m contour line. It has dense forests but sparse population. For the next 160 km a more open type of country prevails and the escarpment, still built of basalt, becomes more prominent. Near Hoshangabad, the rock type changes; the Vindhya range comes down very close to the Narmada river and presents a terraced slope built of hard stand stones alternating with shales. The strong sand stones of Kaimur, Rewa and Bhander are the principal makers of the Vindhyan scarpland. The **Narmada Valley** lies to the extreme south of the central highlands. It is a rift valley caused by tectonic forces in which the Narmada river flows from east to west and empties itself in the Arabian Sea.

4. The Peninsular Plateaus. The Peninsular Plateaus constitute the largest physiographic division of India facing the Bay of Bengal in the east and the Arabian Sea in the west. Its maximum length from Pachmarhi in the north to Cape Comorin (Kanniyakumari) in the south is 1600 km and its maximum width from the Sahyadri in the west to the Rajmahal hills in the east is 1400 kms. The peninsular plateaus consist of five distinct physiographic subdivisions, namely (*i*) Western hills, (*ii*) North Deccan plateau, (*iii*) South Deccan plateau, (*iv*) Eastern plateaus and (*v*) Eastern hills.

(*i*) The **Western hills** cover all the three sections of the Sahyadris (Western Ghats) namely Northern Sahyadri, Middle Sahyadri and Southern Sahyadri. (*ii*) the **North Deccan plateau** comprises Satpura range and the Maharashtra plateau. The Satpura range extends in east-west direction between the Narmada river in the north and the Tapi river in the south. It represents folding and upheaval and is an ancient tectonic range. Its present physiography is that of scarped blocks (on the whole steeper towards the Tapi), largely covered with Deccan Lavas but with some inliers of gneissic plateau country. To the south of Solapur is the Maharashtra plateau, almost whole of which is formed of plateau basalt, which on weathering has given rise to rolling plains with intervening shallow valleys. The west-flowing Tapi river forms its northern boundary. Further south is the Godavari river which enters Maharashtra plateau at Nasik and flows for 650 km eastwards to the farthest end of this region. (*iii*) **The South Deccan** plateau can be divided into Telangana plateau and the Karnataka plateau. The Godavari river, after receiving a number of tributaries, enters the **Telangana plateau** and divides it into two parts. The northern part is very hilly and forested and is sparsely populated. The southern part is dotted with low hills and shallow depressions. One such depression, surrounded by low hills, 130 m high provided the site for the living cities of Hyderabad-Securadabad. The **Karnataka plateau** can also be divided into two sections on the basis of altitude. These sections are the northern section and the Mysore plateau. The Krishna and the Tungabhadra flow through the northern section. **The Mysore plateau** is the loftiest and well defined plateau of South India. This plateau is bounded by the Sahyadri in the west, the Eastern Ghats in the east and the Nilgiris in the south. Physiographically the Mysore plateau may be divided into two sections *viz.* Malnad and Maidan. The **Malnad** is a hilly area bordering the Sahyadri. It has a mean elevation of about 1000 m and its average width is 35 km. It is dissected into steep hills and deep valleys and has dense forests. The **Maidan** consists of rolling plains with low granitic hills. Cauvery is the most important river. (*iv*) **The Eastern plateaus** consist mainly of the plateaus of **Chotanagpur** of which Ranchi plateau and Hazaribagh plateau are the major parts. Rounded hills of massive granite and slightly elevated terraces of older flood plains mark the topography of the Ranchi plateau. The Damoder river rises in the hills of Chotanagpur plateau and drains through Ranchi. Hazaribagh, Dhanbad, Santhal Parganas, Bankura and

Burdwan. It flows in a rift valley and traverses a distance of 541 km before it joins the Hugli river near Kolkata. To the west of the Chotanagpur plateau is the **Bhagelkhand plateau.** It is bounded by the Ganga plain in the north, Maikala hills in the south and Kaimur hills in the west. Its general slope is in the north and north-west direction as is indicated by the flow of the Son river and its tributaries. The Mahanadi basin lies in the southern part of the Eastern plateau and the central part of the Mahanadi basin is known the Chhattisgarh basin. To its south lies the **Dandakaranya.** It encompasses the districts of Bastar, Kalahandi and Koraput and some parts of Andhra Pradesh. The region is well demarcated and enjoys the central location between Chhattisgarh basin in the north, Andhra Pradesh in the south, Maharashtra Plateau in the west and Eastern coastal plains towards the east. It has an undulating topography with well marked elevations and depressions.

5. East Coast. The eastern coastal strip lies between the Eastern Ghats and Bay of Bengal and stretches from the Ganga delta to Cape Comorin (Kanniyakumari). It is marked by a number of deltas such as the deltas of the Mahanadi, the Godavari, the Krishna, and the Cauvery. It is known by different names in different parts. In Orissa (Odisha) it is known as Utkal plain which includes the Mahanadi delta with Cuttack at its head. From the southern limit of the Utkal plain, stretch the Andhra plain. Rivers Godavari and Krishna flow through this region and form deltas in their lower reaches. In the south of the Andhra plain is the Tamil Nadu plain. This plain is about 675 km long and 100 km wide. The Cauvery delta is the most important physiographic feature of this plain. In Tamil Nadu and Andhra Pradesh, the East coast is called the Payan Ghat which extends from Cape Comorin (Kanniyakumari) northwards to the united deltas of the Krishna and the Godavari for 1100 km with an average width of 100-130 km.

6. West Coast. The west coast strip extends from the Gulf of Cambay (Gulf of Khambhat) in the north to Cape Comorin (Kanniyakumari) in the south and from the Western Ghats in the east to the Arabian sea coast in the west. It is made up of mud brought down by the short streams originating from the Western Ghats. At the northern end are two peninsulas namely Kutch (Kachchh) and Kathiawar and the vast extensive plain of Gujarat. To the south of the Gujarat plain are the coastal plains which are divided into three plains. Starting from north to south, they are (*i*) the Konkan coast, (*ii*) the Karnataka coast and (*iii*) the Kerala cost. The limits of these areas are conforming to the state boundaries.

7. The Islands. India is blessed with a large number of islands in both the Bay of Bengal and the Arabian sea. There are hundreds islands in the Bay of Bengal which are known as the Andaman and Nicobar Islands. The Andaman islands are divided into three main islands *i.e.* North, Middle and South. Separated from these islands by the Duncan passage is the Little Andaman. The North Andaman Island is 80 km long and has a maximum width of 20 km. The Middle Andaman is much wider and less indented. It is 70 km long and 30 km wide. The South Andaman consists of parallel ranges and valleys. Port Blair, the capital of Andaman Nicobar Islands and the most important port town lies in the South Andaman. Off these main islands lie numerous smaller islands. South of Andamans are the Nicobar islands, consisting of 19 islands 12 of which are inhabited. The Great Nicobar is the largest, occupying 862 sq km. The Car Nicobar is the northernmost island, 229 km from Port Blair.

In the Arabian Sea, there are three types of islands. (*i*) Amindivi Islands (consisting of six main islands of Amini, Keltan, Chetlat, Kadmat, Bitra and Perumul Par). (*ii*) Laccadive Islands (consisting of five major islands of Androth, Kalpeni, Karavatti, Pitti and Suheli Par) and (*iii*) Minicoy. At present these islands are collectively known as Lakshadweep.

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Drainage

INTRODUCTION

India is blessed with hundreds of large and small rivers which drain the length and breadth of the country. Rivers constitute the most useful natural resource. They have attracted the attention of planners, economists, geographers, geologists, hydrologists and a host of other specialists from different fields. They are a great source of water for irrigation, industry and domestic purpose and offer innumerable sites for producing hydro-electricity. Almost all the fertile areas of the country have been formed by the depositional work of rivers. Many rivers are used as channels for inland water transport. Fishing has become an important occupation along the rivers courses.

According to an estimate made by **S.P. Dasgupta**, the annual yield of water in the rivers of the country is 1,858,100 million cubic metres of which more than one third (33.8%) is contributed by the Brahmaputra, followed by the Ganga (25.2%), the Godavari (6.4%), Indus (4.3%), the Mahanadi (3.6%), the Krishna (3.4%), and the Narmada (2.9%). The remaining 20.4 is contributed by other rivers (percentages are calculated for basin areas in Indian territory only).

Drainage Systems of India

There are several bases for classifying drainage systems of India. The main types of drainage systems are briefly described below :

1. Size of the Catchment area. River systems of India are divided into three categories depending on their size. *Major river basins* have catchment area of 20,000 sq km and above. *Medium river basins* have catchment are between 2,000 and 20,000 sq km and river basins with catchment area less than 2,000 sq km are known as *minor river basins.*

2. Origin. Depending upon the origin of rivers two broad drainage systems of India are generally recognised, (*a*) The Himalayan rivers including the Indus, the Ganga, the Brahmaputra and their tributaries and (*b*) The Peninsular rivers which include along with their tributaries, a large number of rivers such as the Mahanadi, the Godavari, the Krishna, the Cauvery, the Narmada and the Tapi.

3. Orientation to the sea. The Indian drainage is divided into two major drainage systems on the basis of orientation to the sea. These include : (*i*) the Bay of Bengal drainage and (*ii*) Arabian sea drainage. About

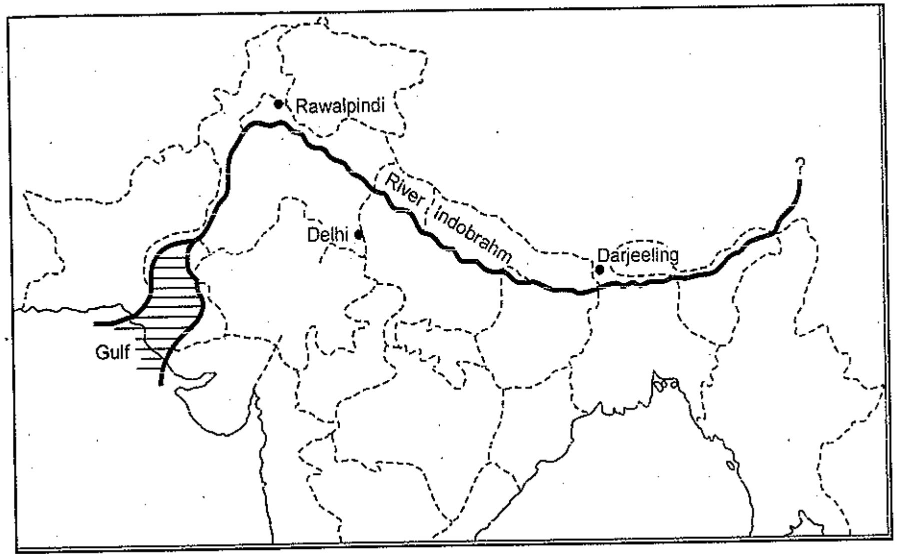

FIG. 4.1. The supposed course of the Indo-Brahm River (According to Pascoe)

77 per cent of the drainage area of the country is oriented towards the Bay of Bengal. It consists of a large number of rivers like the Ganga, the Brahmaputra, the Mahanadi, the Godavari, the Krishna, the Cauvery, the Penneru, the Penneiyar, the Vaigai, etc. The Arabian Sea drainage spreads over 23 per cent of the country's surface flow area which commands river basins like the Indus, the Narmada, the Tapi, the Sabarmati, the Mahi and the large number of swift flowing western coast rivers descending from the Sahyadris.

It may be mentioned here that the area covered by the above mentioned drainage systems differs markedly from the amount of water carried by them.

Over 90 per cent of the water carried by the Indian rivers is housed into the Bay of Bengal; the rest is drained into the Arabian Sea or forms inland drainage. This lop sided distribution is due to the location of the watershed separating the drainage systems falling into the Bay of Bengal and the Arabian Sea. This 2,736 km long watershed runs from Kanniyakumari through the Western Ghats, the Ajanta, the Maikala, the Vindhayas and the Aravalis ranges to the Shiwalik hills near Haridwar **(Fig. 4.3)**.

THE HIMALAYAN RIVER SYSTEMS

Three Major river systems *viz.* the Indus, the Ganga and the Brahmaputra comprise the Himalayan river systems. Many of the Himalayan rivers existed even before the Himalayan ranges were uplifted. These rivers originate in the Tibetan side beyond the mountain ranges of the Himalayas. The gorges of the Indus, the Satluj, the Alaknanda, the Gandak, the Kosi and the Brahmaputra clearly indicate that these rivers are older than the mountains themselves. It is believed that they continued to flow all through the building phase of the Himalayas; their banks rising steeply while the beds went lower and lower, thus cutting deep gorges through the rising Himalayan ranges. Thus, many of the Himalayan rivers are typical examples of *antecedent drainage*. The evolution and flow of the Himalayan rivers is described as under :

Evolution of the Himalayan Rivers

1. The Indo-Brahm or Shiwalik River Theory

Some of the unwarranted features of the Himalayan rivers such as the longitudinal courses of the Indus, the Satluj and the Brahmaputra; deep gorges cut by the rivers across the Himalaya; and still westerly flowing tributaries in their upper reaches are a great puzzle and require proper explanation. This

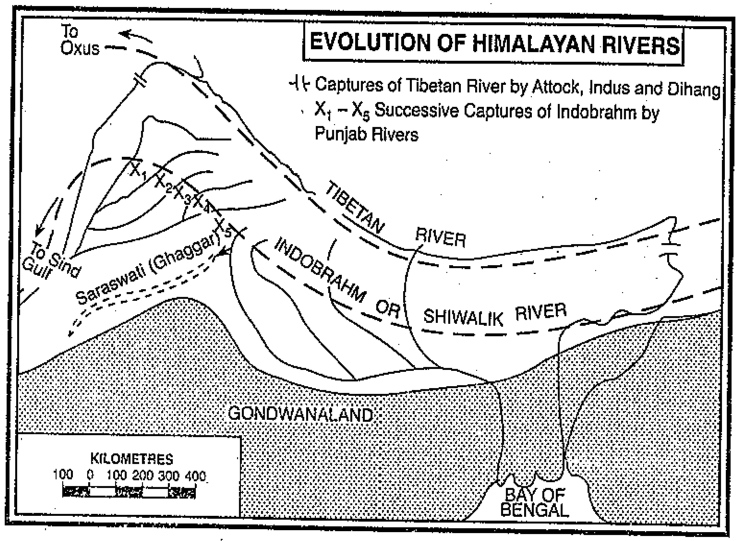

FIG. 4.2. Evolution of the Himalayan Rivers

has been partly done by assuming a mighty river which flowed from Assam to Punjab and even beyond upto Sind. This hypothetical ancient river was called the ***Indo-Brahm*** by **E.H. Pascoe** who thought that the present day Indus and Brahmaputra were the severed parts of the original river. However, it was named as the ***Shiwalik River*** by E.G. Pilgrim who considered that the course of the primitive river is occupied by the present day Shiwalik hills. Pascoe and Pilgrim presented an elaborate and comprehensive hypothesis, independently in 1919, on the assumption that the Shiwalik deposition occurred along this great river. The river came into being due to earth movements which took place in *Tertiary* period and is believed to be successor of the *Himalayan sea*. In the *Eocene Epoch* a gulf extended from Sind to Afghanistan and from there extended eastward and south-eastward through Kohat and Punjab to the neighbourhood of Nainital. This gulf gave place to a great river. With its headwater consisting of portions of the Brahmaputra, this master stream flowed along the foot of the Himalayas first westward and then north-westward as far as north-western Punjab where it turned southward more or less along the course of the modern Indus, and emptied itself into the Arabian Sea. Later, this mighty stream got dismembered into the following systems and sub-systems :

(*a*) the Indus,

(*b*) the five tributaries of the Indus in Punjab,

(*c*) the Ganga and its Himalayan tributaries, and

(*d*) the stretch of the Brahmaputra in Assam and its Himalayan tributaries.

The dismemberment was the result of the following two events :

(*i*) Upheavals in the western Himalayas including the Potwar Plateau in the Pleistocene age and

(*ii*) Headward erosion by the tributaries of the Indobrahma river.

As a result of the above mentioned dismemberment of the Indobrahma river, the Indus and its tributaries, the Ganga and its tributaries and the Brahmaputra and its tributaries came into being. It is supposed that the Yamuna was first a tributary of the Indus. During the late Pleistocene and early Holocene ages, it joined with the Sarswati somewhere near Suratgarh and continued to flow as Ghaggar, finally joining the Indus. Some other scholars believe that it reached upto Rann of Kachchh as an independent river. Later on, it changed its course due to tectonic disturbance along the Aravali axis and was annexed by the Ganga to become its tributary.

Pascoe also envisaged a great '*Tibetan River*' flowing north–westwards along the Tsangpo—Manasarovar Lakes—Satluj—Gartang —Indus trough. This river might have emptied itself into the Oxus Lake, or might have debouched on to the plains by one of a number of transverse gaps such as Photu Pass. This river also was disrupted by headward erosion by Ayeyarwadi—Chindwin, the Meghna—Brahmaputra, the Satluj and the Indus. According to de Terra, the rivers of Karakoram and Ladakh might have flowed south-eastward or eastward. Its capture in the east might have been executed by Dihang, a tributary of the Brahmaputra.

However, this theory has been challenged on the following grounds :

(*i*) It is not necessary to imagine a stream of the size of Indobrahma flowing all along the length of the Himalayas to explain the occurrence of the Shiwalik deposits. These could be brought down by the rivers flowing down the slopes of the Himalayas. **M.S. Krishnan** and **N.K.N. Iyngar** (1940) found it difficult to accept the existence of such a mighty river on geological as well as physiographical grounds.

(*ii*) The evidences furnished by the depositional history in the Ganga delta and in Assam does not fit well with the concept of Indobrahma stream.

(*iii*) The width, thickness and lithology of the Tipam sand stones of Assam which were deposited in an estuary situated so close to the source of the Indobrahma also speak against this theory.

(*iv*) The upper course and the source of the Satluj river also do not fit in this theory. It is fed by underground water from the Manasarovar lake and it flows in a deep canyon cut in the soft fluviated beds of Nari Khorsum. The upper course of the Satluj is distinctly arid and the river appears to be a *misfit*. This could be explained if it were an old outlet of the '*Tibetan River*'. Pascoe argues that the Satluj captured a part of the '*Tibetan River*' and then lost again to the rejuvenated Tsangpo after the Dihang had cut back into the furrow. This argument has been rejected by many scholars.

E. Ahmad (1965 and 1971) has given his own interpretation of evolution of the Himalayan drainage. He believed that the Tethys remained as a basin of sedimentation from the Cambrian to the Eocene period but the major portion of the Himalayan region was occupied by the Gondwana landmass. During the *first Himalayan upheaval* in Oligocene period, part of the Tethyian geosyncline and probably the Gondwana shield covering the major part of the Himalayan region was uplifted. Most probably, this marks the initiation of the Himalayan drainage. The Tethys was raised into a landmass with a median mass of high Tibetan plateau in the centre and two bordering ranges namely the Kun Lun in the north and the Himadri in the south. The drainage started from the southern edge of the median mass and flowed south towards the foredeep. As the formation of east-west ranges created east-west valleys, the rivers partly flowed along these valleys. This is indicated by the upper course of several rivers such as the Indus, the Satluj, the Brahmaputra, the Shyok, the Arun, etc. Since the whole of the Tethys was not fully raised to become land surface, there existed patches of sea along the margins and the drainage lines were not fully defined.

The *second Himalayan upheaval* during the mid-Miocene period increased the altitude of the medium mass and the bordering ranges. The remnant sea was also raised to form landmass. The rise in land resulted in greater and more invigorated drainage. Along with these changes, the region to the south of the first Himalayan range was raised as Lesser Himalayan range. Earlier streams on the southern margin of the Tibetan plateau cut down deep valleys to maintain their courses. Along the southern slopes of the lesser Himalayas, a number of consequent streams also emerged which drained into the southern foredeep.

The *third Himalayan upheaval* during the Pleistocene period resulted in the folding of the Shiwalik foredeep into hill ranges. Also the height of earlier ranges and the Tibetan plateau was raised. The rise in the Tibetan plateau blocked the streams that had gone northward into the Tibetan sea. These streams were diverted east or west which probably led to the formation of the trans-Himalayan master stream. This master stream was broken into two (the proto-Indus and the proto-Brahmaputra) by the formation of the Kailas Range. The uplift of the Shiwalik range gave rise to the last set of consequents originating on the crest of the range emptying into older streams.

2. Multiple River Theory

An alternative explanation regarding the evolution of the Himalayan drainage has been offered by the Multiple River Theory. The protagonists of this theory find it difficult to accept the existence of a large river like the Indo-Brahm or Shiwalik on geological and physiographical grounds.

This theory postulates that the Eocene sea extended upto Sind, Rajasthan and from Punjab to Jammu and thereafter Lansdowne and Nainital. This was connected to Tethys. Existence of such a sea is evidenced by the presence of shallow water bodies indicative of coast near Landsdowne. This limit also coincides with the eastern continuation of one of the ridges of the Aravali Range which presumably acted as barrier. At the same time, another ridge extended from the Rajmahal Hills to the Meghalaya or Shillong plateau (Rajmahal—Garo gap) which is now occupied by the Ganga-Brahmaputra basin. The sea was broken by the first upheaval of the Himalayas to form an isolated basin in which sediments were deposited. In the next upheaval, a pronounced foredeep all along the southern border of the Himalayas was formed. This foredeep contained numerous lagoons in which flowed streams from the Peninsula and the newly uplifted Himalayas. These streams brought sediments which later came to be known as Shiwalik deposits. The outlet of this foredeep was through the Rajmahal-Garo gap in the Bay of Bengal and the Arabian Sea in the west. Later on the lagoons got dried up and numerous transverse streams flowing from the Himalayan region formed what is now known as the Himalayan drainage.

THE INDUS RIVER SYSTEM

The Indus (Sanskrit—Sindhu, Greek—Sinthos; Latin—Sindus), along with its tributaries forms one of the largest drainage systems of the world. It is from this river that India got her name. The Indus valley has been the cradle of one of the oldest civilizations in the world—'the Indus Valley Civilization'.

The mighty Indus rises near Manasarovar Lake from the glaciers of the Kailas Range in Western Tibet (31°15′ N and 81°40° E) at an elevation of 5,182 metres. Starting from its source, it flows for a distance of 257 km in the north west direction in the trans-Himalaya region under name of *Singge Khabab* until it is joined by the Dhar. A short distance lower down, it enters India at an elevation of 4,206 m and continues to flow in the same north-west direction between the Ladakh and the Zaskar Ranges. The gradient of the river in this course is very gentle (about 30 cm per km). Here it encircles the town of Leh and is joined by the Zaskar river. About 50 km before Skardu, it is joined by the Shyok at an elevation of about 2,700 m. The *Gilgit, Gortang, Dras, Shiger, Hunza* are the other Himalayan tributaries of the Indus. After passing through a 480 km long antecedent and very deep gorge (5,181 metres at Bunji north of Nanga Parbat), it takes a sharp southerly bend and reaches Attock at an altitude of about 610 m. Here it ends its mountainous journey and is joined by the Kabul river from Afghanistan. Thereafter it flows through the Potwar plain and crosses the Salt Range. Some of the important tributaries below Attock include the Kurram, Toch and the Zhob-Gomal. Just above Mithankot, about 805 km from the sea, at an elevation of 79 m the Indus receives from *Panjnad (Panchnad)*, the accumulated waters of the five eastern tributaries—the Jhelum, the Chenab, the Ravi, the Beas and the Satluj. The river finally empties itself into the Arabian Sea, south of Karachi after forming a big delta. The total length of the Indus river from its source to its mouth is about 2,880 km out of which only 709 km length falls in India. The average annual flow of water in the Indus river is 110,450 million cubic metres at Kalabagh.

The left bank tributaries are big rivers in themselves and deserve a brief mention here. These rivers join together one by one before they ultimately meet the main river.

The Jhelum rises in a spring at Verinag in the south-eastern part of the Kashmir Valley. It flows northwards from its source to Wular Lake and further down south-westwards. The river flows through the Kashmir Valley and forms a 200 m deep defile with almost vertical walls through Pir Panjal Range below Baramula. A number of tributaries notably the Lidar, the Sind and the Pohru, which rise in Kashmir, join the main river. At Muzaffarabad, the river takes a sharp hairpin swing southward and the Kishaganga joins it on its right bank. Thereafter, it forms the India-Pakistan boundary for 170 km and emerges at the Potwar Plateau near Mirpur. After skirting the outlying spurs of the Salt Range it debouches on the plains near the city of Jhelum about 402 km from its source. About 322 km lower, it joins the Chenab at Trimmu. The river is navigable for about 160 km out

TABLE 4.1. The Indus Drainage System

Name of the river	Source	Length in km	Area drained (sq km)	Volume of average annual flow (in million cubic metres)
Indus	Near Manasarovar Lake (31°15′N, 81°40′E at 5,182 m elevation	2,880 (709 in India)	1,178,440 (321,284 in India)	1,10,450 at Kalabagh in Pakistan
Jhelum	Verinag	724	34,775 upto Indo-Pak Border	27,890 at Mangla in Pakistan
Chenab	Bara Lacha Pass	1,180	26,155 upto Indo-Pak Border	29,000 at Marala in Pakistan
Ravi	Near Rohtang Pass	725	14,442 (5,957 in India)	8,000 at Madhopur
Beas	Near Rohtang Pass at 4,062 m height	460	20,303	15,800 at Mandi
Satluj	Manasarovar-Rakas Lakes at 4,570 m altitude	1,450 (1,050 in India)	25,900	16,600 at Rupnagar

of a total length of 724 km. The average annual flow of water in the river at Mangla is 27,890 million cubic metre. The catchment area upto the Indo-Pakistan border is 34,775 sq km.

The Chenab originates from near the Bara Lacha Pass in the Lahul-Spiti part of the Zaskar Range. Two small streams on opposite sides of the pass, namely ***Chandra*** and ***Bhaga***, form its headwaters at an altitude of 4,900 m. The united stream, called the ***Chandrabhaga*** flows in the north-west direction through the Pangi valley, parallel to the Pir Panjal range, and enters Jammu and Kashmir as the Chenab river at an elevation of 1,838 m. Near Kistwar, it cuts a deep gorge, at places 1,000 m deep. Here, it flows for 290 km between steep cliffs of high mountains and turns southwards and flows in this direction for a short distance. Further, it turns to the west and enters the plain area near Akhnur in Jammu and Kashmir after traversing a distance of about 330 km. From here it swings to the south-west through the plains of Pakistani Punjab for a distance of 644 km to reach Panchnad where it joins the Satluj after receiving the waters of Jhelum and Ravi rivers. The total length of the river is 1,180 km. Its catchment area upto the Indo-Pakistan border is 26,155 sq km. Its annual flow at Marala is 29,000 million cubic metres.

The Ravi has its source in Kullu hills near the Rohtang Pass in Himachal Pradesh. Flowing in a northwest direction from its source, it drains the area between the Pir Panjal and the Dhaola Dhar ranges. After crossing Chamba, it takes a south-westerly turn and cuts a deep gorge in the Dhaola Dhar range. It enters Punjab Plains near Madhopur and later enters Pakistan 26 km below Amritsar. It debouches into the Chenab a little above Rangpur in Pakistani Punjab after flowing for a distance of 725 km from its source. Its total catchment area is 14,442 sq km of which only 5,957 sq km lies in India. The annual flow of water in this river at Madhopur is 8,000 million cubic metres.

The Beas originates near the Rohtang Pass, at a height of 4,062 m above sea level, on the southern end of the Pir Panjal Range, close to the source of the Ravi. Fairly steep in its upper portion (24 metres per km) it crosses the Dhaola Dhar range through a deep gorge 900 m deep from Lorji to Talwara. On meeting the Shiwalik hills the river sweeps sharply northward, then bending round the base of the hills it takes a southerly direction and debouches on the plain. Thereafter, it takes a south-westerly direction and meets the Satluj river at Harike in Punjab. It is a comparatively small river which is only 460 km long but lies entirely within the Indian territory. Its total catchment area is 20,303 sq km. The river carries about 15,800 million cubic metres of water at Mandi.

The Satluj rises from the Manasarovar-Rakas Lakes near Darma Pass in western Tibet at a height of

4,570 m within 80 km of the source of the Indus. Like the Indus, it takes a north-westerly course upto the *Shipki La* on the Tibet-Himachal Pradesh boundary. Here the river flows at an altitude of about 3,000 m above sea level. It cuts deep gorges where it pierces the Great Himalaya and the other Himalayan ranges. In Nari Khorsan province of Tibet, it has created an extraordinary canyon, comparable to the Grand Conyon of Colorado; the channel here is 900 m deep. Its tributaries in Himachal Pradesh are short in length except the Spiti, which drains a large trans-Himalayan area and joins it at Namgia near the Shipki La. Before entering the Punjab plain, it cuts a gorge in Naina Devi Dhar, where the famous Bhakra dam has been constructed. After entering the plain at Rupnagar (Ropar), it turns westwards and is joined by the Beas at Harike. From near Ferozepur to Fazilka it forms the boundary between India and Pakistan for nearly 120 km. During its onward journey it receives the collective drainage of the Ravi, Chenab and Jhelum rivers and about 70 km further downstream, it joins the Indus a few kilometres above Mithankot. Out of its total length of 1,450 km, it flows for 1,050 km in Indian territory. It drains an area of 25,900 sq kms and its average annual flow at Rupnagar (Ropar) is 16,660 million cubic metres.

The water assets of the Indus river system are shared by India and Pakistan according to the Indus Water Treaty signed between the two countries on 19th September, 1960. According to this treaty, India can utilize only 20 per cent of its total discharge of water.

THE GANGA RIVER SYSTEM

The Ganga river system consists of the master river Ganga and a large number of its tributaries. This system drains a very large area comprising the middle part of the Himalayas in the north, the northern part of the Indian Plateau in the south and the Ganga Plain in-between.

The Ganga originates as Bhagirathi from the Gangotri glacier in Uttar Kashi District of Uttarakhand at an elevation of 7,010 m. Alaknanda joins it at Devaprayag. But before Devaprayag is reached, the Pindar, the Mandakini, the Dhauliganga and the Bishenganga rivers pour into the Alaknanda and the Bheling flows into the Bhagirathi. The Pindar river rising from Nanda Devi and East Trisul (6,803 m) joins Alaknanda at Karan Prayag and Mandakini or Kali Ganga meets at Rudra Prayag. The combined water of the Bhagirathi and the Alaknanda flows in the name of the Ganga below Devaprayag. After travelling 280 km from its source, the Ganga reaches Haridwar, debouches from the hills and enters plain area. From here it flows in south and south-east direction for a distance of 770 km to reach Allahabad. Here it is joined by the Yamuna which is its most important tributary. It sweeps another 300 km eastwards to reach the Bihar plain. Near Rajmahal Hills it turns to the south-east and south of Farraka, it ceases to be known as the Ganga. It bifurcates itself into Bhagirathi-Hugli in West Bengal and Padma-Meghna in Bangladesh. After traversing 220 km further down in Bangladesh, the Brahmaputra (or the Jamuna as it is known here) joins it at Goalundo and after meeting Meghna 100 km downstream the Ganga joins the Bay of Bengal.

Before entering the Bay of Bengal, the Ganga, along with the Brahmputra, forms the largest delta of the world between two arms : the Bhagirathi / Hugli and the Padma / Meghna covering an area of 58,752 sq km. The delta front of the Ganga is a highly indented area of about 400 km length extending from the mouth of the Hugli to the mouth of the Meghna. The delta is made of a web of distributaries and islands and is covered by dense forests called the ***Sunderbans***. A major part of the delta is a low-lying swamp which is flooded by marine water during high tide.

The total length of the Ganga river from its source to its mouth (measured along the Hugli) is 2,525 km, of which 310 km in Uttarakhand, 1,140 km is in Uttar Pradesh, 445 km is in Bihar and 520 km in is West Bengal. The remaining 110 km stretch of the Ganga forms the boundary between Uttar Pradesh and Bihar. The river flows majestically from Gangotri to Bay of Bengal with an average gradient of 2.77 m per km.

The Ganga is joined by a large number of tributaries both from the left as well as from the right. Majority of them originate in the Himalayan ranges but some of them have their sources in the Peninsular plateau.

The Yamuna is the largest and the most important tributary of the Ganga. It originates from the Yamnotri glacier on the Bandarpunch Peak in

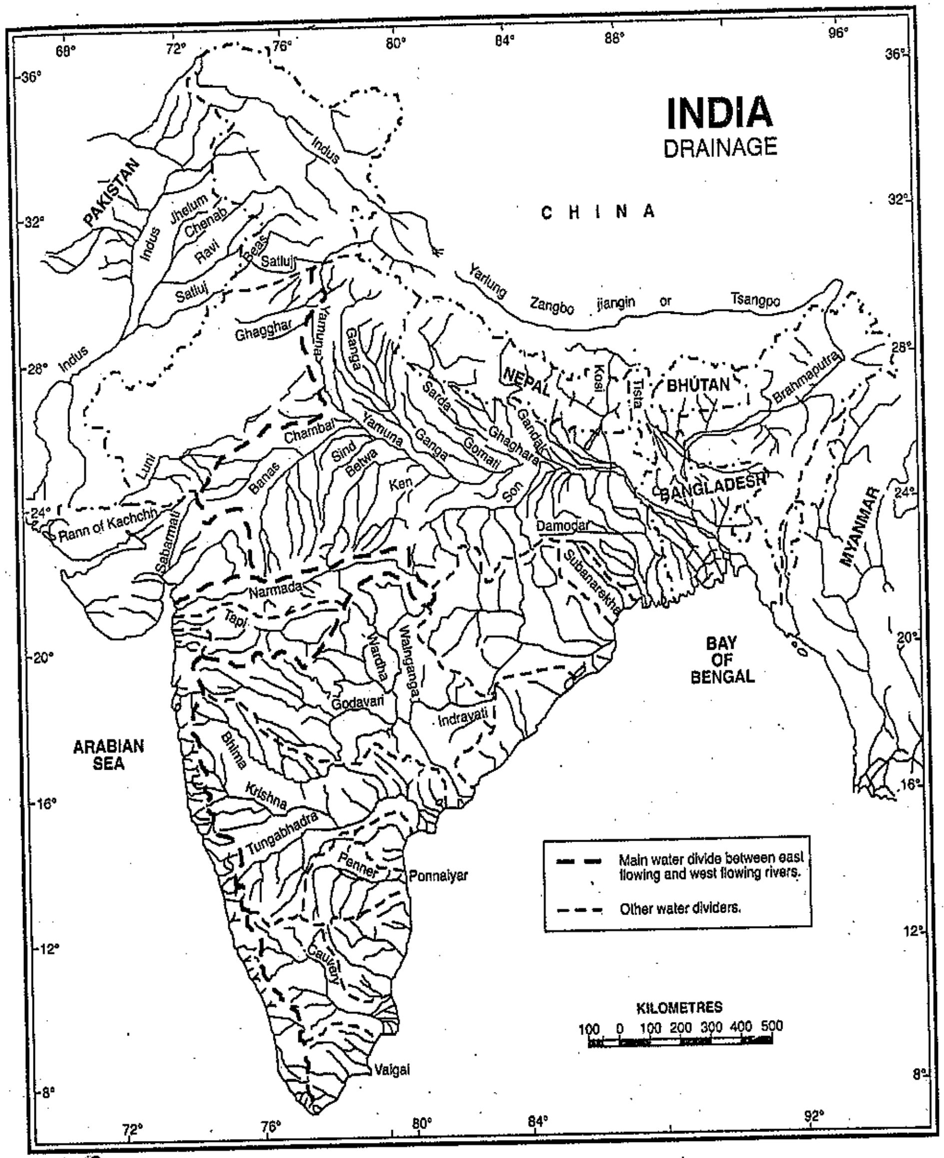

FIG. 4.3. India : Drainage

Garhwal in Uttarakhand at an elevation of 6,330 m, a source which is very close to that of the Ganga itself. After cutting across the Nag Tibba, the Mussoorie and the Shiwalik ranges it emerges out of the hilly area and enters plains near Tajewala. Many small streams such as the Rishiganga, the Uma and the Hanuman Ganga join it in the mountains. Its main affluent in the upper reaches is the *Tons* which also rises from the Bandarpunch glacier at an altitude of 3,900 m and joins Yamuna below Kalsi before the latter leaves the hills. At this site, the water carried by the *Tons* is twice the water carried by the Yamuna. After completing a journey of about 300 km in the plain area, it is joined by the 256 km long Hindon near Ghaziabad in Uttar Pradesh. The Yamuna takes a southerly course upto Mathura and south-easterly in its onward journey upto Allahabad where it unites with the Ganga. Between Agra and Allahabad, the Yamuna receives some important tributaries originating from the Peninsular Plateau. These are the Chambal, the Sind, the Betwa and the Ken. The total length of the Yamuna from its origin to its confluence with the Ganga at Allahabad is 1,376 km.

The Chambal rises 15 km south-west of Mhow in the highlands of Janapao Hills (700 m) in the Vindhya Range in Madhya Pradesh and takes a north-westerly course through the Malwa Plateau. It then enters a gorge at Chaurasigarh, 312 km from its source. The gorge is 96 km long and stretches upto Kota city. Below Kota, it turns to north-east and after reaching Pinahat, it turns to the east and runs nearly parallel to the Yamuna before joining it in Etawah district of Uttar Pradesh. The river flows much below its banks due to severe erosion because of poor rainfall and numerous deep ravines have been formed in the Chambal Valley, giving rise to **badland topography**. The total length of the river is 1,050 km. *The Banas* is an important tributary of the Chambal. It originates in the southern part of the Aravali Range, and takes a north-eastern course to join the Chambal near Sawai Madhopur. **The Sind** originates in Vidisha Plateau of Madhya Pradesh at an elevation of 543 m. It flows for a distance of 415 km before it joins the Yamuna. It drains an area of 25,085 sq km. **The Betwa** rises at an elevation of 470 m in Bhopal district and joins the Yamuna near Hamirpur. It has a total length of 590 km and a catchment area of 45,580 sq km. **The Dhasan** is its important tributary. The 360 km long **Ken river** rising from the Barner Range of Madhya Pradesh is another tributary which joins the Yamuna near Chila; some 60 km downstream from the mouth of the Betwa.

The Son river springs from the Amarkantak Plateau, not far from the origin of the Narmada, at an elevation of about 600 m. After flowing for some distance to the north, it meets the Kaimur Range which turns its course to the north-east. It passes over the cascades in the hill reaches and further beyond through the Palamau district of Jharkhand. It joins the Ganga about 16 km upstream of Danapur in Patna district of Bihar after flowing for a distance of 784 km from its source. It has a total catchment area of 71,259 sq km in which there are wide fluctuations of water flow changing with the change of season. The important tributaries of the Son are the *Johilla*, the *Gopat*, the *Rihand*, the *Kanhar* and the North *Koel*. Almost all the tributaries join it on its right bank.

The Damodar river rises in the hills of the Chotanagpur plateau and flows through a rift valley. It used to cause devastating floods as a result of which it earned the dubious name of ***'Sorrow of Bengal'***. After flowing through Bankura and Burdwan districts of West Bengal, it joins the Hugli 48 km below Kolkata. The total length of the river is 541 km and its catchment area is 25,820 sq km.

Still more important tributaries of the Ganga originate in the Himalayas and join it on its left bank. The major tributaries of this category, apart from the Yamuna, are the Ramganga, the Gomati, the Ghaghra, the Gandak, the Burhi Gandak, the Bagmati, and the Kosi.

The Ramganga river rises in the Garhwal district of Uttarakhand at an altitude of 3,110 m and enters the Ganga Plain near Kalagarh. It joins the Ganga at Kannauj after traversing a distance of 596 km. The Khoh, the Gangan, the Aril, the Kosi, and the Deoha (Gorra) are important tributaries which join the Ramganga. Its basin covers 32,493 sq km.

The Ghaghra river originates near the Gurla Mandhata peak, south of Manasarovar in Tibet. Obviously it is a river of the trans-Himalayan origin and carries sufficient water. It is known as the *Karnaili* in Western Nepal. It first flows south-east and then south-southwest cutting across the Great Himalaya through a succession of steep defiles. Its important tributaries are the *Sarda*, the *Sarju* on the bank of which Ayodhya is located and the *Rapti*. The Ghaghara joins the Ganga a few kilometres downstream of Chhapra in Bihar after a 1,080 km long journey from its source. Soon after reaching the plain area, its stream gets divided into many branches of which, *Koriyab* and *Garwa* are important. These two streams meet again in Bahraich district of Uttar Pradesh. From here, the river bed is sandy and sudden bends start occurring in the stream. Flowing over a wide sandy expanse, this river crosses Gorakhpur, Deoria, Azamgarh and Balia districts of Uttar Pradesh

as a divided stream. The total catchment area of the river is 127,950 sq km out of which 45% is in India and the rest lies in Nepal and Tibet. The river has a high flood frequency and has shifted its course several times. Its average annual flow is 94,000 million cubic metres.

The Kali river also rises in the high glaciers of snow covered region of the trans-Himalaya. It has several feeders in the high ranges and forms the boundary between Nepal and Kumaon for most of its transit across the mountains. It is known as the ***Sarda*** or ***Chauka*** after it reaches the plains near Tanakpur. Below this point it takes a south-easterly course and joins the Ghaghara.

The Gandak which originates near the Tibet-Nepal border at a height of 7,620 m receives a large number of tributaries in Nepal Himalaya, the most outstanding being the *Kali Gandak*, the *Mayangadi*, the *Bari* and the *Trishuli*. It debouches into the plains at Tribeni and pours into the Ganga at Hajipur in Bihar after flowing for a distance of 425 km in India. Its drainage area is 46,300 sq km out of which 7,620 sq kms, is in India. The average annual flow is 52,200 million cubic metres.

The Burhi Gandak originates from the western slopes of Sumesar hills near the India-Nepal border and flows in south-east direction. It joins the Ganga opposite Monghyr town. Its length is 610 km and its drainage area is 12,200 sq km.

The Kosi river consists of seven streams namely ***Sut Kosi, Tamba Kosi, Talkha, Doodh Kosi, Botia Kosi, Arun*** and ***Tamber*** and is popularly known as ***Saptkaushiki***. These streams flow through a large part of eastern Nepal which is known as the ***Sapt Kaushik*** region. *Arun* is the main stream which rises to the north of Gosainthan. The sources of seven streams of the Kosi are located in snow covered areas which also receive heavy rainfall. Consequently, huge volume of water flows with tremendous speed. Coming out of the Saptakosi region, the streams flow in south-west direction. Seven streams mingle with each other to form three streams named the ***Tumar***, ***Arun*** and ***Sun Kosi***. These three streams contribute respectively 44%, 37% and 19% of the total water flow in the river. They unite at Triveni north of the Mahabharata Range to form the Kosi. The river enters the *Tarai* of Nepal after cutting a narrow gorge for 10 km in the Mahabharata Range at Chatra. The Kosi flows for a distance of 730 km in India and joins the Ganga near Kursela. The total drainage area of the river is 86,900 sq km out of which 21,500 sq km lies in India.

Soon after debouching onto the plain the river becomes sluggish and large scale deposition of eroded

TABLE 4.2. The Ganga Drainage System

Name of the river	Source	Length (in km)	Area drained (sq km)	Volume of average annual flow (in million cubic metres)
Ganga	Gangotri Glacier at 7,010 m	2,525	861,404	1,52,000 at Allahabad, 4,59,040 at Patna
Yamuna	Yamnotri Glacier at 6,330 m	1,376	366,223	93,020 at Allahabad
Chambal	Near Mhow (Madhya Pradesh)	1,050	139,468	30,050 at confluence with the Yamuna
Ramganga	Garhwal district at 3,110 m	596	32,493	15,258
Ghaghara	Near Gurla Mandhota peak south of Manasarovar	1,080	127,950	94,400
Gandak	Tibet-Nepal border at 7,620 m	425 in India	46,300 (7,620 in India)	52,200
Kosi	Sikkim-Nepal-Tibet Himalaya	730 in India	86,900 (21,500 in India)	61,500

material takes place. The river channel is braided and it shifts its course frequently. This has resulted in frequent devastating floods and has converted over 10,000 sq km cultivable land into waste land in Bihar. Thus the river is often termed as the ***'Sorrow of Bihar'***. In order to tame this river, a barrage was constructed in 1965 near Hanuman Nagar in Nepal. Embankments for flood control have been constructed as a joint venture of India and Nepal.

THE BRAHMAPUTRA RIVER SYSTEM

The Brahmaputra (meaning the *son of Brahma*) rises in the great Chemayungdung glacier in the Kailas Range of the Himalayas a little south of the Lake Konggyu Tsho at an elevation of about 5,150 m located at 30° 31′ N latitude and 82° 10′ E longitude. This source is about 150 km away from the source of the Indus and only 35 km from the birth place of the Satluj. Both these rivers flow westwards while the Brahmaputra flows eastwards from this region. *Mariam La* separates the source of the Brahmaputra from the Manasarovar Lake. With a total length of 2,900 km the Brahmaputra is one of the longest rivers of the world and passes through Tibet, India and Bangladesh.

Known as the ***Tsangpo*** (meaning 'The Purifier'), in Tibet and ***Yarlung Zangbo Jiangin*** in Chinese language, the Brahmaputra flows eastwards in Southern Tibet for about 1,800 km and for most part of this journey it passes through the depression formed by the *Indus-Tsangpo Structure Zone* between the Great Himalayas in the south and the Kailas Range in the north. Inspite of the exceptionally high altitude of the land through which the Tsangpo flows, it has a gentle slope and the river is sluggish and has a wide navigable channel for about 640 km from Lhatse Dzong down-stream. This is one of the most remarkable navigable waterways of the world where boats sail at an altitude of 3,000 metres and above. Its bed is 3,525 m high at Tradom (Teladuomu) and 3,300 m at Shigatse. It receives a large number of tributaries in Tibet. The first major tributary is the Raga Tsangpo from the north meeting the Tsangpo near Lhatse Dzong. The river Ngangchu flows through the trade centre of Gyantse in the south and joins the main river near Zhikatse. Further east, the Kyichu (Gya Chhu) from the north runs past the sacred town of Lhasa and joins it near Chushul Dz. At Tsela Dz, the river is joined by the Griamda from the north.

Towards the end of its journey in Tibet, it abruptly turns to north-east and north and then traverses in a succession of rapids between high mountains of Gyala Peri (7,151 m) and Namcha Barwa (7,756 m). Further, it turns to the south and south-west and cuts across the eastern Himalaya through the Dihang or Siang Gorge and emerges from the mountains near Sadiya in the Assam Valley. Here it first flows under the name of Siong and then as the Dihang. The Dihang gorge is only 50 metres wide at places but is 5,485 m below Namcha Barwa. The steepness of its slope can be judged from the fact that its altitude falls suddenly from 2,450 m north of Namcha Barwa to only 135 m at Sadiya. Here it is joined by two important tributaries *viz.* the Dibàng (or Sikang) from the north and Lohit from the south forming what looks like a '*delta in reverse*'.

From Sadiya onwards, this mighty river is known as the ***Brahmaputra*** and flows majestically in the Assam Valley for a distance of about 720 km. Here also, a large number of tributaries, both from the north and from the south, pay their tribute to the master river. The main streams merging with the Brahmaputra from the north are, Subansiri, Kameng, Belsiri, Dhansiri (north), Nyera Ama, Manas—Mora—Manas, Champaman, Gangadhar, Raidah, Dharla and Tista. The Tista was a tributary of the Ganga prior to the devastating floods of 1787 after which it diverted its course eastwards to join the Brahmaputra. Those pouring in the main river from the south are the Dibru, Burhi Dihing, Noa Dihing, Dikhu, Dhansiri (south) and Kalang.

The Brahmaputra has a braided channel for most of its passage through Assam. There is a constant shifting of the river channels and the sandy shoals. Its southward shift in the Assam plains has been quite conspicuous in the recent years. It carries a lot of silt and there is excessive meandering. The river is nearly 16 km wide at Dibrugârh and forms many islands, the most important of which is *Majuli*. It is 90 km long and measures 20 km at its widest, having an area of 1,250 sq km. This island has 144 villages with a population of over 1,50,000. With rainfall concentrated during the monsoon months only the river has to carry enormous quantities of water and silt which results in disastrous floods in the rainy season. The floods caused by the Brahmaputra in Assam Valley affect on an average an area of 8 to 10 lakh sq km. The Brahmaputra is thus truly a *River of Sorrow*. However, the river is navigable for a distance of 1,384 km upto Dibrugarh from its mouth and serves as an excellent inland water transport route.

Traversing round the stairs of the Garo Hills, the Brahmaputra bends southwards and enters Bangladesh near Dhubri. It flows for a distance of 270 km in the name of Jamuna river and joins the Ganga at Goalundo. The united stream of the Jamuna and the Ganga flows further in the name of Padma. About 105 km further downstream, the Padma is joined on the left bank by the Meghna, originating in the mountainous region of Assam. From the confluence of Padma and Meghna, the combined river is known as the ***Meghna*** which makes a very broad estuary before pouring into the Bay of Bengal.

THE PENINSULAR DRAINAGE

The Indian Peninsula is traversed by a large number of rivers which have existed for a much longer period than the Himalayan rivers. As such the peninsular rivers have reached mature stage and have almost reached the base level of their erosion. This is characterised by broad, shallow and largely graded valleys. The beds have very subdued gradient except for a limited tract of river where faulting has allowed steepening of the gradient. Almost the entire peninsula presents a senile topography showing features of mature drainage.

The velocity of water in the rivers and the load carrying capacity of the streams is low due to low gradient and the rivers form big deltas at their mouths. This is especially observed in the east flowing rivers pouring into the Bay of Bengal. But the west flowing rivers of Narmada and Tapi as well as those originating from the Western Ghats and falling in the Arabian Sea form estuaries in place of deltas.

However, there are instances of superimposed and rejuvenated drainage represented by waterfalls. The Jog on the Sharvati (289 m), Yenna of Mahabaleshwar (183 m), Sivasamundram on the Cauveri (101 m), Gokak on the Gokak (55 m), Kapildhara (23 m) and Dhuandar (15 m) on the Narmada are the major waterfalls in the Peninsular India.

Evolution of the Peninsular Drainage

Geologists believe that the Sahyadri-Aravali axis was the main water divide in the geological past. One hypothesis assumes that the existing peninsula is the remaining half of bigger landmass. The Western Ghats were located in the middle of this landmass dividing the entire drainage into two symmetrical parts—one flowing in the east and the other flowing in the west. But the western part of the Peninsula cracked and submerged in the Arabian Sea and disturbed the symmetrical plan of the rivers on either side of the watershed during the early Tertiary period. During the collision of the Indian plate, a second major distortion was introduced in the Peninsular block and it was subjected to subsidence and consequent trough faulting through which now flow main west flowing rivers of the Peninsula, namely the Narmada and the Tapi. This is amply proved by the straight coastline, steep western slope of the Western Ghats, and the absence of delta formations on the western coast.

Another view is put forward keeping in view the exceptional behaviour of the Narmada and the Tapi. It is believed that these two rivers do not flow in the valleys formed by the rivers themselves. Rather they have occupied two fault planes or alluvium filled rifts in rocks running parallel to the Vindhyas. These faults are supposed to be caused by bend or 'sagging' of the northern part of the Peninsula at the time of upheaval of the Himalayas. According to **D.N. Wadia** (1975) the Peninsular block, south of the cracks, tilted slightly eastwards thus giving new orientation to the entire drainage towards the Bay of Bengal. While this line of thought explains the present drainage system of the Peninsular India with greater satisfaction, it still leaves some questions to which there is no satisfactory answer. **R.C. Mehdiratta** (1962) argues that tilting should have increased the gradient of the river valleys and caused some rejuvenation of the rivers. This type of phenomenon is absent in the Peninsula, barring a few exceptions such as waterfalls, as mentioned earlier.

The Peninsular River Systems

Although the general direction of flow of the Peninsular rivers is from west to east, a careful study reveals at least three main directions of flow :

(*i*) The Mahanadi, the Godavari, the Krishna, the Cauvery and several smaller rivers draining south-east into the Bay of Bengal.

(*ii*) The Narmada and the Tapi flowing west as well as several small streams originating from the Western Ghats flow westwards into the Arabian Sea.

(*iii*) Tributaries of the Ganga and the Yamuna such as the Chambal, the Betwa, the Ken, the Son and the Damodar flow in the north-easterly direction.

The East Flowing Rivers of the Peninsula

The Mahanadi (literally meaning big river) is an important river of the Peninsular India. It has its source in the northern foothills of Dandakaranya near Sihawa in Raipur District of Chhattisgarh at an elevation of 442 m. Its upper course lies in the saucer-shaped basin called the 'Chhattisgarh Plain'. This basin is surrounded by hills on the north, west and south as a result of which a large number of tributaries join the main river from these sides. The main tributaries are the *Ib* (251 km), the *Mand* (241 km), the *Hasdo* (333 km) and the *Sheonath* (383 km) on the left bank and the *Ong* (204 km), the *Jonk* (196 km), and the *Tel* (295 km) on the right bank. From its source, the river takes a north easterly course. Beyond Seorinarayan it flows eastwards and after entering Odisha, it turns southwards below the Hirakud Dam. Further below it turns eastwards near Sonepur. On reaching the Eastern Ghats, the river flows through a narrow Gorge for 23 km near Tikkarpara Range and finally emerges in a delta at Naraj 11 km west of Cuttack. The Mahanadi finally empties itself in the Bay of Bengal after flowing for a distance of 857 km. The delta of Mahanadi spreads over an area of 9,500 sq km and is over 150 km broad.

The Godavari is the largest river system of the Peninsular India and is next only to the Ganga and the Indus Systems regarding sanctity, picturesqueness and utility and is held in reverence as *Vridha Ganga* or *Dakshina Ganga*. Its total length is 1,465 kilometres. The source of this river is in the Trimbak Plateau of North Sahyadri near Nashik in Maharashtra which is only 80 km from the shore of the Arabian Sea. From its source it flows eastwards in a narrow rocky bed upto Nashik but the river valley opens out below this point. It receives a large number of tributaries both from the left as well as from the right. But the left bank tributaries are more in number and larger in size than the right bank tributaries. The *Manjra* (724 km) is the only important right bank tributary. It originates from Jamkhed Hill in Central Maharashtra and joins the Godavari near Kondalwadi after passing through the Nizam Sagar. The *Penganga*, the *Wardha*, the *Wainganga*, the *Indravati* and the *Sabari* are important left bank tributaries. The *Penganga* (676 km) rises from the Buldana Range and joins the Wardha River (483 km) near Ghughus. The Wardha in its turn joins the Wainganga. The united Wardha and Wainganga rivers become the short span *Pranhita* river which joins the Godavari below Sironcha. The *Indravati* river from the Kondhan Hills of Eastern Ghats joins the master river about 48 km downstream from Sironcha. Below its confluence with Indravati, the Godavari flows in a gorge, 60 km long and 200 m wide through the Eastern Ghats. It is located about 100 km from the mouth of the river and is supposed to be formed due to faulting. Below Rajahmundry, the river divides itself into two main streams, the *Gautami Godavari* on the east and the *Vashishta Godavari* on the west and forms a large delta before it pours into the Bay of Bengal. The current at Rajahmundry is not rapid and varies from 1.2 to 3.3 metres per second. The delta has a front of 120 km and projects about 35 km into the sea. The delta of the Godavari is of *lobate type* with a round bulge and many distributaries. The Godavari causes heavy floods in its lower course below Polawaram. The Godavari is navigable upto a distance of 300 km from its mouth.

The Krishna is the second largest east flowing river of the Peninsula. It rises in the Western Ghats just to the north of Mahabaleshwar, about 64 km from the Arabian Sea and flows for a distance of 1,400 km to the Bay of Bengal in a general easterly direction. The *Koyna*, the *Ghataprabha*, the *Malprabha*, the *Bhima*, the *Tungabhadra*, the *Musi* and the *Muneru* are its important tributaries. **The Koyna** is a small tributary but is very famous for Koyna Dam. This dam was perhaps the main cause of the devastating earthquake in 1967. **The Bhima** originates from the Matheron Hills and joins the Krishna 26 km from Raichur after flowing in the south-easterly direction for a distance of 861 km. Mula, Mutha Ghod and Nora are its sub-tributaries. **The Tungabhadra** is formed by the unification of the *Tunga* and the

Bhadra originating from Gangamula in the Central Sahyadri. Its total length is 531 km. At Wazirabad, it receives its last important tributary, the *Musi*, on whose banks the famous city of Hyderabad is located. The Krishna forms a large delta spreading over an area of 4,600 sq km with a shoreline of about 120 km. The Krishna delta appears to merge with that formed by the Godavari and extends about 35 km into the sea.

Kaveri (Cauvery) is the most revered and sacred river of south India and is designated as the '*Dakshina Ganga*' or '*the Ganga of the South*'. The Source of this river lies at Taal Cauvery on the Brahmagiri range of hills in the Western Ghats at 1,341 m elevation (12° 25′ N and 75° 34′ E) situated in the Coorg Plateau (Coorg district of Karnataka). It flows eastwards for a distance of about 800 km before it empties in the Bay of Bengal. This river is unique in the sense that its upper catchment area receives rainfall during summer by the south-west monsoon and the lower catchment area during winter season by the retreating north-east monsoon. It is, therefore, almost a perennial river with comparatively less fluctuations in flow and is very useful for irrigation and hydroelectric power generation. Thus the Cauvery is one of the best regulated rivers and 90 to 95 per cent of its irrigation and power production potential already stands harnessed.

The Cauvery river falls rapidly by 450 m from its source of origin within a short distance of 8 km. The middle course of the river over the 750 m high Mysore Plateau is characterised by broad and sweeping meanders. The river descends from the South Karnataka Plateau to the Tamil Nadu Plains through the Sivasamudram waterfalls (101 m high). The river which was more than one kilometre wide above the Sivasamudram Falls, narrows down considerably below it and enters a long, picturesque gorge, 200 m deep at places, cut through the Eastern Ghats. The river divides itself into two distinct channels at Srirangam. The northern channel is called Kollidam (Coleroon) while the southern one retains the name Cauvery. The delta formation starts from a point about 16 km away from Tiruchchirappalli. The Cauvery has formed a quadrilateral delta spreading over an area of 8,000 sq km. It has almost a straight front which runs for a distance of 130 km along the coast of Bay of Bengal.

The water flowing in the Cauvery is supplemented by a large number of tributaries which join the master river at different places. The main tributaries are the *Herangi*, the *Hemavati*, the *Lokpavani*, the *Srimsha* and the *Arkavati* from the north and the *Laksmantirtha*, the *Kabani*, the *Suvarnavati*, the *Bhavani* and the *Amravati* from the south.

Among the other east flowing rivers of the Peninsular India are, from north to south, the Subarnarekha, the Brahmani, the Penneru, the Ponnaiyar and the Vaigai. **The Subarnarekha** originates from he Ranchi Plateau in Jharkhand at an elevation of 600 m and flows in south-east direction forming the boundary between West Bengal and Odisha in its lower course. It joins Bay of Bengal forming an estuary between the Ganga and Mahanadi deltas. Its total length is 395 km. **The Brahmani** river comes into existence by the confluence of the *Koel* and the *Sankh* rivers near Rourkela. It has a total length of 800 km. Its main tributaries are the *Kura*, the *Sankhad* and the *Tikra*. Its mouth becomes the northern end of the Mahanadi delta. **The Penneru** river springs from the *Nandi Durg* peak in Karnataka and flows in northward direction. It then enters Andhra Pradesh and takes an easterly course. It forms a narrow estuary before it joins the Bay of Bengal. The total length of the river is 597 km. The principal tributaries of this river are the *Jayamangali*, the *Kunderu*, *Saigileru*, *Chitravari*, *Papagni* and *Cheyyeru*. The *Ponnaiyar* is a small stream which is confined to the coastal area only. South of the Cauvery delta, there are several streams, of which the *Vaigai* is the longest. This flows through dry channels and tends to get lost intermittently and appear again on the surface.

The west flowing rivers of the Peninsula

The west flowing rivers of the Peninsular India are fewer and smaller as compared to their east flowing counterparts. The two major west flowing rivers are the *Narmada* and the *Tapi*. This exceptional behaviour of these two rivers is explained by the supposition that they do not flow in the valleys formed by themselves but have usurped for their channels two fault planes running parallel to the Vindhyas. These faults are supposed to have originated with the bending or '*sagging*' of the northern part of the Peninsula at the time of upheaval of the Himalayas. It is interesting to note that the Peninsular rivers which fall into the Arabian Sea do not form *deltas*, but only *estuaries*. This is due to the fact that the west flowing rivers, especially the Narmada and the Tapi flow through hard rocks and are not able to form distributaries before they enter the sea. The Sabarmati, Mahi and Luni are other rivers of the Peninsular India which flow westwards. Hundreds of small streams originating in the Western Ghats flow swiftly westwards and join the Arabian Sea.

The Narmada is the largest of all the west flowing rivers of the Peninsular India. It rises from the western flanks of the Amarkantak plateau about 22°40'N and 81°45'E at an elevation of 1,057 m in Shahdol district of Madhya Pradesh and flows westwards through a rift valley between the Vindhyan Range on the north and the Satpura Range on the south. Its total length from its source in Amarkantak to its estuary in the Gulf of Khambhat is 1,310 km. For 1,078 km, it flows through Madhya Pradesh. For the next 32 km, it forms the boundary between Madhya Pradesh and Maharashtra and for another 40 km between Maharasthra and Gujarat. The remaining 160 km of its course is in Gujarat. After flowing for 400 km from the source, the river slopes down Jabalpur, where it cascades 15 m into a gorge to form the most spectacular and world famous *Dhuan Dhar (Cloud of Mist) Falls*. Since the gorge is composed of marble, it is popularly known as the *Marble Rocks*. The average descent of the river in its upper basin is 7-9 metres per kilometre. Below Jabalpur, it flows in a narrow elongated and well defined basin and forms a few rapids. It makes two waterfalls of 12 m each at Mandhar and Dardi. Near Maheshwar the river again descends from another small fall of 8 m, known as the Sahasradhara Falls. Emerging from the hills near Gardeshwar, it meanders through an alluvial plain past Bharuch and makes an estuary before entering the Gulf of Khambhat. There are several islands in the estuary of the Narmada of which Aliabet is the largest. At its confluence with the sea, the mouth of the river is about 28 km wide. The Narmada is navigable upto 112 km from its mouth.

Since the river flows through a narrow valley confined by precipitous hills, it does not have many tributaries. The absence of tributaries is especially noted on the right bank of the river where the *Hiran* is the only exception. It is 188 km long and flows parallel to the Bhanru Range in Jabalpur district before falling into the Narmada, north-east of Chhindwara. The other right bank tributaries are the *Orsang*, the *Barna* and the *Kolar*. A few left bank tributaries drain the northern slopes of the Satpura Range and join the Narmada at different places. The important tributaries joining the Narmada on its left bank are the *Burhner* (177 km), the *Banjar* (184 km), the *Shar* (129 km), the *Shakkar* (161 km) the *Tawa* (172 km) and the *Kundi* (169 km).

The Tapi (also known as the *Tapti*) is the second largest west flowing river of the Peninsular India and is known as ***'the twin'*** or ***'the handmaid'*** of the Narmada. It originates from the sacred tank of Multai on the Satpura Plateau in Betul district of Madhya Pradesh at an elevation of 730 m above sea level. It first traverses on open plain and then plunges into a rocky gorge of the Satpura hills between the Kalibhit Range in Nimar and Chikalda in Berar. At a distance of 192 km from its source, the river enters the Nimar region. After crossing the Nimar region of Madhya Pradesh it enters the Khandesh Plain of Maharashtra, lying between the Satpura and the Ajanta Ranges. On entering the Khandesh Plain, it receives the *Purna* river on the left bank. This is the main tributary of the Tapi which originates in the Gawilgarh Hills and joins the main river near Bhusawal. Further west it crosses the Western Ghats through a deep and narrow valley, passes through the alluvial plain of Surat and makes an estuary before falling into the Gulf of Khambhat.

The total length of the river is 730 km. About 48 km stretch of its course is tidal and the river is navigable for only about 32 km from the sea. The important tributaries of this river apart from the Purna River, are the Betul, Patki, Ganjal, Dathranj, Bokad, Bokar Suki, More, Kanki, Guli, Aner, Arunavati, Gomai and Valer on right bank and Ambhora, Khursi, Khandu, Kapra, Sipra, Garja, Khokri, Utaoli, Mona, Vaghur, Girna, Bori, Panjhara, Buray and Amravati on the left bank.

The Sabarmati is the name given to the combined streams the *Sabar* and *Hathmati*. It rises from the hills of Mewar in the Aravali Range and is 320 km long. It flows through a gorge at Dharoi and falls into the Gulf of Khambhat. The important

TABLE 4.3. Major Rivers of the Peninsular India

Name of the river	Source	Length in km	Area drained (sq km)	Volume of average annual flow (million cubic metres)	Important tributaries
Mahanadi	Dandakaranya near Sihawa in Raipur district of Chhattisgarh	857	141,600	67,000	Ib, Mand, Hasdo, Sheonath, Ong, Jonk, Tel
Godavari	Trimbak Plateau near Nashik in Maharashtra	1,465	312,812	105,000	Manjra, Penganga, Wardha, Wainganga, Indravati, Sabari, Pranhita
Krishna	Near Mahabaleshwar in Maharashtra	1,400	258,948	67,670	Koyna, Ghatprabha, Malprabha, Bhima, Tungabhadra, Musi, Muneru
Cauvery	Taal Cauvery Western Ghats	800	87,900	20,950	Herangi, Hemavati, Lokpavani, Shimsha, Arkavati, Lakshmanatirtha, Kabani, Suvanavati, Bhavani, Amaravati
Narmada	Amarkantak Plateau	1,310	98,795	40,700	Hiran, Orsang, Barna, Kolar, Burhner, Banjar, Shar, Shakhar, Tawa, Kundi
Tapi	Multai in Betul Distt. of M.P.	730	65,145	17,980	Purna, Betul, Patki, Ganjal, Dathranj, Bokad, Amravati

tributaries of this river are the *Hathmati*, the *Sedhi*, the *Wakul*, the *Harnav*, the *Meshwa* and the *Vatrak*. The average annual flow of this river is 3,200 million cubic metres.

The **Mahi** river rises in the Vindhyas at an elevation of 500 m and empties itself into the Gulf of Khambhat after flowing for a distance of 533 km. The main tributaries of this river are the *Som*, the *Anas* and the *Panam*.

The **Luni** or the **Salt River** (*Lonari or Lavanavari* in Sanskrit) is named so because its water is brackish below Balotra. Its source lies to the west of Ajmer in the Aravalli at an elevation of 550 m and it flows in a south-west direction. It is a small stream but has got the distinction of flowing through the Thar Desert. The river is known as the *Sagarmati* in its upper course. It is joined by the Sarsuti after passing Govindgarh and it is from this confluence that the river gets its proper name as the Luni. It traverses for a distance of 482 km and is finally lost in the marshy grounds at the head of the Rann of Kachchh. The river has a low gradient and flows through a wide plain without a well marked valley.

West flowing Rivers of the Sahyadris

About six hundred small streams originate from the Western Ghats and flow westwards to fall into the Arabian Sea. The western slopes of the Western Ghats receive heavy rainfall from the south-west monsoons and are able to feed such a large number of streams. Although only about 3% of the areal extent of the basins of India is drained by these rivers, they contain about 18% of the country's water resources. The important rivers falling in this category are the Mandovi, Zuari and Rachol in Goa; Kalinadi, Gangavalli-Bedti, Sharavati, Tadri and Netravati in Karnataka, and Beypore, Pannam, Bharatapuzha, Periyar and Pamba in Kerala. Most of the streams flow swiftly down the steep slope and some of them make waterfalls. The *Jog* or *Gersoppa Falls* (289 m) made by the Sharavati river is the most famous waterfall of India.

Inland Drainage

Some rivers of India are not able to reach the sea and constitute inland drainage. Large parts of the Rajasthan desert and parts of Aksai Chin in Ladakh have inland drainage. The *Ghaggar* is the most important river of inland drainage. It is a seasonal stream which rises on the lower slopes of the Himalayas and forms boundary between Haryana and Punjab. It gets lost in the dry sands of Rajasthan near Hanumangarh after traversing a distance of 465 km. Earlier, this river was an affluent of the Indus, the dry bed of the old channel is still traceable. Its main tributaries are the Tangri, the Markanda, the Saraswati and the Chaitanya. It contains a lot more water in rainy season when its bed becomes 10 km wide at places. Most of the streams draining western slopes of the Aravalli Range dry up immediately after they enter the sandy arid areas to the west of this range.

Differences between the Himalayan and the Peninsular River Systems

The Himalayan rivers are quite different from the rivers of the Peninsular India from the point of view of the drainage features and hydrological characteristics. A brief summary of these differences is given below :

Basis	The Himalayan River System	The Peninsular River System
1. Name	These rivers originate from the lofty Himalayan ranges and are named as the Himalayan rivers.	These rivers originate in the Peninsular Plateau and are named as Peninsular rivers.
2. Basins	These rivers have large basins and catchment areas. The total basin area of the Indus, the Ganga and the Brahmaputra is 11.78, 8.61 and 5.8 lakh square kilometres respectively.	These rivers have small basins and catchment areas. The Godavari has the largest basin area of 3.12 lakh square kilometres only which is less than one-third the basin area of the Indus.
3. Valleys	The Himalayan rivers flow through deep I-shaped valleys called gorges. These gorges have been carved out by down cutting carried on side by side with the uplift of the Himalayas. These are examples of *antecedent drainage*.	The Peninsular rivers flow in comparatively shallow valleys. These are more or less completely graded valleys. The rivers have little erosional activity to perform. These are examples of *consequent drainage*.
4. Water Flow	The Himalayan rivers are perennial in nature, *i.e.*, water flows throughout the year in these rivers. These rivers receive water both from the monsoons and snow-melt. The perennial nature of these rivers makes them useful for irrigation.	The Peninsular rivers receive water only from rainfall and water flows in these rivers in rainy season only. Therefore, these rivers are seasonal or non-perennial. As such these rivers are much less useful for irrigation.
5. Stage	These rivers flow across the young fold mountains and are still in a youthful stage.	These rivers have been flowing in one of the oldest plateaus of the world and have reached maturity.
6. Meanders	The upper reaches of the Himalayan rivers are highly tortuous. When they enter the plains, there is a sudden reduction in the speed of flow of water. Under these circumstances these rivers form meanders and often shift their beds.	The hard rock surface and non-alluvial character of the plateau permits little scope for the formation of meanders. As such, the rivers of the Peninsular Plateau follow more or less straight courses.
7. Deltas and Estuaries	The Himalayan rivers form big deltas at their mouths. The Ganga-Brahmaputra delta is the largest in the world.	Some of the Peninsular rivers, such as the Narmada and the Tapi form estuaries. Other rivers such as the Mahanadi, the Godavari, the Krishna and the Cauvery form deltas. Several small streams originating from the Western Ghats and flowing towards the west enter the Arabian Sea without forming any delta.

RIVER BASINS OF INDIA

River basin is the area drained by the main river and its tributaries. For example, Ganga basin is the area drained by the main Ganga river and its tributaries like Yamuna, Ghaghara, Gondak, Kosi and their sub-tributaries. In a large country like India, it is natural to have different types of river basins. Depending on the size of their catchment area : **Dr. K.L. Rao** (1977), divided the Indian river basins into following three categories :

(*i*) **Major river basins** with catchment area of 20,000 sq km and above account for 85 per cent of the total run-off of all the rivers of India. They are fourteen in all and are in high rainfall areas (*i.e.* 63 million cubic metre per 100 sq km). There are three river systems to the north of Tropic of Cancer, seven between Tropic of Cancer and 20°N latitude and four in the Peninsular India.

(*ii*) **Medium river basins** with a catchment area between 2,000 sq km and 20,00 sq km account for 7% of the total run off of all the rivers. They are 44 in all and have medium rainfall (*i.e.* 45 million cubic metres per 100 sq km). The medium river basins are divided into three sub-groups depending upon their direction of flow. Of them 19 are west flowing, 21 are east flowing and the remaining 4 flow in other directions.

(*iii*) **Minor river basins** with a catchment area below 2,000 sq km account for 8 per cent of the total run off of all the rivers of India. There are 55 such river basins. They are located either in dry areas or in the coastal areas, especially on west coast where the rivers are much shorter due to narrow coastal plain between the coast and the Western Ghats.

Major River Basins

India has 14 major river basins. They are Indus, Ganga, Brahmaputra, Mahanadi, Godavari, Krishna, Kaveri, Narmada, Tapi, Penneru, Brahmani, Mahi,

TABLE 4.4. Surface Flow in Major River Basins of India

Sl. No.	River basins	Basin area*		Annual water yield		Rate of flow	Storage capacity
		(km²)	%	(million m³)	%	(m³/km²)	(million m³)
	Major rivers						
1.	Ganga	861,404	26.2	468,700	25.2	442,170	33,467
2.	Indus	321,284	9.8	79,500	4.3	247,441	14,419
3.	Godavari	312,812	9.5	118,000	6.4	377,223	14,859
4.	Krishna	258,948	7.9	62,800	3.4	243,403	29,860
5.	Brahmaputra	258,008	7.8	627,000	33.8	1,081,034	142
6.	Mahanadi	141,589	4.3	66,640	3.6	470,658	7,926
7.	Narmada	98,795	3.0	54,600	2.9	970,658	2,550
8.	Kaveri	87,900	2.7	20,950	1.1	237,770	5,428
9.	Tapi	65,145	2.0	17,982	0.9	267,770	8,140
10.	Penneru	55,213	1.7	3,238	0.2	58,646	1,978
11.	Brahmani	39,033	1.2	18,310	1.0	202,701	3,953
12.	Mahi	34,481	1.0	11,800	0.6	388,681	4,140
13.	Subarnarekha	19,296	0.6	7,940	0.4	411,484	283
14.	Sabarmati	21,895	0.7	3,800	0.2	173,556	1,017
	Medium & minor rivers	711,833	21.6	296.840	16.0	417,008	18,452
	Total (India)	**3,287,782**	**100.0**	**1,858,100**	**100.0**	**565,153**	**146,826**

*Area means basin area in India

Source : S.P. Das Gupta, 1989.

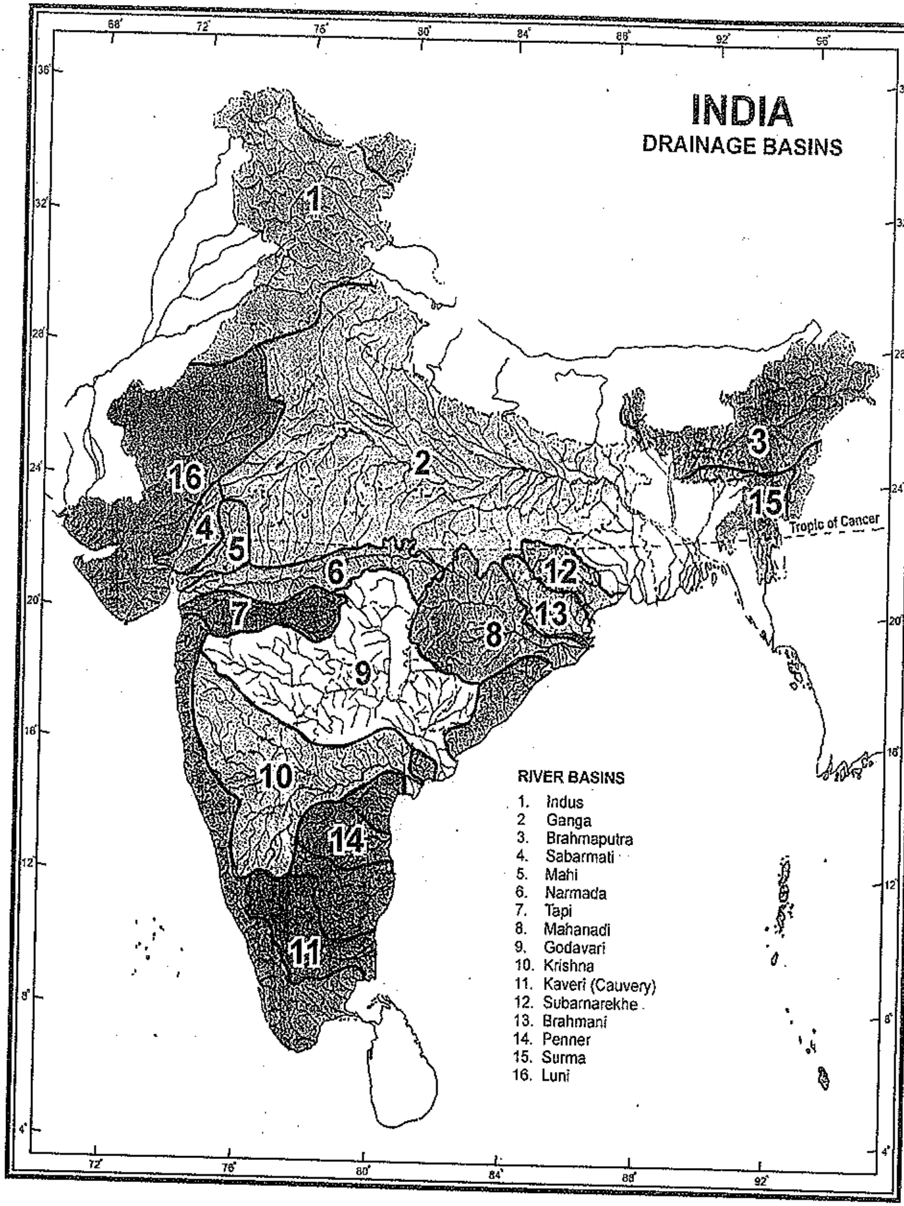

Fig. 4.4. India : Drainage Basins

Sabarmati and Luni. S.P. Das Gupta has treated Subarnarekha also as the major river basin although its basin area is less than 20 thousand sq km (**Table 4.4**). Some other geographers tend to treat Surma and Luni also as major river basins as is indicated in **Fig. 4.4**.

A brief description of some of the important river basins is given as under :

1. The Indus River Basin. The Indus river originates near Manasarover Lake from the glaciers of the Kailas Range in the western part of Tibet, enters India at the border of Jammu and Kashmir with China and traverses this state between the Ladakh and the Zaskar Ranges. The whole of Jammu and Kashmir state excepting its northern and the north-eastern tips is included in this basin. It receives a large number of tributaries on its right bank and its five left bank tributaries *viz.* the Satluj, the Beas, the Ravi, the Jhelum and the Chenab are big rivers in themselves. The Indus has a total drainage area of 1,178,440 sq km out of which about 453,250 sq km lies in the Himalayan mountains and foothills, the rest lies in the Indus plain of India and Pakistan. As a result of partition, Indus drainage basin has been divided between India and Pakistan with major portion going to Pakistan and India has to content with only 321,284 sq km which is about 26.2 per cent of the total drainage area. Apart from Jammu and Kashmir, the whole of Punjab, almost the whole of Himachal Pradesh, northern fringe of Haryana and northern tips of Rajasthan are included in this basin.

2. The Ganga River Basin. Originating from the Gangotri glacier in the Western Himalayas, the Ganga flows towards the south in Uttarakhand and then turns towards the east, flowing through Uttar Pradesh and Bihar and then turn towards the south-east to empty itself in the Bay of Bengal. This mighty river is joined by a large number of tributaries like Yamuna, Ghaghara, Gondak, Kosi, Son etc. In fact, the Ganga has the largest basin in India which stretches over an area of 861,404 sq km and amounts to 26.2% of the total river basin area of India. This basin is shared by ten states. These states are Uttarakhand and Uttar Pradesh (34.2%), Madhya Pradesh and Chhattisgarh (23.1%), Bihar and Jharkhand (16.7%), Rajasthan (13.0%), West Bengal (8.3%), Haryana (4.0%) and Himachal Pradesh (0.5%). The Union Territory of Delhi accounts for 0.2% of the total area of the Ganga Basin.

3. The Brahmaputra River Basin. Like the Indus, the Brahmaputra river also has its source in the western part of Tibet and it flows from west to east in a depression between the Great Himalayas and the Kailas Range. On reaching the extreme east, it takes a sharp turn in the south-west direction and enters India after cutting through the Himalayan range. Its total basin area is 2,58,008 sq km, in India, which is about 7.8 per cent of the total basin area of the country. Most of the drainage area of this river lies in Assam, Arunachal Pradesh and Sikkim. The northern parts of Nagaland and Meghalaya are also included in this basin.

4. The Mahanadi River Basin. Originating from the foothills of Dandakaranya in Chhattisgarh, this river flows in to the east and joins the Bay of Bengal after traversing over a distance of 857 km. The total basin area of this river is 141,589 sq km which is about 4.3% of the total basin area of India. Its major tributaries are Ib, Mand, Hasdo, Seomath, Org, Jonk and Tel. This basin spreads over a large part of Chhattisgarh and middle of Odisha.

5. The Godavari River Basin. The Godavari has the largest basin area of 3,12,812 sq km (9.5% of India) which is larger than even that the great Brahmaputra in Indian territory. Originating in the Trimbak Plateau in Maharashtra, it is joined by a large number of tributaries like Manjra, Penganga, Wardha, Wainganga, Indravati, Sabari and Pranhita. 48.6 per cent is in Maharashtra, 23.8 per cent in Andhra Pradesh and Telangana, 20.7 per cent in Madhya Pradesh and Chhattisgarh, 5.5 per cent in Odisha and only 1.4 per cent in Karnataka.

6. The Krishna River Basin. The Krishna has the second largest basin area of 258,948 sq km (7.9% of all India) after that of the Godavari in the Peninsular India. Originating from the north of Mahabaleshwar, it flows in the east and joins the Bay of Bengal. Its important tributaries are Koyna, Ghataprabha, Malprabha, Bhima, Musi, Tungabhadra and Muneru. Its basin area is quite wide in the west in the states of Maharashtra and Karnataka and narrows down considerably in Telengana and Andhra Pradesh and it is narrowest in the delta region.

7. The Kaveri (Cauvery) River Basin. Originating in the Western Ghats, it traverses 800 km in the eastern direction before joining the Bay of Bengal. The tributaries joining the main river from the north are the Herangi, the Hemavati, the Lakpavani, the Srimsha and the Arkawali while those joining from the south are the Lakshmantirtha, the Kabani, the Suvarnavati, the Bhavani and the

Amravati. Its total basin area is 87,900 sq km (2.7% of the India) which is shared by two states of Karnataka and Tamil Nadu.

8. The Narmada River Basin. This river originates from the Amarkantak Plateau and flows westward to join the Arabian sea in the Gulf of Khambhat after forming an estirary. Since it flows through a rift valley, it does not receive any tributary worth the name as a result of which its basin is elongated, quite long in the east and west direction and quite narrow in the north-south direction. The total area of this basin is 98,795 sq km (3.0% of all India), most part of which lies in Madhya Pradesh with small part lying in Gujarat.

9. The Tapi River Basin. South of the Narmada river flows the Tapi river in the east-west direction. It originates from the Maltai Tank in Betul district of Madhya Pradesh and traverses a distance of 730 km before entering the Arabian sea. Its total basin area of 65,145 sq km which is about 2.0% of the all India basins. Like the Narmada, the Tapi river also does not have large tributaries and its basin area is alongated with its long side in east-west direction.

10. The Penneru River Basin. The Penneru river originates from the Nandi Durg in Karnataka and enters Andhra Pradesh where its flows in an easterly direction to join the Bay of Bengal after forming a small estuary. This is a comparatively small river basin covering an area of 55,213 sq km (1.7%).

11. The Brahmani River Basin. The Brahmani river takes its birth at the confluence of the Koel and the Sankh rivers near Rourkela. Tributaries like Kura, Sankhad and Tikra join the main river enabling the Brahmani river basin to spread over an area of 39,033 sq km (1.2%) in the state of Odisha.

12. The Mahi River Basin. This 533 km long river originates in the Vindhyas and empties itself in the Gulf of Khambat. The Son, the Anas and the Panam are its main tributaries. Its total basin area is 34,481 sq km which is shared by Rajasthan (47%), Gujarat (34%) and Madhya Pradesh (19%).

13. The Sabarmati River Basin. This 320 km long river is the combined name of the Sabar and the Hathmati which originate in the hills of Mewar in the Aravali range and empties itself in the Gulf of Khambhat. Its main tributaries are the Hathmati, the Sedhi, the Wakul, the Harnav, the Mehswa and the Vatrak. The total basin area is 21,895 (0.7%), which entirely lies in Gujarat.

14. The Luni River Basin. Part of this river has salty water as a result of which it is known as the Luni river. It originates in the west of Ajmer and flows through the Thar Desert and is lost in the marshy grounds at the head of the Ranu of Kachchh. It flows through a wide plain without a well marked valley. This river has a vast basin which spreads over Rajasthan and Gujarat.

River Regimes

River regime is the seasonal fluctuation in the volume of water in a river. The climatic differences in the sources of the Himalayan and the Peninsular rivers lead to the differences in the drainage patterns of these two areas. The Himalayan rivers are perennial because their regimes depend upon water supply both from rainfall and snow-melt. Thus, the regimes of the Himalayan rivers are both monsoonal as well as glacial. On the other hand, the Peninsular rivers receive water from rainfall only and their regimes are only monsoonal.

Fig. 4.5 shows hydrographs of two Himalayan and two Peninsular rivers depicting their regimes. These graphs show the monthly discharge of water flowing in these rivers. This discharge is measured in *cusecs* (cubic feet per second) or *cumecs* (cubic metres per second).

The Ganga has minimum flow from January to June. The maximum is attained in August or September. The rate of flow steadily falls after September. The Ganga has, thus, a typical monsoonal regime. However, there is enough water in this river before the monsoon rains mainly because of snow-melt in the Himalayas. Another Himalayan river, the Jhelum attains its maximum flow in June or even in May mainly because of Himalayan snow-melt. An interesting difference between the regimes of the two rivers is seen in the range of variation between the maximum and the minimum flow. This difference is sharper in the case of the Ganga than the Jhelum. The mean maximum discharge of the Ganga at Farakka is about 45,000 cusecs, while the mean minimum is only 1,300 cusecs. The Jhelum, however, has a less voluminous discharge, the respective mean maximum

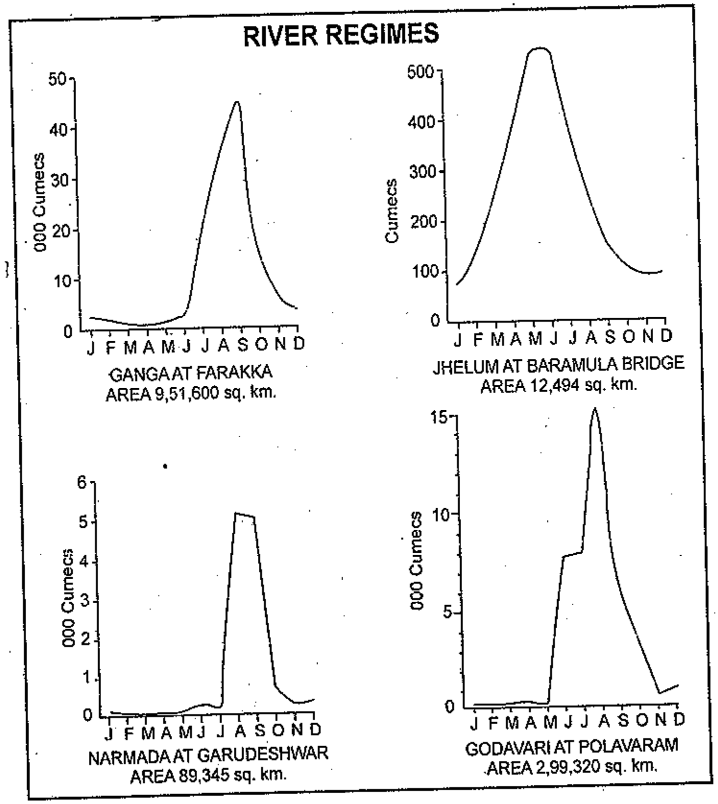

FIG. 4.5. River Regimes

flow being 600 cusecs and the mean minimum 50 cusecs.

The two Peninsular rivers display interesting differences from the Himalayan rivers in their regimes. The Narmada has a very low volume of discharge from January to July which suddenly rises in August when the maximum is attained. The river, however, maintains its fall as spectacular as the rise in August. The Godavari flows at a low level until May. It has a double maxima—one in May-June and other in July-August. After August, there is a sharp fall in discharge, although the volume of flow in October and November is higher than in any of the months from January to May. The mean maximum discharge of the Godavari at *Polauaram* is 3,200 cusecs, while the mean minimum flow is only 50 cusecs. The respective values for the Narmada, as recorded at Garudeshwar, are 2,300 cusecs and 15 cusecs.

Usability of Rivers

Rivers are of great use for us because they comprise a great source of fresh water. In fact most of our requirements of fresh water are met by rivers. The volume of annual precipitation in the country is estimated at about 37,00,400 million cubic metres. A large part of it seeps into the ground and some part is lost by evaporation and transpiration. We use river waters for a variety of purposes such as irrigation, hydro-electric production navigation etc. Large quantity of water is supplied to cities and villages for domestic consumption. A large number of industries also depend upon water.

1. Irrigation. The largest amount of river water is used for irrigation. Indian rivers carry about 18,58,100 million cubic metres of water per year. Due to uneven topography and seasonal flow of the rivers, all this amount is not usable. About 5,55,166 million cubic metres river waters are actually used for irrigation through canals. This amounts to about 30 per cent of the annual flow of the Indian rivers.

2. Hydro-electric Production, Large rivers have great water power potential. The Himalayas in the north, the Vindhyas, the Satpura and the Aravalli in the west, the Maikala and Chhotanagpur in the east, the Meghalaya plateau and Purvachal in the northeast, and Western and the Eastern Ghats of the Deccan plateau offer possibilities of large scale water power development. Sixty per cent of the total river flow is concentrated in the Himalayan rivers, 16 per cent in the Central Indian rivers (the Narmada, the Tapi, the Mahanadi, etc.), and the rest in the rivers of the Deccan plateau. Dependable power generation from the peninsular rivers requires impounding of water during the monsoon months. The Himalayan rivers do not have such problem as their flow is appreciable even during the critical winter months. They, however, have other kind of problems, namely, difficulty in construction of large storage on account of narrow valleys, high seismicity of the region and vast alluvial plain with no variation of relief. The country has an exploitable power potential of about 41 million KW at 60 per cent load factor from these rivers.

3. Navigation. The Ganga and the Brahmaputra in the north and northeastern part of the country, the Mahanadi in Odisha, the Godavari and the Krishna in Andhra and Telangana the Narmada and the Tapi in Gujarat, and the lakes and tidal creeks in coastal states possess some of the important and useful waterways of the country. In the past they were of great importance, which suffered a great deal with the advent of rail and roads. Withdrawal of large quantities of water for irrigation resulted in dwindling flow of many rivers. The most important navigable risers are the Ganga, the Brahmaputra and the Mahanadi. The Godavari, the Krishna, the Narmada and the Tapi are navigable near their mouths only.

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Climate

INTRODUCTION

Climate of a country includes the study of temperature, rainfall, atmospheric pressure, as well as the direction and velocity of winds over a long period of time. These elements of climate are largely influenced by latitudinal extent, relief, and a real distribution of land and water. The *Tropic of Cancer* passes through the middle of the country. In the north, the Indian subcontinent is separated from the rest of Asia by the Himalayan ranges as a result of which the cold air masses from Central Asia cannot enter India. During winter, the northern half of India is warmer by 3°C to 8°C than other areas located on these latitudes. Thus the whole of India, south of the Himalayas is climatically treated as a tropical country. According to **L.D. Stamp,** "India is basically a tropical country although its northern part is situated in the temperate belt." In the south, the Indian coasts are washed by the Arabian Sea and the Bay of Bengal branches of the Indian Ocean which give it a typical tropical monsoon climate. *India is par excellence, a tropical monsoon country.*

DIVERSITY IN THE UNITY OF INDIAN MONSOON CLIMATE

Notwithstanding its broad climatic unity, the climate of India has many regional variations, expressed in the pattern of winds, temperature and rainfall, rhythm of seasons and the degree of wetness or dryness. These climatic differences are due to location, altitude, distance from sea and relief. The vast size of the country, coupled with its topographical variations is responsible for a great variety of climatic conditions in India. **Blanford** was highly impressed by climatic diversities of India and stated "We may speak of climates but not the climate of India, for the world itself affords, no greater contrast than is to be met with at one and the same time within its limits." ***Marsden*** too believed that India possesses all types of climate found in the world. The main examples of diversities in the monsoonal unity of Indian climate are briefed as under :

1. The day temperature in the month of June may soar to 48°-50°C at Barmer in Rajasthan while it may hardly reach 22°C at

Gulmarg or Pahalgam in Kashmir at the same time.

2. On a December night, the temperature may dip to –40°C at Dras or Kargil in J&K while it may be as high as 20°C-22°C at Thiruvananthapuram or Chennai at the same time.
3. Mawsynram in Meghalaya receives as high as 1,221 cm of annual rainfall while at Jaisalmer (Rajasthan) the annual rainfall rarely exceeds 12 cm. Tura, in the Garo Hills, may sometimes receive as much rainfall in a single day as is received by Jaisalmer in 10 years.
4. The Ganga delta and the coastal plains of Odisha are hit by strong rain storms almost every third or fifth day in July and August, while the Coromandel Coast, a thousand kilometres to the south, goes dry during these months.
5. The people of Mumbai and the Konkan Coast do not have to suffer the extremes of climate but these extremes affect the life of people of interior parts of the country such as Delhi and Agra.
6. Places like Goa, Hyderabad, Bhubaneshwar and Patna get rains by the first quarter of June while the rains are awaited till the end of June or early July at places like Agra, Delhi and Chandigarh.

FACTORS INFLUENCING THE CLIMATE OF INDIA

The climate of India is a complex phenomenon and is influenced by a large number of geographical factors. Some of the important factors are briefly discussed as under :

1. Location and Latitudinal Extent. The mainland of India extends roughly from 8°N to 37°N and the Tropic of Cancer passes through the middle of the country. Areas south of the Tropic of Cancer are closer to the equator and experience high temperature throughout the year. The northern parts on the other hand lie in the warm temperate zone. Hence they experience comparatively lower temperatures. Some places record considerably low temperatures particularly in winter. Water bodies comprising the Arabian sea and the Bay of Bengal surround the peninsular India and make climatic conditions mild along the coastal areas.

2. Distance from the Sea. Areas near the coast have equable or *maritine climate*. On the contrary, interior locations are deprived of the moderating influence of the sea and experience extreme or *continental climate*. For example the annual range of temperature at Kochi does not exceed 3°C whereas it is as high as 20°C at Delhi. Similarly, the amount of annual rainfall at Kolkata is 119 cm which falls to a low of 24 cm at Bikaner.

3. The Northern Mountain Ranges. As mentioned earlier, India is separated from the rest of Asia by the impenetrable wall of the Himalayan mountain ranges. These ranges protect India from the bitterly cold and dry winds of Central Asia during winter. Further, these mountain ranges act as an effective physical barrier for rain bearing south-west monsoon winds to cross the northern frontiers of India. Thus, the Himalayan mountain ranges act as a climatic divide between the Indian Sub-continent and Central Asia.

4. Physiography. Physiography of India has a great bearing on major elements of climate such as temperature, atmospheric pressure, direction of winds and the amount of rainfall. In fact, physical map of India is very closely related to the climatic conditions of the country. Places located at higher altitude have cool climate even though they are located in the peninsular India, *e.g.*, Ooty. Several hill stations and the Himalayan ranges are much cooler than the places located in the Great Plain of North India. The greatest control of physiography in the peninsular India is seen in the distribution of rainfall. The south-west monsoon winds from the Arabian sea strike almost perpendicular at the Western Ghats and cause copious rainfall in the Western Coastal plain and the western slopes of the Western Ghats. On the contrary, vast areas of Maharashtra, Karnataka, Telangana, Andhra Pradesh and Tamil Nadu lie in *rainishadow* or *leewood* side of the Western Ghats and receive scanty rainfall. The physiographic control of the mighty Himalayas over the climate of the country goes without saying. The monsoon winds from the Bay of Bengal are bifurcated into two branches by the physiographic features. One branch goes to the

Brahmaputra valley through the Meghalaya plateau. Here the funnel shaped Cherrapunji valley forces the moisture laden monsoon winds to rise along the steep slope and make this area the wettest place in the world. The other branch of monsoons from the Bay of Bengal enters the Ganga valley. Its northward-movement is obstructed by the Himalayan ranges and it advances westwards up the Ganga plain. Initially this branch causes heavy rainfall but the amount of rainfall decreases as the monsoons loose much of the moisture content while advancing westwards.

5. Monsoon Winds. The most dominating factor of the Indian climate is the 'monsoon winds' as a result of which it is often called the ***monsoon climate***. The complete reversal of the monsoon winds brings about a sudden change in the seasons—the harsh summer season suddenly giving way to eagerly awaited monsoon or rainy season. The south-west summer monsoons from the Arabian sea and the Bay of Bengal bring rainfall to the entire country. The north-eastern winter monsoon travel from land to sea and do not cause much rainfall except along the Caromandel coast after getting moisture from the Bay of Bengal.

6. Upper Air Circulation. The changes in the upper air circulation over Indian landmass influences the climate of India to a great extent. Jet streams in the upper air system influence the Indian climate in the following ways :

(i) Westerly Jet Stream. Westerly jet stream blows at a very high speed during winter over the sub-tropical zone. This jet stream is bifurcated by the Himalayan ranges. The northern branch of this jet stream blows along the northern edge of this barrier. The southern branch blows eastwards south of the Himalayan ranges along 25° north latitude. Meteorologists believe that this branch of jet stream exercises a significant influence on the winter weather conditions in India. This jet stream is responsible for bringing western disturbances from the Mediterranean region in to the Indian sub-continent. Winter rain and heat storms in north-western plains and occasional heavy snowfall in hilly regions are caused by these disturbances. These are generally followed by cold waves in the whole of northern plains.

(ii) Easterly Jet Stream. Reversal in upper air circulation takes place in summer due to the apparent shift of the sun's vertical rays in the northern hemisphere. The westerly jet stream is replaced by the easterly jet stream which owes its origin to the heating of the Tibet plateau. This leads to the development of an easterly cold jet stream centered around 15°N latitude and blowing over peninsular India. This helps in the sudden onset of the south-west monsoons.

7. Tropical Cyclones and Western Disturbances. Tropical cyclones originate in the Bay of Bengal and Arabian Sea and the influence large parts of the peninsular India. Majority of the cyclones originate in the Bay of Bengal and influence the weather conditions during the south-west monsoon season. Some cyclones are born during the retreating monsoon season, *i.e.*, in October and November and influence the weather conditions along the eastern coast of India.

The western disturbances originate over the Mediterranean sea and travel eastward under the influence of westerly jet stream. They influence the winter weather conditions over most of Northern-plains and Western Himalayan region.

8. El-Nino Effect. El-Nino is a narrow warm current which occasionally appears off the coast of Peru in December (See **Fig. 5.9**). It is a temporary replacement of the cold Peru current which normally flows along the coast. This current is responsible for wide spread floods and droughts in the tropical regions of the world. Sometimes it becomes more intense and increases the surface water temperatures of the sea by 10°C. This warming of tropical Pacific waters affects the global pattern of pressure and wind systems including the monsoon winds in the Indian Ocean. Meteorologists believe that the severe droughts of 1987, 2009 and 2014 in India were caused by El-Nino.

9. La Nina. After an El-Nino, weather conditions return to normal. However, some times trade winds become so strong that they cause abnormal accumulation of cold water in the central and eastern Pacific region. This event is called ***La Nina***, which in effect is the complete reversal of El Nino. A La Nina also marks an active hurricane season. But in India, the presence of La Nina portends exceptionally good news. It is the harbinger of heavy monsoon showers in India.

La Nina usually follows a strong El Nino. How the two weather pattern anomalies compare :

El Nino the little boy	La Nino the little girl
• Trade winds weaken, warm waters move east	• Strong Pacific trade winds blow from surface water westward.
• Pacific jet stream is pulled further south than normal; picks up storms the jet stream could normally miss	• Cold water rises to the surface
• Weakens Indian monsoons	• Strengthens Indian monsoons
• El Nino occurs after 3 to 5 years	• La Nino occurs roughly half as often as El Nino; lasts from 1 to 3 years.

10. Southern Oscillation. There is a strange linkage of meteorological changes often observed between the Indian and the Pacific Oceans. It has been noticed that whenever the surface level pressure is high over the Indian Ocean, there is low pressure over the Pacific Ocean and *vice-versa*. This inter-relation of high and low pressure over the Pacific and the Indian Ocean is called ***Southern Oscillation.*** When the winter pressure is high over the Pacific Ocean and low over the Indian ocean, the south-west monsoons in India tend to be stronger. In the reverse case, the monsoons are most likely to be weaker.

THE MONSOON WINDS

The term monsoon has been derived from the Arabic *mausin* or from the Malayan *monsin* meaning '*season*'. Thus the monsoons are seasonal winds which reverse their direction of flow with the change of season. They flow from sea to land during the summer and from land to sea during winter. In other words, the monsoon is a double system of seasonal winds, that is, the sum of summer and winter winds. There seems to be a lack of agreement on a precise definition of the monsoon and different scholars have tried to define the monsoon winds in different ways.

According to **A.A. Rama Sastry**, "*Monsoons are large scale seasonal wind systems flowing over vast areas of the globe, persistently in the same direction, only to be reversed with the change of season.*" H.G. **Dobby** is of the opinion that "*reversal of wind system is the key-note of the monsoonal climate*". The reversal of the monsoon wind system is fully emphasised by **Conrad**. According to him, "*a true thermal monsoon demands a complete reversal of winds, that is an angle of about 180° between the dominant winds at extreme seasons*". This is further elaborated by **P.A. Menon**, when he expressed the opinion that "*the main criterion used in demarcating the monsoon areas is the reversal of wind systems between summer and winter*". Thus between July and January there should be a shift of nearly 180° in the prevailing wind direction with seasonal wind showing high degree of steadiness. The reversal of monsoon winds take place in a definite manner keeping rhythm with change of season. Therefore, it is often said that *rhythm is the key-note of the monsoonal climate.* Some scholars tend to treat the monsoon winds as land and sea breezes on a large scale. **Koppen** (1923), **Hann** (1932) and **Angot** (1943) believe that the "*monsoons represent simply a land and sea breezes on a large scale, and that the annual period of the monsoon corresponds to the diurnal period of the breezes.*"

While discussing the monsoon winds **C.S. Ramage** (1971) suggested the following four features of monsoon winds :

(*i*) The prevailing wind direction should shift by at least 120° between January and July.

(*ii*) The average frequency of prevailing wind directions in January and July should exceed 40 per cent.

(*iii*) The mean resultant wind velocity in at least one of the months should exceed 3 m/s.

(*iv*) There should be fewer than one cyclone-anticyclone alternation every two years, in either month, over a five degree latitude/longitude grid.

On the basis of above criteria he demarcated the area of the monsoon region as a rectangle roughly extending from 35° N to 25° S latitudes and 30° W to 173° E longitudes.

Mechanism of the Monsoons

The origin of monsoons is still shrouded in mystery. Several attempts have been made to explain the mechanism of the monsoons but no satisfactory explanation is available till date. Over the years many mysteries of the monsoons have been unravelled but still much remains to be done. The theories regarding the monsoons are generally divided into following two broad categories :

1. Classical Theory, and
2. Modern Theories.

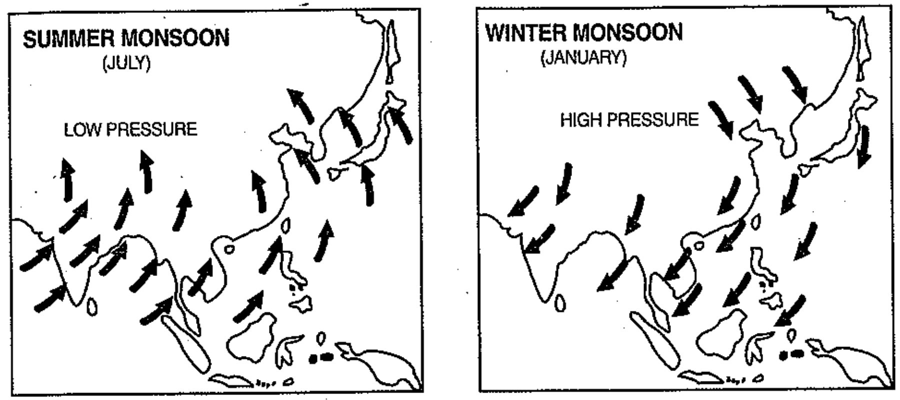

FIG. 5.1. Summer and Winter Monsoon

1. Classical Theory. Although monsoons are mentioned in our old scriptures like the *Rig Veda* and in the writings of several Greek and Buddhist scholars, the credit for first scientific study of the monsoon winds goes to the Arabs. Near about the tenth century, Al Masudi, an Arab explorer from Baghdad, gave an account of the reversal of ocean currents and the monsoon winds over the north Indian Ocean. Date of commencement of monsoons at several places was reported by Sidi Ali in 1554 A.D.

In 1686 the famous Englishman Sir Edmund Halley explained the monsoon as resulting from thermal contrasts between continents and oceans due to their differential heating. Accordingly, Halley conceived summer and winter monsoons depending upon the season.

(*a*) ***Summer Monsoon.*** In summer the sun shines vertically over the *Tropic of Cancer* resulting in high temperature and low pressure in Central Asia while the pressure is still sufficiently high over Arabian Sea and Bay of Bengal. This induces air flow from sea to land and brings heavy rainfall to India and her neighbouring countries.

(*b*) ***Winter Monsoon.*** In winter the sun shines vertically over the Tropic of Capricorn. The north western part of India grows colder than Arabian Sea and Bay of Bengal and the flow of the monsoon is reversed (**Fig. 5.1**).

Halley's ideas are basically the same as those involved in land and sea breeze except that in the case of the monsoon day and night are replaced by summer and winter, and the narrow coastal strip and adjacent sea are replaced by large portions of continents and oceans.

2. Modern Theories. Halley's classical theory based on differential heating of land and water as the main driving force of the monsoon winds dominated the scene for about three centuries. However, the monsoons do not develop equally everywhere and the thermal concept of Halley fails to explain the intricacies of the monsoons. Besides differential heating, the development of monsoon is influenced by the shape of the continents, orography, and the conditions of air circulation in the upper troposphere. Therefore, Halley's theory has lost much of its significance and modern theories based on air masses and jet stream are becoming more relevant. Although Halley's ideas have not yet been outrightly rejected, studies during the last six decades have thrown much light on the genesis of the monsoons. During these years, Flohn, Thompson, Stephenson, Frost, M.T. Yin, Hwang, Takahashi, E. Palmen, C. Newton and Indian meteorologists including P. Koteswaram, Krishnan, Raman, Ramanathan, Krishna Murti, Rama

Rattan, Ramaswami, Anant Krishnan, etc. have contributed a lot to the study of the monsoon winds.

Air Mass Theory. The southeast trade winds in the southern hemisphere and the northeast trade winds in the northern hemisphere meet each other near the equator. The meeting place of these winds is known as the ***Inter-Tropical Convergence Zone (ITCZ)***. Satellite imagery reveals that this is the region of ascending air, maximum clouds and heavy rainfall. The location of ITCZ shifts north and south of equator with the change of season. In the summer season, the sun shines vertically over the *Tropic of Cancer* and the ITCZ shifts northwards. The southeast trade winds of the southern hemisphere cross the equator and start blowing from southwest to northeast direction under the influence of *coriolis force* (**Fig. 5.2**). These displaced trade winds are called ***south-west monsoons*** when they blow over the Indian sub-continent. The front where the south-west monsoons meet the north-east trade winds is known as the ***Monsoon Front***.

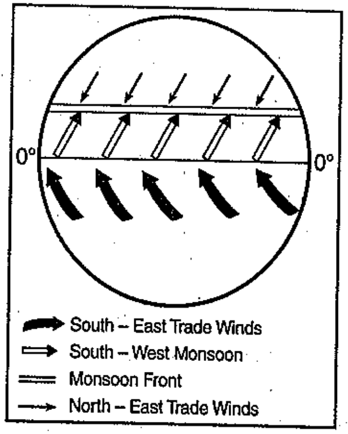

FIG. 5.2. Northward shifting of ITCZ and the wind system in summer season of northern hemisphere.

In the month of July the ITCZ shifts to 20°- 25° N latitude and is located in the Indo-Gangetic Plain and the south-west monsoons blow from the Arabian Sea and the Bay of Bengal (**Fig. 5.3**). The ITCZ in this position is often called the ***Monsoon Trough***.

H. Flohn of the German Weather Bureau, while rejecting the classical theory of origin of monsoons suggested that the tropical monsoon of tropical Asia is simply a modification of the planetary winds of the tropics. He thinks of the thermal low of northern India and the accompanying monsoon as simply an unusually great northward displacement of the Northern Inter-Tropical Convergence Zone (NITCZ). The seasonal shift of the ITCZ has given the concept of Northern Inter-Tropical Convergence Zone (NITCZ) in summer (July) and Southern Inter-Tropical Convergence Zone (SITCZ) in winter (Jan.). The fact that the NITCZ is drawn to about 30° latitude may be associated with the unusually high temperature over north India. According to this interpretation the main westerly current of the monsoon is simply the expanded equatorial westerlies which lie embedded in the great mass of tropical easterties or the trade winds. NITCZ is the zone of clouds and heavy rainfall.

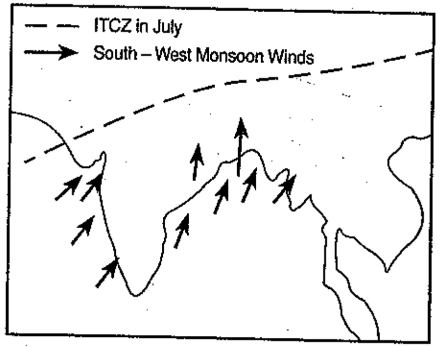

FIG. 5.3. ITCZ and S.W. Monsoon winds

Jet Stream Theory. Jet stream is a band of fast moving air from west to east usually found in the middle latitudes in the upper troposphere at a height of about 12 km. The wind speeds in a westerly jet stream are commonly 150 to 300 km p.h. with extreme values reaching 400 km p.h. Jet stream is the latest theory regarding the origin of the monsoons and has earned world wide acceptance and acclaim from the meteorologists.

M.T. Yin (1949), while discussing the origin of the monsoons expressed the opinion that the burst of monsoon depends upon the upper air circulation. The low latitude upper air trough shifts from 90° E to 80° E longitude in response to the northward shift of the western jet stream in summer. The southern jet becomes active and heavy rainfall is caused by south-west monsoons.

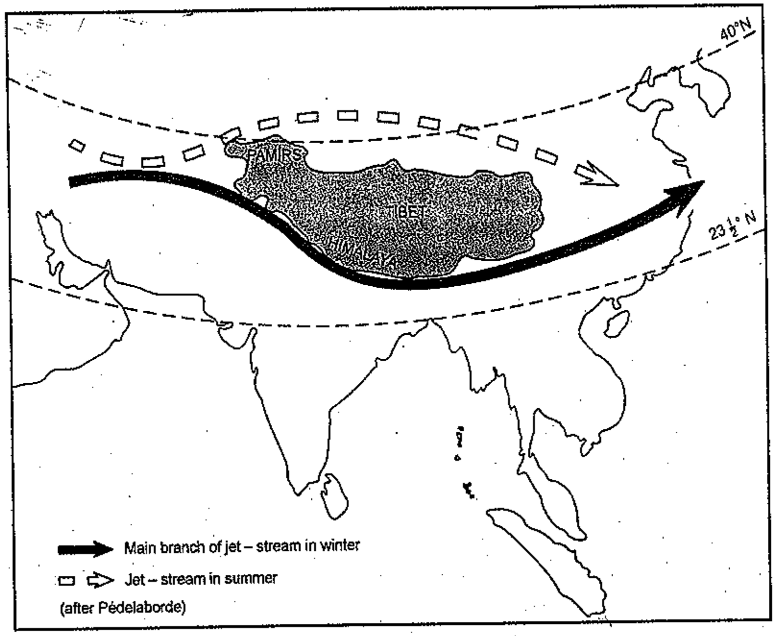

FIG. 5.4. Jet Stream (After Pedelaborde)

Yin's ideas are well recognised by **Pierre Pedelaborde** (1963), in his book entitled ***'The Monsoon'***. The map, showing the seasonal shift of the westerly jet stream, has been reproduced in **figure 5.4**. It shows that in winter the western jet stream flows along the southern slopes of the Himalayas but in summer it shifts northwards, rather dramatically, and flows along the northern edge of the Tibet Plateau. The periodic movements of the Jet stream are often indicators of the onset and subsequent withdrawal of the monsoon.

P. Koteswaram (1952), put forward his ideas about the monsoon winds based on his studies of upper air circulation. He has tried to establish a relationship between the monsoons and the atmospheric conditions prevailing over Tibet Plateau. Tibet is an ellipsoidal plateau at an altitude of about 4,000 m above sea level with an area of about 4.5 million sq km This plateau is surrounded by mountain ranges which rise 6,000-8,000 m above sea level. It gets heated in summer and is 2°C to 3°C warmer than the air over the adjoining regions. Koteswaram, supported by Flohn, feels that because the Tibet Plateau is a source of heat for the atmosphere, it generates an area of rising air. During its ascent the air spreads outwards and gradually sinks over the equatorial part of the Indian Ocean. At this stage, the ascending air is deflected to the right by the earth's rotation and moves in an anti-clockwise direction leading to anticyclonic conditions in the upper troposphere over Tibet around 300-200 mb (9 to 12 km). It finally approaches the west coast of India as a return current from a south-westerly direction and is termed as equatorial westerlies (**Fig. 5.5**). It picks up moisture from the Indian Ocean and causes copious rainfall in India and adjoining countries.

The south-west monsoon in southern Asia is overlain by strong upper easterlies with a pronounced jet at 100 to 200 mb. These easterly winds, which often record speeds exceeding 100 knot are known as the ***Easterly Jet Stream of the tropics***. The Easterly Jet Stream was first inferred by P. Koteswaram and P.R. Krishna in 1952 and aroused considerable interest among tropical meteorologists. A careful study of the jets would suggest that the core of the easterly jet is at 13 km (150 mb) while that of the westerly jet is at 9 km. Over India, the axis of the strongest winds in the easterly jet may extend from

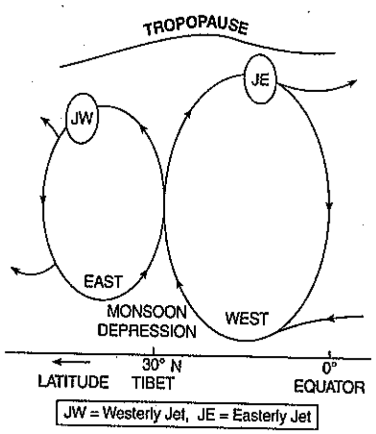

FIG. 5.5. Monsoon as Thermal Engine (After P. Koteswaram)

the southern tip of the peninsula to about 20° N latitude. In this jet stream wind speeds exceeding 100 knot may be recorded. **Figure 5.6** shows the axis of the easterly jet at 12 km (200 mb). The figure shows that there is the subtropical westerly jet to the north of the Himalayas besides the easterly jet over the peninsular India. It has already been made clear in **Fig. 5.4** that the westerly jet stream is located along the southern slopes of the Himalayas in winter but it suddenly shifts to the north with the onset of the monsoon. The periodic movements of the sub-tropical jet stream provide a useful indication of the onset and subsequent withdrawal of the monsoon. In fact, northward movement of the subtropical jet is the first indication of the onset of the monsoon over India.

Recent observations have revealed that the

intensity and duration of heating of Tibet Plateau has a direct bearing on the amount of rainfall in India by the monsoons. When the summer temperature of air over Tibet remains high for a sufficiently long time, it helps in strengthening the easterly jet and results in heavy rainfall in India. The easterly jet does not come into existence if the snow over the Tibet Plateau does not melt. This hampers the occurrence of rainfall in India. Therefore, any year of thick and widespread snow over Tibet will be followed by a year of weak monsoon and less rainfall.

Thomson (1951), Flohn, (1960) and Stephenson (1965) have expressed more or less similar views but Flohn's concept is widely accepted. These ideas can be explained by considering the winter and the summer conditions over large parts of Asia.

Winter. This is the season of outblowing surface winds but aloft the westerly airflow dominates. The upper westerlies are split into two distinct currents by the topographical obstacle of the Tibet Plateau, one flowing to the north and the other to the south of the plateau. The two branches reunite off the east coast of China (**Fig. 5.7**). The southern branch over northern India corresponds with a strong latitudinal thermal gradient which, along with other factors, is responsible for the development of southerly jet. The southern branch is stronger, with an average speed of about 240 km p.h. at 200 mb compared with 70 to 90 km p.h. of the northern branch. Air subsiding beneath this upper westerly current gives dry outblowing northerly winds from the subtropical anticyclone over northwestern India and Pakistan. The surface winds blow from northwest over most parts of northern India.

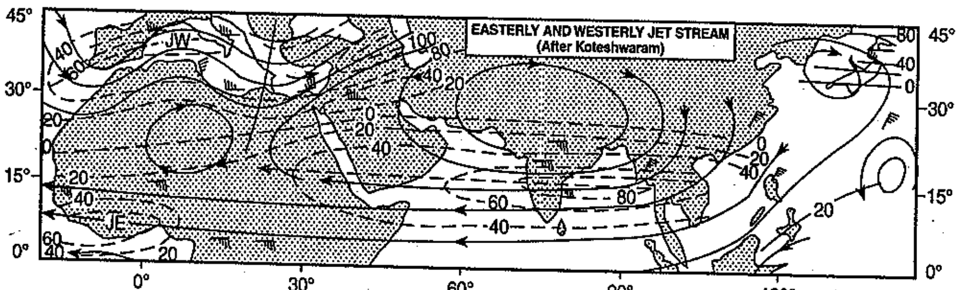

FIG. 5.6. Axis of the Easterly and Westerly Jet stream at 12 km (after Koteswaram) Jet axis are shown by thick broken lines

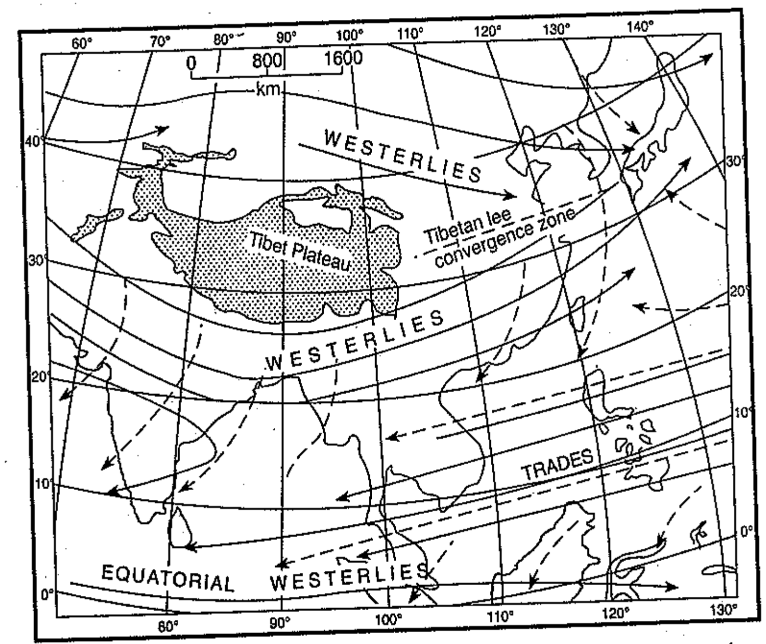

FIG. 5.7. The characteristic air circulation over southern and eastern Asia in winter. Solid lines indicate air flow at about 3000 m and dashed lines that at about 600 m. The names refer to the wind systems aloft.

The upper jet is responsible for steering of the western depressions from the Mediterranean Sea. Some of the depressions continue eastwards, redeveloping in the zone of jet stream confluence about 30° N, 105° E beyond the area of subsidence in the immediate lee of Tibet.

Summer. With the beginning of summer in the month of March, the upper westerlies start their northward march, but whereas the northerly jet strengthens and begins to extend across central China and into Japan, the southerly branch remains positioned south of Tibet, although weakening in intensity. The weather over northern India becomes hot, dry and squally due to larger incoming solar radiation. By the end of May the southern jet begins to break and later it is diverted to the north of Tibet Plateau. Over India, the Equatorial Trough pushes northwards with the weakening of the upper westerlies south of Tibet, but the burst of the monsoon does not take place until the upper-air circulation has switched to its summer pattern (**Fig. 5.8**). The low level changes are related to the high level easterly jet stream over southern Asia about 15° N latitude.

T.N. Krishnamurti used data of the upper atmosphere to calculate the patterns of divergence and convergence at 200 mb for the period of June-August, 1967. He observed an area of strong divergence at 200 mb over northern India and Tibet, which coincides with the upper-level divergence associated with the easterly jet. Similarly he found a northerly component to the flow from this region which represents the upper branch of the *Hadley cell*. These happenings are closely related to the Indian monsoon. **S. Rama Rattan** opined that the development of monsoon winds is deeply connected with the jet stream in addition to the differential heating of land and sea. The upper air circulation in summer has anticyclonic pattern between 40° N and 20° S whereas cyclonic conditions prevail at the surface. Western and eastern jets flow to the north and south of the Himalayas respectively. The eastern jet becomes powerful and is stationed at 15° N latitude. This results in more active south-west monsoon and

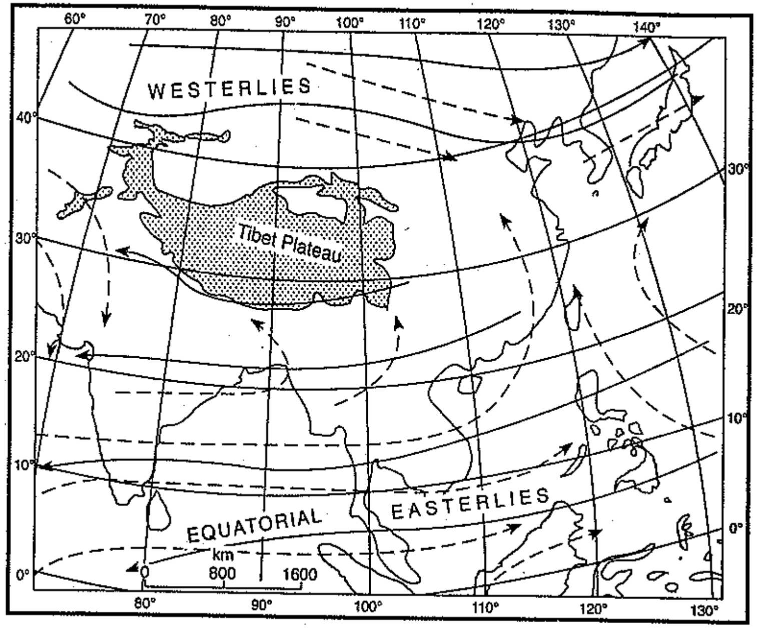

FIG. 5.8. The characteristic air circulation over southern and eastern Asia in summer. Solid lines indicate air flow at about 6,000 m and dashed lines that at about 600 m. Note that the low-level flow is very uniform between about 600 and 3,000 m.

heavy rainfall is caused. **Raman** and **Ramanathan** while discussing the tropical easterly jet stream suggested that the easterly winds become very active in the upper troposphere after the beginning of the rainy season. The latent heat produced due to cloud cover results into *inversion of temperature* and causes rainfall. **Ananth Krishnan** is of the opinion that the south-west monsoons are deeply influenced by the subtropical cyclones in the upper troposphere between 20° and 25° N latitudes. These winds start developing in the beginning of the summer season and shift to 30° N about 5-6 weeks later. Besides intensive heat between 20° and 40° N latitudes gives further strength to the south-west monsoons. **S. Parthasarthy** in his essay on *'Trying to solve the Monsoon Riddle'* expressed the view that the monsoons are influenced by the north-east trade winds. A weak north-east trade wind results in weak monsoon and leads to drought conditions.

The Indian monsoons, particularly the south-west monsoons, have generated a lot of interest among the meteorologists all over the world. Concerted efforts on data collection and of intensive studies of monsoon regimes by various meteorological services and organisations from different nations have been made during the last six decades. Much has been done but much more is yet to be done. The first attempt was made during International India Ocean Expedition (IIOE) from 1962 to 1965. It was organised jointly by the International Council of Scientific Unions. (ICSU), Scientific Committee on Ocean Research (SCOR) and UNESCO with World Meteorological Organisation (WMO) joining the meteorology programme. Special oceonographic and atmospheric studies were carried out with the aid of research vessels, instrumented aircrafts, rockets as well as special upsonde and dropsonde soundings. Two more experiments were conducted, jointly, by India and the former USSR in 1973 and 1977, with limited participation from other countries. These experiments are known as the ***Indo-Soviet Monsoon Experiment (ISMEX)*** and Monsoon-77 respectively. It was observed from these experiments that there is a specific zone off the coast of Kenya where the

monsoons from the southern hemisphere crossed the equator on their way to India. It was also observed that the fluctuations in the intensity of low-level across the equator resulted in the fluctuations of rainfall over Maharashtra. Upper air observations over the Bay of Bengal were also made in 1977.

More intensive data collection effort was made under the aegis of another international experiment—the Monsoon Experiment in 1979. It is popularly known as ***MONEX-1979***. It was organised jointly by Global Atmospheric Research Programme (GARP) of the International Council of Scientific Unions (ICSU) and the World Meteorological Organisation (WMO) under their World Weather Watch (WWW) programme. It is so far the largest scientific effort made to extend the frontiers of our knowledge of the monsoons by the international scientific community. As many as 45 countries pooled their talents and resources under the aegis of the United Nations for this great venture. Some idea of the dimensions of this experiment may be had from the fact that in May 1979 as many as 52 research ships were deployed over the tropical oceans between 10° N and 10° S latitudes. Besides 104 aircraft missions were successfully completed over different parts of the Pacific, the Atlantic and the Indian Ocean.

The great MONEX was designed to have three components considering the seasonal characteristics of the monsoon :

(*i*) Winter Monex from 1 December 1978 to 5 March 1979 to cover the eastern Indian Ocean and the Pacific along with the land areas adjoining Malaysia and Indonesia.

(*ii*) Summer Monex from 1 May to 31 August 1979 covering the eastern coast of Africa, the Arabian Sea and the Bay of Bengal along with adjacent landmasses. It also covered the Indian Ocean between 10° N to 10° S latitudes.

(*iii*) A West African Monsoon Experiment (WAMEX) over western and central parts of Africa from 1 May to 31 August 1979.

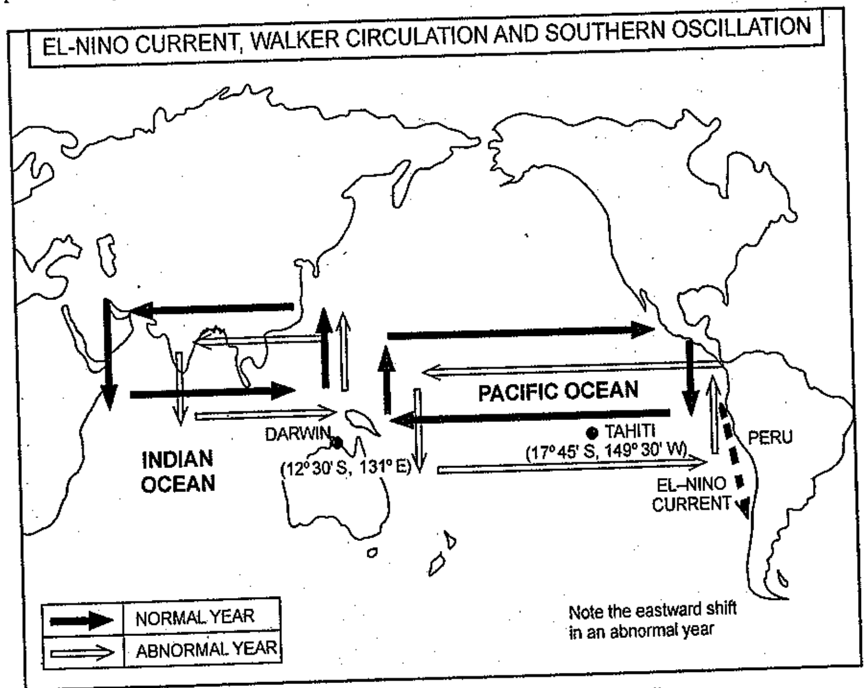

FIG. 5.9. El Nino, Walker Circulation and Southern Oscillation

International MONEX Management Centres (IMMC) were set up in Kuala Lumpur and New Delhi to supervise the winter and summer components of the experiment.

MONEX-1979 suffered some setback due to abnormal behaviour of the monsoons in that year. None of the cold surges was intense in China Sea during the winter MONEX. A strong anticyclone developed in the Arabian Sea in summer of 1979. The southwest monsoon was deflected southwards before touching the Kerala coast under the influence of this anticyclone and started blowing parallel to the coast. Consequently the onset of southwest monsoon over Kerala was delayed by 12 days. Moreover, July was characterised by several weak or break-monsoon occurrences and there was only one monsoon depression. Therefore, 1979 was not a normal monsoon year and MONEX failed to study the normal behaviour of the monsoons. But the vagaries of the monsoon are proverbial and in a scientific and analytical understanding of the monsoons, a study of anomalies is perhaps more important. It is in this context that MONEX-1979 assumes unparalled significance.

Teleconnections, the Southern Oscillation and the El Nino. Recent studies have revealed that there seems to be a link between meteorological events which are separated by long distances and large intervals of time. They are called ***meteorological teleconnections***. The one which has aroused considerable interest among the meteorologists is the difference between an El Nino and the Southern Oscillation. ***El Nino*** (EN) is a narrow warm current which appears off the coast of Peru in December. In Spanish, it means *The Child Christ* because it appears around Christmas. In some years this warm current is more intense than usual.

The El Nino phenomenon, which influences the Indian monsoon, reveals that when the surface temperature goes up in the southern Pacific Ocean, India receives deficient rainfall. However, there had been some years during which the El Nino phenomenon did not occur, but India still got deficient rainfall, and conversely, India received sufficient rainfall during an El Nino year. A study of the one hundred years from 1870 to 1970 of the Indian monsoons shows that out of 43 deficient monsoon years, 19 were associated with an El Nino. On the other hand, there were 6 El Nino years which were also years of good monsoon rain. Analysis of meteorological data for three decades from 1972-73 to 2013-14 shows that out of 14 draught years 9 had been El Nino years and 5 were non El Nino years. Years 1972-73, 1979-80, 1987-88, 2009-10 and 2013-14 were the years of severe drought and witnessed strong El Nino. On the other hand, years 1991-92, 1994-95, 1997-98, 2004-095 and 2006-07 were no El Nino year and India still had to face drought conditions (**Fig. 5.10**). Thus, although there is

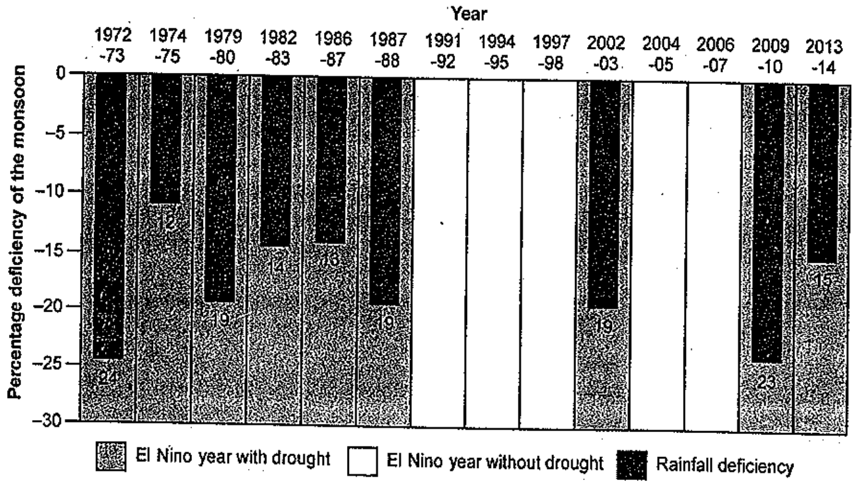

FIG. 5.10. El Nino and monsoon rainfall in India (Based on data from IMD)

a tendency for poor monsoons to be associated with an El Nino, there is no one-to-one correspondence.

Southern Oscillation (S.O.) is the name ascribed to the curious phenomenon of *sea-saw pattern* of meteorological changes observed between the Pacific and Indian oceans. This great discovery was made by Sir Gilbert Walker in 1920. While working as the head of the Indian Meteorological service, he noticed that when the pressure was high over equatorial south Pacific, it was low over the equatorial south Indian Ocean and vice versa. The pattern of low and high pressures over the Indian and Pacific Oceans (S.O.) gives rise to vertical circulation along the equator with its rising limb over low pressure area and descending limb over high pressure area. This is known as ***Walker Circulation***. The location of low pressure and hence the rising limb over Indian Ocean is considered to be conductive to good monsoon rainfall in India. In other words when there is low pressure over the Indian Ocean in winter months, the chances are that the coming monsoon will be good and will bring sufficient rainfall. Its shifting eastward from its normal position, such as in El Nino years, reduces monsoon rainfall in India. Due to the close association between an El Nino (E.N.) and the Southern Oscillation (S.O.), the two are jointly referred to as an ENSO event. Some of the predictors used by Sir Gilbert Walker are still used in long-range forecasting of the monsoon rainfall.

The main difficulty with the Southern Oscillation is that its priodicity is not fixed and its period varies from two to five years. Different indices have been used to measure the intensity of the Southern

TABLE 5.1. Southern Oscillation Index (SOI) and associated weather phenomena

Positive SOI :	Negative SOI :
(*i*) Tahiti pressure greater than that of Port Darwin.	(*i*) Port Darwin pressure exceeds that of Tahiti.
(*ii*) Pressure high over east Pacific and low over Indian Ocean.	(*ii*) Pressure high over Indian Ocean and low over east Pacific.
(*iii*) Low rainfall over eastern Pacific and prospects of good monsoon rain over India and Indian Ocean.	(*iii*) Low rainfall or poor monsoon over Indian Ocean and higher than usual rain over east Pacific.

Oscillation, but the most frequently used is the Southern Oscillation Index (SOI). This is the difference in pressure between Tahiti (17°45'S, 149°30'W) in French Polynesia, representing the Pacific Ocean and Port Darwin (12°30'S, 131°E), in northern Australia representing the Indian Ocean. The positive and negative values of the SOI *i.e.* Tahiti minus the Port Darwin pressure are pointers towards good or bad rainfall in India (see the following table)

Scientists of India Meteorological Department (IMD) joined an international study programme called the Tropical Oceans and Global Atmosphere (TOGA) in 1985. This is an interesting and ambitious programme which investigates both teleconnections effects and the internal variability. As a follow up to TOGA, the climate variability (CLIVAR) was set up in January 1995, to develop an internationally operational climate forecasting system.

Another major programme is the Indian Middle Atmospheric Programme (IMAP) initiated by the Department of Space. This programme has been launched to augment the existing weather prediction scheme.

After the severe drought of 1987, parametric and power regression models have been developed to forecast monsoon rainfall by utilising signals from 15 parameters. Some of the parameters are global while others are regional. These parameters are divided into four broad categories, *viz:* (*a*) temperature, (*b*) pressure (*c*) wind pattern and (*d*) snow cover and are listed below :

(*a*) Temperature related parameters

1. El Nino in current year
2. El Nino in previous year
3. Northern India (March)
4. East coast of India (March)
5. Central India (May)
6. Northern hemisphere (Jan. and Feb.)

(*b*) Wind related parameters

7. 500 hPa (1 hecta pascal, equals 1 mb) ridge (April)
8. 50 hPa ridge-trough extent (Jan. and Feb.)
9. 10 hPa (30 km) westerly wind (Jan.)

(c) Pressure anomaly (SOI)

10. Tahiti-Darwin (Spring)
11. Darwin (Spring)
12. South America, Argentina (April)
13. Indian Ocean Equatorial (Jan.-May)

(d) Snow cover related parameters

14. Himalayan (Jan.-March)
15. Eurasian (Previous December)

It was observed in late eighties that whenever more than 50% parameters showed favourable signals, the monsoon rainfall in India was normal and when 70% or more parameters were favourable, the monsoon rainfall was above normal.

Somewhat similar set of predictors for monsoon was suggested by H.N. Srivastava and S.S. Singh in 1994 while discussing long range weather forecasting techniques.

One more parameter, *viz.*, surface pressure anomaly of north-eastern hemisphere was also added later on, thus making a total of 16 parameters. These 16 parameters have been used by the IMD to develop the power regression model. Although this model has been forecasting rainfall in India with greater accuracy since 1989, it is far from being an elaborate and foolproof model. A model capable of forecasting area specific rainfall is yet to be built. The study of data flowing from MONEX, TOGA and other experiments is continuing and our meteorologists are hopeful of discovering more parameters which may help in developing better models capable of predicting rainfall more accurately.

SEASONAL RHYTHM

Indian climate is characterised by distinct seasonality. Seasons come and go one after the other with surprising precision. They depict the annual cycle of weather and reflect the changing moods of nature. Each season has its distinct features. India Meteorological Department (IMD) has recognised the following four distinct seasons:

1. The cold weather season or winter season,
2. The hot weather season or summer season,
3. The south-west monsoon season or Rainy season, and
4. The season of the retreating monsoon or cool season.

1. The Cold Weather Season or Winter Season

The cold weather season commences in November and continues till March. Clear sky, pleasant weather, low temperature and humidity, high range of temperature, cool and slow northern winds are the chief characteristics of this season.

(*a*) **Temperature.** The northern two thirds of the country have mean temperatures below 21°C, with afternoon temperatures of 27°C. January is the coldest month when the temperature in the Ganga plain varies from 12.5° to 17.5°C. The mean minimum temperatures are about 5°C over northwest India and 10°C over the Gangetic plains. However, on individual days the temperatures may fall much below the mean values. The night temperature often falls below freezing point in many hilly areas. Dras Valley in Kashmir is the coldest place in India. The minimum temperature recorded at Dras was –45°C on 28th December, 1908.

The southern one-third has rather warm conditions and does not have a distinctly defined winter weather. The isotherm of 20°C runs in east-west direction, roughly parallel to the Tropic of Cancer and divides India climatically in the northern and southern parts. To the south of this isotherm the temperatures are invariably above 20°C. In the extreme south the temperature may be well above 25°C (**Fig. 5.11**). January temperature at Thiruvananthapuram is 31°C. The diurnal range of temperature, especially in interior parts of the country, is very high. It may reach 15°C over western India.

(*b*) **Pressure and Winds.** High air pressure prevails over large parts of north-west India due to low temperature conditions there. Normally the pressure varies from 1015 to 1020 mb. However, pressure is comparatively lower in south India. The isobar of 1019 mb is seen in north-west India while the isobar of 1013 mb touches the southern tip of the country (**Fig. 5.12**). The winds start blowing from high pressure area of north-west to low pressure area of south-east. The wind velocity is low due to low pressure gradient. Depending upon the pressure and

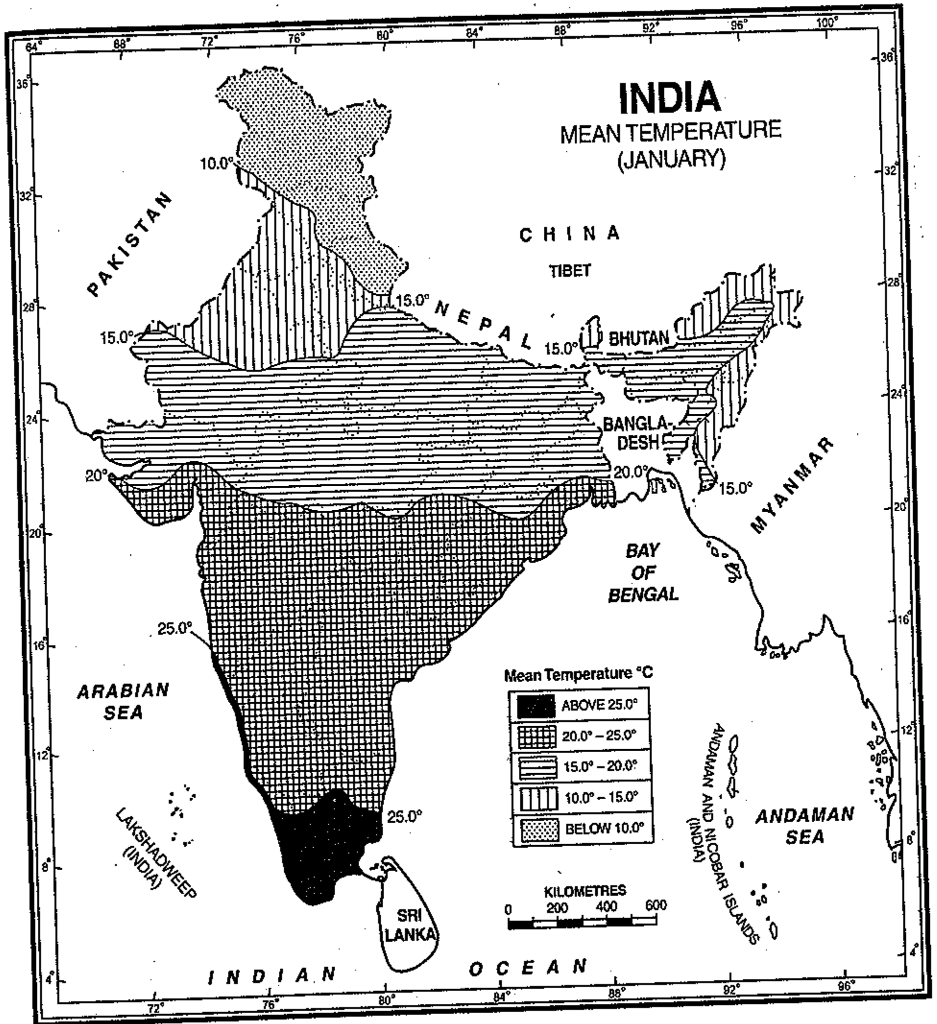

FIG. 5.11. Mean temperature (January)

physiography, the winds blow from west and north-west in Punjab, Haryana, Uttar Pradesh and Bihar, from north-west in Bengal and from north-east in the Bay of Bengal.

Western Disturbances and Tropical Cyclones. Although sky is generally clear, the spell of fine weather is often broken due to inflow of depressions from the west. These low pressure depressions are called ***western disturbances***. They originate in the Mediterranean Sea and enter India after crossing over Iraq, Iran, Afghanistan and Pakistan. On their way, their moisture content is augmented from the Caspian sea and the Persian Gulf. They are often in an occluded form when they reach India. They intensify over Rajasthan, Panjab, and Haryana. They move eastwards across the sub-Himalayan belt and reach right upto Arunachal Pradesh (**Fig. 5.12**), causing light rain in the Indus-Ganga plains and snowfall in the Himalayan belt. After the passage of the disturbance, widespread fog and cold waves lowering

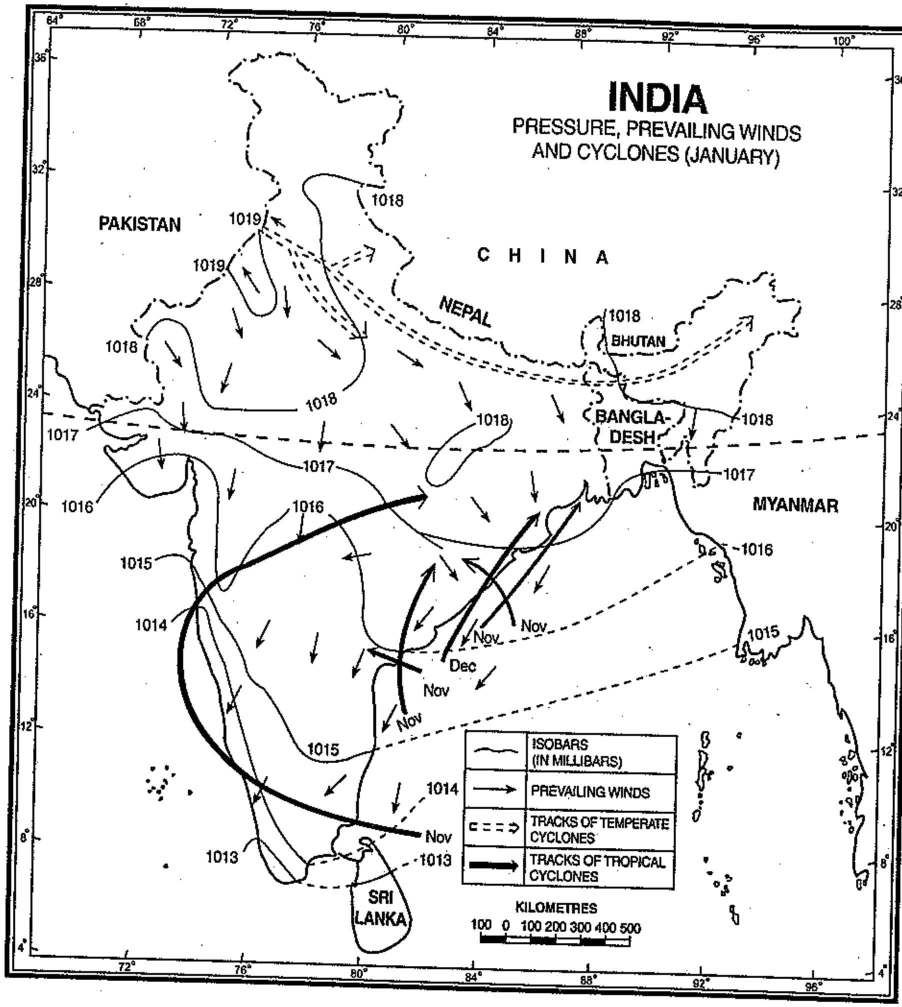

FIG. 5.12. India : Pressure, Prevailing Winds and Cyclones in January

the minimum temperature by 5° to 10°C below normal are experienced. Haze is common in morning and evening.

Fog occurring in this season causes great inconvenience for transport in general and air transport and particular in the northern part of India. According to Met unit at Indira Gandhi International Airport, New Delhi the average duration of occurrence of fog at the airport is 85 hours. However, there are great variations in the foggy hours from year to year as is clear from **table 5.2.** Larger the duration of fog hour, greater the inconvenience for transport.

The frequency of the western disturbances varies from year to year but on an average 3 to 5 disturbances per month are experienced. According to **W.G. Kendrew**, the number of disturbances reaching India are 2 in November, 4 in December, 5 each in January and February and 4 in March. The *jet stream* plays an important role in bringing these disturbances to India.

TABLE 5.2. Hours of dense fog (Visibility below 200 metres)

Season (Year)	Hours of dense fog
2000-01	112
2001-02	78
2002-03	190
2003-04	169
2004-05	100
2005-06	52
2006-07	66
2007-08	16
2008-09	167
2009-10	174
2010-11	50
2011-12	55
2012-13	60

Source : Met. unit at Indira Gandhi International Airport, New Delhi.

This is the season of least tropical cyclone activity and the frequency decreases with the advancement of season. This is due to low sea surface temperature and the location of ITCZ farthest south in this season. The storms which are born in the Bay of Bengal strike Tamil Nadu and some of them cross the southern peninsula over to the Arabian Sea. Some storms originate in the Arabian Sea and move towards either north or west.

(*c*) **Precipitation.** The retreating winter monsoons blow from land to sea and do not cause much rainfall. These winds pick up some moisture while crossing the Bay of Bengal and cause winter rainfall in Tamil Nadu, south Andhra Pradesh, south-east Karnataka and south-east Kerala. The highest seasonal rainfall of about 75 cm between October and December occurs along the south-eastern coast of Tamil Nadu and adjoining parts of Andhra Pradesh. Thereafter, it gradually decreases except for a small area towards north-east Kerala.

The western disturbances also cause a little rainfall in north-west India. The amount of rainfall gradually decreases from the north and north-west to east. The average rainfall during three months from December to February is about 60 cm in the Himalayan region, 12 cm in Punjab, 5.3 cm at Delhi and 1.8 cm to 2.5 cm in U.P. and Bihar. Although very small in amount, this rainfall is extremely useful for rabi crops, especially the wheat crop. The north-eastern part of India also gets rainfall during the winter months. Arunachal Pradesh and Assam may get as much as 50 cm of rainfall during these months. The distribution of winter rainfall in India is shown in **Fig. 5.13.**

2. The Summer Season

Period from March to June is called the ***summer season***. High temperature and low humidity are the chief characteristics of this season. Hence it is also known as ***hot weather season*** or ***hot dry summer season***. Sometimes, it is referred to as ***pre-monsoon*** period.

(*a*) **Temperature.** As the season advances, sun's vertical rays move northwards and large parts of the country, south of the Satpura range, are heated up. There is a progressive northward march of warmth as the sun proceeds towards the north, the southern parts being distinctly warmer in March and April whereas in June, north India has much higher temperatures. In March, the highest temperatures are nearly 40°C in the southern parts of the Deccan plateau; in April the highest temperature of about 45°C is recorded in the northern parts of Madhya Pradesh; in May the scene of highest temperature shifts to Rajasthan where temperatures as high as 48°C may be recorded and in June the maximum temperature is in Punjab and Haryana. The highest temperatures so far recorded are 50.5°C at Alwar on 10th May, 1956 and 50.6°C at Ganganagar on 14th June, 1935. The highest temperatures are recorded in May but in certain areas June is the month of the highest temperatures. In fact the highest temperatures are recorded just before the onset of the southwest monsoons. Even the minimum temperature at night rarely falls below 20°C mark. It ranges from 20° to 25°C over northern and central India and slightly higher in the south with a pocket of over 27°C over central parts of Deccan. The diurnal range of temperature is also very high. It may be as high as 18°C in Rajasthan and adjoining areas of Madhya Pradesh.

However, the maximum summer temperatures are comparatively lower in the southern parts of the country due to moderating effect of the sea. The mean

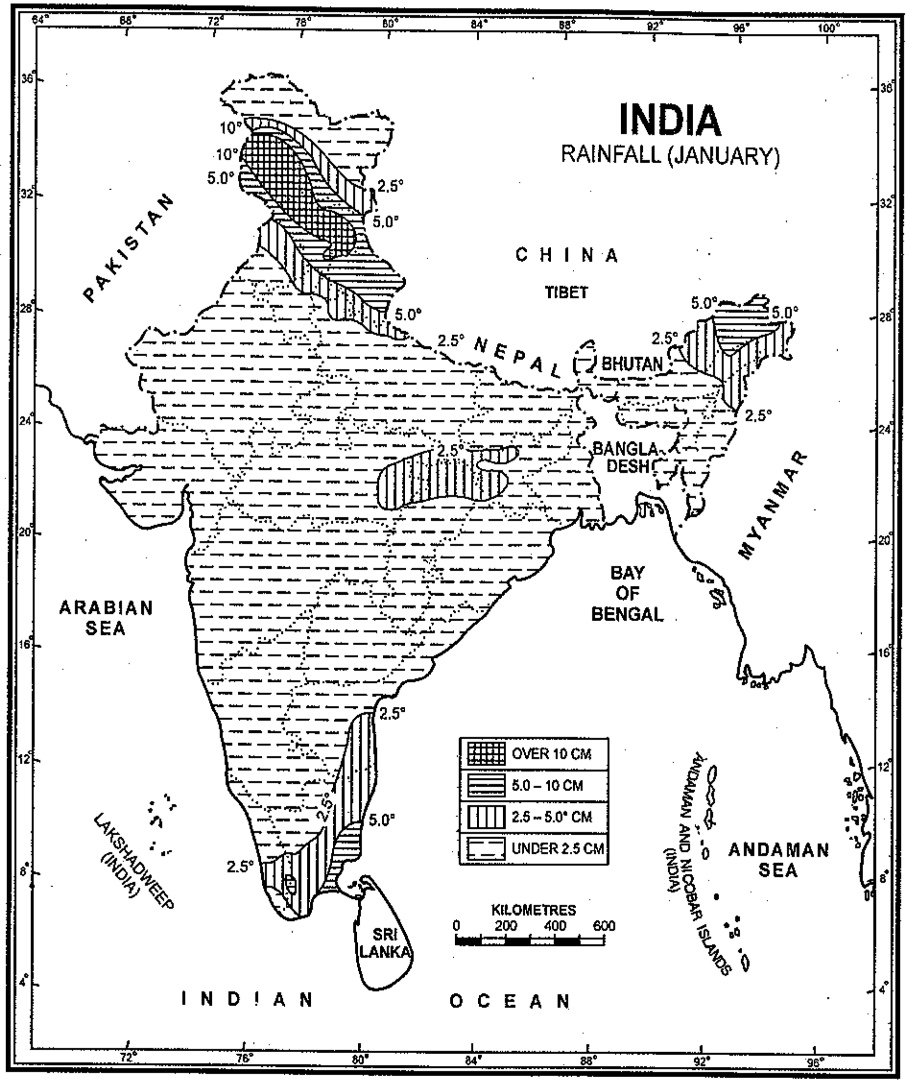

FIG. 5.13. Rainfall (January)

maximum temperature at most places is about 26°–30°C. The temperatures along the west coast are comparatively lower than those prevailing on the east coast due to the prevailing westerly winds. The large contrast between land and sea temperatures is observed from the closely packed isotherms running more or less parallel to the coast (**Fig. 5.14**).

Northern and central parts of India experience *heat waves* in this season. A *heat wave* is generally defined with reference to the normal maximum temperature of a particular region. According to Indian convention, departure of the maximum temperature of the order of 6° to 7°C above normal is termed as ***'moderate'*** and 8°C and more as ***'severe'***

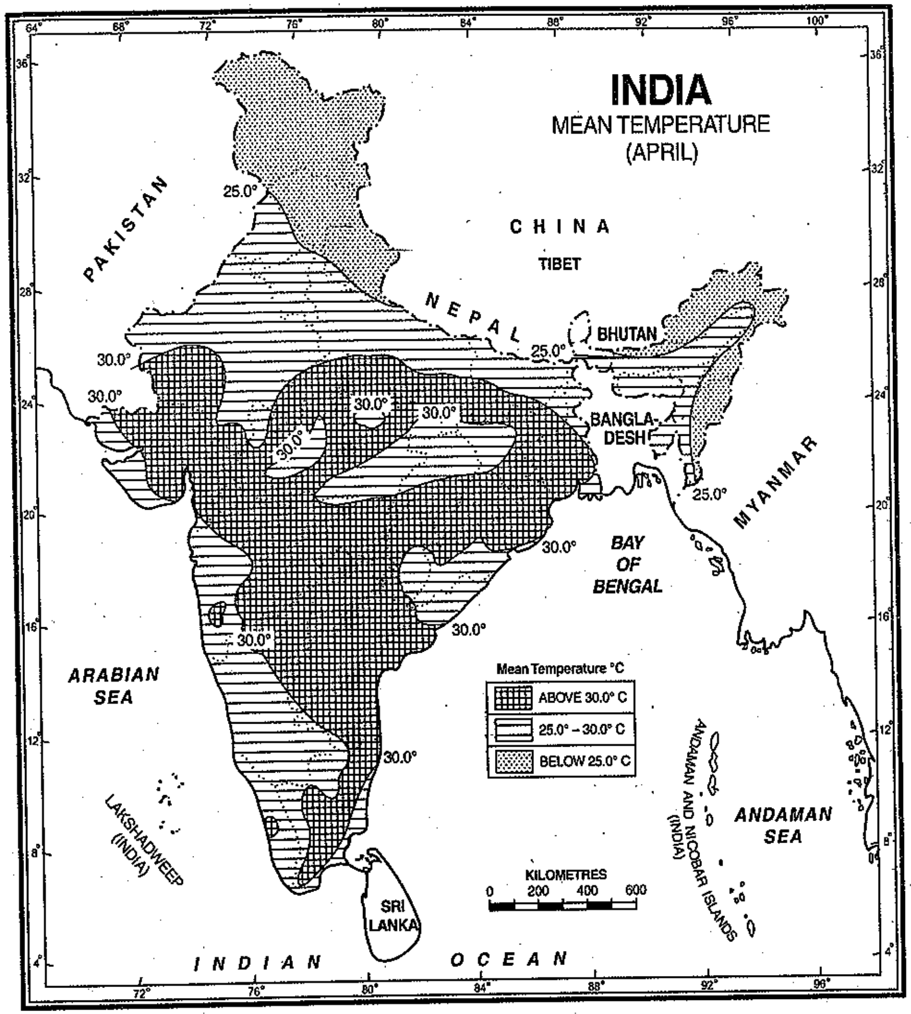

FIG. 5.14. Mean Temperature (April)

heat wave. Most of the heat waves develop over Rajasthan, Punjab and Haryana. This is due to the location of these areas far away from the sea. From here they spread over Uttar Pradesh and Bihar. The strong north westerly winds with a long land trajectory over hot regions check the onward march of the sea breeze over eastern coastal belt and create heat wave conditions over coastal Odisha and Andhra Pradesh. The heat waves start striking by the end of April and their maximum occurrence is in May and June till the onset of southwest monsoon. The normal duration of heat waves is 4 to 5 days. However, heat waves are rare over the peninsula south of 13°N latitude due to maritime conditions prevailing there.

(b) Pressure and Winds. The atmospheric pressure is low all over the country due to high temperature. Unusually low pressure is noticed in north-west India where temperatures are exceptionally high. The overall pressure gradient is low. The difference of pressure between the extreme north and south of the country does not exceed 3-4 mb. The isobars run more or less parallel to the coast indicating differences in pressure conditions over land and sea.

There is a marked change in the direction and speed of the winds from the winter conditions. The winds are by and large light and variable. However, there are some exceptions. In May and June, high temperature in northwest India builds steep pressure gradient which is often of the order of 1.0 to 1.5 mb per degree of latitude. Under such conditions, hot, dust laden and strong wind known as ***loo*** blows. Loo normally starts blowing by 9.00 A.M., increases gradually and reaches maximum intensity in the afternoon when the temperature is maximum. It blows with an average speed of 30-40 km per hour and persists for days together; often 3 to 10 days at a stretch. The strong dust storms resulting from the convective phenomena are locally known as ***andhis*** which literally mean ***blinding storms***. They are essentially duststorms, which move like a solid wall of dust and sand. The wind velocity often reaches 50-60 kms. per hour and the visibility is reduced to a few metres ; sometimes the visibility is nil. Such dust storms are common in Rajasthan, Haryana, Punjab, Jammu region, Delhi, Uttar Pradesh, Bihar and Madhya Pradesh. They are invariably short lived but the squall and showers which follow these storms bring down the temperature sharply and afford much needed relief, although temporary, from the scorching heat.

The strong convectional movements with divergence related to the westerly jet stream or westerly disturbances in the upper troposphere lead to thunderstorms in eastern and north-eastern part of the country. They normally originate over Chota Nagpur plateau and are carried eastwards by westerly winds. The areas with highest incidence of thunderstorms are Assam, Arunachal Pradesh, Nagaland, Mizoram, Manipur, Tripura, Meghalaya, West Bengal and the adjoining areas of Odisha and Jharkhand. In West Bengal and the adjoining areas of Jharkhand, Odisha and Assam, the direction of squalls is mainly from the northwest, and they are called ***norwesters***. They are often very violent with squall speeds of 60 to 80 km per hour. Hailstones sometimes accompany showers and occasionally attain the size of a golf ball. They cause heavy damage to standing crops, trees, buildings, livestock and even lead to loss of human lives. However, they are, some times, useful for tea, jute and rice cultivation. In Assam, these storms are known as ***'Barodoli Chheerha***. The period of maximum occurrence of these storms is the month of *Vaisakh* (mid-March to mid-April) and hence, they are locally known as ***Kalabaisakhis***, the *black storms* or a *mass of dark clouds of Vaiasakha*. In the south the thunderstorms occur in Kerala and adjoining parts of Karnataka and Tamil Nadu, particularly during evenings and nights. The highest occurrences are in the extreme south-western tip with seasonal incidence of 38 days over Thiruvananthapuram. This frequency gradually decreases northwards and is only 14 days at Mangalore.

Western Disturbances and Tropical Cyclones. The western disturbances which influence large parts of north-west and north India during the winter season still persist with their frequency and intensity gradually decreasing with advancement of this season. Approximately 4, 3 and 2 western disturbances visit north-west India in March, April and May respectively. These disturbances cause changes in weather conditions by bringing cloudiness and convective activity in this part of the country. They also cause snowfall in higher reaches of the Himalayas.

This is also the season of tropical cyclones originating in the Bay of Bengal and Arabian Sea. A few cyclones are formed in the Bay of Bengal in the month of March but they do not affect the mainland of India. Their frequency rises steeply in April and the number of cyclones originating in May is more than double than those originating in April. About three-fourths of the tropical cyclones are born in the Bay of Bengal and the rest originate in the Arabian Sea. Most of the depressions in April originate to the south of 10°N while those originating in May are born to the north of this latitude. About 60 per cent of the storms of this season initially move west or north-west but later they recurve northeast and strike Bangladesh and the Arakan Coast of Myanmar. About 30 per cent of the storms cross the Indian coast and a few dissipate over the sea itself. The whole of the east coast of India, the coastal areas of Bangladesh and Arakan Coast of Myanmar are liable to be hit by tropical storms in May. Many of them are quite severe and cause heavy damage to life and

property. In the Arabian Sea, major storms are formed in May between 7° and 12° N latitudes. About 75 per cent originate to the west of 70° E longitude and move away from the Indian coast in a north-westerly direction and dissipate in the sea. About 25 per cent originate close to the Indian coast. They move towards the north-east and hit somewhere along the west coast of India.

(c) Precipitation. As mentioned earlier, this is a dry season. But this is not a totally rainless season although only one per cent of the annual rainfall of India is received during this season. In the northeastern parts of the country, dust storms bring little rainfall. Rajasthan, Gujarat and Madhya Pradesh receive less than 2.5 cm rainfall during this season. The precipitation in Kashmir is mainly in the form of snow or sleet in March and early April and is caused by western disturbances. Higher reaches more than 5,000 metre above sea level experience snowfall even in May. These disturbances move eastwards and cause snowfall or thunderstorms in central and eastern Himalayas till the end of April. The *norwesters* bring about 50 cm of rainfall in Assam and about 10 cm in West Bengal and Odisha. The intensity of rainfall is

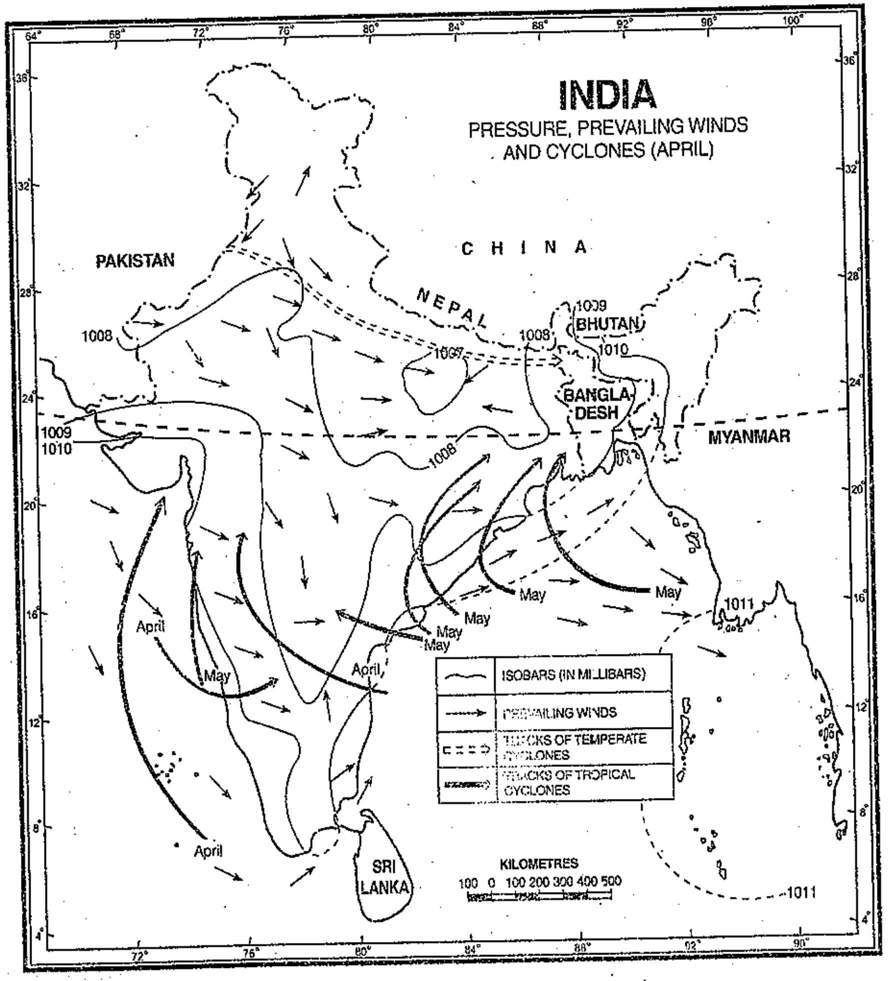

FIG. 5.15. Pressure, Winds and Cyclones (April)

high. Often as much as 5 cm of rain is recorded in one hour but the rainfall is short lived. The rainfall brought by the norwesters is known as the ***spring storm showers***. In Assam the rainfall received in May is about two-thirds of the rainfall received in June. This small amount of rainfall is very useful for the cultivation of tea, jute and rice and is known as ***tea showers*** in Assam. Coastal areas of Kerala and Karnataka receive about 25 cm of rainfall from thunderstorms. These thunderstorms also cause about 10 cm of rainfall in the interior of south India. Such showers are called ***mango showers*** in Tamil Nadu and Andhra Pradesh because they are very beneficial to mango crop. In Karnataka they are called ***cherry blossoms*** due to their salutary effect on the coffee plantations. The distribution of rainfall in April is shown in **Fig. 5.16.**

3. The Rainy Season

The rainy season in India starts with the onset of the southwest monsoon in June and continues till the middle of September. This is also called the ***monsoon season***, the ***southwest monsoon season***, the ***wet season*** and the ***hot-wet season***. The weather conditions all over the country change with the onset of the monsoon winds. High heat, high humidity, extensive clouding and several spells of moderate to heavy rain with strong surface winds are the chief characteristics of this season.

(*a*) **Temperature.** There is a significant fall in temperature with the beginning of rainy season. The June temperature in south India is 3° to 6°C lower than the May temperature.

Similarly July temperature in northwest India is 2° to 3°C lower than the June temperature. But once the temperature falls from its dry summer level, it remains more or less uniform throughout the rainy season. However, the temperature rises again in September with the cessation of rains and secondary maximum temperature period is experienced all over the country. Also there is rise in temperature whenever there is break in the monsoons and rainfall does not occur for a number of days. Night temperatures are more uniform than the day temperatures. The diurnal range of temperature is small due to clouds and rains. It ranges between 4°C and 8°C when the monsoon is fully established.

The highest temperatures of over 32°C are experienced in the Thar desert of Rajasthan. At places especially west of the Aravali the temperature may be as high as 38° to 40°C. This is due to lack of clouds and the predominance of continental airmass. The remaining parts of northwest India also have temperatures above 30°C. The temperatures are quite low over the Western Ghats due to high elevation and also due to heavy rainfall, but the rainshadow area is comparatively warmer on account of low elevation and scanty rainfall. The coastal areas of Tamil Nadu and adjoining parts of Andhra Pradesh have temperatures above 30°C because they receive little rainfall during this season.

(*b*) **Pressure and Winds.** The temperatures in northwest India are still very high as a result of which low pressure conditions prevail there. The most conspicuous feature of the surface pressure distribution during this season is an elongated trough across the Ganga basin right upto the head of Bay of Bengal. This is called the ***monsoon trough***. There are frequent changes in its location and intensity depending upon the weather conditions. The atmospheric pressure in most parts of north India is less than 1,000 mb. It increases steadily southwards where it ranges between 1,008 mb and 1,010 mb. The isobar of 1,009 mb crosses parts of Kerala and Tamil Nadu besides Arabian Sea and the Bay of Bengal.

Under the influence of the above mentioned pressure distribution, winds blow in a southwest to northeast direction from Arabian sea and Bay of Bengal. They maintain this direction throughout peninsular India. But their direction undergoes a change in Indo-Gangetic plain where they move from east to west.

(*c*) **Rainfall.** India's three fourths of the total annual rainfall is received during this season. In some areas it is much more than this average. For example, the average rainfall over the plains of India in this season is about 92 cm, or about 87 per cent whereas during the remaining part of the year only 14 cm of rainfall occurs. This season has the maximum number of rainy days as a result of which it is called the '***wet season***'.

Rainfall during this season all over the country is caused by southwest monsoons coming from the Indian Ocean. **Figure 5.19** shows *isolines* of normal

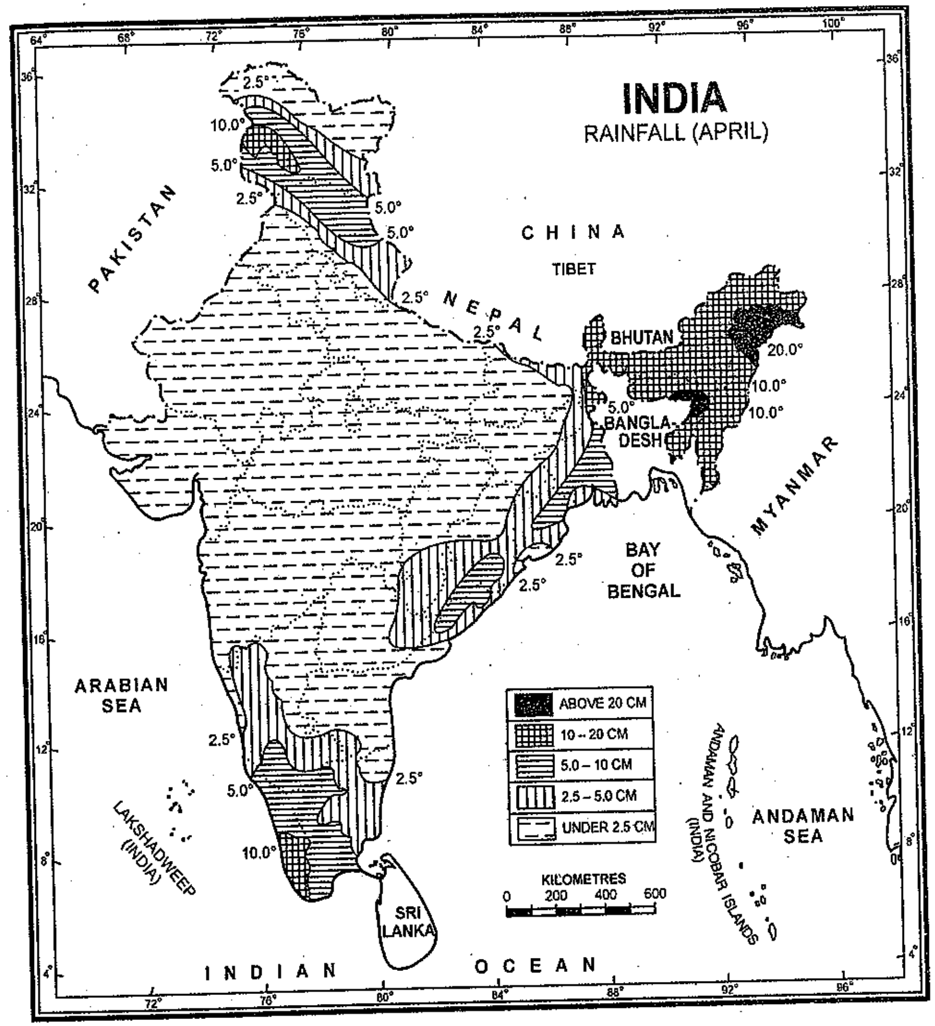

FIG. 5.16. Distribution of rainfall (April)

dates of arrival of the monsoons in different parts of the country. It is clear from this map that the normal date of the arrival of the monsoon is 20th May in Andaman and Nicobar Islands. It is worth mentioning that the advance of the monsoon is much faster in the Bay of Bengal than in the Arabian Sea. This is evident from the pronounced curve shown by isolines of the monsoon onset in **Fig. 5.19**. The monsoon current advances to nearly 20°N latitude in Bay of Bengal by the third week of May, when it is still south of Kerala at about 7°N latitude in the Arabian Sea. The normal date of onset of the southwest monsoon over Kerala *i.e.* the first place of entry in the mainland of India is 1st June. The monsoons advance with startling suddenness accompanied with a lot of thunder, lightning and heavy downpour. This sudden onset of rain is termed as ***monsoon burst***. Although the normal date of onset of the southwest monsoon on the southern tip of the peninsula is 1st June, the actual onset may be earlier or later than this date. On 60%

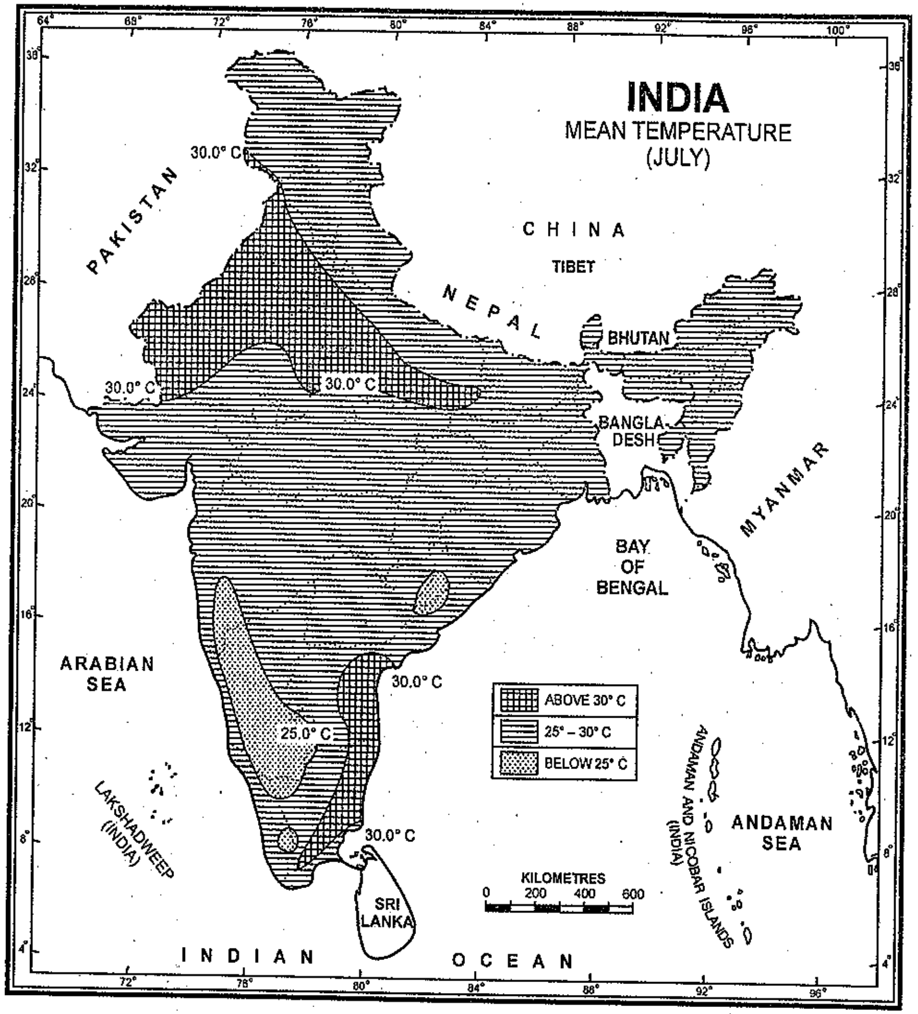

FIG. 5.17. Mean Temperature (July)

occasions, the onset occurs between 29th May and 7th June. The earliest onset was on 11th May in 1918 and 1955, while the most delayed onset was on 18th June in 1972. Satellite imagery is used to identify the advance of the monsoon on a day to day basis.

The progress of the monsoon winds beyond south Kerala is in the form of two branches *viz.* the Arabian Sea branch and the Bay of Bengal branch. The Arabian Sea branch gradually advances northwards. It reaches Mumbai by 10th June and spreads over Saurashtra-Kachchh and central parts of the country by 15th June. The progress of the Bay of Bengal branch is no less spectacular. It spreads rather rapidly over most of Assam. The normal date of its arrival at Kolkata is 7th June. On reaching the foothills of the Himalayas the Bay branch is deflected westward by the Himalayan barrier and it advances up the Gangetic plain. The two branches meet roughly along the line running through Agra and Ferozepur and merge with each other to form a single current. The

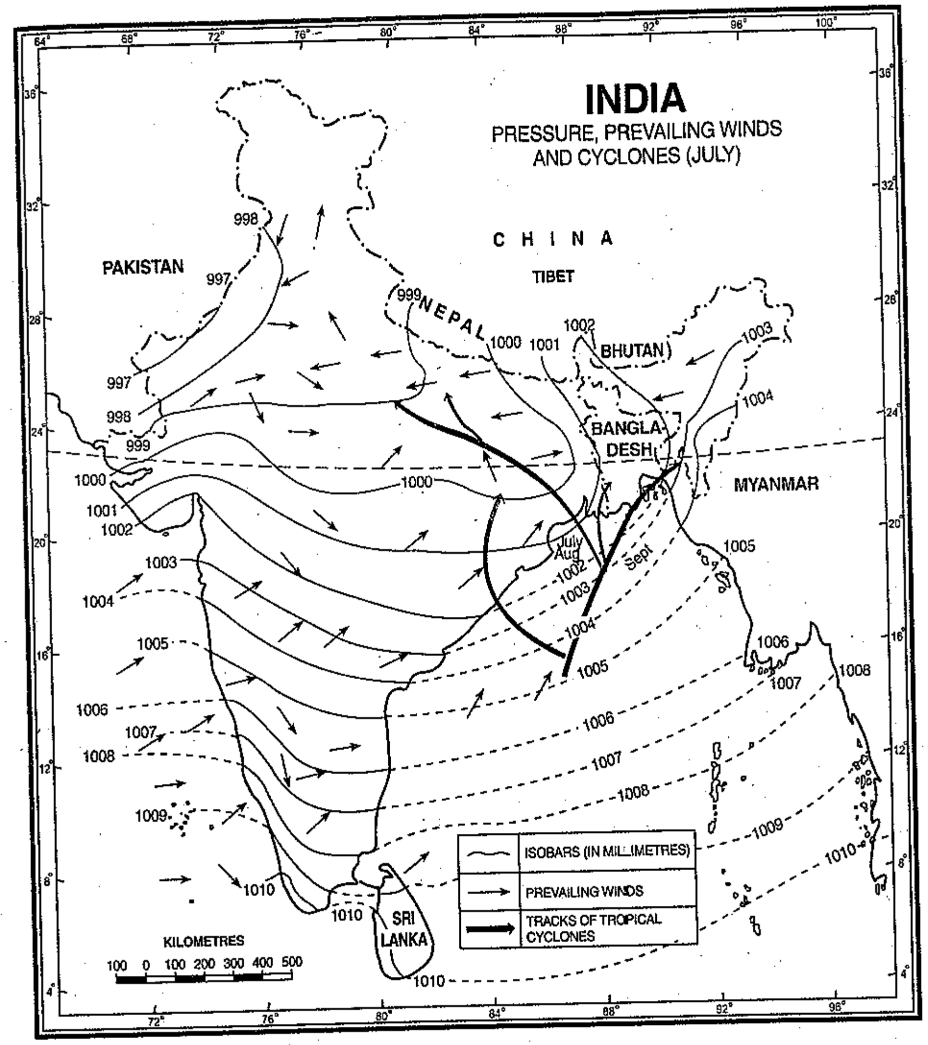

FIG. 5.18. Pressure, Prevailing Winds and Cyclones (July)

combined current gradually extends to west Uttar Pradesh, Haryana, Punjab, Rajasthan and finally to Himachal Pradesh and Kashmir. By the end of June the monsoon is usually established over most parts of the country. By mid-July, the monsoon extends into Kashmir and the remaining parts of the country, but only as a feeble current because, by this time, it has shed most of its moisture. It is often difficult to say whether the Arabian Sea branch or the deflected Bay of Bengal branch will be the first to arrive. For example, at a place like Delhi, the first showers are sometimes brought by the Bay of Bengal branch from the east but on a number of other occasions it is the Arabian Sea branch which brings the first monsoon rain from the south. It is interesting to note that the Arabian Sea branch of the monsoon is much more powerful than the Bay of Bengal branch for two reasons : (*i*) The Arabian Sea is larger than the Bay of

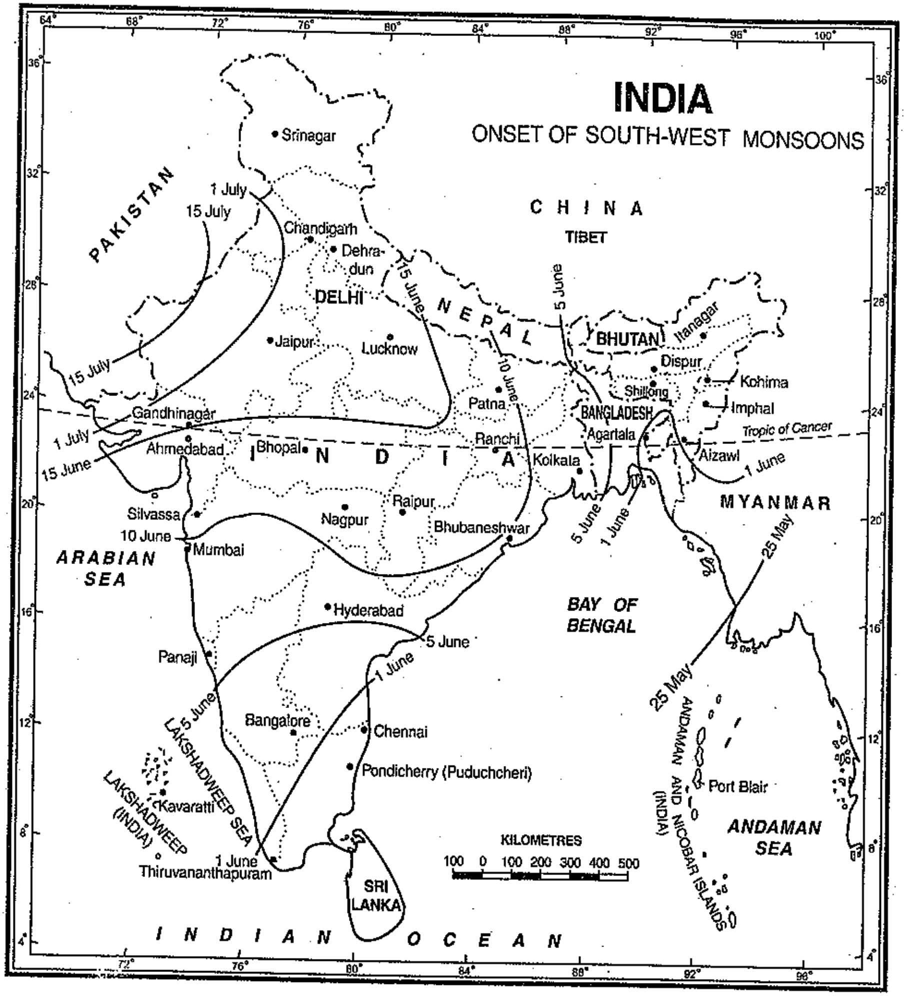

FIG. 5.19. Normal dates of onset of south-west Monsoons

Bengal, and (*ii*) the entire Arabian Sea current advances towards India, whereas only a part of the Bay of Bengal current enters India, the remainder proceeding to Myanmar, Thailand and Malaysia.

The Arabian Sea branch of the southwest monsoons is divided into three distinct streams on arriving in the mainland of India.

The first stream impinges on the west coast of India and gives extremely heavy rainfall of over 250 cm particularly between 10° to 20°N. latitudes where the imppinge is perpendicular to the direction of the Western Ghats. The Western Ghats rise abruptly like a wall from the western coastal plains more or less parallel to the coastline. This wall like mountain range forces the moisture laden southwest monsoons from the Arabian Sea to ascend the slope thereby giving heavy rainfall in the west coastal plain and still heavier rainfall on the western slopes of the Western Ghats, *i.e.*, the windward side of the mountain range. But these winds have to descend the

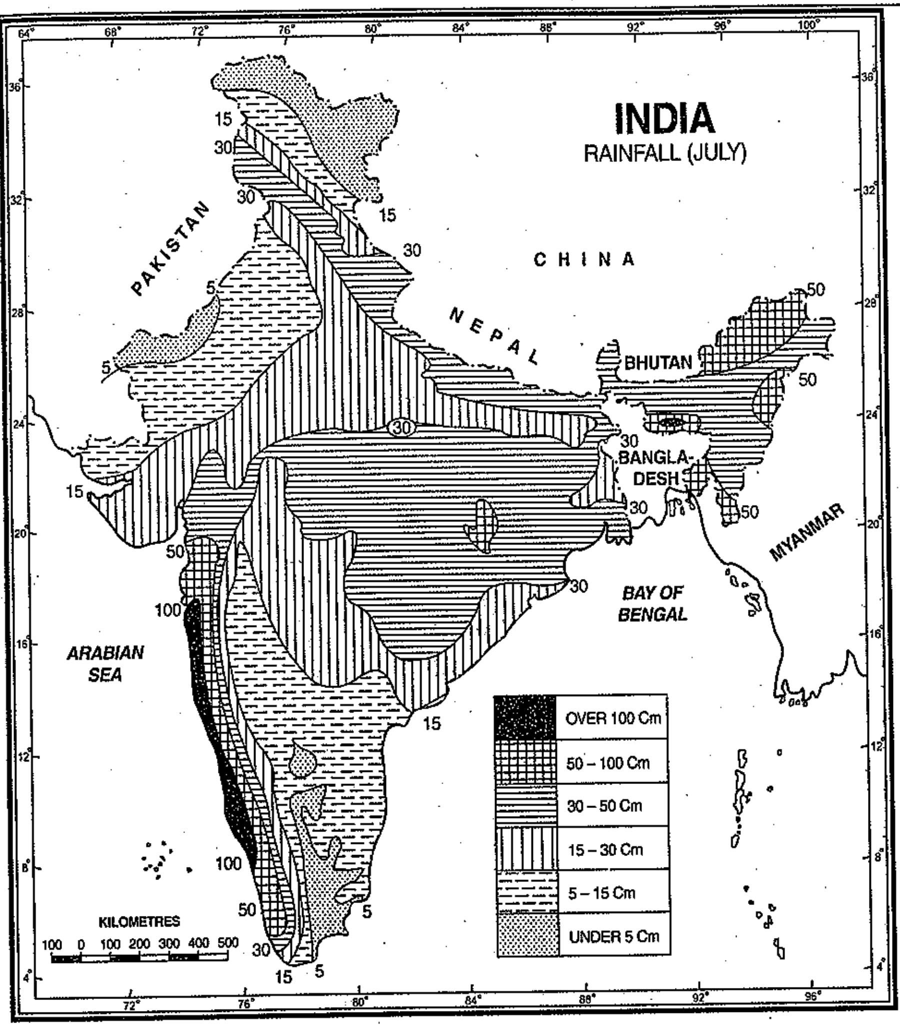

FIG. 5.20. Rainfall (July)

slope after crossing the crest of the ghats. In the process their temperature rises and their humidity decreases. Therefore, they cause little rainfall and the area east of the Ghats is called the ***'leeward side'*** or the ***'rain shadow region'***. Thus while Mumbai on the west coast records about 190 cm, Khandala about 50 km east a bit below the crest gets 60 cm and Pune about 160 km away from Mumbai on the leeward side receives only 50 cm rainfall during the monsoon season. This phenomenon is observed almost all along the Western Ghats. The crest of the Western Ghats receives about 400 to 500 cm annual rainfall which is drastically reduced to about 30-50 cm within a distance of 80-100 km leeward from the crest. This speaks volumes of orographic control of the monsoon rainfall. There is a narrow belt of marked aridity on the immediate leeward side of the Western Ghats. But once it is passed, the air starts rising again and the amount of rainfall increases further east.

The second stream enters Narmada–Tapi troughs and reaches central India. It does not cause much rain near the coast due to the absence of any major orographic obstacle there. Nagpur receives about 60 cm rainfall from this stream.

The third stream moves in a north-easterly direction parallel to the Aravali Range. Since the orientation of the Aravali Range is parallel to the direction of the prevailing monsoon winds, it does not offer major obstacle in the way of the winds and these winds move further without causing much rainfall. Consequently the whole of Rajasthan is a desert area. However, some orographic effect is discernible here as the south-eastern edge of the Aravali Range comes in the way of the monsoon winds and receives reasonably good rainfall. Mt. Abu gets about 170 cm rainfall while the surrounding plains have only 60 to 80 cm rainfall.

The Bay of Bengal Branch of the southwest monsoon is divided into two distinct streams :

The first stream crosses the Ganga-Brahmaputra delta and reaches Meghalaya. It is here that the orographic effect on the monsoon winds and the consequent amount of rainfall is most pronounced. Cherrapunji, a small town (25° 15′ N, 91° 44′ E), located at an elevation of 1,313 m above mean sea level receives an annual rainfall of 1,102 cm, major portion of which occurs from June to August. Till recent times, this has been considered as the highest amount of rainfall for any station in the world. But the recently recorded observations have shown that Mawsynram (25° 18′ N, 91° 35′ E) located at 1,329 m above sea level just 16 km to the west of Cherrapunji records higher annual rainfall of 1,221 cm. Both the stations are located on the southern slopes of the Khasi hills at the northern end of a deep valley running from south to north. When the monsoon winds blow from the south, they are trapped within the funnel shaped valley and strike Cherrapunji and Mawsynram in a perpendicular direction and give copious rains. However, the heaviest rainfall occurs when the winds blow directly on the Khasi hills. Cherrapunji and Mawsynram receive more rainfall in a day than the annual rainfall of many parts of the country. The highest records of rainfall in a day for these two stations are 103.6 cm and 99 cm respectively. The rainfall is well over 200 cm in most parts of the north eastern states. But the amount of rainfall decreases sharply on the leeward side of the Khasis. Guwahati, only 90 km from Cherrapunji gets only 161 cm of rainfall.

The second stream of the Bay of Bengal branch goes to the Himalayan foothills and after reaching there, it is deflected to the west by the size and orientation of the Himalaya and brings widespread rainfall to Ganga plain. The rainfall by this stream is characterised by a steady decline as we move from east to west up the plain. For example, Kolkata gets 119 cm, Patna 105 cm, Allahabad 91 cm, Delhi 51 cm and Bikaner only 24 cm rainfall during the south-west monsoon period.

The eastern coastal belt, particularly in Tamil Nadu, remains relatively dry during the south-west monsoon period. This is because the Tamil Nadu coast lies in the rainshadow area of the Arabian Sea current and is parallel to the Bay of Bengal current.

Break in the Monsoon. During the rainy season, particularly, in July and August, there are certain periods when the monsoons become weak. The cloud formation decreases and rainfall practically ceases over the country outside the Himalayan belt and southeast peninsula. This is known as ***break in the monsoon***. The latest studies have revealed that the breaks are likely to occur more frequently during the second week of August. The normal duration of the break is about a week but on some occasions this could be longer. The longest breaks have been known to persist for two to three weeks, but such occasions are rare. The breaks are believed to be brought about by the collapse of the Tibetan High. This results in the northward shifting of the *monsoon trough*. The axis of the trough lies at the foothills of the Himalayas during the break period. Even when most parts of the country have to content without rainfall during the break period, heavy rainfall occurs over the sub-Himalayan regions and the southern slopes of the Himalayas. This leads to high flooding of the rivers having their catchment areas in the Himalayas. On an average one or two breaks do occur during the rainy season. Statistical studies of the monsoon show that in 85 out of 100 years there is a break in the monsoons.

Monsoon Depressions. A major part of the monsoon rainfall is generated by depressions originating in the Arabian Sea but more so in the Bay of Bengal. Some depressions develop over land also.

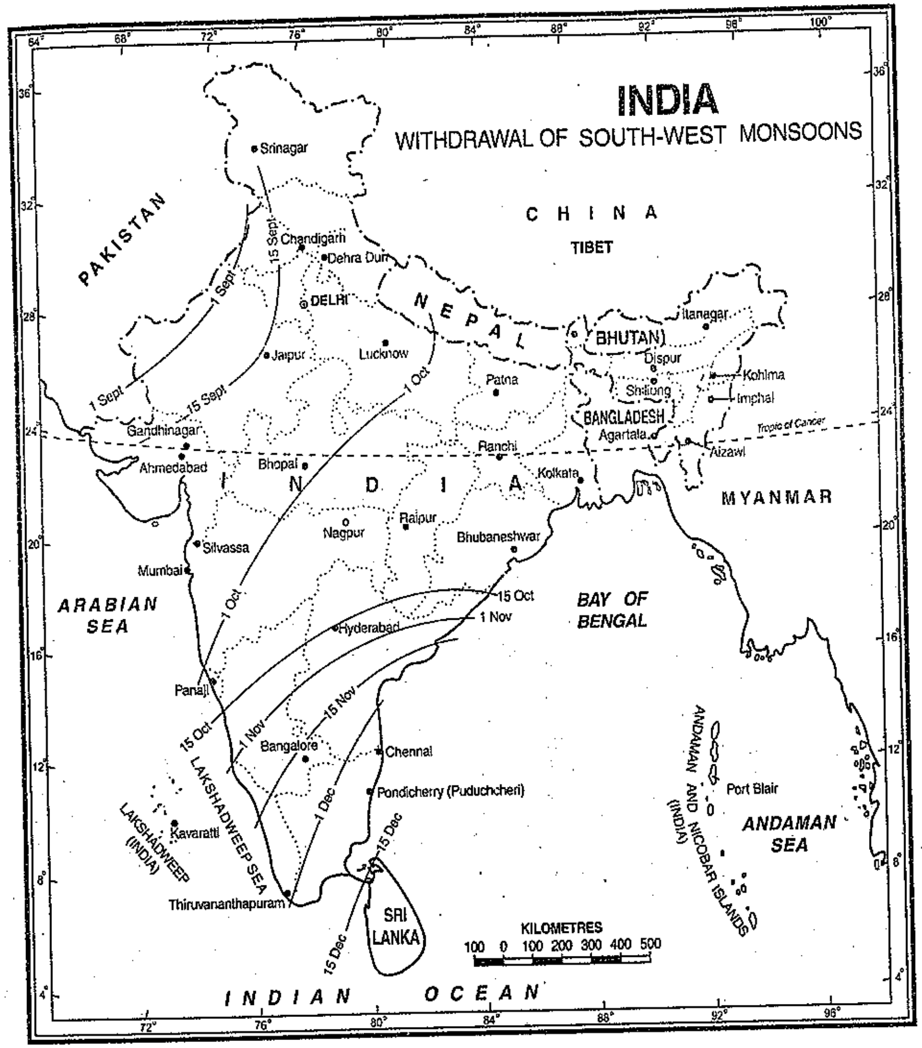

FIG. 5.21. Normal dates of withdrawal of Monsoon

About 3-4 depressions are formed per month from June to September. Almost all of them are sucked inward through the deltas of great rivers, the Ganga, the Mahanadi, the Godavari, the Krishna and the Cauvery and cause heavy rain in these areas.

In June the depressions in the Bay of Bengal originate between 16° N and 21° N and west of 92° E. The majority of them move towards the north-west. During July and August they originate north of 18° N and to the west of 90° E and move generally in a west north-westerly direction. In September the Bay storms originate to the north of 15° N and to the west of 90° E. Majority of the cyclones move along the monsoon trough and most of them merge with the seasonal low over north-west India (**Fig. 5.18**).

In the Arabian Sea the formation of depressions in June is between 17°N and 20°N. They move either in north-west or in northerly direction and may affect

Gujarat or Maharashtra. Storms during August and September are rare and are formed close to Maharashtra-Gujarat coast.

Most of the rainfall in central and northern parts of the country is caused by these depressions. The satellite imagery shows thick clouds associated with these depressions. Sometimes they give excessive rainfall, as much as 60 cm in a single day, resulting in heavy loss of life and property. The absence of depressions or a change in their tracks result in deficit or no rain.

Chief Characteristics of Monsoonal Rainfall

(*i*) Rainfall by the southwest monsoon is seasonal in character, the major part of which is received between June and September.

(*ii*) Monsoonal rainfall is largely orographic in its mode of occurrence and is governed by relief. The Himalayas and the Western Ghats are the main rainfall controlling relief features. The Himalayas obstruct the moisture laiden monsoon winds from the Indian Ocean and cause rainfall in the northeastern States and in the Indus-Ganga-Brahamputra plain. Again the windward side of Western Ghats receive more than 250 cm annual rainfall whereas most parts of the leeward side of the Western Ghats receive less than 60 cm annual rainfall.

(*iii*) The amount of rainfall decreases with increasing distance from the sea. For example Kolkata receives 119 cm during the southwest monsoon period. Patna 105 cm, Allahabad 76 cm and Delhi 56 cm.

(*iv*) The monsoon rains occur in wet spells of a few days interspersed with rainless interval known as ***'breaks'***. The breaks in rainfall are related to tropical cyclones which originate in the Bay of Bengal.

(*v*) The rainfall by the southwest comes in the form of heavy downpour which results in large scale run off and soil erosion.

(*vi*) Indian monsoon rains are vital for agrarian economy of the country.

(*vii*) There are large scale spatial variations in the distribution of rainfall. The amount of annual rainfall varies from about 12 cm in western Rajasthan to over 250 cm in the west coastal plains.

(*viii*) Monsoons often fail to keep date. Sometimes the beginning of rains is delayed considerably over the whole of country or a part thereof.

(*ix*) Sometimes the monsoons withdraw before the scheduled time causing considerable damage to the crops.

4. The Cool Season

The cool season starts with the beginning of the withdrawal of southwest monsoon in the middle of September and continues upto November, after which the winter season starts. The monsoons withdraw from the extreme north-west end of the country in September, from the peninsula by October and from the extreme south-eastern tip by December. Due to retreat of the monsoon, this season is also called the ***season of retreating monsoon***. Sometimes it is referred to as the ***post monsoon season***.

A simple comparison of **figure 5.19** with **5.21** will show that the south-west monsoons reach north-west India last of all and withdraw from there first of all. Therefore, the duration of the south-west monsoon period is minimum there. In Punjab, for example, the south-west monsoons reach in the first week of July and withdraw from there in the second week of September, giving only two and a half months of monsoon activity. As against this, the south-west monsoons reach Coromandel coast in the first week of June and withdraw from there only in the middle of December. Thus the south-west monsoons remain active for more than six months over the Coromandel coast. Unlike the *sudden burst* of the advancing monsoons, the withdrawal is rather gradual and takes about three months.

(*a*) **Temperature.** With retreat of the monsoons, the clouds disappear and the sky becomes clear. The day temperature rises a little at the initial stage but soon starts falling rather steeply. In October the day temperature over larger parts of Rajasthan is 37°C. It decreases to 33°C in the peninsula and to 30°C in north-east India. Nights are cool with minimum temperature varying from 20° to 25°C. In the

Himalayan region the minimum temperatures reach freezing point. The average temperature in most parts of the country varies from 25° to 30°C. **Figure 5.22** shows the distribution of temperature in the month of October. The diurnal range of temperature increases due to lack of cloud cover.

(*b*) **Pressure and Winds.** As the monsoons retreat, the elongated trough of the low pressure across the Indus-Ganga plains weakens and gradually shifts southward. By October it reaches the Bay of Bengal and moves further southwards as the season advances. The axis of low pressure roughly runs in an east-west direction along 13°N latitude. The surface pressure in most parts of the country varies from 1,010 to 1,012 mb. Consequently the pressure gradient is low.

This is the season when south-west monsoons yield place to the north-east monsoons. Unlike the south-west monsoon, the onset of the north-east monsoon is not clearly defined. In fact, on many

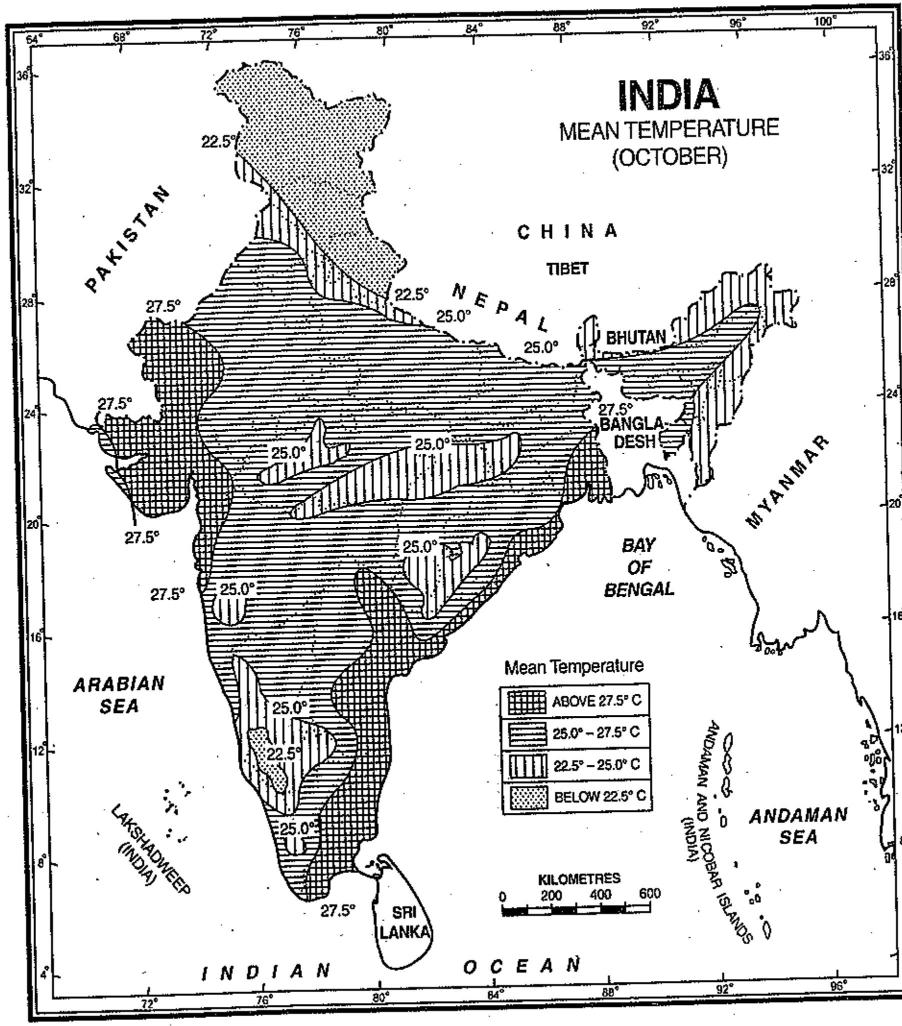

FIG. 5.22. Mean Temperature (October)

occasions, the meteorologists fail to draw a clear demarcation between the withdrawal of the summer monsoon and the onset of winter monsoon over peninsular India. However, the direction of winds over large parts of the country is influenced by the local pressure conditions. (**Fig. 5.23**).

Cyclones. This is the season of the most severe and devastating tropical cyclones originating in the Indian seas especially in the Bay of Bengal. The highest frequency of the cylcones is in the month of October and the first half of November. More cyclones are born in October and then in November and more cylcones originate in the Bay of Bengal than in the Arabian Sea. In October, the Cyclones of the Bay of Bengal originate between 8°N and 14°N. Initially they move in a west or northwesterly direction , but many of them later recurve and move towards the north-east; About 55 per cent of the Bay storms cross or affect the Indian coast. The areas most vulnerable to these storms include the coastal belts of

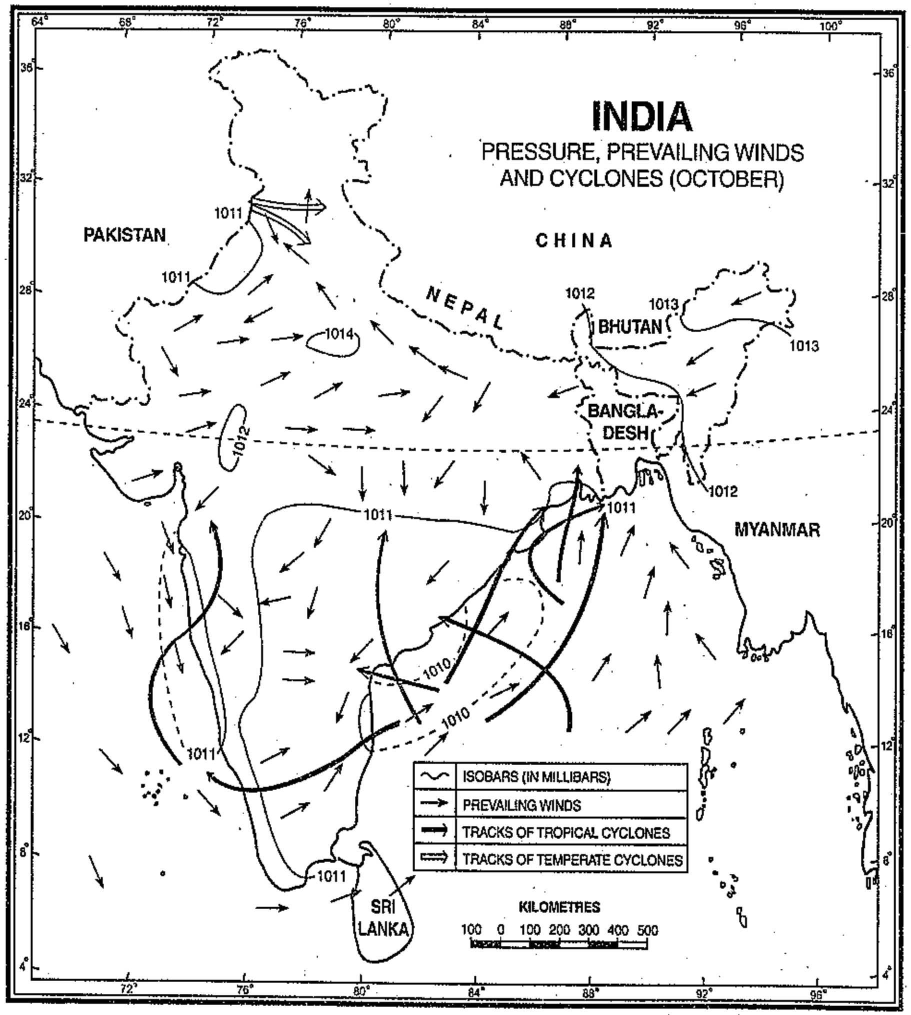

FIG. 5.23. Pressure, Winds and Cyclones (October)

Tamil Nadu, Andhra Pradesh, Odisha and West Bengal. Many of the cyclones which strike the eastern coast of India, south of 15°N latitude cross the southern Peninsula and enter Arabian Sea. During this process, they may weaken, but on re-entry over the Arabian sea they reintensify into cyclonic storms. The storms of Arabian sea originate between 12°N and 17°N latitudes in October and between 8° N and 13° N latitudes in November. Generally they move away from the coast in a north-westerly direction. But about 25% of them later recurve northeast and strike the Maharashtra or Gujarat coast.

The cyclones originating in the Bay of Bengal and the Arabian Sea are accompanied by strong surface winds, dense clouds, thundering and heavy downpours. A rainfall of 50 cm in a day is not uncommon, the highest record being around 86 cm in 24 hours at Purnea in Bihar. The heavy rainfall may continue for 2-3 days.

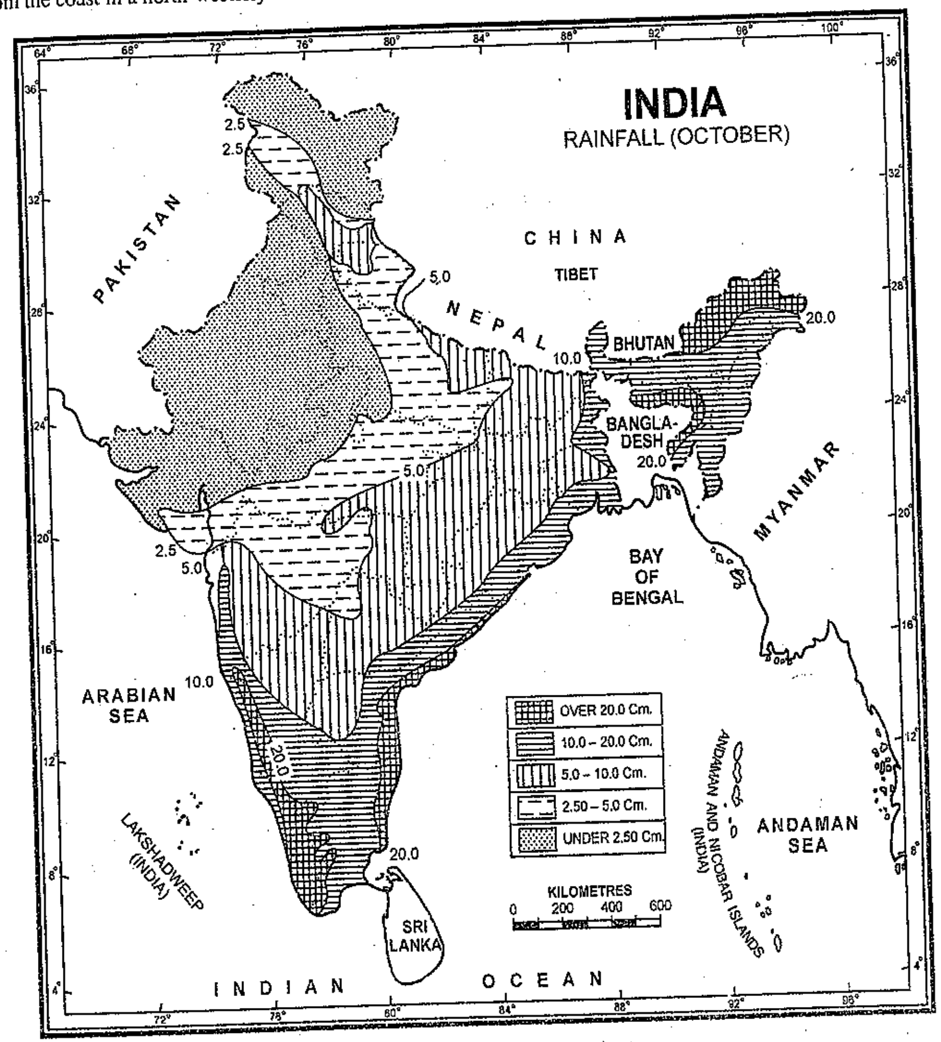

FIG. 5.24. India : Rainfall (October)

In north-west India the western disturbances produce clouding and light rainfall in the otherwise fine weather. The average incidence of western disturbances is 1 to 3, the frequency showing increasing trend with the advance of the season. The precipitation is in the form of snow in higher reaches of Jammu and Kashmir, Himachal Pradesh and in Kumaon Hills.

(*c*) **Precipitation.** The humidity and cloud cover are much reduced with the retreat of the south-west monsoons and most parts of the country remain without much rainfall. However, October-November is the main rainy season in Tamil Nadu and adjoining areas of Andhra Pradesh to the south of the Krishna delta as well as a secondary rainy period for Kerala. In fact Kerala has bi-modal pattern of rainfall with main rains in the south-west monsoon season and subsidiary rains in this season. The retreating monsoons absorb moisture while passing over the Bay of Bengal and cause this rainfall. According to a study conducted by Krishna Rao and Jagannathan the average rainfall in Tamil Nadu in October and November is 38.25 cm which is about 38.73 per cent of the annual rainfall received here. However, the coastal areas receive about 50% of their annual rainfall during this season.

Annual Rainfall

Figure 5.25 shows the distribution of annual rainfall in India. The average annual rainfall of India is about 118 cm which is the highest for a country of such vast dimensions anywhere in the world. But there are large spatial and temporal variations. Large parts of Meghalaya receive about 1,000 cm annual rainfall while on the other end of the scale, some districts in south-west Rajasthan hardly receive annual rainfall of 15 cm. In the extreme south, Kanniyakumari and Nellai Kattabomman districts get less than 30 cm during the south-west monsoon, while heavy rains of 200 cm or more, lash the nearby Kerala Coast. India can conveniently be divided into following regions depending upon the annual average rainfall received by these regions.

Areas of very high rainfall. Areas receiving an annual rainfall of 200 cm and above are termed as areas of very high rainfall. These include the west coast from Thiruvananthapuram in the south to Mumbai in the north. The average annual rainfall in this belt is 200-400 cm with localized areas in between receiving 400-800 cm annual rainfall. Almost the whole of Assam, Nagaland, Meghalaya, Mizoram, Arunachal Pradesh, Sikkim, parts of Manipur, Tripura and north-eastern tip of West Bengal also receive 200 cm or more, with isolated pockets receiving over 400 cm. Meghalaya (*the abode of clouds*) is the wettest part of the country with Mawsynram and Cherrapunji getting 1,221 and 1,102 cm of annual rainfall respectively.

Areas of high rainfall. These areas receive 100-200 cm annual rainfall. They include eastern slopes of the Western Ghats, major part of the northern plain, Odisha, Madhya Pradesh, Andhra Pradesh and Tamil Nadu. The *isohyet* (the line joining places of equal rainfall) of 100 cm rainfall runs southwards from Gujarat coast roughly parallel to the crest of the Western Ghats upto Kanniyakumari. The rainfall to the west of this line is above 100 cm. To the north, the 100 cm isohyet trends eastward passing over the southern parts of Jammu and Kashmir, Himachal Pradesh and northern Uttar Pradesh.

To the east of Allahabad, it bends to the west passing over Bundelkhand in Uttar Pradesh. Turning west-south-westwards, it runs over western Madhya Pradesh, eastern Maharashtra, northern Andhra and Telangana.

Areas of low rainfall. These areas receive 50-100 cm annual rainfall and include large parts of Gujarat, Maharashtra, western Madhya Pradesh, Andhra Pradesh, Karnataka, eastern Rajasthan, Punjab, Haryana and parts of Uttar Pradesh.

Areas of very low rainfall. These are desert and semi-desert areas receiving less than 50 cm of annual rainfall. They include large areas of western Rajasthan, Kachchh and most of Ladakh region of Jammu and Kashmir.a

Variability of Annual Rainfall

Rainfall in India does not change with space only but with time also. There are large variations in the total amount of rainfall from year to year. Variability of annual rainfall is computed with the help of the following formula.

Coefficient of Variability (CV)

$$= \frac{\text{Standard Deviation}}{\text{Mean}} \times 100$$

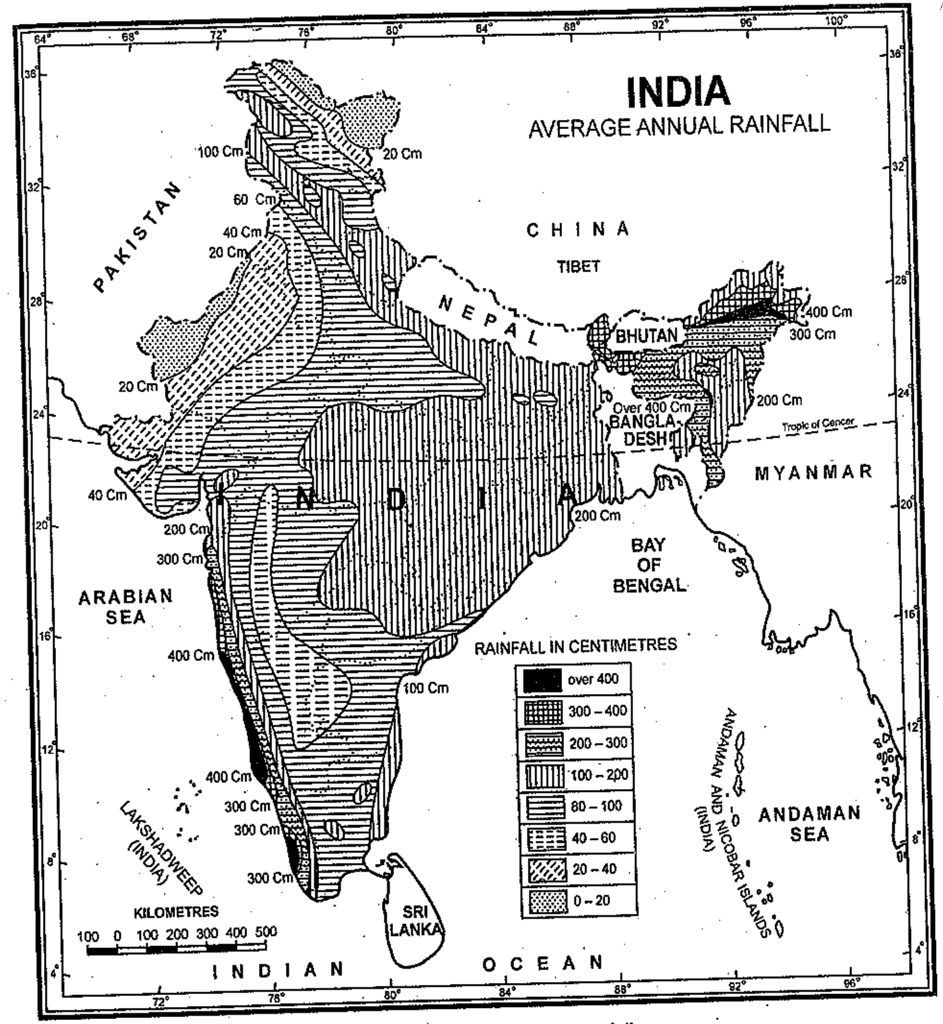

FIG. 5.25. Average Annual Rainfall

The coefficient of variation indicates the amount of fluctuation in rainfall recorded over a long period of time from the mean values. **Figure 5.26** shows the values of the coefficient of variation of monsoon rainfall in India. It generally ranges between 15 and 35 per cent for the country as a whole. The coefficient of variation in large parts of Rajasthan, Gujarat, and parts of Haryana and Panjab is well over 40 per cent. In extreme western parts of Rajasthan and Gujarat, it exceeds 60% and reaches 80% in the extreme west of Rajasthan. Incidentally these are the areas which receive minimum rainfall. The other areas of low rainfall and high coefficient of variation are Leh and Ladakh in the north and Rayalaseema in the south.

The areas of low coefficient of variation include the west coast, the sub-Himalayan belt including Sikkim, Arunachal Pradesh, Assam and West Bengal and the north-eastern hilly regions of Nagaland, Manipur and Mizoram. The coefficient of variation in these areas ranges between 15 and 20 per cent. These areas receive heavy annual rainfall of about 200 cm. In general the variability increases from west into the interior of the plateau as well as from Odisha and West Bengal towards the north and north-west.

A major conclusion that can be drawn from the above description is that the variability is highest where the amount of rainfall is the lowest. In other words, *the rainfall variability is inverse to total*

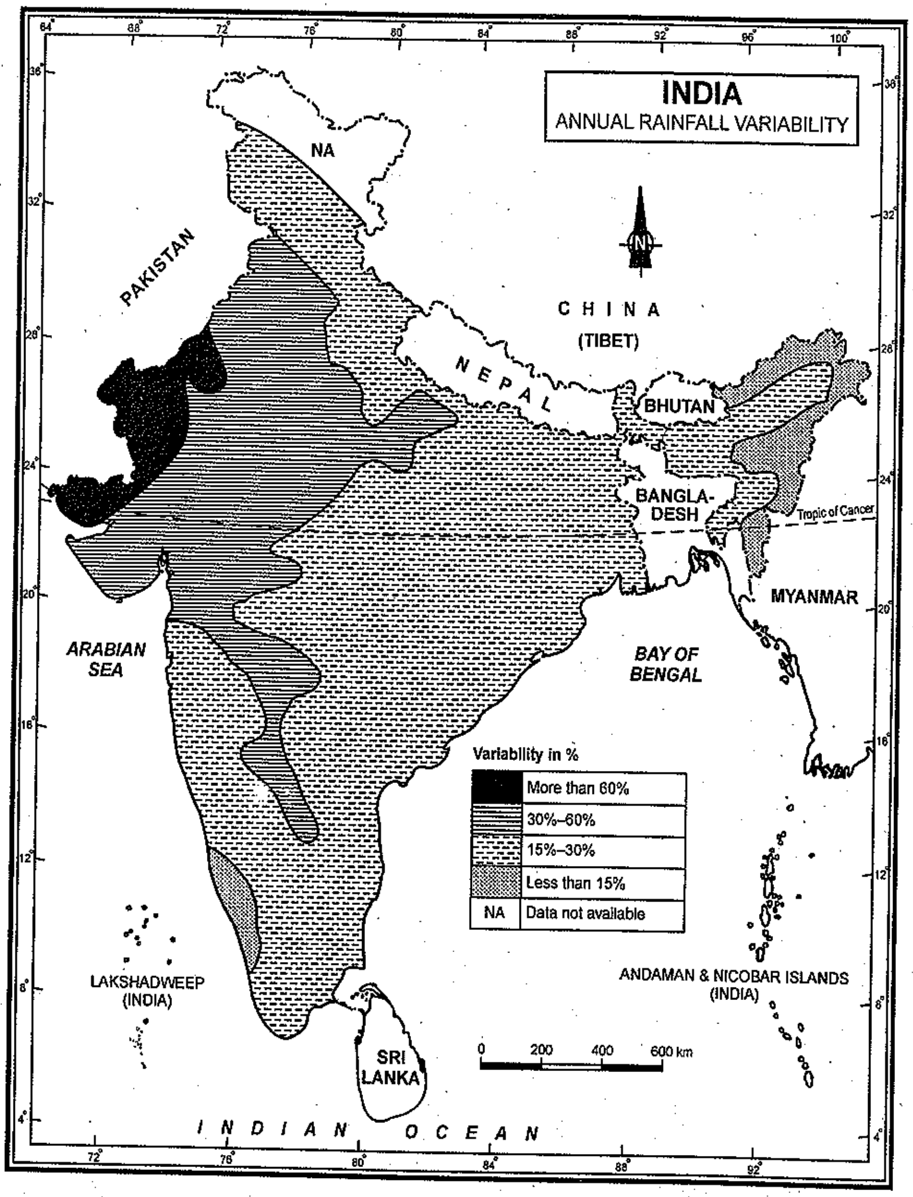

FIG. 5.26. Coefficient of variation of monsoon rainfall

amount of rainfall and reliability of rainfall is inversely proportional to the coefficient of variability. As such the spatial distribution of rainfall variability has a great bearing on Indian agricultural productivity. Since the areas of high variability are also the areas of low rainfall, they suffer from chronic deficiency of water, frequent droughts and crop failures. The areas with marginal rainfall are the worst sufferers.

However, the study of the coefficient of variation helps us in delineating those parts of the country where long range prediction will be useful. This prediction is not much required in areas of small coefficient of variation. For example, we can safely say that the actual rainfall will be within 10 to 15 per cent of the normal rainfall in Assam and West Bengal. But in Rajasthan and adjoining areas of north-west India the rainfall may vary by as much as thirty to fifty per cent or even more from the normal. Similarly the variability of the annual rainfall is high in large part of the Indian Peninsula. Evidently these are the areas where advance information about seasonal rainfall plays a crucial role.

PECULIARITIES AND SIGNIFICANCE OF INDIAN CLIMATE

Indian climate is primarily dominated by south-west monsoons and is peculiar in many ways. The extremes of temperature, rainfall and humidity are well known. The rainfall from the monsoon winds is variable and quite undependable. The monsoon may advance much before its due date or may be considerably delayed. Further, the amount of rainfall may be more than the normal or there may be deficient rains. Some parts of the country may be facing the fury of floods due to heavy rains while the other parts may be reeling under drought conditions due to scanty rainfall. The variability of rainfall in time and space plays havoc with agriculture which shatters the very foundation of economy in a predominantly agricultural country like India. It is often said that *Indian budget is a gamble in the monsoon*. In fact *monsoon is the pivot upon which the whole economic life of India swings*. Nowhere else in the world, so many people over so vast a land are so intimately wedded to the monsoon regime as they do in India. Another peculiar feature of the Indian rainfall is that it is concentrated in a few months of the year. Of the country's total rainfall, about 75 per cent is received in the monsoon months from June to September, 13 per cent comes in the post monsoon season, 10 per cent in the pre-monsoon season and the remaining 2 per cent in the winter season. At the same time, it is worth mentioning that one part or the other gets rainfall in each month of the year *i.e.* in no month

TABLE 5.3. Distribution of Rainfall

Percentage of the total land area	Amount of annual rainfall (cm)
11	above 200
21	125 to 200
37	75 to 125
24	35 to 75
7	Below 35

of the year the whole of India is completely dry. In January and February, north-west India gets rainfall from the western disturbances. In March thunderstorms start influencing Assam and West Bengal and give occasional pours till the arrival of the monsoons in June. Rainfall by south-west monsoons continues till the withdrawal of monsoons. Coromandel coast receives rainfall by the north-east monsoons in the winter season.

It has already been mentioned that the distribution of rainfall in India is very uneven. According to the calculations made by census of India in 1951 only 11 per cent area of India gets over 200 cms. of annual rainfall while about one third of the total land area of the country has to content with a mere 75 cm annually. Table 5.3 gives areal distribution of rainfall in India.

Indian rainfall is basically torrential in nature. Much of the rainfall is received in 3-4 months of the rainy season. Even in this season the actual rainy days are 40-45 only. The heaviest downpours occur in association with cyclones which originate in the Bay of Bengal and the Arabian Sea. A rainfall of 50-60 cm in a rainy day is not uncommon. The highest record, as already mentioned, is 103.6 cm in 24 hours at Cherrapunji. This place gets rainfall of 1,102 cm in 180 rainy days. Sri Ganganagar receives 12 cm of rain in 10-12 rainy days. Hence the statement, *it pours, it never rains in India*, is true whether it be Meghalaya or Rajasthan. The sudden heavy downpour results in devastating floods and excessive soil erosion.

Another very important aspect of Indian rainfall is that it is largely controlled by orography. The effects of the Himalayas and the Western Ghats on the amount and distribution of rainfall and the inability of the Aravalis to cause rainfall have already been discussed. The whole of India would have been a vast desert but for the size and lie of the Himalayas and the Western Ghats. Therefore, we can easily say that the *rainfall over the country is primarily orographic.*

CLIMATIC REGIONS OF INDIA

Although India has tropical monsoon climate as a whole, there are large regional variations in important climatic elements such as rainfall and temperature. This is quite natural for a vast country like India having subcontinental dimensions. Variations in rainfall are much more marked than those of temperature. Hence, most geographers have given more importance to rainfall than to temperature. The first attempt to divide India into climatic regions was made by Blanford towards the close of the 19th century. Among the subsequent attempts made to divide India into climatic regions, those made by W.G. Kendrew, L.D. Stamp, Koppen, Thornthwaite, G.T. Trewartha and Johnson are worth mentioning. Among the Indian geographers, attempts made by Subrahmanyam (1955), Bharucha and Shanbhag (1957) and R.L. Singh (1971) deserve appreciation.

Stamp's Classification of Climatic Regions

Dr. L. Dudley Stamp's classification of Indian climate is very much akin to that suggested by **W.G. Kendrew**. This classification is empirical, arbitrary and subjective, but uses quantitative limits to the regions in easily understood units like temperature and rainfall. Stamp's schemes has been presented here with slight modifications here and there. Stamp used 18°C isotherm of mean monthly temperature for January to divide the country into two broad climatic regions, *viz.*, temperate or continental zone in the north and tropical zone in the south. A look at **Fig. 5.27** will show that this line runs roughly across the root of the peninsula, more or less along or parallel to the Tropic of Cancer. The two major climatic regions are further divided into eleven regions depending upon the amount of rainfall and temperature.

A. The Temperate or Continental India has been divided into following five regions :

1. The Himalayan region (heavy rainfall)
2. The north-western region (moderate rainfall)
3. The arid low land
4. The region of moderate rainfall
5. The transitional zone

B. The tropical India has been divided into following six regions :

6. Region of very heavy rainfall
7. Region of heavy rainfall
8. Region of moderate rainfall
9. The Konkan Coast
10. The Malabar Coast
11. Tamil Nadu

A. Climatic regions of temperate or continental India

1. The Himalayan Region. This region embraces the entire Himalayan mountain area which includes from west to east, Jammu and Kashmir, Himachal Pradesh, large parts of Uttarakhand, the north hill region of West Bengal, Sikkim and Arunachal Pradesh. The winter and summer temperatures are 4°-7°C and 13°-18°C respectively. The higher reaches are perpetually under snow and ice. The average annual rainfall exceeds 200 cm in the east but it is much less in the west. Shimla in the west and Darjeeling in the east are its representative cities.

2. The North-western Region. It includes the northern parts of Punjab and southern parts of Jammu and Kashmir. The winter and summer temperatures are 16°C and 24°C respectively. Amritsar is its representative city.

3. The Arid Lowland. This is a vast dry area which includes the Thar desert of Rajasthan, south western part of Haryana and Kachchh of Gujarat. The average temperature in winter varies from 16° to 24°C which may shoot up to 48°C in summer. Jaipur is its representative city. The average annual rainfall does not exceed 40 cm.

4. The region of moderate rainfall. Parts of Punjab, Haryana, western Uttar Pradesh, Union Territory of Delhi, north-west Plateau area of Madhya Pradesh and eastern Rajasthan are areas of average rainfall with an annual rainfall of 40 to 80 cm. Temperatures in January and July are 15°-18°C and 33°-35°C respectively. Most of the rainfall occurs in summer. Delhi represents this region very well.

5. The Transitional Zone. Eastern Uttar Pradesh and Bihar comprise the transitional zone between areas of average rainfall on the west and areas of heavy rainfall in the east. The average annual rainfall in this zone is 100-150 cm. The temperatures in January and July vary between 15°-19°C and 30°-35°C. Patna is the representative city of this zone.

B. Climatic Regions of Tropical India

6. Region of very heavy rainfall. These areas receive more than 200 cm of annual rain and include large parts of Meghalaya, Assam, Tripura, Mizoram

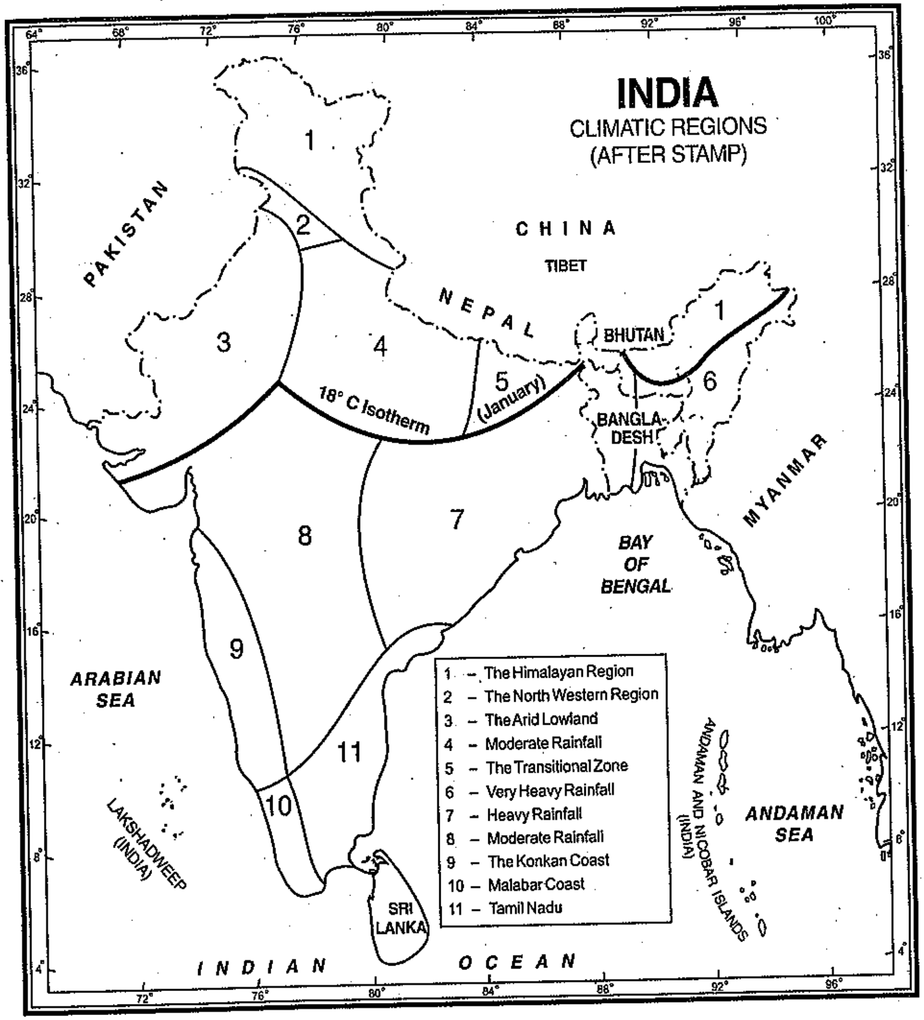

FIG. 5.27. Climatic Regions of India (After Stamp)

and Nagaland. Temperatures remain around 18°C in January and rise to 32°-35°C in July. Cherrapunji and Mawsynram in Meghalaya receive 1,102 cm and 1,221 cm of annual rainfall respectively.

7. Region of heavy rainfall. Chhattisgarh, Jharkhand, Gangetic West Bengal, Odisha and coastal Andhara Pradesh receive 100-200 cm annual rainfall and are termed as areas of heavy rainfall. The rainfall is primarily brought by the monsoon winds coming from the Bay of Bengal. The cyclones originating in the Bay of Bengal also bring some rainfall. The amount of rainfall decreases as we move from east to west and from north to south. The January and July temperatures range from 18°-24°C to 29°-35°C respectively. Kolkata is the representative city of this region.

8. Region of moderate rainfall. It includes mostly those areas between Western and Eastern Ghats which receive annual rainfall of 50-100 cm. Rainfall is comparatively low because this region lies in the rain shadow area of the Western Ghats. The average temperature in winter is 18°-24°C which rises to 32°C in summer. This region is represented by Hyderabad in Telangana.

9. The Konkan Coast. Extending from Mumbai in the north to Goa in the south, the Konkan Coast receives over 200 cm annual rainfall brought by the Arabian Sea branch of the south-west monsoons. The temperature remains fairly high and varies from 24°-27°C. Thus the annual range of temperature is very low; to the tune of 3°C only. Mumbai is the representative city of this region.

10. The Malabar Coast. It extends from Goa to Kanniyakumari and receives heavy annual rainfall of over 250 cm. The rainfall is mainly brought by the south-west monsoon winds coming from the Arabian Sea and continues for about nine months in a year. The temperature remains in the vicinity of 27°C and the annual range of temperature is only 3°C. This region is represented by Thiruvananthapuram.

11. Tamil Nadu. It includes Tamil Nadu and adjoining areas of Andhra Pradesh. The rainfall varies from 100 to 150 cm and is mainly caused by the retreating monsoons from north-east during November and December. The temperature remains somewhere around 24°C. There is not much change in summer and winter temperature and the annual range of temperature is only 3°C. Chennai is the representative city of this region.

Koppen's Classification of Climatic Regions

Dr. Wladimir Koppen of the University of Graz (Austria) first published his scheme of classification of world climates in 1901 and subsequently modified it a number of times, the major revisions being in 1918 and 1931. His latest work was published in 1936 in which he presented a new scheme of climatic classification.

This classification is based upon annual and monthly means of temperature and precipitation. It accepts the native vegetation as the best expression of the totality of a climate, so that many of the climatic boundaries are based upon vegetation. Koppen has expressed the view that the effectiveness of precipitation in vegetation growth depends not only upon the amount of precipitation, but also upon the intensity of evaporation and transpiration. Much of the water obtained from precipitation is lost from the soil and plants by evaporation and transpiration and is not available for vegetation growth. Thus a certain amount of rain falling in hot and dry climate may not be as useful to vegetation as the same amount of rain falling in a cool and humid climate.

Koppen has suggested five major types of climate which correspond with five principal vegetation groups. Each climatic type is represented by a capital letter explained as under:

A : Tropical rainy climate with no cool season. Temperature of the coolest month above 18°C.

B : Dry climate in which there is an excess of evaporation over precipitation.

C : Middle-latitude rainy climate with mild winters. Average temperature of coldest month below 18°C but above −3°C. Average temperature of warmest month over 10°C.

D : Middle-latitude rainy climate with severe winters. Average temperature of coldest month below −3°C and that of warmest month above 10°C.

E : Polar climate with no warm season. Average temperature of the warmest month below 10°C.

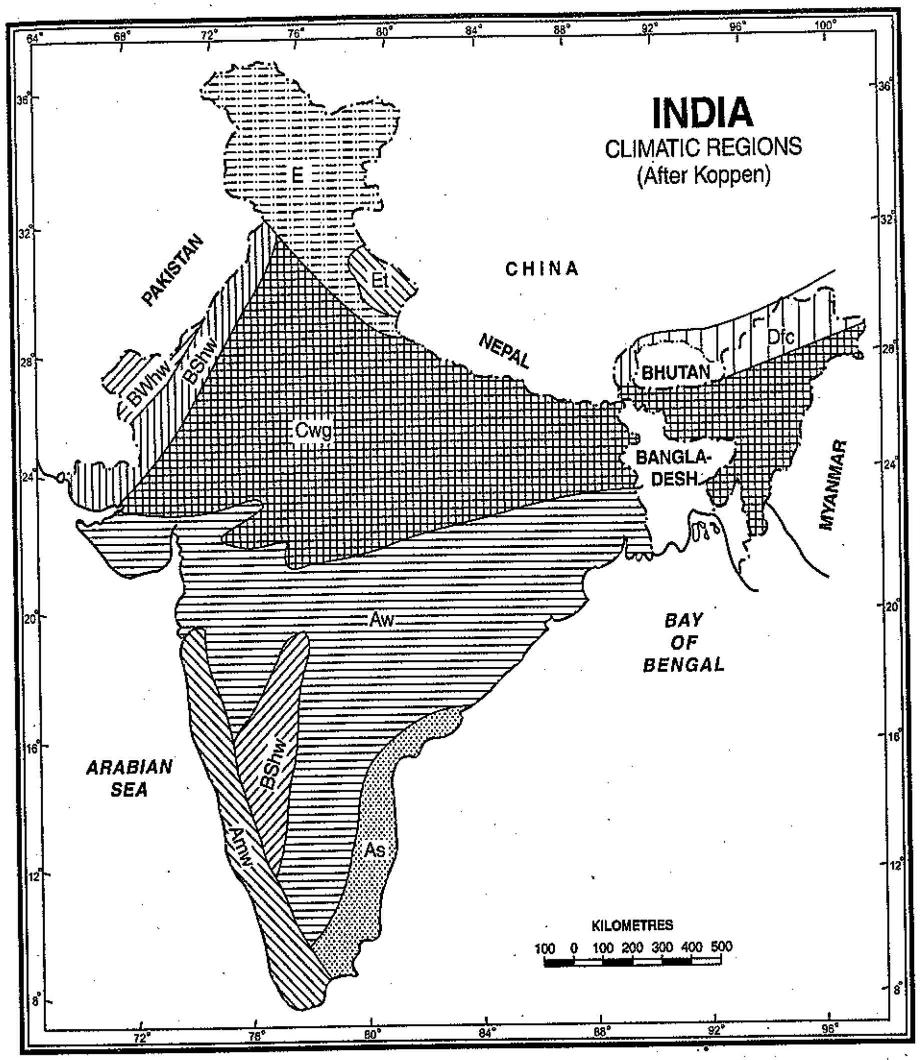

FIG. 5.27. Koppen's Climatic Regions of India

The above mentioned major climatic types are further subdivided depending upon the seasonal distribution of rainfall or degree of dryness or cold. They are designated by small letters *a, c, f, h, m, g, s* and *w* each having a specific meaning as per details given below:

a : hot summer, average temperature of the warmest month over 22°C

c : cool summer, average temperature of the warmest month under 22°C

f : no dry season

w : dry season in winter

s : dry season in summer

g : Ganges type of annual march of temperature; hottest month comes before the solstice and the summer rainy season.

h (heiss) : average annual temperature under 18°C

m (monsoon) : short dry season.

The capital letters *S* and *W* are employed to designate the two subdivisions of dry climate : semi arid or *Steppe (S)* and arid or *desert (W)*. Capital letters *T* and *F* are similarly used to designate the two subdivisions of polar climate : *tundra (T)* and *icecap (F)*.

Koppen divided India into nine climatic regions making use of the above scheme (**Fig. 5.28**).

1. Amw (Monsoon type with short dry winter season). This climate is found in the western coastal region, south of Mumbai. This area receives over 300 cm of annual rainfall in summer from the south-west monsoons.

2. As (Monsoon type with dry season in high sun period). This is the region in which rainfall occurs in winter and summer is dry. Coromandel coast experiences this type of climate. Coastal Tamil Nadu and adjoining areas of Andhra Pradesh are included in it. The amount of rainfall, mostly in winter is 75-100 cm and is received from the retreating monsoons.

3. Aw (Tropical Savanah type). This climate is found in most parts of the peninsular plateau barring Coromandel and Malabar coastal strips. The northern boundary of this climatic region roughly coincides with the Tropic of Cancer. The average annual rainfall is about 75 cm which is received in summer season from the south west monsoons. Winter season remains dry.

4. BShw (Semi-arid Steppe type). Some rainshadow areas of Western Ghats, large part of Rajasthan and contiguous areas of Haryana and Gujarat have this type of climate. Rainfall varies from 12 to 25 cm and most of it occurs in summer. Winter is completely dry. Some arid steppe vegetation is found here.

5. BWhw (Hot desert type). Most of western Rajasthan has hot desert type of climate where the amount of annual rainfall is less than 12 cm. Temperatures are very high in summer. Natural vegetation is almost absent.

6. Cwg (Monsoon type with dry winters). This type of climate is found in most parts of the Ganga Plain, eastern Rajasthan, Assam and in Malwa Plateau. The summer temperature rises to 40°C which falls to 27°C in winter. Most of rainfall occurs in summer and winter is dry.

7. Dfc (Cold, Humid winters type with shorter summer). Some of the north-eastern states such as Sikkim, Arunachal Pradesh and parts of Assam have this type of climate. Winters are cold, humid and of longer duration. The winter temperatures are about 10°C. Summers are short but humid.

8. Et (Tundra Type). This climate is found in the mountain areas of Uttarakhand. The average temperature varies from 0 to 10°C. There is fall in temperature with altitude.

9. E (Polar Type). The higher areas of Jammu & Kashmir and Himachal Pradesh experience polar climate in which the temperature of the warmest month varies from 0° to 10°C. These areas are covered with snow for most part of the year.

Thornthwaite's Classification of Climatic Regions

Following Koppen, Thornthwaite presented his classification of climates in 1931 and revised it in 1933 and 1948. Though his first two classifications are more or less similar, the classification put forward by him in 1948 was markedly different. While in the 1931 classification, the plant was viewed as a meteorological instrument for measuring climatic character, in the 1948 classification, vegetation is regarded as a physical mechanism by means of which water is transported from soil to the atmosphere; *it is the machinery of evaporation as the cloud is the machinery of precipitation.* The combined loss through evaporation from the soil surface and transpiration from plants is called ***evapotranspiration***. His classification is based on the principle that '*the plant is in the nature of a meteorological instrument which is capable of measuring all the integrated climatic elements*'. Under this system climatic types are identified and their boundaries determined empirically by noting vegetation, soil and drainage features.

It has been suggested by Thornthwaite that the plant growth depends not only upon precipitation but rather it is affected by precipitation effectiveness. *The precipitation effectiveness is determined by dividing total monthly precipitation by evaporation and is called the P/E ratio.* The sum of 12 monthly P/E ratios is called the P/E index. Based upon the P/E index, Thornthwaite recognised five humidly provinces each of which appears to be associated with a characteristic vegetation.

Humidity Province	Characteristic Vegetation	P/E Index
A, wet	Rainforest	128 and above
B, humid	Forest	64-127
C, subhumid	Grassland	32-63
D, semiarid	Steppe	16-31
E, arid	Desert	Under 16

The five principal humidity provinces are subdivided into four subtypes based upon seasonal concentration of precipitation.

r = rainfall adequate in all seasons

s = rainfall deficient in summer

w = rainfall deficient in winter

d = rainfall deficient in all seasons.

Thornthwaite also recognised six temperature provinces based upon thermal efficiency :

Temperature Province	T/E Index
A', tropical	128 and above
B', mesrothermal	64-127
C', microthermal	32-63
D', taiga	16-31
E', tundra	1-15
F', frost	0

A total of 120 combinations of three elements, precipitation effectiveness, seasonal concentration of rainfall, and thermal efficiency are possible but Thornthwaite recognised only 32 climatic types on the world map of climatic classifications prepared by him. Of these only 12 climatic types are found in India.

1. AA'r is tropical wet climate in which the P/E as well as T/E index is above 128. Rainfall occurs in all the seasons and dense rain forests grow. This climate is found along the west coast and in Tripura and Mizoram.

2. BA'w is tropical humid climate in which thick forests grow. T/E ratio is above 128 but P/E ratio is 64-127. Rainfall is deficient in winter. This climate is found on the eastern slopes of the Western Ghats and in West Bengal.

3. BB'w is temperate humid climate which is mainly found in parts of Assam, Meghalaya Mizoram and Nagaland. P/E index and T/E index vary from 64 to 127. The rainfall is deficient in winter. Such a climate is useful for the growth of vegetation.

4. CA'w covers large parts of the peninsular India. The T/E index is 128 and above but the P/E index falls to 32-63. Being a comparatively dry climate, it is suitable for grasslands only.

5. CA'w' is similar to *C A'w* with the only difference that the rainfall occurs in winter. Most of Tamil Nadu and the neighbouring parts of Andhra Pradesh enjoy this climate.

6. CB'w is temperate subhumid climate which covers most of the northern plain of India. The T/E index is 64 to 127 and the P/E index is still lower ranging between 32 and 63. This climate is suitable for grasslands.

7. DA'w is a tropical semi-arid climate which is mainly found in the northern Gujarat and southern Rajasthan. T/E index is 128 or above while P/E index is 16 to 31. This climate is suitable for steppe type of vegetation.

8. DB'd is temperate semi arid climate in which rainfall is deficient in all the seasons. T/E index is 64-127 while P/E index is 16-31. This climate is found in Jammu and Kashmir and is suitable for steppe vegetation.

9. DB'w is similar to DB'd climate with the only difference that the rainfall is deficient in winter. Parts of Punjab, Haryana and Rajasthan as well as some parts of rainshadow area in the peninsular India experience this climate.

10. D' is a taiga type climate in which T/E index is 16 to 31. It is found in Jammu and Kashmir, Himachal Pradesh, Punjab, and Uttarakhand in the west and Arunachal Pradesh, Sikkim and parts of upper Assam in the east.

11. E' is a cold tundra type of climate which is found in higher reaches of the Himalayas.

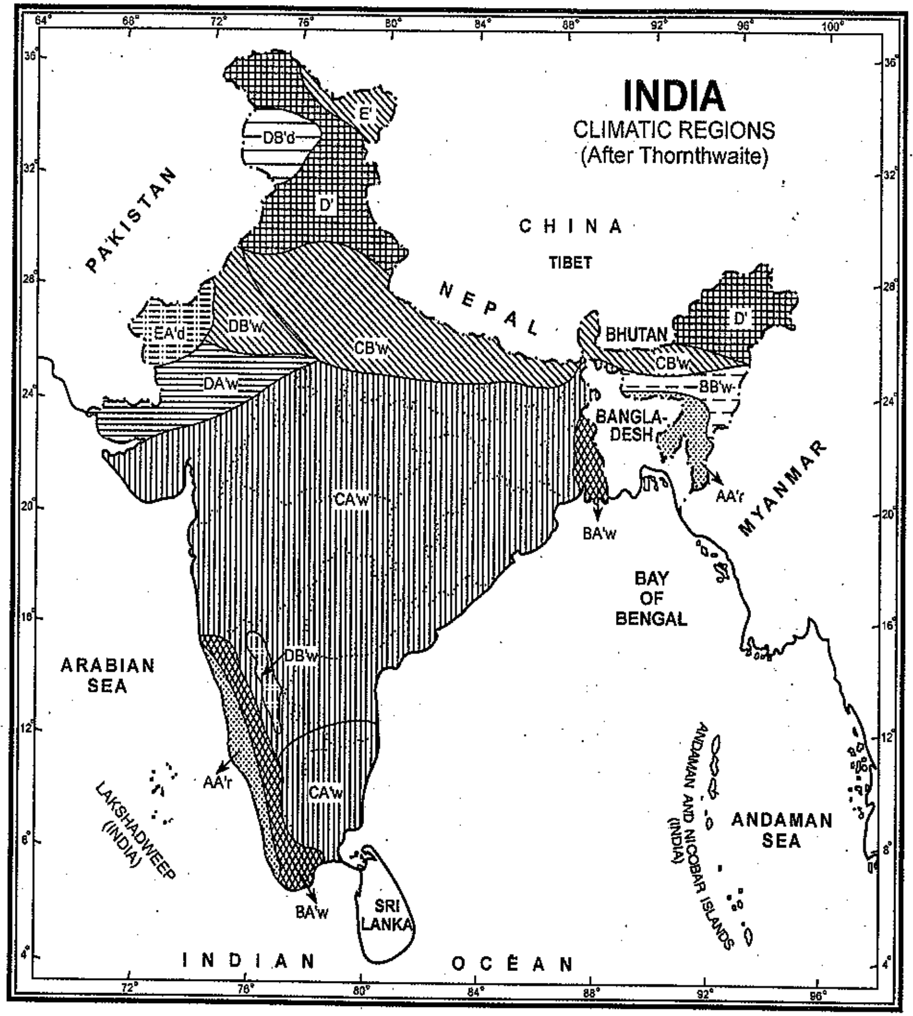

FIG. 5.29. India : Climatic Regions after Thornthwaite classification of climates

12. EA'd is extremely hot and dry climate in which T/E index is over 128 and P/E index remains below 16. Rainfall is deficient throughout the year. This type of climate is found in western part of Rajasthan.

Trewartha's Classification of Climatic Regions

Prof. Glenn T. Trewartha of the University of Wisconsin in the U.S.A., modified and simplified Koppen's classification and presented his own classification in his book entitled 'An Introduction to Climate'. He has recognised six major climates of the world. They are :

A. Tropical humid climates
B. Dry climates
C. Humid mesothermal climates
D. Humid microthermal climates
E. Boreal climates
F. Polar climates

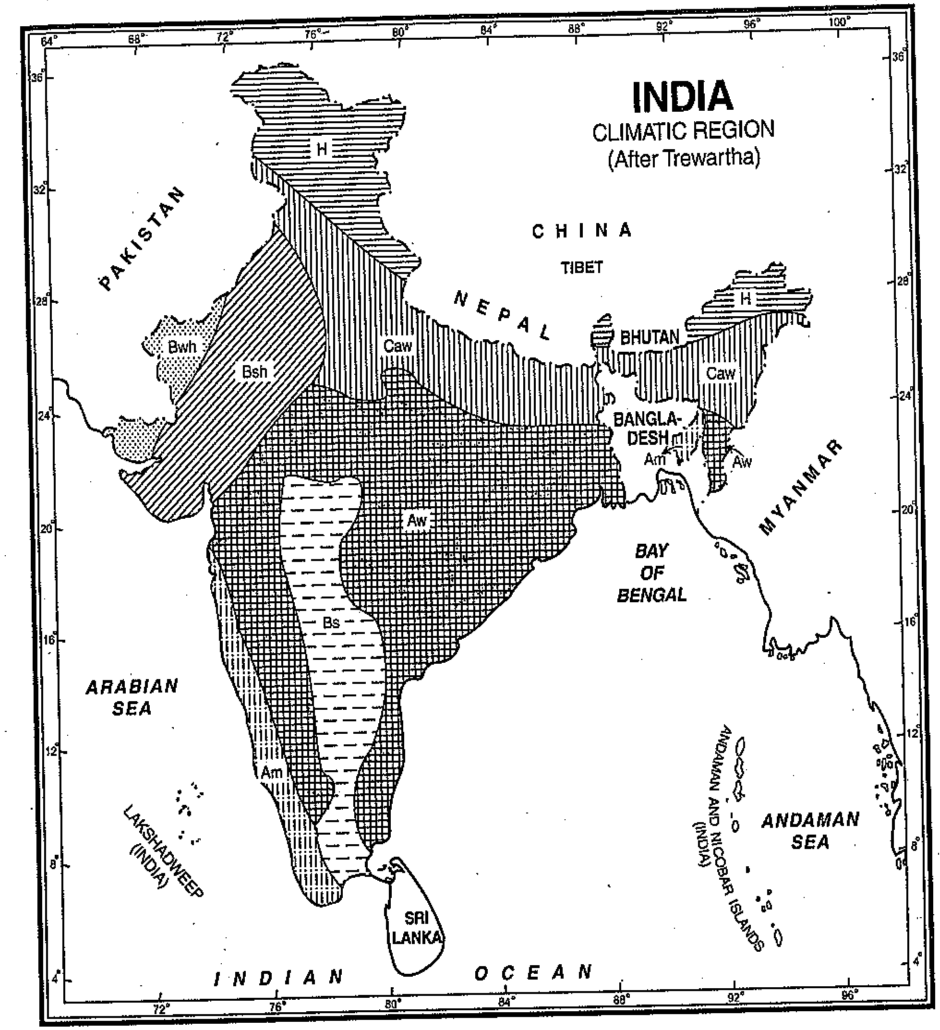

FIG. 5.30. Climatic Regions of India (after Trewartha)

In addition, he recognised H. undifferentiated climate of highlands.

Out of the above climatic types four types *viz. A, B, C* and *H* are found in India. These four types have further been divided into seven sub-types. A brief description of each climatic type is given below :

A is tropical humid climate in which temperature does not fall below 18°C. It has two subdivisions.

(i) *Am* is tropical monsoon type with average annual temperature of 27°C and annual rainfall of over 250 cm. Western Coastal plain and Tripura have this climate.

(ii) Aw is tropical wet and dry (savanna) type. The temperature here also remains at 27°C but the annual rainfall is much less, about 100 cm. The entire rainfall occurs in summer season. A major part of peninsular plateau and north-eastern state of Mizoram experience this climate.

B is a dry climate in which the annual rainfall is always less than 100 cm. This climate is divided into following three sub types.

(*i*) ***Bs*** is semi arid or steppe type which is found in the rain shadow of the Western Ghats. The average temperature is above 27°C but the rainfall is below 100 cm. Rainfall occurs mainly in summer and supports grasslands.

(*ii*) ***Bsh*** is tropical and subtropical desert climate in which the average annual temperature is above 27°C and the rainfall declines to 50-100 cm. Large parts of Gujarat, Rajasthan and south-west Haryana experience this type of climate.

(*iii*) ***Bwh*** is middle latitude desert climate which is found in west Rajasthan and Kachchh region of Gujarat. Here the temperatures are sufficiently high but the annual rainfall further declines to a low of 20 cm. This climate supports only thorny bushes.

C is mesothermal or subtropical climate in which winter is dry and cold.

Caw. Most parts of the northern plain of India have this type of climate where winter temperature falls below 18°C. Most of the rainfall occurs in summer and the amount of rainfall decreases from east to west. Western disturbances give light winter rainfall in the western part.

H climate indicates undifferentiated highlands where the temperatures are invariably low. Higher areas have snowfall in winter. Rainfall is caused by the monsoon winds in summer and by western disturbances in winter. Most of the Himalayan region including Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh have this climate.

R.L. Singh's Classification of Climatic Regions

Following Kendrew and Stamp, Dr. R.L. Singh presented his climatic divisions of India in 1971. He divided the country into 10 climatic divisions based on the temperature conditions of the hottest and the coldest months and average annual rainfall.

1. Per Humid North-East. As its name indicates, it covers most parts of the north-eastern states including Sikkim, Assam, Arunachal Pradesh, Nagaland, Tripura, Mizoram, and Meghalaya. The July temperature is 25°-33°C which falls to 11°-24°C in January. The average annual rainfall at most of places is 200 cm although there are places which record over 1,000 cm of rainfall.

2. Humid Sahyadri and West Coast. It includes Sahyadri (Western Ghats) and its western coastal belt extending from Narmada Valley in the north to Kanniyakumari in the south. Temperature in January is 19°-28°C which rises to 26°-32°C in July. The average annual rainfall is about 200 cm but at places it may be much higher especially on the western slopes of the Western Ghats.

3. Humid South-East. Odisha, West Bengal, Chhattisgarh and Jharkhand are included in it. January and July temperatures are 12°-27°C and 26°-34°C respectively. The average annual rainfall is 100-200 cm.

4. Subhumid Transition. It embraces the eastern part of Uttar Pradesh, Bihar and northern part of Jharkhand. January temperature is 9° to 24°C which rises to 24°-41°C in July. The average annual rainfall is 100-200 cm.

5. Subhumid Littorals. Eastern Tamil Nadu and coastal Andhra Pradesh have subhumid littoral climate. May is the hottest **month** when the temperature rises to 28°-38°C. In January the temperature falls to 20°-29°C. Summers are dry but winters are wet. The area as a whole receives 75-150 cm annual rainfall, most of which is caused by retreating monsoons in November-December.

6. Subhumid Continental. This climate is primarily found in the Ganga plain where January and July temperatures are 7°-23°C and 26°-41°C respectively. The average annual rainfall varies from 75 to 150 cm.

7. Semi arid and Subtropical. This climate prevails in the Satluj-Yamuna water divide which includes Punjab, Haryana, eastern Rajasthan and the Union Territories of Delhi and Chandigarh. The average rainfall is 25 to 100 cm, most of which falls in summer. Some rainfall is caused in winter by western disturbances. January temperatures are 6°-23°C which rise to 26°-41°C in May.

8. Semi arid Tropical. Large parts of Gujarat, Maharashtra, Madhya Pradesh, Chhattisgarh, Karnataka and Telangana have semi arid tropical

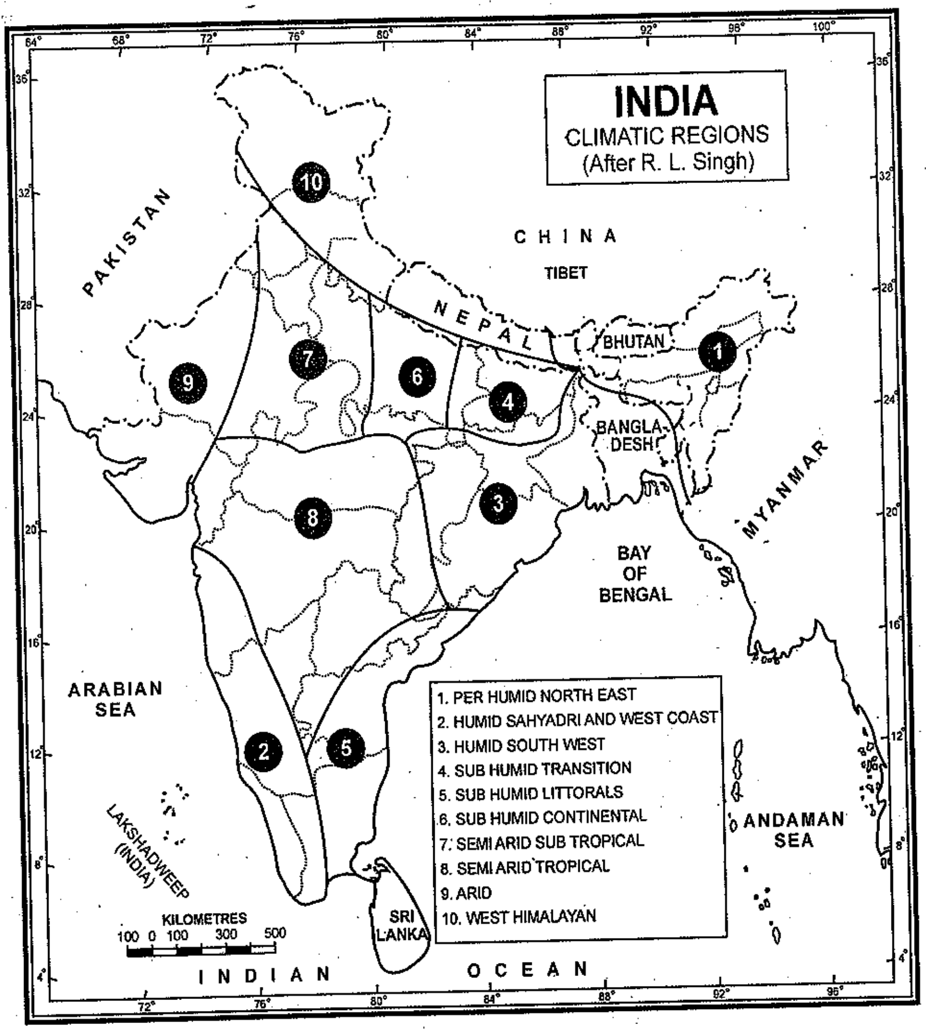

FIG. 5.31. India's Climatic Regions after R.L. Singh

climate. Temperature varies from 13°-29°C in January and from 26°-42°C in July. The average annual rainfall varies from 50 to 100 cm.

9. Arid. The areas of arid climate comprise the Thar desert and includes western Rajasthan, south-west Haryana and Kachchh region of Gujarat. This is extremely dry climate in which the annual rainfall is only 25 cm and at places it is as little as 10 cm. January temperatures are 5°-22°C which rise to 20°-40°C in June. The range of temperature, both diurnal and annual, is very large.

10. West Himalayan. This climate is found in west Himalayan region which includes Jammu and Kashmir, Himachal Pradesh and Uttarakhand. The July temperature is 5°-30°C which dips to 0°-4°C in January. The annual rainfall is 150 cm. The rainfall is caused by south-west monsoons in summer and by western disturbances in winter.

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CHAPTER 6

Natural Vegetation and Wildlife

INTRODUCTION

Natural vegetation is the primeval plant cover unaffected by man either directly or indirectly. The word forest is derived from Latin 'fores' meaning outside, the reference being to a village boundary or fence and it must have included all uncultivated and uninhabited land. In general, a forest is defined as an area set aside for the production of timber and other forest produce or maintained under woody vegetation for certain benefits which it provides. Ecologically, a forest is a plant community, predominantly of trees and other woody vegetation, usually with a closed canopy.

FACTORS INFLUENCING VEGETATION

The geographical factors which influence natural vegetation include climate, soil and topography. The main climatic factors are rainfall and temperature. Generally speaking, rainfall is more important than temperature except in the Himalayas. The seasonal rainfall regime, the length of dry season and its relation to the march of temperature, are also important. The amount of annual rainfall has a great bearing on the type of vegetation. Areas receiving 200 cm or more rainfall per annum have stands of evergreen rain forests while monsoon deciduous forests dominate in areas with rainfall between 100 and 200 cm. In areas having 50 to 100 cm rainfall there are drier deciduous or tropical savana grading into open thorny scrub while those with less than 50 cm rainfall have only dry thorny scrub and low open bush merging into semi desert. In higher altitudes of the Himalayas and the hills of the Peninsula at elevation of more than 900 metre above sea level, temperature plays a more important role. As the temperature falls with altitude in the Himalayan region the vegetal cover changes from tropical to sub-tropical, temperate and finally alpine. Changes in soil conditions have given birth to different types of vegetation in different parts of the country. Mangrove forests, swamp forests, and beach and sandy coastal

forests are some of the outstanding examples of influence of soil on natural vegetation. Topography in the narrow sense is responsible for certain minor types *e.g.* alpine flora, tidal forests, etc.

CLASSIFICATION OF NATURAL VEGETATION

A great variety of vegetation is found in different parts of India due to unequal distribution of rainfall and temperature as well as their seasonal variation, besides varied edaphic and biotic conditions. A generalised classification of Indian forests is, therefore, a difficult job. Various systematic classifications have been made by a number of botanists and ecologists. **H.G. Champion** (1936) distinguished 116 types of vegetation in India, some with further sub-divisions. Champion's classification has been much simplified by **G.S.Puri** (1960), **Legris** (1963), **Champion** and **S.K. Seth** (1968) and **S.S. Negi** (1990). Based on the suggestions of these scholars India's vegetation can be divided into 5 main types and 16 sub-types as per details given below :

A. Moist Tropical Forests

1. Tropical Wet Evergreen
2. Tropical Semi-Evergreen
3. Tropical Moist Deciduous
4. Littoral and Swamp

B. Dry Tropical Forest

5. Tropical Dry Evergreen
6. Tropical Dry Deciduous
7. Tropical Thorn

C. Montane Sub-tropical Forests

8. Sub-tropical broad leaved hill
9. Sub-tropical moist hill (pine)
10. Sub-tropical dry evergreen

D. Montane Temperate Forests

11. Montane Wet Temperate
12. Himalayan Moist Temperate
13. Himalayan Dry Temperate

E. Alpine Forests

14. Sub-Alpine
15. Moist Alpine scrub
16. Dry Alpine scrub

A. MOIST TROPICAL FORESTS

1. Tropical Wet Evergreen Forests. These are typical rain forests which grow in those areas where the annual rainfall exceeds 250 cm, the annual temperature is about 25°-27°C, the average annual humidity exceeds 77 per cent and the dry season is distinctly short. Due to high heat and high humidity, the trees of these forests do not shed their leaves annually, at least not together, and are termed as evergreen forests. These are lofty, very dense multilayered forests with mesosphytic evergreens. The trees often reach 45 metres in height, individual trees exceed 60 metres. The entire morphology looks like a green carpet when viewed from above. The sun light cannot reach the ground and owing to deep shade, the undergrowth is formed mainly of tangled mass of canes, bamboos, ferns, climbers, etc. A variety of orchids flourishes on the trees.

The true evergreen forests are found along the western side of the Western Ghats (between 500 to 1370 metres above sea level) south of Mumbai, in a strip running from north-east to south-west direction across Arunachal Pradesh, Upper Assam, Nagaland, Manipur, Mizoram and Tripura upto a height of 1070 metres and in the Andaman and Nicobar Islands.

The timber of these forests is fine-grained, hard and durable as a result of which it has high commercial value. The important species of these forests are mesua, white cedar, calophyllum, toon, dhup, palaquium, hopea, jamun, canes, etc. in the Western Ghats, and gurjan, chaplasha, jamun, mesua, agar, muli, bamboo etc. in the Himalayan region. Although these forests contain valuable commercial species, they have not been properly exploited due to dense undergrowth, absence of pure stands and lack of transport facilities.

2. Tropical Semi-Evergreen Forests. Bordering the areas of tropical wet evergreen forests, are comparatively drier areas of the tropical semi-evergreen forests. Here the annual rainfall is 200-250 cm, the mean annual temperature varies from 24°C to 27°C and the relative humidity is about 75 per cent. Obviously these forests are found on the Western coast, Assam, lower slopes of the Eastern Himalayas, Odisha and Andamans.

The semi-evergreen forests are less dense but more gregarious (especially in Assam) than the wet evergreen forests. At places, these forests represent a transition from wet evergreen to deciduous forests. Further, these forests are characterised by many species, frequently buttressed trunks, rougher and thicker bark, heavy climbers, less bamboos and abundant epiphytes. The important species of these forests are aini, semul, gutel, mundani, *hopea*, benteak, kadam, irul, laurel, rosewood, mesua, haldu, kanju, byasal, kusum, thorny bamboo, etc. on the Western Ghats, and bonsum, white cedar, Indian chestnut, *litsa*, hollock, champa, mango, etc. in the Himalayan region.

3. Tropical Moist Deciduous Forests. These forests are found in areas of moderate rainfall of 100 to 200 cm per annum, mean annual temperature of about 27°C and the average annual relative humidity of 60 to 75 per cent. Such areas include a belt running along the Western Ghats surrounding the belt of evergreen forests both on the western and the eastern slopes, a strip along the Shiwalik range including terai and bhabar from 77° E to 88° E, Manipur and Mizoram, hills of eastern Madhya Pradesh and Chhattisgarh, Chota Nagpur Plateau, most of Odisha, parts of West Bengal and in the Andaman and Nicobar islands.

The trees of these forests drop their leaves for about 6-8 weeks during the spring and early summer when sufficient moisture for the leaves is not available. The sub-soil water is not enough to enable the trees to retain their leaves throughout the year. The general appearance is burnt up and bare in April-May. These forests again become green when the leaves grow with the onset of the rainy season. Tropical moist deciduous forests present irregular top storey of different species, 25 to 60 metres high, heavily buttressed trees and fairly complete shrubby undergrowth with patches of bamboos, climbers and canes.

These are very useful forests because they yield valuable timber and several other forest products. The main species found in these forests are teak, sal, padauk, laurel, white chuglam, badam, dhup, chikrosi, kokko, haldu, rosewood, mahua, bijasal, lendi, semul, irul, dhaman, amla, kusum, tendu, paula, jamun, bamboo, etc. It is comparatively easy to exploit these forests due to their high degree of gregariousness.

These forests occupy a much larger area than the evergreen forests but large tracts under these forests have been cleared for cultivation.

4. Littoral and Swamp Forests. These forests occur in and around the deltas, estuaries and creeks prone to tidal influences and as such are also known as *delta* or *tidal* forests. While littoral forests occur at several places along the coast, swamp forests are confined to the deltas of the Ganga, the Mahanadi, the Godavari, the Krishna and the Cauvery. The most peculiar feature of these forests is that they can survive and grow both in fresh as well as brackish water. Dense mangroves occur all along the coastline in sheltered estuaries, tidal creeks, backwaters, salt marshes and mudflats covering a total area of 6,740 sq km which is about seven per cent of the world's total mangrove area. It provides useful fuel wood. The most pronounced and the densest is the *Sunderban* in the Ganga delta where the predominant specie *Sundri* (Heriteera) grows abundantly. It provides hard and durable timber which is used for construction and building purposes as well as for making boats.

The important species found in these forests are Sundri, burguiera, sonneratia, agar, bhendi, keora, nipa, amur, bhara, *rhizophora*, *screw pines*, canes and palms, etc.

B. DRY TROPICAL FORESTS

5. Tropical Dry Evergreen Forests. Along the coasts of Tamil Nadu are areas which receive annual rainfall of about 100 cm mostly from the north-east monsoon winds in October-December. Here, the mean annual temperature is about 28°C and the mean humidity is about 75 per cent. These areas are covered by the tropical dry evergreen forests. The growth of evergreen forests in areas of such low rainfall arouses great botanical interest, and the reason for such a phenomena is difficult to explain. It may be due to the seasonal distribution of rainfall. Most of rainfall occurs in winter. The chief characteristics of these forests are short statured trees, upto 12 m high, with complete canopy, mostly of coriaceous leaved trees of short boles, no canopy layer differentiation, bamboos are rare or absent and grasses not conspicuous. The important species are *khirni, jamun, kokko, ritha, tamarind, neem,*

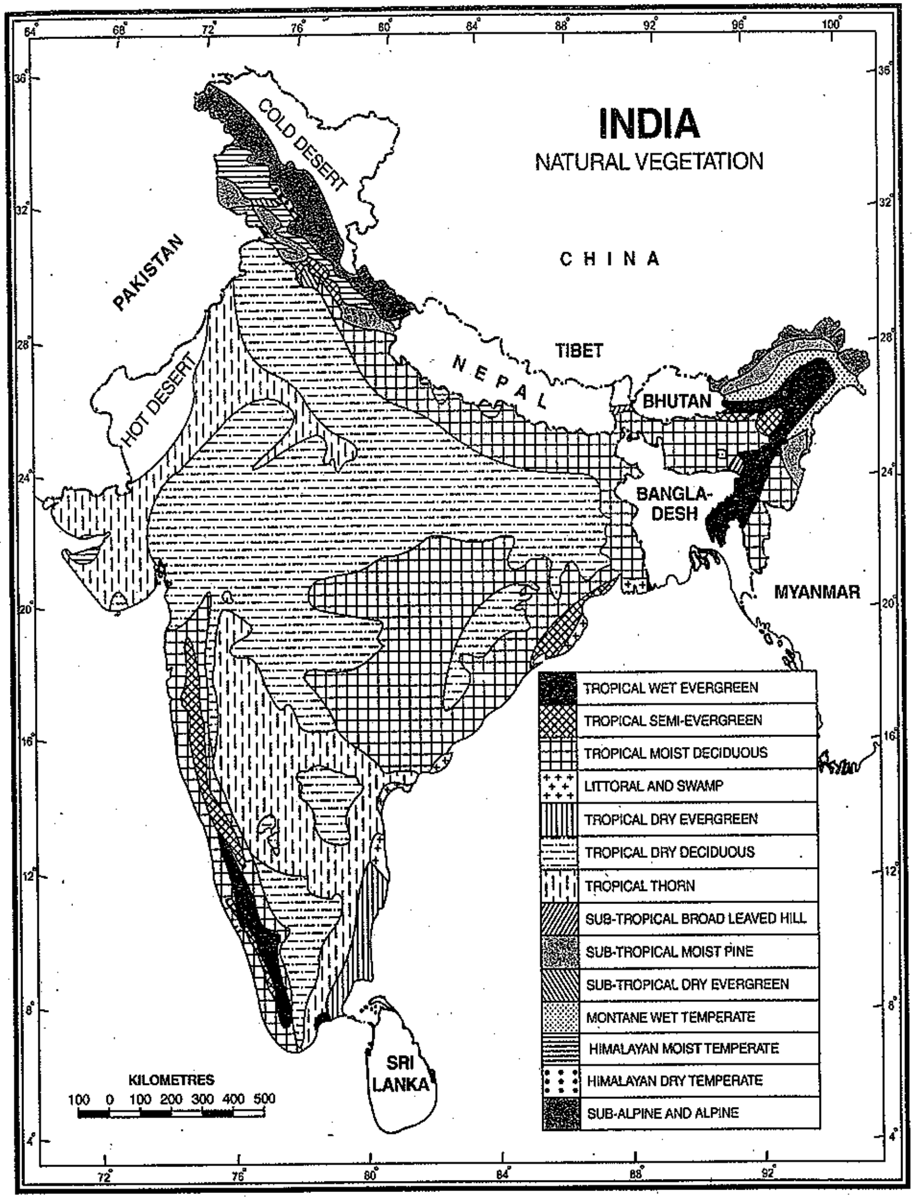

FIG. 6.1. India : Natural Vegetation

machkund, toddypalm, gamari canes, etc. Most of the land under these forests has been cleared for agriculture or casuarina plantations.

6. Tropical Dry Deciduous Forests. These are similar to moist deciduous forests and shed their leaves in dry season. The major difference is that the species of dry deciduous forests can grow in areas of comparatively less rainfall of 100-150 cm per annum. They represent a transitional type; on the wetter side, they give way to moist deciduous and on the drier side they degenerate into thorn forests. Such forests are characterised by closed and rather uneven canopy, composed of a mixture of a few species of deciduous trees, rising upto a height of 20 metres or so. Enough light reaches the ground to permit the growth of grass and climbers. Bamboos also grow but they are not luxuriant.

The tropical dry deciduous forests are widely distributed over a large area. They occur in an irregular wide strip running north-south from the foot of the Himalayas to Kanniyakumari except in Rajasthan, Western Ghats and West Bengal. The important species are teak, axlewood, tendu, bijasal, rosewood, amaltas, palas, haldu, kasi, bel, lendi, common bamboo, red sanders, anjair, harra, laurel, satinwood, papra, achar, sal, khair, ghont, etc.

Large tracts of this forest have been cleared for agricultural purposes and these forests have suffered from severe biotic factors such as over cutting, over grazing and fire, etc.

7. Tropical Thorn Forests. In areas of low rainfall (less than 75 cm), low humidity (less than 50 per cent) and high temperature (25°-30°C), there is not much scope for thick forests and only tropical thorn forests are found. The trees are low (6 to 10 metres maximum) and widely scattered. Acacias are very prominent, widely and pretty evenly spaced. Euphorbias are also conspicuous. The Indian wild date is common, especially in damper depressions. Some grasses also grow in the rainy season.

These forests are found in the north-western parts of the country including Rajasthan, south-western Panjab, western Haryana, Kachchh and neighbouring parts of Saurashtra. Here they degenerate into desert type in the Thar desert. Such forests also grow on the leeside of the Western Ghats covering large areas of Maharashtra, Karnataka, Telangana, Andhra Pradesh and Tamil Nadu. The important species are khair, reunjha, neem, babul, thor, cactii, khejra, kanju, palas, ak, nirmali, dhaman, etc.

C. MONTANE SUB-TROPICAL FORESTS

8. Sub-tropical Broad-leaved Hill Forests. These forests are found in the eastern Himalayas to the east of 88°E longitude at altitudes varying from 1000 to 2000 m where the mean annual rainfall is 75 cm to 125 cm, average annual temperature is 18°-21°C and the average humidity is 80 per cent. They form luxurious forests of evergreen species, are fairly high (20-30 metres) and dense. Evergreen oaks and chestnuts predominate with some ash and beech. Sals and pines may occur on lower and higher margins respectively. Climbers and epiphytes are common.

These forests are not so distinct in the southern parts of the country due to restricted area of southern hills. They occur in the Nilgiri and Palni hills at 1070-1525 metres above sea level. It is essentially a "stunted rain-forest" and is not so luxuriant as the true tropical evergreen. The higher parts of the Western Ghats such as Mahabaleshwar, the summits of the Satpura and the Maikal Range, highlands of Bastar and Mt. Abu in the Aravali Range also carry sub-types of these forests. But most of these forests have been destroyed, reduced and changed beyond recognition.

9. Sub-tropical Moist Pine Forests. These forests also occur at the same height as the wet hill forests *i.e.* at 1000 to 2000 metres above sea level but in the western Himalayas between 73°E and 88°E longitudes. Some parts of Arunachal Pradesh, Manipur, Naga Hills and Khasi Hills of Meghalaya are also covered by such forests at similar altitudes. Chir or Chil is the most dominant tree which forms pure stands. It provides valuable timber for furniture, boxes and buildings. It is also used for producing resin and turpentine. There is often a grassy floor with bulbous plants and little undergrowth, except for stunted evergreen oaks in wetter areas.

10. Sub-tropical Dry Evergreen Forests. Like the tropical moist evergreen, this occurs in a restructed area and is found in the *Bhabar*, the Shiwaliks and the western Himalayas upto about 1000 metres above sea level. Here the rainfall is 50-100 cm (15 to 25 cm in December-March). The summers are sufficiently hot and winters are cold enough for the occurrence of frequent frost. This is a low, practically scrub forest with small evergreen stunted trees and shrubs, including thorny species, herbs and grasses. Olive, acacia *modesta* and *pistacia* are the most predominant species. Considerable tracts are covered by dwarf creeping palm *Nonnorpops*.

D. MONTANE TEMPERATE FORESTS

11. Montane Wet Temperate Forests. This variety of forests grows at a height of 1800 to 3000 m above sea level in areas where the mean annual rainfall is 150 cm to 300 cm, the mean annual temperature is about 11°C to 14°C and the average relative humidity is over 80 per cent. This is mainly found in the higher hills of Tamil Nadu and Kerala, in the Eastern Himalayan region to the east of 88°E longitude including the hills of West Bengal, Assam, Arunachal Pradesh, Sikkim and Nagaland. These are closed evergreen forests in which the trees are mostly short-boled and branchy attaining a large girth. Leaves are dense and rounded. Branches are clothed with mosses, ferns and other epiphytes. Woody climbers are common. The trees rarely achieve a height of more than 6 metres.

Deodar, Chilauni, Indian chestnut, birch, plum, *machilus*, *cinnamomum*, *litsea*, *magnolia*, blue pine, oak, hemlock, etc. are important species.

12. Himalayan Moist Temperate Forests. Occurring in the temperate zone of the Himalayas between 1500 and 3300 metres where the annual rainfall varies from 150 cm to 250 cm, the Himalayan moist temperate forests cover the entire length of this mountain range in Kashmir, Himachal Pradesh, Uttarakhand, Darjeeling and Sikkim. Such forests are mainly composed of coniferous species, mostly pure, 30 to 50 m high. In the wetter east, the broad leaved evergreens are mixed with the dominant conifirs. Pines, cedars, silver firs, spruce, etc. are most important trees. They form high but fairly open forest with shrubby undergrowth including oaks, rhododendrons, laurels and some bamboos. In comparatively drier western parts where the rainfall varies from 115 to 180 cm especially to the west of 80°E longitude, deodar dominates the scene and forms pure stands. It provides fine wood which is of much use for construction, timber and railway sleepers.

13. Himalayan Dry Temperate Forests. These are predominantly coniferous forests with xerophytic shrubs in which deodar, chilgoza, oak, ash, maple, olive, celtis, parrotia, etc. are the main trees. Such forests are found in the inner dry ranges of the Himalayas where south-west monsoon is very feeble and the precipitation is below 100 cm, mostly snow. Such areas are in Ladakh, Lahul, Chamba, Kinnaur, Garhwal and Sikkim.

E. ALPINE FORESTS

The Alpine forests occur all along the Himalayas at altitudes ranging between 2,900 to 3,500 m or even upto 3800 m above sea level, depending upon the location and the variety of species. These forests can be divided into : (1) sub-alpine; (2) moist alpine scrub and (3) dry alpine scrub. The sub-alpine forests occur at the upper limit of tree forest adjoining alpine scrub and grasslands and comprise of dense growth of small crooked trees and large shrubs with coniferous overwood. It is a mixture of coniferous and broad-leaved trees in which the coniferous trees attain a height of about 30 m while the broad leaved trees reach only 10 m. Fir, kail, spruce, rhododendron, plum, yew, etc. are important species. *The moist alpine scrub* is a low evergreen dense growth of rhododendron, birch, berberis and honeysuckle which occurs from 3,000 metres and extends upto snowline. *The dry alpine scrub* is the uppermost limit of scrub xerophytic, dwarf shrubs, over 3,500 metres above sea level and found in dry zone. Juniper, honeysuckle, artemesia, potentilla, etc. are important species.

TABLE 6.1. India : Area under Forests

Sl. No.	Forest Group	Area in million hectares	Percentage of total area
1.	Tropical Wet Evergreen	5.120	8.0
2.	Tropical Semi-evergreen	2.624	4.1
3.	Tropical Moist Deciduous	23.680	37.0
4.	Littoral and Swamp	0.384	0.6
5.	Tropical Dry Evergreen	0.128	0.2
6.	Tropical Dry Deciduous	18.304	28.6
7.	Tropical Thorn	1.664	2.6
8.	Sub-tropical Broad-leaved	0.256	0.4
9.	Sub-tropical Moist Hill (pine)	4.224	6.6
10.	Sub-tropical Dry Evergreen	1.600	2.5
11.	Montane Wet Temperate	2.304	3.6
12.	Himalayan Moist Temperate	2.176	3.4
13.	Himalayan Dry Temperate	0.192	0.3
14.	Alpine (including sub-alpine, moist and dry alpine scrub)	1.344	2.1
	Total	64.000	100.0

Source : K.P. Sagreiya, Forests and Forestry (1994) p. 67.

As different forest groups grow under different geographical conditions, the area covered by each group differs greatly. The extent of forests of different groups for the country as a whole, is given in **table 6.1**:

Apart from the major classification of Indian forests described earlier, the Indian forests may also be classified on the basis of statutes, ownership, composition and exploitability.

1. Legal or Administrative Classification. This classification has been done to protect the forests against indiscriminate destruction. From legal or administration point of view, the Indian forests have been divided into : (*i*) Reserved, (*ii*) Protected and (*iii*) Unclassed. Reserved and protected forests are permanent forests which are maintained for regular supply of timber and other forest products as well as for ecological reasons. They cover about 54 per cent and 29 per cent of the total forest area respectively. The unclassed forests amounting to about 17 per cent of the total forest areas is largely degraded, unproductive and unprofitable forest.

2. Classification based on Ownership. Most of the forests are owned by the government through different departments such as forest department. Some of the forest land is owned by corporate bodies. A negligible proportion of less than 1 per cent is privately owned. Some forest land in Meghalaya, Odisha, Panjab, and Himachal Pradesh is privately owned.

3. Classification according to Composition. Mainly two types of forests are recognised according to composition. They are (*i*) Coniferous and (*ii*) Broad leaved. The ***Coniferous forests*** cover only 3.5 million hectares and are mainly confined to the Himalayan ranges. Some species of the coniferous forests are deodar, chir, fir, spruce, pine, etc. Though they contain valuable softwood timber, they are not properly exploited due to their inaccessibility, difficult terrain and lack of transport facilities. The ***broad leaved*** forests are widely spread and cover about 95 per cent of the total forest area of the country. Sal and teak are the most important species and provide valuable timber. They cover about 16.55 per cent and 13.82 per cent of the total area under broad leaved forests respectively. Bamboo covers about 7.48 per cent of the total area under broad leaved forests. The other species of the broad leaved forests are rosewood, Indian laurel, shistram, garyan and benteak.

4. Classification according to Exploitability. From the exploitability point of view, the forests can be classified into : (*i*) exploitable (*ii*) potentially exploitable and (*iii*) others. About half of our forests are exploitable. Most of them supply non-coniferous timber. About one fourth of the forests are potentially exploitable. Both the exploitable and potentially exploitable forests occur in Assam, Arunachal Pradesh, Tripura, Western Ghats, Satpura, Maikal, Chota Nagpur plateau, Andaman and Nicobar Islands, Odisha and adjoining areas of Andhra Pradesh and Chhattisgarh. Large proportion of our forests is inaccessible for effective exploitation and are also termed as *non-merchantable*. They lie in the high reaches of the Himalayas in Kashmir and Arunachal Pradesh where they cannot be exploited due to lack of transport facilities.

GEOGRAPHICAL DISTRIBUTION OF FOREST AREA

The total geographical area of the country is 32,87,263 sq km out of which an area of 6,77,816 sq km or 20.6 per cent was under forests in 2003 (**Table 6.2**). This is much below the average of 30.4 per cent for the world. The picture is very gloomy when we compare our percentage of forests area with 34.4 per cent of Canada, 36.0 per cent of Germany, 41.07 per cent of the U.S.A., 52.00 of Zaise, 56.10 per cent of Brazil, 57.8 per cent of Sweden and 67.6 per cent of Japan. India with about 17.5 per cent of the world's population has nearly 2 per cent of the total forests, and if the forest growing stock has been correctly estimated, it is one of the lowest per unit area *i.e.*, less than 1 per cent of that of the forests of the world. According to the National Forest Policy, the minimum desired area which is considered safe for a tropical country like India is about 33 per cent. As per broad policy recommendations, about 60 per cent of the area in the Himalayas and the Peninsular hills and 20 per cent in the Great Plains should be under forests. Furthermore, the per capita forest area in India is bare 0.06 hectares against the world average of 1.08 hectares. The per capita forest cover is 1.8 hectares in the U.S.A., 3.2 hectares in Sweden, 3.5 hectares in Russia, 5.1 hectares in Australia, 8.6

hectares in Brazil and 22.7 hectares in Canada. The production of Indian forests is also very low, being only 0.5 cubic metre per hectare a year as against the world average of 2.1 cubic metres per hectare per year. Thus the useful forest resources are extremely inadequate for a predominantly agricultural country like India.

The forest resources are very unevenly distributed in India. Madhya Pradesh has the largest area of over 76 thousand sq km under forests (**Table 6.3**). The other states with considerable area under forests are Arunachal Pradesh (68 thousand sq km), Chhattisgarh (56 thousand sq km), Odisha (48 thousand sq km), Maharashtra (47 thousand sq km) and Andhra Pradesh including Telangana (44 thousand sq km). Incidently, most of them are very large states and the total forest area is not a good index of forest prosperity.

Percentage of forest area to total area can serve as a better index of the forest cover. Unfortunately, the forests are conspicuous by their absence where they are needed the most. For example only 5 per cent of the total area in the thickly populated Ganga plain is under forests. In north-west India about 11 per cent of the area is under forests while the forests cover about 20 per cent of the area in Tarai. As per percentage of forest area to total area, Andaman Nicobar Islands. Arunachal Pradesh, Mizoram and Nagaland are very rich areas. These regions have over 80 per cent of their geographical area under forests. Lakshadweep, Manipur, Meghalaya, Tripura and Goa are also in a comfortable position as more than half of their geographical area is covered by forests. Forest cover is reasonably good in the states of Assam, Chhattisgarh, Himachal Pradesh, Jharkhand, Kerala, Madhya Pradesh, Odisha, Sikkim, Uttarakhand and the union territory of Dadra and Nagar Haveli where more than one-fourth of the geographical area is under forests. But there are other states where the percentage of forest area to total area is desperately low. For example, Punjab, Haryana and Rajasthan have very low of 3.09, 3.59 and 4.63 per cent of their land under forests. These happen to be the lowest percentages in any geographical region in the country. Other large and important states like Uttar Pradesh (5.86%), Bihar (5.92%), Gujarat (7.51%) and Jammu and Kashmir (9.57%) also have very low percentage of the area under forests. These states do not have even one-tenth of the area covered by forests. Rajasthan and Gujarat receive scanty rainfall and experience arid and semi-arid climate. Much vegetation cover is not expected under such conditions. In states like Punjab, Haryana, Uttar Pradesh and Bihar vast forest tracts have been cleared to make land available for cultivation. These are very rich areas from agriculture point of view. Among the union territories, Chandigarh, Daman and Diu, Delhi and Puducherry are poor states. In Jammu and Kashmir, the low percentage of the forest area is primarily due to low rainfall, steep barren slopes and snow covered peaks. The semi-arid lands of Maharashtra, Karnataka, Andhra Pradesh, Telangana,

TABLE 6.2. India : Forest Cover Estimates (sq km)

Cycle	Year	Satellite and Sensor	Data Period	Forest Cover
First	1987	Landsat-Mss	1981-83	640,819
Second	1989	Landsat-TM	1985-87	638,804
Third	1991	Lansat-TM	1987-89	639,364
Fourth	1993	Lansat-TM	1989-91	639,386
Fifth	1995	IRS-1B LISSII	1991-93	638,879
Sixth	1997	IRS-1B LISSII	1993-95	633,397
Seventh	1999	IRS-IC/ID LISSIII	1996-98	637,293
Eighth	2001	IRS-IC/ID LISSIII	2000	675,538
Ninth	2003	IRS-IDLISSIII	2002	677,816

Source : State of Forest Report 2005.

TABLE 6.3. India : Statewise Area under Forest (sq km) in 2005

State /Union Territory	Geographical Area	Total Forest	Dense Forest	Open Forest	Percentage of forest area to geographical area
STATES					
Andhra Pradesh (including Telangana)	2,75,069	44,372	24,329	20,043	16.13
Arunachal Pradesh	83,743	67,777	52,388	15,389	80.93
Assam	78,438	27,645	12,831	14,804	35.24
Bihar	94,163	5,579	3,114	2,465	5.92
Chhattisgarh	1,35,191	55,863	38,728	17,135	41.32
Goa	3,702	2,164	1,150	1,014	58.45
Gujarat	1,96,022	14,715	6,138	8,577	7.51
Haryana	44,212	1,587	526	1,061	3.59
Himachal Pradesh	55,673	14,369	8,928	5,441	25.81
Jammu & Kashmir	2,22,236	21,273	10,529	10,744	9.57
Jharkhand	79,714	22,591	11,622	10,969	28.34
Karnataka	1,91,791	35,251	22,090	13,153	18.38
Kerala	38,863	15,595	9,660	5,935	40.13
Madhya Pradesh	3,08,245	76,013	41,082	34,931	24.66
Maharashtra	3,07,713	47,476	28,384	19,092	15.43
Manipur	22,327	17,086	6,464	10,622	75.37
Meghalaya	22,429	16,988	7,176	9,842	75.74
Mizoram	21,081	18,684	6,306	12,378	88.63
Nagaland	16,579	13,719	5,838	7,881	82.75
Odisha	1,55,707	48,374	28,194	20,180	31.07
Punjab	50,362	1,558	723	855	3.09
Rajasthan	342,239	15,850	4,470	11,380	4.63
Sikkim	7,096	3,262	2,410	852	45.97
Tamil Nadu	1,30,058	23,044	12,440	10,604	17.72
Tripura	10,486	8,155	5,030	3,125	77.77
Uttarakhand	53,483	24,492	18,398	6,044	45.70
Uttar Pradesh	2,40,928	14,127	5,979	8,148	5.86
West Bengal	88,752	12,413	6,079	6,334	13.99
UNION TERRITORIES					
A. & N. Islands	8,249	6,629	6,005	624	80.36
Chandigarh	114	15	9	6	13.6
D.& N. Haveli	491	221	130	91	45.01
Daman & Diu	112	8	2	6	7.14
Delhi	1,483	176	54	122	11.87
Lakshadweep	32	25	15	10	78.12
Pondicherry	480	42	7	25	8.75
India	3287263	677088	387216	289872	20.60

Source : Data computed from Statistical Abstract, India, 2007, p. 150.

and Tamil Nadu in the rain-shadow of the Western Ghats receive much less rainfall and are devoid of thick forest growth. The coastal areas of Tamil Nadu and Andhra Pradesh receive sufficient rainfall in winter and support good forest cover but most of the forests in this region have been cleared for cultivation.

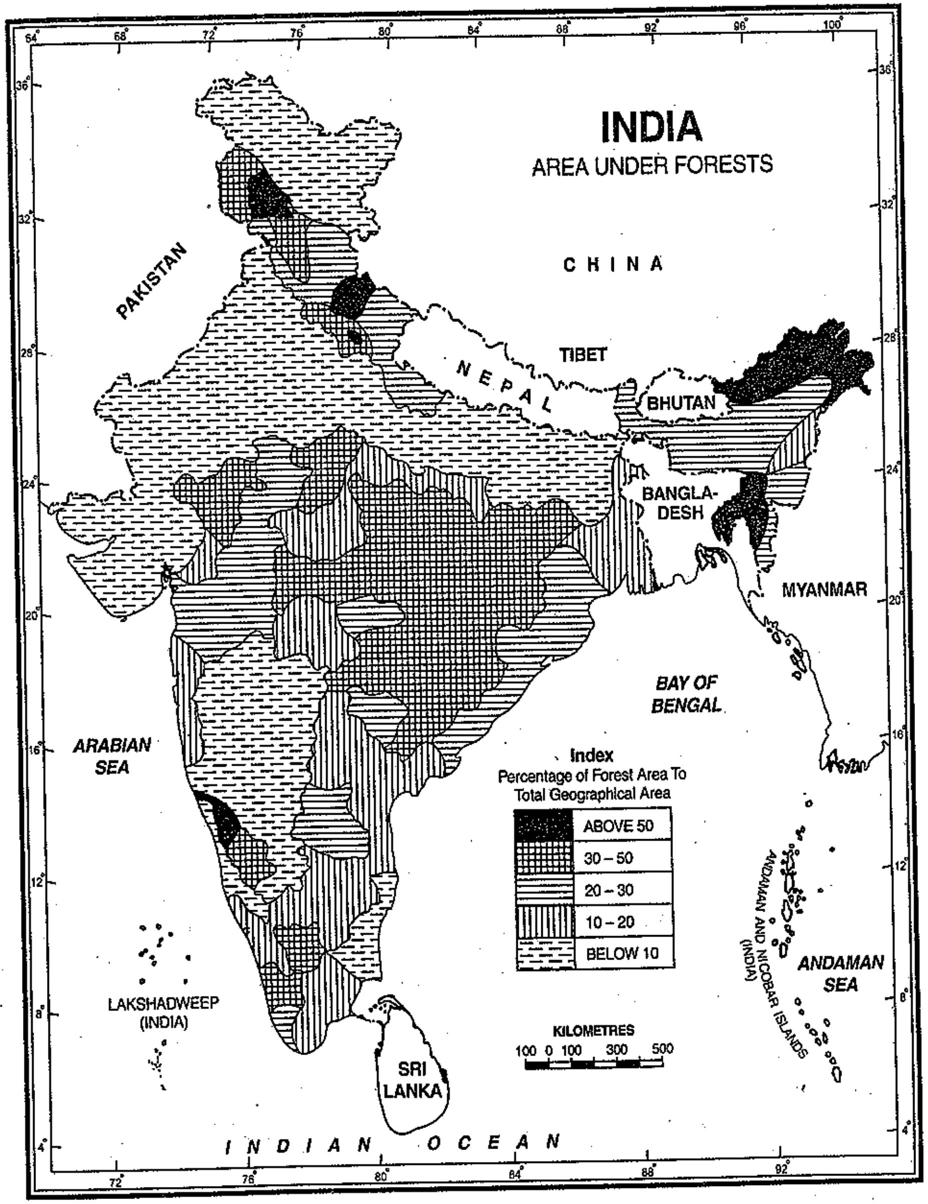

FIG. 6.2. India : Area under Forests

The forest areas do not follow political boundaries, and as such it would be better to study their growth and distribution according to the geographical conditions governing them. The areas more conductive for the forest growth are those receiving heavy rainfall, having sufficiently high temperature and soils as well as relief suitable for forest growth (see **figure 6.2**). **Table 6.4** would help in understanding the geographical distribution of forests in India.

TABLE 6.4. Geographical Distribution of Forests in India

Sl. No.	Geographical Region	Percentage of total forest of India
1.	Himalayan Region	18.00
2.	The Great Plain of India	5.00
3.	Peninsular plateaus and Hills	57.00
4.	Western Ghats and Western Coastal Plain	10.00
5.	Eastern Ghats and Eastern Coastal plain	10.00
	Total	100.00

FOREST PRODUCTS

Forests constitute one of the major natural resource of India. They produce a large variety of woods which are used as fuel, timber and industrial raw material. They also provide many more things out of which bamboos, canes, herbs, drugs, lac, grasses, leaves, oils, etc. are important. Accordingly the forest products of India are classified into two categories *viz*., major products and minor products.

Major Forest Products

Major forest products consist of timber, smallwood and fuelwood including charcoal. Indian forests produce about 5,000 species of wood, of which about 450 are commercially valuable. Both hard and soft woods are obtained from Indian forests. *Hard woods* include important species such as teak, mahogany, logwood, iron-wood, ebony, sal, greenheart, kikar, semal, etc. These woods are used for furniture, wagons, tools, etc. *Soft woods* include deodar, poplar, pine, fir, cedar, balsam, etc. They are light, strong, fairly durable and easy to work and as such are very useful for constructional timbers. They also provide useful raw materials for making paper pulp. It is interesting to note that 70 per cent of hard wood is burnt as fuel and only 30 per cent is used in industries while 70 per cent of the soft wood is used in industries and only 30 per cent is burnt as fuel. Forests meet about 40 per cent of energy needs of the country including more than 80 per cent of the rural energy requirements. The current production of wood is about 52 million cubic metres out of which about 40 million cubic metres or nearly 77 per cent of total is used as fuel wood. The current production of wood is too short of our present demand which is increasing at an alarming rate. The increase in demand for industrial wood will be much more keeping in view the large scale industrialisation in the country.

Minor Forest Products

Minor forest products include all products obtainable from the forests other than wood and thus comprise products of vegetable and animal origin. Some of the imporant forest products of minor nature are described as under :

1. Grasses, bamboos and canes
2. Tans and Dyes
3. Oils
4. Gums and Resins
5. Fibres and Flosses
6. Leaves
7. Drugs, spices and poisons
8. Edible products
9. Animal products

1. Grasses, Bamboos and Canes. Different types of grasses grow in different parts of the country. Most of the grasses are used as fodder or for thatching, but some grasses are better used for cordage, matting and as an important raw material for manufacturing paper. Grasses like *sabai*, *bhabar* and elephant are used for papermaking. *Sabai* is the most important grass which provides the basic raw material for paper industry. It is a perennial grass which grows on the bare slopes of the sub-Himalayan tract and in Bihar, Odisha, West Bengal, Madhya Pradesh and western part of Himachal Pradesh. Annually over two million tonnes of sabai grass is collected and supplied to paper mills. The roots of *khus* grass are used for making cooling screens. *Munj*, a tall grass is used for making chicks, stools, chairs, etc. and the leaves are twisted into strings.

Bamboo belongs to grass family but grows like a tree. It is woody, perennial and tall. It may attain a height of as much as 30 metres. More than 100 species of bamboo grow in the Indian forests covering an area of over one lakh sq km. Andhra Pradesh and Telangana (19.7 thousand sq km), Madhya Pradesh (14.9 thousand sq km), Odisha (10.5 thousand sq km), Assam (10.0 thousand sq km), Arunachal Pradesh (7.8 thousand sq km) and Karnataka (6.0 thousand sq km) are the main areas of its growth. The bulk of production comes from Andhra Pradesh, Telangana, Tripura, Rajasthan, Mizoram, Madhya Pradesh, Maharashtra, Gujarat, Karnataka, Kerala, Manipur, Punjab, Nagaland, and Andaman and Nicobar Islands. Bamboo is called the *poor man's timber* as it provides cheap material for roofing, walling, flooring, matting, basketry, cordage, carthoods and a host of other things. Young tender culms are eaten; the seed is collected and eaten as grain. However, the most significant commercial use of the bamboo is for making pulp for the production of paper and newsprint. Of the total bamboo consumed in India, 32 per cent is for construction, 30 per cent for rural use, 17 per cent for making paper pulp, 7 per cent for packaging and the remaining 14 per cent for other purposes.

Cane grows abundantly in moist forests of Andaman and Nicobar Islands, Karnataka, Madhya Pradesh, Kerala, Maharashtra, Nagaland, Manipur, Arunachal Pradesh and Mizoram. These are major producers of cane in India. Some parts of Assam, West Bengal, Kerala, Tamil Nadu, Jharkhand, Chhattisgarh and Odisha are also suitable for growth of cane. It is mainly used for making strings, ropes, mats, bags, baskets, furniture, walking sticks, umbrella handles, sports goods, etc.

2. Tans and Dyes. Tannins are secretion products of plant tissues. Tanning materials are used in leather industry. The most commonly used tanning materials are mangrove, amla, oak, hemlock, anwal, wattle, myrobalans, ratanjot, flowers of dhawri, babul, avaram, etc.

Some of the important dyes are obtained from red sander (bright red), khair (chocolate), flowers of Palas, fruits of *Mallotus phillipensis*, bark of wattle and roots of *Morinda tinctoria*. About two lakh tonnes of tans and dyes are produced every year in India.

3. Oils. A large number of plants and trees which grow in Indian forests contain several types of oils which are used to manufacture soaps, cosmetics, confectionary, pharmaceutical preparations and many more things. Commercially important oils are those obtained from sandalwood, lemon grass, khus and *euclyptus globulus*.

4. Gums and Resins. Gums are exuded from the stems or other parts of different trees, partly as a natural phenomenon and partly by injury to the bark or wood or blazing the tree. The most important gum is Karaya obtained from *Sterculia urens* or *S. villosa* trees of dry deciduous forests. It is mainly used in textiles, cosmetics, confectionery, medicines, inks, pastes, cigars, etc. Madhya Pradesh is the largest producer of gums in India. This state is closely followed by Maharashtra, Andhra Pradesh (including Telangana), Gujarat and Karnataka are other producers. A large proportion of Indian gums is exported to the USA, the UK and France.

Resin is obtained mainly from Chir pine which grows in the Himalayan region in Arunachal Pradesh, Uttarakhand, Himachal Pradesh, Jammu and Kashmir and some parts of Punjab. The main producers are Arunachal Pradesh, Punjab and Jammu and Kashmir. Some resin is produced in Manipur also. Crude resin consists of two principal constituents; a liquid known as oil of turpentine (25%) and a solid called resin (75%). They are separated after distillation. Turpentine is mainly used as a solvent for paints and varnish, synthetic camphor, pine oil, disinfectants, pharmaceutical preparations, wax, boot polish and industrial perfumes. Resin is an important raw material for several industries of which paper, paint, varnish, soap, rubber, water proofing, linoleum, oils, greases, adhesive tape, phenyl, plastic, etc. are important.

5. Fibres and Flosses. Fibres are obtained from the tissues of some trees. Most of such fibres are coarse and are used for rope making. However, the fibres of Ak (*Calotropis* spp.) is fine, strong and silky which is used for making fishing nets. Flosses are obtained from certain fruits and are used for stuffing pillows, mattresses, etc.

6. Leaves. Different types of leaves are obtained from the trees and are used for different purposes, the most important being the tendu leaves used as wrappers for *bidis*. The tendu tree grows in large numbers in Madhya Pradesh, Andhra Pradesh, Telangana, Bihar, Maharashtra, Gujarat, Rajasthan, Karnataka and Uttar Pradesh. About 6 lakh tonnes of tendu leaves are produced every year in India. With 246 thousand tonnes, Madhya Pradesh is the largest producer in India. Bihar with 53.5 thousand tonnes is the second largest producer. Andhra Pradesh and Telangana (51.2 thousand tonnes), Maharashtra (33 thousand tonnes) and Gujarat (12.9 thousand tonnes) are also important producers. Some quantity of leaves is also produced in Rajasthan, Karnataka and West Bengal. Tendu leaves and *bidis* are exported to Pakistan, Bangladesh, Sri Lanka and some other Asian and African countries.

Leaves of *Bauhinia vahlii* are converted into plates and leaf cups and are also used as wrappers by vendors of sweets.

7. Drugs, Spices and Poisons. Thousands of drugs are obtained from fruits, flowers, roots, stems and leaves of different types of trees, plants and herbs. Quinine is the most important drug obtained from the Indian forests.

Spices are used to add aroma or pungency to food to flavour certain dishes. The important spices are galangal, cinnamon or *Dalchini*, lesser cardamom (*Chhoti Ilayachi*), greater cardamom (*Badi Ilayachi*), etc.

Indian forests produce some poisonous substances which can act as good medicines when taken in small, regular doses. Some outstanding poisons are strychnine, aconite, datura, ganja etc.

8. Edible Products. Fruits, flowers, leaves or roots of various species provide edible products. Mango, *bel*, *ber*, *jamun*, *khirni*, *phalsa*, *sitaphal*, etc. are important fruits obtained from the forests. Among the kernels cashewnut, *akhrot* or walnut, *achar*, *chilgoza* and *kimal* are important. *Amla*, *anar*, *imli*, *karaunda*, *munga*, *kachnar*, *kaith*, *mushroom*, *zimikand*, *guchchi*, etc. are important products used as pickles or vegetables. Palmyrah, palm, mahua, corolla are used to obtain liquor and their seeds are eaten. *Tejpata*, used for flavouring curries are leaves of a small evergreen tree.

9. Animal Products. Lac is the most important animal product obtained from the forests. It is secreted by a minute insect (*Laccifer lacca*) which feeds on the saps of a large variety of trees like palash, peepul, kusum, sissoo, sisir, kul, gular, ber, banyan, jujuba and ghont. These trees grow extensively in the Chota Nagpur plateau of Jharkhand, eastern districts of Madhya Pradesh, Chhattisgarh, western border areas of West Bengal, eastern part of Maharashtra, northern districts of Odisha and to a lesser extent in Assam, Andhra Pradesh, Tamil Nadu, Uttar Pradesh, Karnataka and Punjab. India practically holds a monopoly in the production of lac. The current annual production of lac in India is about 18.5 thousand tonnes which is about 85 per cent of the world production. The main producing states are Jharkhand (40%), Chhattisgarh (30%), W. Bengal (15%), Maharashtra (5%), Gujarat, U.P., Odisha and Assam. About 95% of the total production is exported. Our main customers are the USA, Russia, Germany and U.K. At present it is widely used in medicines, plastics, electrical insulation material, dyeing silk, making bangles, paints, sealing wax, leather and wood finishing, ornamental articles, etc.

The other animal products are honey, wax, silk moths, horns and hides of dead animals, ivory, antlers of deer, etc.

The above mentioned major and minor forest products are used for various purposes and form an important sector of Indian economy. About 3.5 million persons are engaged in different forest activities. About two per cent of the government revenue comes from the forests. There has been a steady increase in government revenue from the forests. In some states like Maharashtra, Uttarakhand, Karnataka, Kerala, Odisha and Andhra Pradesh, gross revenue from forests is far greater than the expenditure on forest activities. Some foreign exchange is also earned by exporting forest products.

INDIRECT USES OF FORESTS

Apart from their direct uses described above, the forests are of immense use to man indirectly also. They prevent soil erosion, regulate the flow of rivers and reduce the frequency and intensity of floods, check the spread of deserts, add to soil fertility and ameliorate the extremes of climate.

1. Prevention and control of soil erosion. Forests play a significant role in the prevention and control of soil erosion by water and wind. The destruction of forest cover leads to increased runoff of rain water and its diminished seepage and storage in soil. The structure of the soil suffers, runoff increases and loosens the soil which is carried away to other regions. The fertility of the soil is thus lost, and it becomes barren and unproductive. The reckless destruction of forests in the Shiwalik hills, Western Ghats, Chota Nagpur plateau and in the Deccan table-land has resulted in serious problem of soil erosion. The most effective way to check soil erosion is to stop reckless cutting of forests and to plant more trees.

2. Flood Control. Roots of the trees absorb much of the rain water and use it slowly during the dry season. Thus they regulate the flow of water and help in controlling the floods. The forest cover acts as a **rain-holder** and a **rain banker**. Trees also act like millions of tiny dams and check the flow of water like a barrage. With the increased rate of deforestation, the frequency and the intensity of floods has increased in different parts of the country. In the absence of forests, the increased runoff along with sand and silt, especially after heavy downpour, comes in as a sudden rush and often gets blocked in the silted streams and causes devastating floods.

3. Checks on spread of deserts. Sand particles are blown away by strong winds in the deserts and are carried over long distances, thus resulting in the spread of deserts. The roots of trees and plants bind the sand particles and do not permit their easy transportation by wind. Therefore, the forests are a great instrument to put a check on the spread of deserts. In the long run, the forests add humidity to the atmosphere and further help in checking the spread of deserts. A great success has been achieved in checking the march of the Thar desert by planting a 650 km long and 8 km wide strip of trees on its periphery.

4. Increase of soil fertility. The fallen leaves of trees add humus to soil after their decomposition. Thus forests help in increasing the fertility of soil.

5. Effect on Climate. Forests have a far reaching effect on climate. They ameliorate the extremes of climate by reducing the heat in summer and cold in winter. They also influence the amount of rainfall by lowering the temperature of moisture laden winds and increase the relative humidity of the air through the process of transpiration. They reduce the surface velocity of winds and retard the process of evaporation.

PROBLEMS OF INDIAN FORESTRY

Indian forests face a number of problems which are both natural and manmade. Some of the major problems are briefly discussed as follows :

1. Inadequate and Dwindling Forest Cover. The biggest problem of the Indian forests is the inadequate and fast dwindling forest cover. It has already been mentioned that forests cover only 20.6 per cent of the area against the required coverage of 33 per cent. Even this small percentage of forest cover is seriously threatened by the increasing demand for major and minor forest products. These products are badly needed for fuel, building and to feed a large number of forest based industries. Vast forest tracts have been cleared for agriculture. Shifting agriculture in different parts of the country has played havoc with forests. Overgrazing is a big factor which is responsible for serious damage to forests. India possesses a livestock population of about 529.70 million of which nearly 304.42 million are bovine animals, about one-tenth of which graze in the forests. Whenever forests are easily accessible, the livestock entirely depends on grazing in them.

A large part of our achievements made by virtue of afforestation are neutralised by diversion of forest land for non-forest use.

2. Low Productivity. Productivity of Indian forests is very low as compared to some other countries. For example, annual productivity of Indian forest is only 0.5 cubic metre per hectare while it is 1.25 cubic metre per hectare in the USA, 1.8 cubic metre per hectare in Japan and 3.9 cubic metre per hectare in France.

3. Nature of Forests and their Uneconomical Utilisation. The forests are thick, inaccessible, slow growing and lack in gregarious stands in many parts of the country. Some of them are very thin and comprise only of thorny bushes. These factors make their utilization uneconomical because there is a good deal of wastage and this makes it very expensive in spite of the cheap labour available in India.

4. Lack of Transport Facilities. One of the biggest problems faced by the Indian forests is the lack of proper transport facilities. About 16 per cent of the forest land in India is inaccessible and does not have proper transport facilities. It must be remembered that the major product of the forests is timber which is a cheap and bulky commodity. As such it cannot afford high freights charged by the railways and roadways. Therefore, Indian forests cannot be economically exploited without the availability of cheap and efficient transport facilities. Unfortunately, in India, the railways serve thickly populated areas only and are not of much use to forests. All weather roads in the forest areas are badly lacking. Water transport has only limited scope. Considering these facts, we can easily say that transport with reference to forests is inadequate in India.

5. Forest Fires. Large tracts of vegetal cover are destroyed every year by forest fires. Forest fires in India are most destructive in dry season. Insufficiency of properly trained personnel to prevent and fight fires is a big handicap.

6. Plant Diseases, Insects and Pests. Large tracts of forest cover suffer from plant diseases, insects and pests which leads to considerable loss of forest wealth. For example, thousands of hectares of sal forests in Madhya Pradesh and Chhattisgarh are being threatened by sal borer for which no remedial measures have been adopted so far. Forest officials are only using the primitive methods of hiring the tribals to catch and kill the insects.

7. Obsolete Methods of Lumbering and Sawing. In most of the Indian forests, obsolete methods of lumbering, sawing etc. are practised. This system leads to a lot of wastage and low forest productivity. Large quantities of inferior wood which could be put to better use through seasoning and preservation treatment remain unutilised or go waste. Saw mills use old obsolete machinery and do not get proper power supply.

8. Lack of Commercial Forests. In India most of the forests are meant for protective purposes and commercial forests are badly lacking. Growing awareness about environmental degradation has forced us to look at forest wealth as a protective agent for environment rather than treating it as a commercial commodity.

9. Lack of Scientific Techniques. Scientific techniques of growing forests are also lacking in India. Only natural growth of forests takes place in India whereas in many developed countries new scientific techniques are being used through which tree growth is quickened. A large number of trees are malformed or consist of species which are slow growing and poor yielders.

10. Undue Concessions to Tribals and Local People. In vast forest tracts, tribals and local people have been granted customary rights and concessions for free-grazing as well as removing timber fuel and minor forest products. They are also allowed to continue with age-old shifting cultivation. These practices have led to the reduction in forest yield. In addition, there has been encroachment on these forests by the village people inhabiting the peripheral areas.

Remedies

At present there is an urgent need of undertaking silvicultural operations on a large scale. This can be done through the following measures :

1. Intensive development schemes for afforestation should be adopted. High yielding varieties should be planted in suitable areas.
2. Improved techniques of logging and extraction should be used.
3. Proper transport facilities should be provided to remote and inaccessible forest areas.
4. Saw mills should get uninterrupted power supply.
5. Latest techniques of seasoning and preservation are necessary to avoid wastage.
6. Proper arrangements to save forests from fires and plant diseases can go a long way to solve several problems.
7. A thorough inventory of forest resources is necessary to make an accurate assessment of our forest resources and make plans for their proper use.
8. Shifting cultivation should be discouraged and tribals depending on this type of cultivation should be provided with alternate sources of livelihood.

9. People associated with forest protection should be properly trained.

SOCIAL FORESTRY

Social forestry means the management and protection of the forests as well as afforestation of barren lands aimed at helping in environmental, social, and rural development as against the traditional objective of securing revenue. It is aptly described as *forestry of the people, by the people and for the people*. The main thrust of social forestry is to reduce pressure on the traditional forest areas by developing plantations of fuelwood, fodder and grasses. The term social forestry was used for the first time by the National Commission on Agriculture in 1976, to denote tree raising programmes to supply firewood, small timber and minor forest produce to rural population. This commission divided social forestry into; (*i*) agro forestry, (*ii*) expansion forestry, (*iii*) rehabilitation of degraded and low grade forests and (*iv*) recreation forestry. The programme was formally launched in 1978 and it became an integral part of the Sixth Plan in 1980. In the second Forestry Conference (1980) it was decided that social forestry scheme should be given priority over barren and waste land, community land and lands along the roads, railways and canals.

Agro forestry, community forestry, commercial farm forestry, non-commercial farm forestry and urban forestry are the main components of social forestry. **Agro forestry** involves the raising of trees and agricultural crops either on the same land or in close association in such a way that all land including the waste patches is put to good use. This enables the farmer to get food, fodder, fuel, fruit and timber from his land. The land gives maximum production and provides employment to rural masses. **Community forestry** involves the raising of trees on public or community lands aimed at providing benefit to the community as a whole. Although the plants and seedlings are provided by the forest department, the protection of plantations is primarily the responsibility of the community as a whole. India is second only to China in community forestry. Remarkable success has been achieved in community forestry in some major states like Gujarat, Tamil Nadu, Rajasthan, Kerala, Karnataka, Uttar Pradesh, Haryana, Odisha and Himachal Pradesh. **Commercial farm forestry** involves growing of trees in the fields in place of food and other agricultural crops. In this way, the farmers grow trees for direct commercial gain. This type of forestry has become very popular in Haryana, Punjab, Gujarat, Uttar Pradesh, Rajasthan and in some parts of south India. Farmers in these areas grow eucalyptus, poplars, and casuarina in their land and sell them to paper, pulp, rayon and match industries and also use them for making packing cases and fuel. The state governments are encouraging this forestry in a big way. **Non-commercial farm forestry** involves tree planting by farmers on their own land for their own use and not for sale. The land mainly used for this purpose includes margins of agricultural fields, wastelands and marginal lands which are not usually cultivated, grasslands and pastures and land around homes and cowsheds. This type of forestry is practised in Gujarat, Haryana, Kerala and Karnataka for obtaining fuel, fodder and fruit. **Urban forestry** pertains to raising and management of trees on public and privately owned lands in and around urban centres. It includes green belts, roadside avenues, recreational parks, wildlife parks, etc. Its main objectives are reduction of environmental pollution, recreation and improving aesthetic values.

FOREST CONSERVATION

Forests comprise a unique gift of nature to man and constitute one of the prized assets of a nation. They play a significant role in the national economy of a primarily agricultural and developing country like India. The agricultural and industrial progress of the country is not only stabilized but accelerated by a proper conservation and utilization of forest resource. As mentioned earlier, the uses of forests, both direct and indirect, are so large that they are aptly termed as *an index of prosperity of a nation*. Keeping in view the benefits which we derive from the forests, it is of utmost importance that strong steps should be taken to conserve forests.

Our increased demand for forests products has led to increasing destruction and degradation of our forests which is causing heavy erosion of top soil, erratic rainfall and frequent devastating floods. In short, depletion of forests has a chain reaction in ecosystem. Though it is a renewable resource, it takes its own time to regenerate. We have been destroying our forest resources so ruthlessly and so quickly that large forest tracts of yesteryears are now devoid of any forest cover. India's woods, once dark and deep, are now a living example of man's ravage and destruction. The saying that *man finds forests but leaves deserts could not be more true to India*. Over the past four decades, about 25 million hectares of land that originally had tree cover has been laid bare for agriculture and other purposes. The latest reports of the National Remote Sensing Agency (NRSA) indicates that the country is losing about 1.3 million hectares of forest cover every year. This will be detrimental to our national interest. *Nature never forgives the abuse of her gifts*. Hence, the urgent need for conservation of forests.

Forest conservation does not mean the denial of use, but rather the proper use without causing any adverse effect on our economy or environment. But any scheme of conservation of forests on a piecemeal basis will not solve the problem. Conservation of forests is a national problem and should be tackled as such. There should be perfect coordination between the forest department and other departments for an effective conservation of forests. People's participation in any forest conservation is of vital importance. ***Van Mahotsava*** was launched in 1950 to make people aware of the importance of planting trees. ***Chipko movement*** is a living example of general public awareness about forests.

The year 2011 has been declared as the International Year of Forests.

Forests have to be developed and worked for obtaining various raw materials and for providing an effective means of flood control, checking soil erosion, for regulating the flow of water in streams and for conserving moisture in the soil. Therefore, a carefully coordinated scientific policy for conservation of forests should be the first step in any scheme of national planning of the country.

While contribution of forests to the nation's economy, apart from their vital role in environment, can never be underestimated, the investment in forestry sector has been rather low. For example, from the first to the sixth Five Year Plans, the investment in forestry was between 0.39 per cent and 0.71 per cent of the total plan outlay. In the seventh Five Year Plan, the allocation was raised to 1.03 per cent of the total plan outlay. But again, the investment in the forestry sector during the eighth Five Year Plan had fallen to 0.94 per cent of the total plan outlay. At present the total investment in forestry is about ₹ 800 crore against the required investment of about ₹ 3,000 crore. This is too small an investment and unless it is increased, it will not be possible to ensure sustainable supply of goods and services for the huge sector of population dependent on forests.

The Forest (Conservation) Act, 1980 enacted to check indiscriminate deforestation/ diversion of forest lands was amended in 1988 to make it more stringent by prescribing punishment for violations. Guidelines have been prepared for working plans. Some salient features are : (*i*) working plans should be up-to-date and stress conservation; (*ii*) preliminary working plan should have multi-disciplinary approach; (*iii*) tribal rights and concessions should be highlighted along with control mechanism; (*iv*) grazing should be studied in detail and specific prescriptions should cover fodder propagation; (*v*) shifting cultivation and encroachments need to be controlled; (*vi*) clear-felling with artificial regeneration should be avoided as far as possible and clear-felling blocks should not exceed 10 hectares in hills and 25 hectares area in plains and (*vii*) banning all felling above 1000 metre altitude for a few years should be considered to allow these areas to recover. Critical areas in hills and catchment areas prone to landslides, erosion, etc. should be totally protected and quickly afforested.

The Indian Council of Forestry Research and Education (ICFRE) was created in 1987 under the Central Ministry of Environment and Forests. Later on it was constituted into an autonomous body on the pattern of the Indian Council of Agricultural Research with its headquarters at Dehra Dun. Following forestry research institutions are working under this organisation :

(*i*) Forest Research Institute, Dehra Dun
(*ii*) Institute of Arid Zone Forestry Research, Jodhpur
(*iii*) Institute of Rain and Moist Deciduous Forests, Jorhat
(*iv*) Institute of Wood Science and Technology, Bengaluru.
(*v*) Tropical Forestry Research Institute, Jabalpur
(*vi*) Institute of Forest Genetics and Tree Breeding, Coimbatore
(*vii*) Temperate Forest Research Centre, Shimla

(*viii*) Centre for Forest Productivity, Ranchi and
(*ix*) Centre for Social Forestry and Environment, Allahabad.

The future welfare and prosperity of India would very much depend upon our ability, effort and success in conserving, developing and proper utilisation of our forest resources. It is, therefore, high time that the nation as a whole awakens to this burning problem for the sake of a better future.

Forest Policy and Law

(*i*) Forest Policy of 1894. Forest policy was first declared by the British Government of India on 19 October, 1894 at the recommendation of **Dr. Voelcker**, a German expert who studied the role of forests vis-a-vis agriculture.

(*ii*) Forest Policy of 1952. With the passage of time and with India becoming an Independent country, major changes of economic and political nature took place. The population, both of human beings and livestock, had increased very substaintially, resulting in a heavier pressure on the forests for securing more land for agriculture and pasturage. The reconstruction schemes also leaned heavily on the forest products. The Government of free India thought it desirable to come out with a new National Forest Policy in 1952. While retaining the major clauses of the earlier forest policy, this policy laid greater emphasis on some other points also. It proposed the classification of forests on a functional basis into *protection forests, national forests and village forests*. The policy recommended the establishment of tree-lands wherever possible. It also stressed upon increasing pastures and timber and made a strong plea against the indiscriminate extension of agriculture by excision of forests. The policy also stressed that the *productive, protective* and *bioaesthetic* roles of forest entitle them to an adequate share of land. It also emphasised the need to protect wildlife. The policy laid stress on, (*i*) weaning the primitive people by persuation, from the baneful practice of shifting cultivation, (*ii*) increasing the efficiency of forest administration by having adequate forest laws, (*iii*) giving requisite training to the staff of all ranks, (*iv*) providing adequate facilities for management of forests and for conducting research in forestry and forest products utilization, (*v*) controlling grazing in the forestry and (*vi*) promoting welfare of the people.

(*iii*) Forest Policy of 1988. The country made rapid strides after Independence under planned development and changes of far reaching consequences occurred in the economic, political, environmental and social set up of the country since the forest policy of 1952 was declared. Therefore, the Government of India came out with a new forest policy in December, 1988. The main plank of the revised forest policy of 1988 is protection, conservation and development of forests. Its aims are : (*i*) maintenance of environmental stability through preservation and restoration of ecological balance (*ii*) conservation of natural heritage ; (*iii*) check on soil erosion and denudation in catchment area of rivers, lakes and reservoirs ; (*iv*) check on extension of sand dunes in desert areas of Rajasthan and along coastal tracts ; (*v*) substantial increase in forest/tree cover through massive afforestation and social forestry programmes ; (*vi*) steps to meet requirements of fuel wood, fodder, minor forest produce and soil timber of rural and tribal populations; (*vii*) increase in productivity of forest to meet the national needs; (*viii*) encouragement of efficient utilisation of forest produce and optimum substitution of wood and (*ix*) steps to create massive people's movement with involvement of women to achieve the objectives and minimise pressure on existing forests.

WILDLIFE

Wildlife comprises animals, birds, and insects living in forests. With large regional variations in physiography, climate and edaphic types, Indian forests offer a wide range of habitat types which are responsible for a large variety of wild life in India. India boasts of more than 90,000 species of animals which is about 6.5% of the word's total species. Indian fauna includes about 6,500 invertebrates, 5,000 mollusc, 2,546 species of fishes, 2,000 species of birds, 458 species of reptiles, 4 species of panthers and over 60,000 species of insects.

Elephant is the largest Indian mammal which only a few centuries ago, was found in large numbers in vast forest tracts of India. There are about 6,000 elephants in the forests of Assam and West Bengal, about 2,000 in Central India and nearly 6,000 in three southern states of Karnataka, Kerala and Tamil Nadu. The one-horned ***rhinoceros***, India's second largest mammal was once found throughout the Indo-Gangetic Plain as far west as Rajasthan. The number of this mammal has drastically decreased and now there are less than 1,500 rhinoceroses in India, confined to the restricted locations in Assam and West Bengal. They survive under strict protection in the *Kaziranga* and *Manas* sanctuaries of Assam and the *Jaldapara* sanctuary of West Bengal. The ***arna*** or wild buffalo is found in Assam and in Bastar district of Chhattisgarh. The ***gaur*** or the Indian bison is one of the largest existing bovine and is found in the forests of Central India. There are about 1,700 ***tigers*** in India mainly found in the forests of eastern Himalayan foothills and in parts of the peninsular India. The number of ***Cheetahs*** had fallen to less than two hundred until successful breeding programme in the *Gir sanctuary* in Gujarat resulted in some recovery. The arboreal clouded *leopard* is found in northern Assam while the *black* ***Panther*** is a widely distributed predator. *Desert* and *jungle* cats live in north western parts of the country. ***Lynx*** live upto 3,010 m in Ladakh. *Brown*, *Black* and *Sloth Bear* are found at high altitudes in the north-western and central Himalayas.

Yak, the ox of snow, is largely found in Ladakh and is tamed to be used as a draught animal. Several species of wild sheep and wild goats are also found in India. The *shapu* or *urial*, *bhoral* the blue sheep, and *nayan*, a huge sheep with curved horns are the main types of wild sheep. *Serow* and *goral* are the goat antelopes of the Himalayas. The Kashmir *markhar*, the *ibex* and the Himalayan *thar* are some of the Himalayan wild goats.

Deer also used to roam widely across the Indian forests, although their number has been drastically reduced. Stag or ***barasingha*** is found in Assam, Chhattisgarh and Madhya Pradesh. The ***Munjac*** or barking deer are found extensively in the lower wooded slopes of the Himalayas and in the forests of southern India. The ***kastura*** or the musk deer, much sought after for its musk pod, live in the birch woods in the higher forests of the Himalayas. ***Thamin*** is a pretty deer found in Manipur containing *Kasturi*.

Several species of ***monkeys*** are found in almost all the forest areas of India, the two commonest being the Rhesus Macaque and the Common ***Langur***. There are wide regional variations in the body structure and behaviour of monkeys in India.

The ***Chinkara*** or the Indian gazelle, the black buck or the Indian antelope, the ***nilgai*** or the blue bull, the mouse deer or the Indian chevrotain, the ***chawsinga*** or the four horned antelope, wild dog, the fox, the jackal, the hyena, the mongoose, shrews, hedgchogs, mole, bats, rodents and squirrels are the other mammals found in the Indian forests.

India also abounds in large variety of reptiles, although many of them are now endangered species. There are more than 200 species or subspecies of snakes, the best known being the ***Cobra***, ***Krait*** and ***Russel's Viper***. These are poisonous snakes while *Dhaman* is a non-poisonous large snake. The length of the King Cobra may be well over five metres which makes him the longest poisonous snake. However, the Rock Python and the Reticulated Python may be seven metres long, weighing over 115 kg. Several snakes living in water are also poisonous, although many of them are non-poisonous. The Blunt Nosed or Marsh Crocodile (the *Magar* or *Mugger*) and the long nosed *Gharial* are important large sized reptiles, although their number has drastically reduced. They are hunted for their skins which fetch handsome price. The big Estuarine Crocodile is still found from the Ganga to the Mahanadi. The lizards include well known Chameleon and the monitor lizard or varanus. They are found both in deserts and forests but are endangered species. India has some important breeding beaches for a number of species of turtle. In Odisha about 3,00,000 Olive Ridley Turtles breed while Hawksbill Turtles breed in southern Tamil Nadu.

India is extremely rich in bird life. There are about 2,000 species of birds in India which is about three times the number of species found in Europe. Although most of the birds have their origin in India, a number of them have their source in other areas. Some birds such as ducks, cranes, swallows, and fly-catchers migrate from central Asia to the wetlands of Bharatpur every winter. Recently, some migratory birds have been seen near Mathura.

Indian bird-life has all the varieties of birds including aquatic, gallinaceous and arboreal. Aquatic birds include a large variety of storks, herons, ducks,

flamingoes, egrets and cormorants. Among the waders and shore birds are the snipes, iluses, gulls, cranes and the lapwings. The Great Indian Bustard, pea fowl, jungle fowl, quail and partridge are the main ground birds. Babblers, barbits, bulbuls, mynas, pigeons, parakeets, doves, cuckoos, rollers, beaters, fly-catchers, orioles, warblers, wagtails, finchlarks, finches, drongos, hoops, etc. are other important birds. India is the home of a large number of birds of prey, the important being owl, eagle, kite, falcon, kestrel, etc. *Peacock* is the ***national bird of India***. Its magnificant plumage symbolizes the colour and wealth of India's bird life.

PRESERVATION OF WILDLIFE

The fast dwindling forest cover in India has adversely affected wildlife in the country. The number of several species has been drastically reduced, some are endangered species, the others are on the verge of extinction while some of them have already disappeared. This is a very serious trend and will disturb the ecological balance. Therefore, it must be checked and reversed at all costs. This calls for urgent measures for preserving wildlife.

Indian Board for Wildlife was constituted in 1952. The main purpose of the board was to advise the Government on the means of conservation and protection of wildlife, construction of national parks, sanctuaries and zoological gardens as well as promoting public awareness regarding conservation of wildlife. The wildlife (Protection) Act, 1972 is a comprehensive law which has been adopted by all states except Jammu and Kashmir (which has its own Act). It governs wildlife conservation and protection of endangered species. The Act prohibits trade in rare and endangered species. An Inter-State Committee has been set up to review the Wildlife (Protection) Act, 1972 and other laws. The wildlife (Protection Amendment Bill 2002 proposes to enhance penalties for violation of the provision of the Act. Under this, export or import of endangered species and their products are governed by the conditions and stipulations laid down therein.

Project Tiger, one of the premier conservation efforts in the country was launched on 1 April 1973. It is a centrally financed scheme under which 27 Tiger Reserves have been set up in 17 states. The tiger population had slid to a near extinction level before the implementation of Project Tiger. There were only 711 tigers in all the 27 tiger reserves in 1979. This figure rose to 1,141 in 1984, 1,327 in 1989, 1,396 in 1993 and 1,575 in 1971. The number tigers further increased to 3642 in 2001 after which there was a sharp decline and their number stood at 1411 only in 2006. Again the number of tigers started increasing and according to 2010 census, India had 1706 tigers, including 70 tigers in the border region of the Sundarbans which was excluded in the 2006 assessment. The 2010 survey was conducted in a more exhaustive manner in 17 states using hidden cameras and DNA tests. Distribution of tigers are the time of 2006 and 2010 census is shown in **table 6.5**.

TABLE 6.5. India : Number of tigers in 2006 and 2010

Area	Number of tigers in 2006	Number of tigers in 2010
1. Shiwalik Gangetic Plains	297	353
2. Central India and Eastern Ghats	602	601
3. Western Ghats	412	534
4. Northeast hills and Brahmaputra flood basins	100	148
5. Sunderbans	—	70
Total	1,411	1,706

However, the sad part of the census report is that the habitat of tigers has shrunk from 93,600 sq km in 2006 to 72,800 sq km in 2010—a loss of 20,800 sq km of tiger territory across the country.

The primary object of the project tiger is "to ensure maintenance of the viable population of tigers in India for scientific, economic, aesthetic, cultural and ecological values, and to preserve for all times, areas of biological importance as a national heritage for the benefit, education and employment of the people". Following are the salient features of project tiger :

- Amendment of the Wild Life (Protection) Act 1972 for providing provisions for constitution of the National Tiger Conservation Authority and the Tiger and other Endangered Species Crime Control Bureau.

- 100 per cent Central Assistance to 38 Tiger Reserves for deployment of Tiger Protection Force, comprising ex-army personnel and local workforce.
- Constitution of the National Tiger Conservation Authority with effect from September 4, 2006.
- Constitution of a multi-disciplinary Tiger and Other Endangered Species Crime Control Bureau

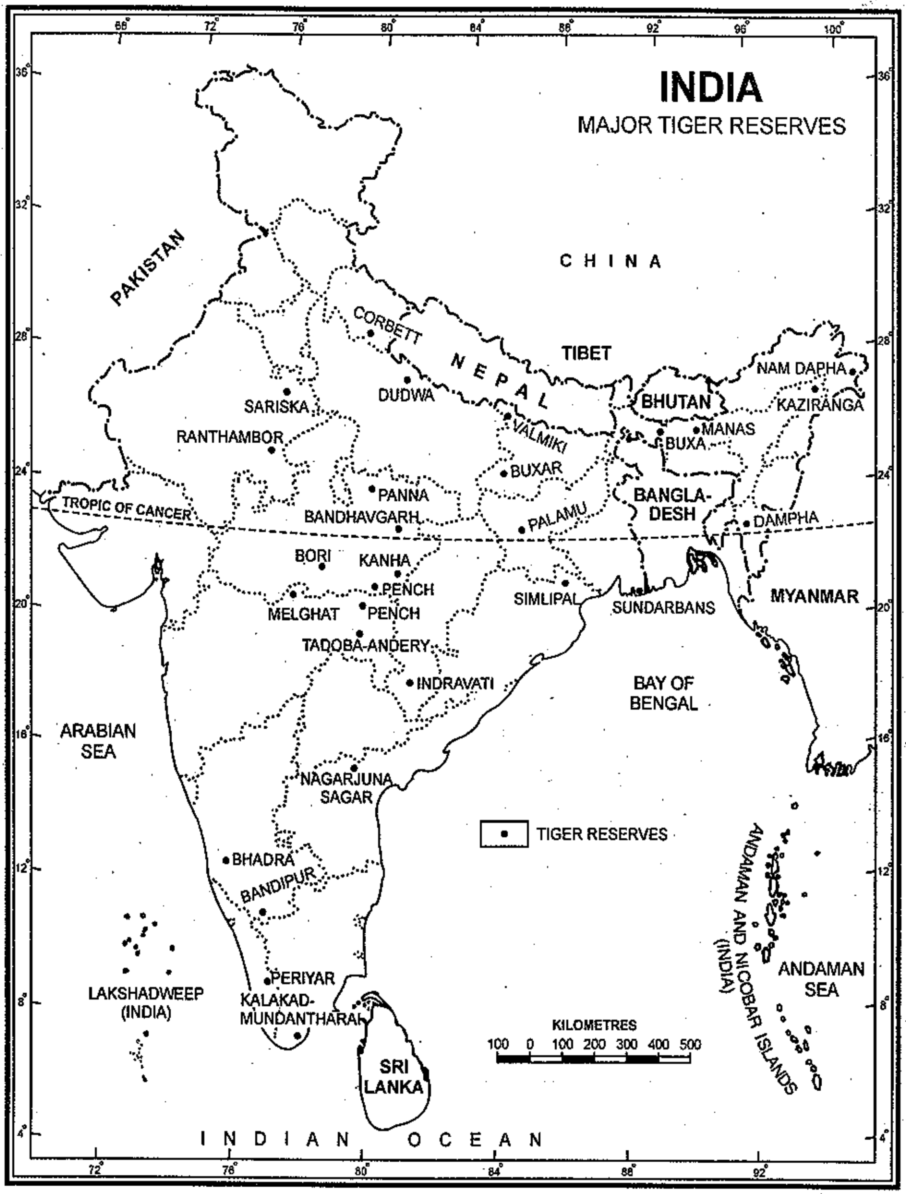

FIG. 6.3. India : Major Tiger Reserves

(Wildlife Crime Control Bureau) with effect from June 6, 2007.

- Approval accorded for declaring eight new Tiger Reserves. Notification for Sahyadri Tiger Reserve in Maharashtra has been issue in January, 2011.
- The revised Project Tiger guidelines have been issued to states for strengthening tiger conservation.
  - A scientific methodology for estimating tiger (including co-predators, prey animals and assessment of habitat status) has been involved and mainstreamed. According to the refined technology, an estimated land of 93,697 sq km has been observed as tiger habitat. An area of 29,284.76 sq km has been notified by 15 Tiger States as core or critical tiger habitat.
  - India has a Memorandum of Understanding (MoU) with Nepal on controlling transboundary illegal trade in wildlife and conservation, apart from a protocol on tiger conservation with China.
  - A Global Tiger Forum of Tiger Range Countries has been created for addressing international issues related to tiger conservation.

Out of 17 tiger states in India 16 states have notified the core or critical tiger habitat under section 38V of the Wildlife Protection Act, 1972 as amended in 2006 covering a total area of 31,407.11 sq km. These states are Andhra Pradesh, Arunachal Pradesh, Assam, chhattisgarh, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Mizoram, Odisha, Rajasthan, Tamil Nadu, Uttarakhand, Uttar Pradesh and West Bengal. Bihar has decided to notify the core or critical tiger habitat (840 sq km).

Approval has been accorded for creation of five more tiger reserves in five different states (**Table 6.6**).

TABLE 6.6. Proposed new tiger reserves

Name of the Tiger Reserve	Name of the state
1. Rataponi	Madhya Pradesh
2. Sunabeda	Odisha
3. Pilibhit	Uttar Pradesh
4. Biligiri Rangantha Temple	Karnataka
5. Mukundara Hills	Rajasthan

Source : India 2013, A Reference Annual, p. 301.

Further, following areas have been suggested by the National Tiger Conservation Authority to States for creation as tiger reserves.

Major tiger reserves are shown in **Figure 6.3**.

Name	*State*
1. Satyamangalam	Tamil Nadu
2. Nazzira-Navegaon	Maharashtra
3. Bor	Maharashtra
4. Suhelwa	Uttar Pradesh

Source : India 2013, A Reference Annual, p. 302.

A tiger crisis cell has also been formed in the Ministry of Environment and Forests. Tiger has been declared as our **national animal**. Honourable Supreme Court has banned tourist entry into core tiger areas with effect from 25th July 2012. The core tiger areas where tourist entry is banned are Corbett, Ranthambar, Panna, Kanha, Melghat, Bandipur, Kaziranga, Bandhavgarh, Nagarajunsagar and Periyar.

Project Elephant was launched as a centrally sponsored scheme in February 1992. Under this project, states having free-ranging population of wild elephants are being given financial as well as technical and scientific assistance to ensure long-term survival of identified viable populations of elephants in their natural habitats. The project is being implemented in 15 states *viz*. Andhra Pradesh, Arunachal Pradesh, Assam, Chhattisgarh, Jharkhand, Karnataka, Kerala, Maharashtra, Meghalaya, Nagaland, Odisha, Tamil Nadu, Tripura, Uttarakhand, and West Bengal. These states are being given financial as well technical assistance in achieving the objectives of this project. Other states with small population of elephants are given assistance for the purpose of census, training of field staff and mitigation of human-elephant conflict.

Crocodile Breeding Project. This project was initiated on April 1, 1974 and the project began on April 1, 1975 in Odisha. Gherial eggs were hatched for the first time in the world at Tikerpada, Distt. Dhankanal, Odisha in June, 1975. A small betal was also hatched at Kurkrail, near Lucknow same year. Crocodile husbandry work was undertaken with a view to sanctuary development. A total of 16 crocodile rearing centres were developed in the country by 1978 in eight states. Out of these 16 sanctuaries, eleven have been declared under the project. Two largest sanctuaries are the Krishna Sanctuary in Andhra Pradesh (3,600 sq km) and the Chambal Sanctuary, a tri-state statuary in Uttar Pradesh, Rajasthan and Madhya Pradesh. Andhra Pradesh has the largest number of five sanctuaries.

Gharial rehabilitation began in 1977 with the release of 26 animals in the Mahanadi River (Odisha). By 1980, 107 animals had been released in the river where their number was reduced to a critical level of just five.

A central Zoo Authority has been set-up for the proper management of zoological parks in the country. It coordinates the activities of over 200 zoos and also supervises the exchange of animals. A national policy on zoos prepared by the authority provides appropriate directions to the government and other zoo operations.

The National Wildlife Action Plan (NWAP) provides the framework of strategy as well as programmes for conservation of wildlife. The first National Wildlife Action Plan of 1983 has been revised and new Wildlife Action Plan (2002-2016) has been adopted. The Indian Board of Wildlife is the apex advisory body overseeing and guiding the implementation of various schemes for wildlife conservation.

National Park. A national parks is relatively large land or water area which contains representative samples and sites of major natural regions, features, scenery, and/or plant and animal species of national or international significance and are of special scientific, educational and recreational interest. Usually the national parks contain one or several entire ecosystems that are not materially altered by human exploitation or occupation. National parks are protected and managed by the government in a natural or near natural state. Visitors enter under special conditions for inspirational, educational, cultural and recreational purposes.

Wile Life Sanctuary. It is more or less similar to a national park which is dedicated to protect the wildlife and concerned species. A wild life sanctuary is an area constituted by competent authority in which killing and capturing of any form of wild life is prohibited, except with permission and boundaries and character of which are sacrosanct. Entry to the sanctuary is restricted, and allowed only under permission of the chief wild life warden, for research photography, tourism or other lawful business with those residing within the sanctuary. The people who are permitted to live in the sanctuary are authorised officers or persons with right over the immovable property within the limits of the sanctuary. Grazing or movement of livestock is regulated and the livestock permitted to enter the sanctuary have to be immunised against communicable diseases. The chief warden is authorised to allow or disallow entry into the sanctuary or construction of roads, building, fences, etc. Hunting is also restricted and strictly regulated. Approval of the government is necessary before the chief warden gives his permission for hunting.

Biosphere Reserves. A biosphere reserve is a unique and representative ecosystem of terrestrial and coastal areas which are internationally recognised within the framework of UNESCO's Man and Biosphere (MAB) programme. It consists of more or less concentric zones with core at the centre which is followed by buffer zone, transitional zone and finally zone of human encroachment (**Fig. 6.4**).

The objectives of Man and Biosphere Programme (MAB) are as follows :

1. Conserve representative samples of all ecosystems and habitat type.
2. Provide long term *in-situ* conservation of genetic diversity.
3. Promote and facilitate basic and applied research and monitoring of wild life.
4. Promote mass education, awareness and capacity building.
5. Promote appropriate sustainable management of natural resources.
6. Dissemination of experience so as to promote sustainable development elsewhere.
7. Biosphere management mandates people's participation for conservation of natural resource and shopping of national landscape.

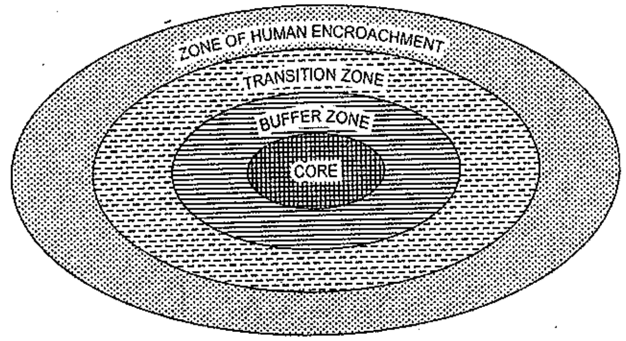

FIG. 6.4. The concept of biosphere reserve

Distinction between National Park, Sanctuary and Biosphere Reserve

National Park	Sanctuary	Biosphere Reserve
1. Hitched to the habitat for particular wild animal species such as tiger, lion, hangul, rhino, etc.	Generally species-oriented such as citrus, pitcher plant, Great Indian Bustard, etc.	Hitched to the whole ecosystem *i.e.* totality of all form of life *i.e.* ecosystem-oriented.
2. In India, the size of a national park may range from 0.04 to 3162 sq km. The most common average size is 100 to 500 sq km (in about 40% case) and 500 to 1,000 sq km (about 15%)	Size range is 0.61 to 7818 sq km. Most common (in about 40%) is 100 to 500 sq km. In 25% cases the size is 500 to 1,000 sq km.	Size range over 5,670 sq km.
3. Boundaries are fixed by legislation	Boundaries are not sacrosant	Boundaries are fix by legislation
4. Except the buffer zone, no biotic interference	Limited biotic interference	Except the buffer zone, no biotic interference.
5. Tourism permissible	Tourism permissible	Tourism normally not permissible.
6. Research and scientific management lacking	Lacking	Managed
7. So far no attention to genepods and conservation	So far not such attention	Attention given

Distribution of National Parks, Wildlife Sanctuaries and Biosphere Reserves

At present there are 100 national parks, 515 wildlife sanctuaries and 17 biosphere reserves.

National Parks. India is one of the mega diversity countries of the world and houses a large number of wild species found nowhere else in the world. This is the reason that India currently as many as 100 national parks spread through the length and breadth of the country. Major national parks are shown in **Fig. 6.5**.

Wildlife Sanctuaries. As mentioned earlier, India currently has 515 wildlife sanctuaries. Like National Parks they provide shelter to a large variety of animal species and can be traced in almost all parts of the country. (**Fig. 6.6**)

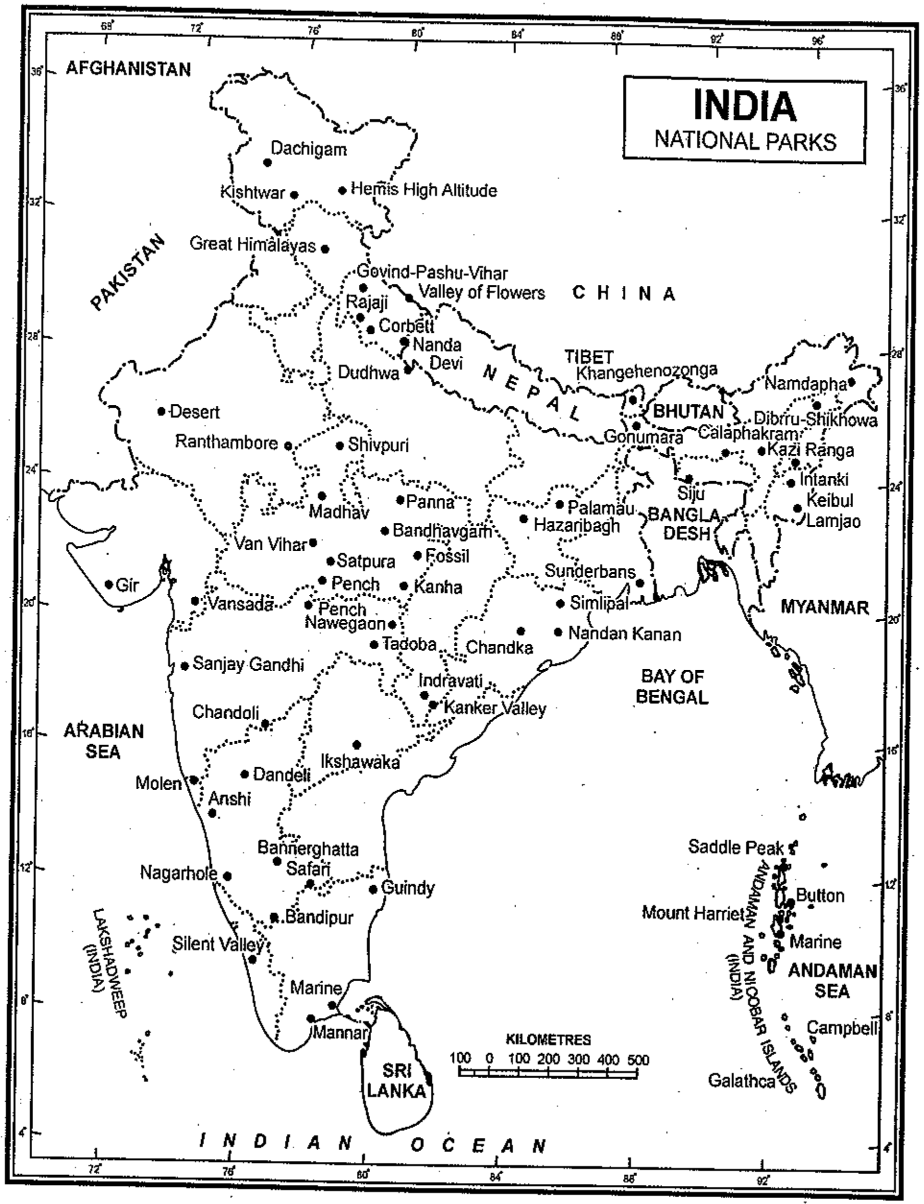

FIG. 6.5. Location of important national parks in India.

Biosphere Reserves

The biosphere reserves are required to meet a minimal set of criteria and adhere to a minimal set of conditions before they are admitted to the World Network of Biosphere Reserves designated by UNESCO. These Reserves are very rich in biological

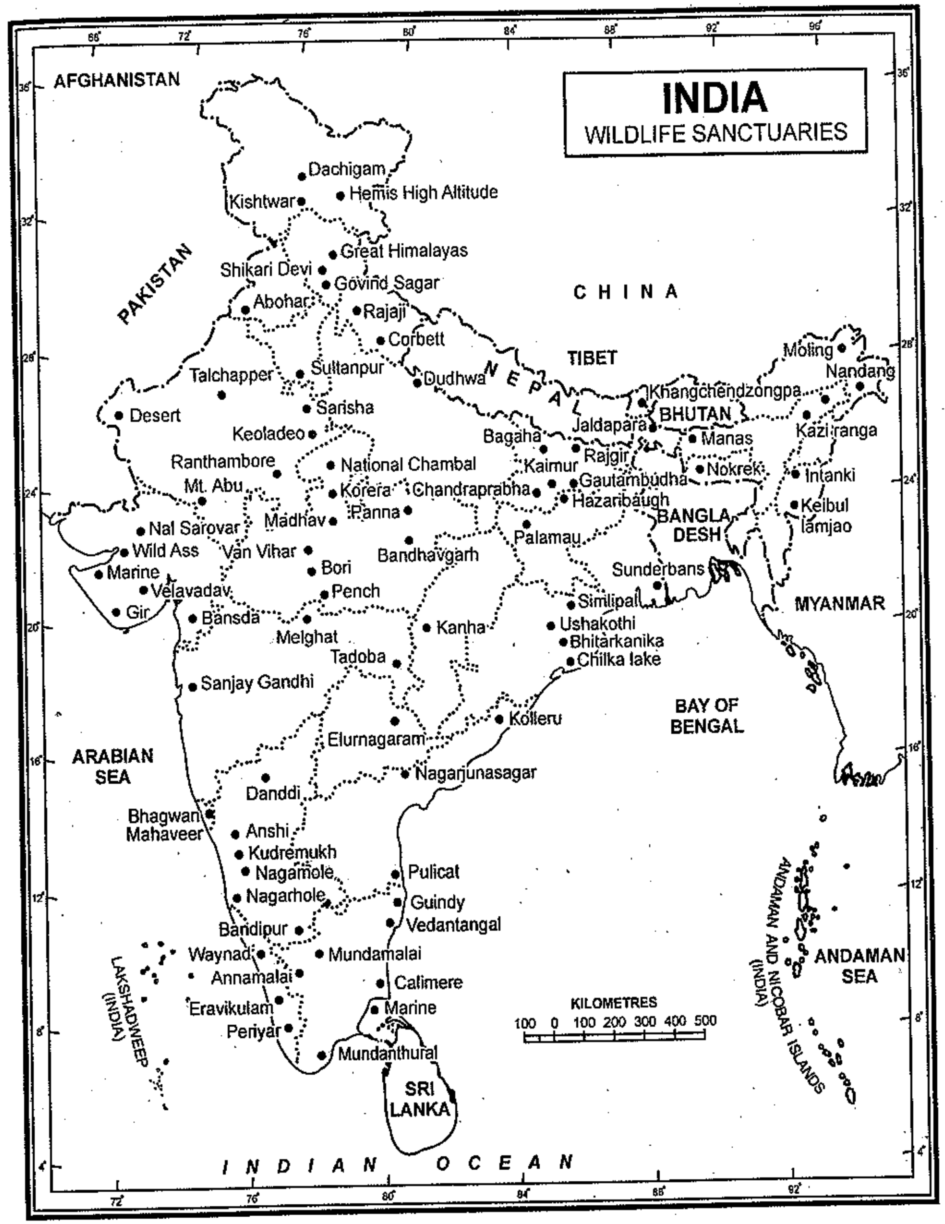

FIG. 6.6. Location of some important wildlife sanctuaries in India.

and cultural diversity and encompass unique features of exceptionally pristine nature. India has been divided into 10 Biogeographic zones and these zones together consist of 25 biogeographic provinces. The

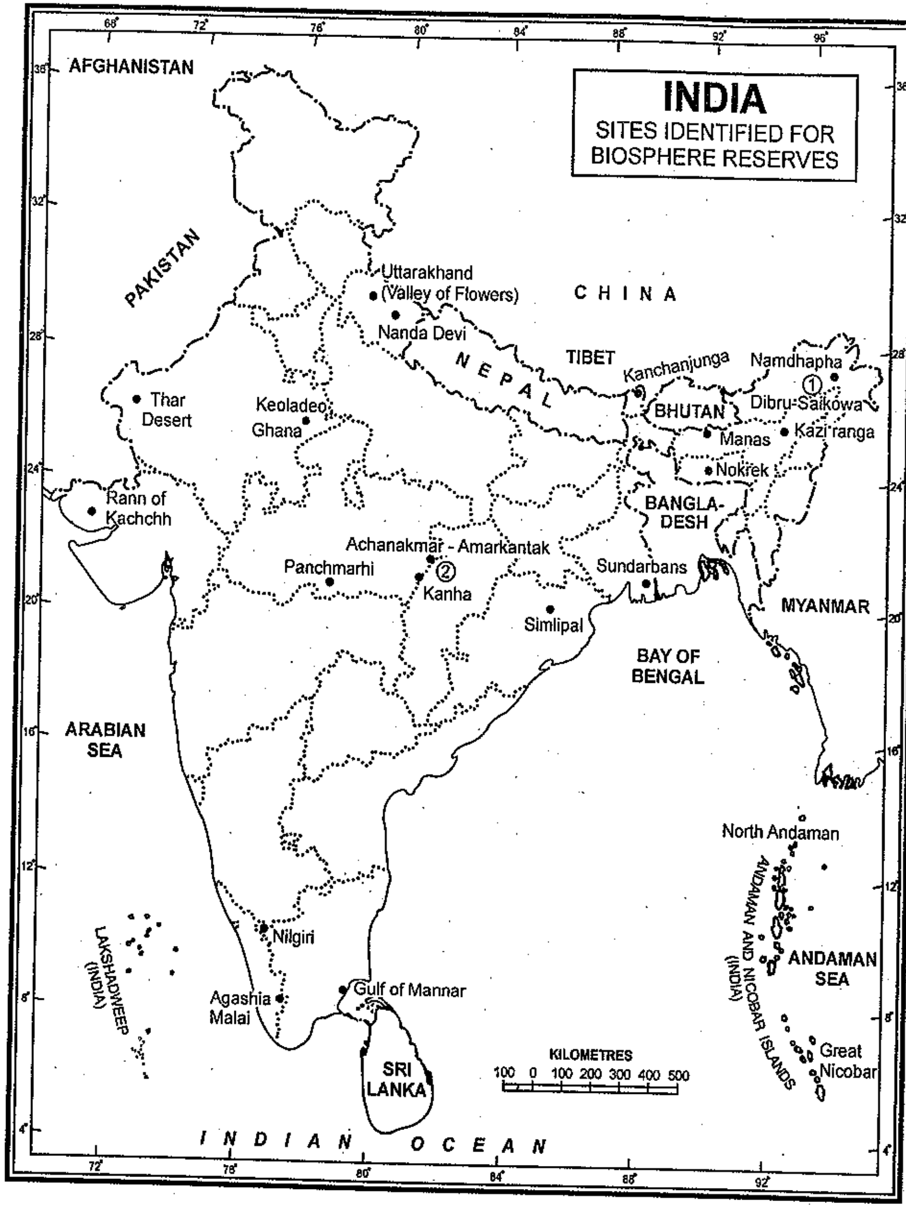

FIG. 6.7. Biosphere Reserves

aim is to designate one representative site as Biosphere Reserve in each bio-geographic province for long term conservation.

The programme was initiated in 1986 and till date 17 sites have been designated as Biosphere Reserves in different parts of the country. Out of

these 17 Biosphere Reserves, 7 Biosphere Reserves have been included in the World Network of Biosphere Reserves till now. They are (*i*) Sundarbans (West Bengal), Gulf of Mammal (Tamil Nadu), (*iii*) Nilgiri (Tamil Nadu, Kerala and Karnataka), (*iv*) Nanda Devi (Uttarakhand), (*v*) Panchmarhi (Madhya Pradesh), (*vi*) Simplipal (Odisha), and (*vii*) Nakrek (Meghalaya). The proposals in respect of Kanchanjunga (Sikkim) and Manas (Assam) are in active consideration of the UNESCO for their recognition on the world network. Strenuous efforts are being made for getting remaining Biosphere Reserves included in the World Network of Biosphere Reserves.

Measures of Conserving Wildlife

The following measures can prove effective tools for conserving wildlife:

(*a*) Ban on hunting should be strictly implemented.

(*b*) Poachers and herdsmen should not be allowed to enter the forests.

(*c*) More national parks and wildlife sanctuaries should be established.

(*d*) Existing national parks and sanctuaries should be further developed and more amenities should be provided in them.

(*e*) Captive breeding of wildlife should be encouraged.

(*f*) Seminars, workshops, exhibitions should be arranged in national parks and sanctuaries to improve the wildlife and general awareness among the public.

(*g*) Adequate medical facilities should be provided in national parks and sanctuaries for the wildlife so that their health is improved.

(*h*) Proper conditions should be created for living and breeding of wild fauna in the national parks and sanctuaries.

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Soils

INTRODUCTION

Soil is the thin surface-layer on the earth, comprising mineral particles formed by the break-down of rocks, decayed organic materials, living organisms, water and air. Soil is formed under specific natural conditions and each of the elements of the natural environment contributes to this complex process, described by the soil scientists as the process of *pedogenesis.*

Soil is a very important natural resource of India because agricultural production is basically dependent on the fertility of soil. The rich, deep fertile soils of the Ganga Plain, especially its delta, and coastal plain of Kerala support high density of population through agricultural prosperity. On the other hand, the shallow and coarse grained soils of Telangana and Rajasthan support only a small population because these soils do not provide a base for prosperous agriculture.

SOIL FORMATION IN INDIAN CONDITIONS

Indian soils, as in other parts of the world, reflect a combination of factors which have contributed to their formation. In Indian conditions, there is wide diversity with respect to geographical conditions such as, physiography, climate and vegetation. Consequently soils display a wide variety of physical and chemical characteristics. In India, soil formation is mainly related to the parent rock material, surface relief, climate and natural vegetation. Animals, insects and man also play an important role in soil formation. Some of the important factors of soil formation are mentioned below :

1. Parent Material. The material for soil formation is mainly derived from the rocks and is termed as the parent material by soil scientists. The parent material determines the colouration of the soil, its mineral composition and texture. India possesses a great variety of parent material which is generally categorised into following six classes :

(*i*) Ancient crystalline and metamorphic rocks
(*ii*) Cuddapah and Vindhyan rocks
(*iii*) Gondwana rocks
(*iv*) Deccan basalts
(*v*) Tertiary and Mesozoic sedimentary rocks of extra peninsular India
(*vi*) Recent and sub-recent rocks.

The surface rocks are exposed to the process of weathering and suffer decay and decomposition. In this process, the rocks are converted into fine grains and provide a base for the soil formation. The *ancient crystalline and metamorphic rocks* constitute greater part of the peninsular region. These rocks are basically granites, gniesses and schists which are rich in ferromagnesian materials. Such rocks give rise to red soils on weathering. The red colour of these soils is largely due to the presence of iron oxide. The *Cuddapah and Vindhyan rocks* have weathered to give calcareous and argillaceous soils. These soils are native. The *Gondwana rocks* give rise to comparatively less mature soils of more or less uniform character but of low fertility. *The Deccan traps* are composed of basalt. Basalts are quite rich in titanium, magnetite, aluminium and magnesium. Consequently the weathering of these rocks has given rise to soils of darker colour. The soil derived from the Deccan trap is fertile with high moisture holding capacity and is popularly known as ***'regur'*** or ***black cotton soil.*** The *Tertiary and Mesozoic* sedimentary rocks of extra peninsular India have given rise to soils with high porosity. These soils are generally immature *recent and sub recent* rocks, result in alluvial soils on weathering.

The soils of the Northern Plain of India have been largely derived from the depositional work of the Himalayan rivers. This depositional work has been continuing for thousands of years. These are alluvial fertile soils consisting of fine silts and clay. These soils have little relation with the original rocks. On the other hand, the soils of peninsular plateau are generally coarse-grained and are closely related to the parent rocks. The peninsular soils are generally less fertile.

2. Relief. Relief influences the process of soil formation in many ways, the most important being the slope of land. Steep slope encourages the swift flow of water and hinders the process of soil formation. There may even be soil erosion in areas of steep slope. Chambal ravines offer an important example of soil erosion. The areas of low relief or gentle slope generally experience deposition and have deep soils. Because of this reason, there are thick layers of fertile alluvial soils in the northern plain of India whereas the soils are generally shallow in the plateau area. The exceptions in the plateau are river basins where the soil layers are sufficiently deep. The degree of slope also largely determines the fertility of soil.

3. Climate. Climate is the single most important factor in soil formation. Most important climatic factors affecting soil formation are the amount and seasonal distribution of temperature and rainfall. Climate controls the type and effectiveness of weathering of the parent material, the quantity of water seeping through the soil and the type of micro-organisms present therein. In areas of heavy rainfall and high temperature, the soils are red or lateritic. Torrential rainfall during the rainy season washes the upper soil and leaches the materials into deeper horizon. During the dry summer season the evaporation exceeds precipitation and through capillary action iron and aluminium sesquioxides are transported to the surface making the soil red. In areas of alternate wet and dry climate, the leached material which goes deep down in the horizon is brought up and the blazing sun bakes the top soil so hard that it resembles a brick. Therefore, this soil is called **lateritic which literally means brick.** In arid and semi-arid regions, evaporation always exceeds precipitation. Under such circumstances, two main factors determine the nature and properties of soils. Firstly there is very little vegetation and the soils badly lack humus content. Hence the soils are invariably of light colour. Secondly, the excess of evaporation makes soils lime accumulating. Thus they are bound to be pedocal in nature. Such soils are widely spread in the extreme western part of the country. In cold climates of the Himalayan region, the process of vegetation decay is very slow and the soils formed under such circumstances are acidic in nature. When the climatic control acts for a sufficiently long period, it reduces the differences in the parent materials. Two different parent materials may develop the same soil in the same type of climate. Similarly, the same parent material may produce two different types of soils in two different types of climates. The crystalline granites produce laterite soil *in relatively moist* parts of the monsoonal region and non-laterite soil in drier areas. Hot summer and low rainfall develops black soil as is found in some parts of Tamil Nadu irrespective of the parent rock. In Rajasthan, both granite and sandstone give birth to sandy soil under arid climate. This soil is poor in organic matter.

4. Natural Vegetation. Natural vegetation reflects the combined effects of relief and climate. The formation and development of soil is very much influenced by the growth of vegetation. The decayed leaf material adds much needed **humus** to soil thereby increasing its fertility. The densely forested areas contain some of the best soils in India. There is a close relationship between the vegetation types and soil types in India.

MAJOR SOIL GROUPS OF INDIA

India is a country of vast dimensions with varied conditions of geology, relief, climate and vegetation. Therefore, India has a large variety of soil groups, distinctly different from one another. Different criteria have been applied to classify Indian soils, the outstanding being geology, relief, fertility, chemical composition and physical structure, etc. Any classification based on any one of the aforesaid criteria has its own inherent drawback. Even the most competent pedologist would find it difficult to present an accurate, complete, comprehensive and generalised account of the Indian soils.

During the British rule in India, a vast body of fascinating accounts had emerged in district gazetteers and official reports. These accounts were generally directed towards the assessment of differential soil fertility and land revenue collection, but did not attempt classification of soil types in the country. The earlier studies of Indian soils were made by foreign scholars like *Volckar* (1893), *Leather* (1898), *Schokalskaya* (1932), *Champion* (1936), etc. Indian scholars including *Wadia* (1935), *Basu* (1937), *Vishwanath and Ukil* (1944), *Chatterjee, Krishnan, and Roychaudhary* (1954) made strenuous efforts to classify soils of India. In 1957, The *National Atlas Organisation* (Kolkata) published a soil map of India in which Indian soils were classified into 6 major groups and 11 broad types. The *Irrigation Atlas of India* (1972) and Spate's *India, Pakistan* and *Ceylon* (1976) utilised the 7th approximation soil classification developed by the U.S. Department of Agriculture (USDA). The 7th approximation defines soil classes strictly in terms of their morphology and composition as produced by a set of natural and human forces. The classification is determined by quantifiable criteria.

Geologically, Indian soils can broadly be divided into two main types : (*a*) Soils of peninsular India and (*b*) Soils of extra-peninsular India.

The soils of Peninsular India are those which have been formed by the deomposition of rocks *in situ, i.e.* directly from the underlying rocks. They are transported and redeposited to a limited extent and are known as sedentary soils. On the other hand, the soils of the Extra-Peninsula are formed due to the depositional work of rivers and wind. They are mainly found in the river valleys and deltas. They are very deep and constitute some of the most fertile tracts of the country. They are often referred to as *transported or azonal soils.*

The Indian Council of Agricultaral Research (ICAR) set up an All India Soil Survey Committee in 1953 which divided the Indian soils into eight major groups. They are (1) Alluvial soils, (2) Black soils, (3) Red soils, (4) Laterite and Lateritic soils, (5) Forest and Mountain soils, (6) Arid and Desert soils, (7) Saline and Alkaline soils and (8) Peaty and Marshy soils (See **Fig. 7.1**). This is a very logical classification of Indian soils and has gained wide acceptance. A brief account of these eight soils is given as under :

1. Alluvial Soils. Alluvial soils are by far the largest and the most important soil group of India. Covering about 15 lakh sq km or about 45.6 per cent of the total land area of the country, these soils contribute the largest share of our agricultural wealth and support the bulk of India's population. Most of the alluvial soils are derived from the sediments deposited by rivers as in the Indo-Gangetic plain although some alluvial soils in the coastal areas have been formed by the sea waves. Thus the parent material of these soils is all of transported origin. The streams bring with them the products of weathering of rocks from the mountains and deposit them in the low-lying areas. The alluvial soils are yet immature and have weak profiles. They differ in consistency from *drift sand to rich loams* and from *silts* to *stiff clays*. A few occasional *kankar* beds are also present. However, pebbly, stony or gravelly soils are rare in this group. The chemical composition of the alluvial soils make this group of soils as one of the most fertile in the world. The proportion of nitrogen is generally low, but potash, phosphoric acid and alkalies are adequate, while iron oxide and lime vary within a wide range. The porosity and texture provide good drainage and other conditions favourable for bumper crops. These soils are easily replenished by the recurrent river floods and support uninterruped crop growth.

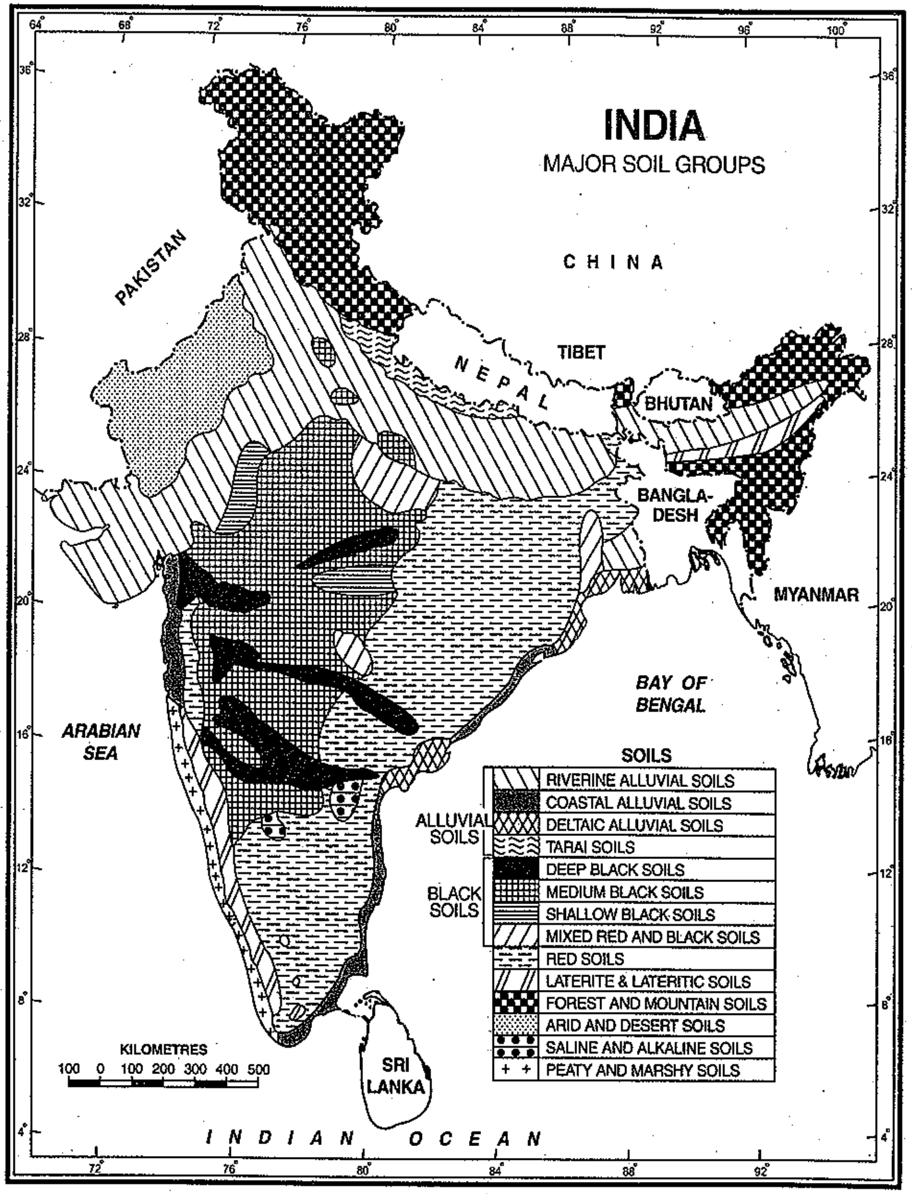

FIG. 7.1. India : Major Soil Groups

The widest occurrence of the alluvial soils is in the Great Indo-Gangetic Plain starting from Punjab in the west to West Bengal and Assam in the east. They also occur in deltas of the Mahanadi, the Godavari, the Krishna and the Cauvery, where they are called ***deltaic alluvium***. Along the coast they are known as ***coastal alluvium***. Some alluvial soils are found in the Narmada and Tapi valleys. Northern parts of Gujarat also have some cover of alluvial soils.

Geologically, the alluvium of the Great plain of India is divided into newer or younger *khadar* and older *bhangar* soils. The ***khadar*** soils are found in the low areas of valley bottom which are flooded almost every year. They are pale brown, sandy clays and loams, more dry and leached, less calcareous and carbonaceous *i.e.* they are less *kankary*. ***Bhangar***, on the other hand, is found on the higher reaches about 30 metres above the flood level. It is of a more clayey composition and is generally dark coloured. A few metres below the surface of the bhangar are beds of lime nodules known as ***kankar***. Along the Shiwalik foothills, there are alluvial fans having coarse, often pebbly soils. This zone is called ***bhabar***. To the south of the *bhabar* is a long narrow strip of swampy lowland with silty soils. It covers an area of 56,600 sq km and is called ***tarai***. The tarai soils are rich in nitrogen and organic matter but are deficient in phosphate. These soils are generally covered by tall grasses and forests but are suitable for a number of crops such as wheat, rice, sugarcane, jute and soyabean under reclaimed conditions.

Due to their softness of the strata and fertility the alluvial soils are best suited to irrigation and respond well to canal and well/tube-well irrigation. When properly irrigated, the alluvial soils yield splendid crops of rice, wheat, sugarcane, tobacco, cotton, jute, maize, oilseeds, vegetables and fruits. Increasing trend of rice cultivation in Punjab and Haryana with the help of intense irrigation is a living example.

2. Black Soils. The black soils are also called ***regur*** (from the Telugu word Reguda) and ***black cotton soils*** because cotton is the most important crop grown on these soils. Several theories have been put forward regarding the origin of this group of soils but most pedologists believe that these soils have been formed due to the solidifaction of lava spread over large areas during volcanic activity in the Deccan Plateau, thousands of years ago. Most of the black soils are derived from two types of rocks, the Deccan and the Rajmahal trap, and ferruginous gneisses and schists occurring in Tamil Nadu. The former are sufficiently deep while the later are generally shallow.

Krebs holds that the regur is essentially a mature soil which has been produced by relief and climate, rather than by a particular type of rock. According to him, this soil occurs where the annual rainfall is between 50 to 80 cm and the number of rainy days range from 30 to 50. The occurrence of this soil in the west deccan where the rainfall is about 100 cm and the number of rainy days more than 50, is considered by him to be an exception.

In some parts of Gujarat and Tamil Nadu, the origin of black cotton soils is ascribed to old lagoons in which the rivers deposited the materials brought down from the interior of Peninsula covered with lava.

Geographically, black soils are spread over 5.46 lakh sq km (*i.e.* 16.6 per cent of the total geographical area of the country) encompassed between 15°N to 25°N latitudes and 72°E to 82°E longitudes. This is the region of high temperature and low rainfall. It is, therefore, a soil group of the dry and hot regions of the Peninsula. These soils are mainly found in Maharashtra, Madhya Pradesh, parts of Karnataka, Telangana, Andhra Pradesh, Gujarat and Tamil Nadu.

The black colour of these soils has been attributed by some scientists to the presence of a small proportion of titaniferous magnetite or even to iron and black constituents of the parent rock. The black colour of this soil may even be derived from crystalline schists and basic gneisses such as in Tamil Nadu and parts of Andhra Pradesh. Various tints of the black colour such as deep black, medium black, shallow black or even a mixture of red and black may be found in this group of soils.

The black soil is highly retentive of moisture. It swells greatly and becomes sticky when wet in rainy season. Under such conditions, it is almost impossible to work on such soil because the plough gets stuck in the mud. However, in the hot dry season, the moisture evaporates, the soil shrinks and is seamed with broad and deep cracks, often 10 to 15 cm wide and upto a metre deep. This permits oxygenation of the soil to sufficient depths and the soil has extraordinary fertility. Remarkably *"self-ploughed"* by loosened particles fallen from the ground into the cracks, the soil "*swallows*" itself and retains soil moisture. This soil has been used for growing a variety of crops for centuries without adding fertilizers and manures, or even fallowing with little or no evidence of exhaustion.

A typical black soil is highly argillaceous with a large clay factor, 62 per cent or more, without gravel or coarse sand. It also contains 10 per cent of alumina, 9-10 per cent of iron oxide and 6-8 per cent of lime and magnesium carbonates. Potash is variable (less than 0.5 per cent) and phosphates, nitrogen and humus are low. The structure is cloddish but occasionally friable. In all *regur* soils in general, and in those derived from ferromagnesian schists in particular, there is a layer rich in *kankar* nodules formed by segregation of calcium carbonate at lower depths. As a general rule, black soils of uplands are of low fertility but they are darker, deeper and richer in the valleys.

Because of their high fertility and retentivity of moisture, the black soils are widely used for producing several important crops. Some of the major crops grown on the black soils are cotton, wheat, jowar, linseed, virginia tobacco, castor, sunflower and millets. Rice and sugarcane are equally important where irrigation facilities are available. Large varieties of vegetables and fruits are also successfully grown on the black soils.

3. Red Soils. This comprehensive term designates the largest soil group of India, comprising several minor types. Most of the red soils have come into existence due to weathering of ancient crystalline and metamorphic rocks. The main parent rocks are acid granites and gneisses, quartzitic and felspathic. The colour of these soils is generally red, often grading into brown, chocolate, yellow, grey or even black. The red colour is due more to the wide diffusion rather than to high percentage of iron content.

The red soils occupy a vast area of about 3.5 lakh sq km which is about 10.6 per cent of the total geographical area of the country. These soils are spread on almost the whole of Tamil Nadu, parts of Karnataka, south-east of Maharashtra, Telangana, Andhra Pradesh, Madhya Pradesh, Chhattisgarh, Odisha and Chota Nagpur in Jharkhand. In the north the red soil area extends in large parts of south Bihar; Birbhum and Bankura districts of West Bengal; Mirzapur, Jhansi, Banda and Hamirpur districts of Uttar Pradesh; Aravallis and the eastern half of Rajasthan, parts of Assam, Nagaland, Manipur, Mizoram, Tripura and Meghalaya.

By and large, the red soils are poor in lime, magnesia, phosphates, nitrogen and humus, but are fairly rich in potash. In their chemical composition they are mainly siliceous and aluminous, with free quartz as sand, the alkali content is fair, some parts being quite rich in potassium. The texture of these soils varies from sand to clay, the majority being loams. On the uplands, the red soils are thin, poor and gravelly, sandy or stony and porous, but in the lower areas they are rich, deep dark and fertile.

The red soils respond well to the proper use of fertilizers and irrigation and give excellent yields of cotton, wheat, rice, pulses, millets, tobacco, oil seeds, potatoes and fruits.

4. Laterite and Lateritic Soils. The word 'laterite' (from Latin word meaning brick) was first applied by Buchanan in 1810 to a clayey rock, hardening on exposure, observed in Malabar. But many authors agree with Fermor's restriction of this term to soils formed as to 90-100 per cent of iron, aluminium, titanium and manganese oxides. According to majority opinion, the laterite soil is formed under conditions of high temperature and heavy rainfall with alternate wet and dry periods. According to Polynov, laterite soils may be "the end products of weathering given sufficiently long time". In the opinion of George Kuriyan, "It is probably the end product of decomposition found in regions of heavy rainfall, more than 200 cm. Such climatic conditions promote leaching of soil whereby lime and silica are leached away and a soil rich in oxides of iron and aluminium compounds is left behind. We have numerous varieties of laterite which have bauxite at one end and an indefinite mixture of ferric oxides at the other. Almost all laterite soils are very poor in lime and magnesia and deficient in nitrogen. Sometimes, the phosphate content may be high, probably present in the form of iron phosphate but potash is deficient. At some places, there may be higher content of *humus*.

Laterite and lateritic soils are widely spread in India and cover an area of 2.48 lakh sq km. They are mainly found on the summits of Western Ghats at 1000 to 1500 m above mean sea level, Eastern Ghats, the Rajamahal Hills, Vindhyas, Satpuras and Malwa Plateau. They also occur at lower levels and in valleys in several other parts of the country. They are well developed in south Maharashtra, parts of Karnataka, Telangana, Andhra Pradesh, Odisha, West Bengal, Kerala, Jharkhand, Assam and Meghalaya.

Due to intensive leaching and low base exchange capacity, typical laterite soils generally lack fertility and are of little use for crop production. But when manured and irrigated, some laterites and lateritics are suitable for growing plantation crops like tea, coffee, rubber, cinchona, coconut, arecanut, etc. In low lying areas paddy is also grown. Some of the laterite soils in Kerala, Karnataka, Chota Nagpur region of Jharkhand, Odisha and Assam respond well to the application of fertilizers like nitrogen, phosphorus and potassium. In some areas, these soils support grazing grounds and scrub forests.

Laterite and lateritic soils have a unique distinction of providing valuable building material. These soils can be easily cut with a spade but hardens like iron when exposed to air. Because it is the end-product of weathering, it cannot be weatherd much further and is indefinitely durable.

5. Forest and Mountain Soils. Such soils are mainly found on the hill slopes covered by forests. These soils occupy about 2.85 lakh sq km which is about 8.67 per cent of the total land area of India. The formation of these soils is mainly governed by the characteristic deposition of organic matter derived from forest growth. These soils are heterogeneous in nature and their character changes with parent rocks, ground-configuration and climate. Consequently, they differ greatly even if they occur in close proximity to one another. In the Himalayan region, such soils are mainly found in valley basins, depressions, and less steeply inclined slopes. Generally, it is the north facing slopes which support soil cover; the southern slopes being too precipitous and exposed to denudation to be covered with soil. Apart from the Himalayan region, the forest soils occur on Western and Eastern Ghats as well as in some parts of the Peninsular plateau.

The forest soils are very rich in *humus* but are deficient in potash, phosphorus and lime. Therefore, they require good deal of fertilizers for high yields. They are especially suitable for plantations of tea, coffee, spices and tropical fruits in Karnataka, Tamil Nadu and Kerala and wheat, maize, barley and temperate fruits in Jammu and Kashmir, Himachal Pradesh and Uttarakhand.

6. Arid and Desert Soils. A large part of the arid and semi-arid region in Rajasthan and adjoining areas of Punjab and Haryana lying between the Indus and the Aravalis, covering an area of 1.42 lakh sq km (or 4.32% of total area) and receiving less than 50 cm of annual rainfall, is affected by desert conditions. The Rann of Kachchh in Gujarat is an extension of this desert. This area is covered by a mantle of sand which inhibits soil growth. This sand has originated from the mechanical disintegration of the ground rocks or is blown from the Indus basin and the coast by the prevailing south-west monsoon winds. Barren sandy soils without clay factor are also common in coastal regions of Odisha, Tamil Nadu and Kerala. The desert soils consist of aeolian sand (90 to 95 per cent) and clay (5 to 10 per cent). Some of these soils contain high percentages of soluble salts, are alkaline with varying degree of calcium carbonate and are poor in organic matter. Over large parts, the calcium content increases downwards and in certain areas the subsoil has ten times calcium as compared to that of the top soil. The phosphate content of these soils is as high as in normal alluvial soils. Nitrogen is originally low but its deficiency is made up to some extent by the availability of nitrogen in the form of nitrates. Thus, the presence of phosphates and nitrates make them fertile soils wherever moisture is available. There is, therefore, great possibility of reclaiming these soils if proper irrigation facilities are available. The changes in the cropping pattern in the Indira Gandhi Canal Command Area is a living example of the utility of the desert soils. However, in large areas of desert soils, only the drought resistant and salt tolerant crops such as barley, rape, cotton, wheat, millets, maize and pulses are grown. Consequently, these soils support a low density of population.

7. Saline and Alkaline Soils. These soils are found in Andhra Pradesh, Telangana and Karnataka. In the drier parts of Bihar, Uttar Pradesh, Haryana, Punjab, Rajasthan and Maharashtra, there are salt-impregnated or alkaline soils occupying 68,000 sq km of area. These soils are liable to saline and alkaline efflorescences and are known by different names such as ***reh***, ***kallar***, ***usar***, ***thur***, ***rakar***, ***karl*** and ***chopan***. There are many undecomposed rock and mineral fragments which on weathering liberate sodium, magnesium and calcium salts and sulphurous acid. Some of the salts are transported in solution by the rivers, which percolate in the sub-soils of the plains. In canal irrigated areas and in areas of high sub-soil water table, the injurious salts are transferred from below to the top soil by the capillary action as a result of evaporation in dry season. The accumulation of these salts makes the soil infertile and renders it unfit for agriculture. It has been estimated that about 1.25 million hectares of land in Uttar Pradesh and 1.21 million hectares in Punjab has been affected by *usar*. In Gujarat, the area around the Gulf of Khambhat is affected by the sea tides carrying salt-laden deposits. Vast areas comprising the estuaries of the Narmada, the Tapi, the Mahi and the Sabarmati have thus become infertile.

8. Peaty and Marshy Soils. Peaty soils originate in humid regions as a result of accumulation of large amounts of organic matter in the soils. These soils contain considerable amount of soluble salts and 10-40 per cent of organic matter. Soils belonging to this group are found in Kottayam and Alappuzha districts of Kerala where it is called ***kari***. Marshy soils with a high proportion of vegetable matter also occur in the coastal areas of Odisha and Tamil Nadu, Sunderbans of West Bengal, in Bihar and Almora district of Uttarakhand. The peaty soils are black, heavy and highly acidic. They are deficient in potash and phosphate. Most of the peaty soils are under water during the rainy season but as soon the rains cease, they are put under paddy cultivation.

Characteristics of Indian Soils. Following are the chief characteristics of Indian soils :

1. The Indian soils have been formed under varied geographical conditions and differ widely in their physical properties, chemical composition and fertility level.
2. Most soils are old and mature. Soils of the peninsular plateau are much older than the soils of the great northern plain.
3. Indian soils are largely deficient in nitrogen, mineral salts, humus and other organic materials.
4. Plains and valleys have thick layers of soils while hilly and plateau areas depict thin soil cover.
5. Some soils like alluvial and black soils are fertile while some other soils such as laterite, desert and alkaline soils lack in fertility and do not yield good harvest.
6. Indian soils have been used for cultivation for hundreds of years and have lost much of their fertility. As such there is urgent need of giving scientific treatment to our soils.
7. Indian climate is characterised by seasonal rainfall and our soils need irrigation during the dry period.
8. Indian soils suffer from soil erosion and other allied problems.

PROBLEMS OF INDIAN SOILS

Indian soils suffer from a number of problems, some of them taking a serious turn. Some of the important problems faced by Indian soils are (*i*) soil erosion, (*ii*) deficiency in fertility, (*iii*) desertification, (*iv*) waterlogging (*v*) salinity and alkalinity (*vi*) wasteland, (*vii*) over exploitation of soils due to increase in population and rise in living standards and (*viii*) encroachment of agricultural land due to urban and transport development.

SOIL EROSION

Soil erosion is the removal of soil by the forces of nature, particularly wind and water, more rapidly than the various soil forming processes can replace it. Soil erosion is a serious menace which is adversely affecting our agricultural productivity and the economy of the country as a whole. Although the process of soil erosion is imperceptibly slow and it can scarcely be detected, the loss over periods of time is indeed very great.

TYPES OF SOIL EROSION

Two natural agents i.e., water and wind, are constantly at work causing soil erosion. Therefore, we can talk of two types of soil erosion *viz.*, water erosion and wind erosion.

Water Erosion. During heavy rains, water removes a lot of soil. Rain drops fall with an approximate speed of 10 metres per second and wash away the top soil. The soils most readily detached by raindrop splash erosion are sands and silt. Coarser particles are not shifted about as much because of their greater volume and weight. Run off water is responsible for much soil erosion, moving the soil

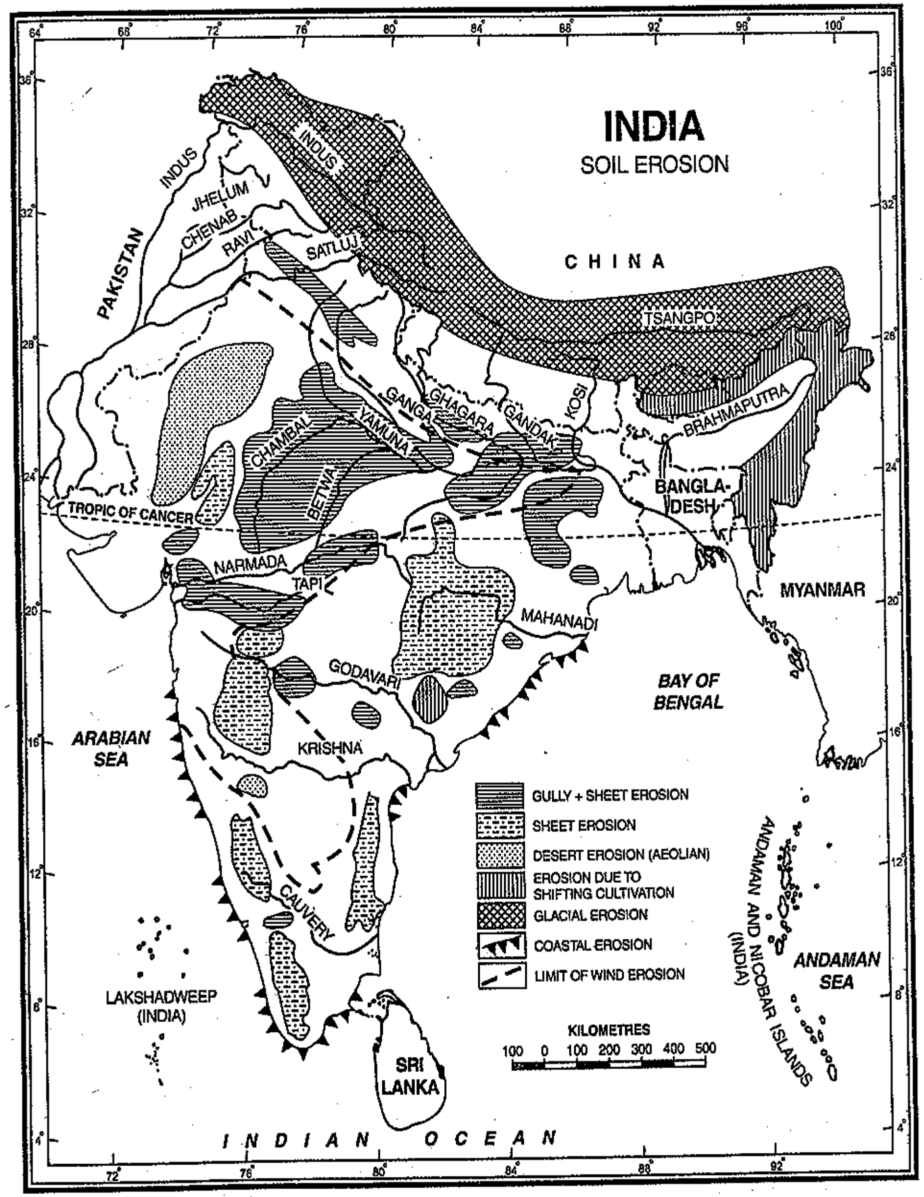

FIG. 7.2. India : Soil Erosion

particles by *surface creep*, *saltation* and *suspension*. Water erosion consisting of *rilling, gullying, sheet-wash and rain peeling process* is mainly confined to the mountains, hills and upper slopes of the piedmont zone. If erosion continues unchecked for a sufficient time, numerous finger-shaped grooves may develop all over the area due to silt laden run off. The whole pattern resembles that of the twigs, branches and trunk of a tree. This is called ***rill erosion***. With further erosion of the soil, the rills may deepen and become enlarged and are ultimately turned into **gullies**. The cutting of soil goes to immense size and volume and the entire area may be turned into **badland topography**. When a gully bed cuts into the soil with an immediate drop of 3 to 4 metres and gradually flattens out, a **ravine** is formed. The depth of a ravine may extend to 30 metres or even more. When the entire top sheet of soil is carried away by water or by wind, leaving behind barren rock, it is called ***sheet erosion***. Sheet erosion is no less harmful than gully erosion. This type of erosion is more prominent on relatively steeper slopes, receiving heavy rainfall. Sheet erosion is particularly harmful because it attacks the top soil relatively early and renders the land almost unfit for cultivation. If one cubic metre of soil be lost from one hectare of land each week for a period of 30 years, the loss would amount to 15 cm from the entire surface.

It is not the total annual rainfall that is important, but rather how and when it comes. A single heavy downpour continuing for a few hours may result in severe soil erosion, while the same amount of rainfall fairly distributed over a longer period may cause little erosion or even may be useful for protecting soil. The slope of the land is a potent factor in determining the velocity of water and the consequent soil erosion. Other things being equal, the steeper the slope the more rapidly does water run down resulting in more soil erosion. Theoretically, *if the rate of flow is doubled, the scouring capacity is increased four times, the carrying capacity thirty two times and the size of the particles carried sixty four times.*

In the coastal areas, tidal waves dash along the coast and cause heavy damage to soil. This is called ***sea erosion***. In the higher reaches of the Himalayan region, soil erosion on a large scale is caused by glaciers. This is called ***glacial erosion*** (**Fig. 7.2**).

Wind Erosion. In arid and semi arid lands with little rainfall, the wind acts as a powerful agent of soil erosion causing heavy loss to agricultural land. Winds blowing at considerable speed, remove the fertile, arable, loose soils leaving behind a depression devoid of top soil. Wind erosion is accentuated when the soil is dry, weakly aggregated, devoid of vegetation cover along with over grazing and the winds are strong. Even modest wind velocities can keep individual particles of humus, clay and silt in suspension. Very fine, fine and medium sands are moved by wind in a succession of bounds and leaps, known as ***saltation***. Coarse sand is not usually airborne but rather is rolled along the soil surface. This type of erosion is called ***surface creep***. Very coarse sand (1.0-2.0 mm in diameter), gravels, peds and clods are too large to be rolled by wind, so wind-eroded soils have surfaces covered with coarse fragments larger than 1.00 mm in diameter. This kind of arid soil surface is known as ***desert pavement***.

HUMAN FACTORS OF SOIL EROSION

Soil erosion is the result of a number of factors, working in isolation or in association with one another. Apart from the natural factors such as torrential rainfall, resulting in swift flow of water, strong winds in dry areas, nature of soil and the physiography, man is an important factor responsible for soil erosion. Man's ill judged activities such as deforestation, overgrazing and faulty methods of agriculture have made soil erosion a serious national problem. Besides diversion of natural drainage courses, wrong orientation of roads and railways, embankments and bridges have also led to soil erosion. Thus it is rightly said that soil erosion is essentially a problem created by man and also faced by man himself.

1. Deforestation. With the increase in population, the pressure on forest resources is increasing with each passing day. This has resulted in reckless cutting of forests which has led to the problem of soil erosion. Roots of trees and plants bind the soil particles and regulate the flow of water, thus saving soil from erosion. Therefore, deforestation invariably results in floods and soil erosion. The large scale damage to soil in Shiwalik range, the *Chos* of Punjab, parts of Haryana and the *ravines* of Madhya Pradesh, Uttar Pradesh and Rajasthan is largely due to deforestation.

2. Overgrazing. Forests and grasslands provide much needed fodder for animals. During the rainy season, there is plenty of growth and animals get enough fodder. But during the long dry period, there is shortage of fodder and the grass is grazed to the ground and torn out by the roots by animals. This leads to loose structure of the soil and the soil is easily washed away by rains. Moreover, soil is pulverised by the hoofs and teeth of animals, especially by sheep and goats and thus proves detrimental to top soil when heavy showers fall on it. Soil erosion due to overgrazing is a common site in the hilly areas of Himachal Pradesh, Uttarakhand, Jammu and Kashmir and in the dry areas of Rajasthan, Madhya Pradesh, Maharashtra, Karnataka and Andhra Pradesh.

3. Faulty Methods of Agriculture. Much of the soil erosion in India is caused by faulty methods of agriculture. The most outstanding are wrong ploughing, lack of crop rotation and practice of shifting cultivation. If the fields are ploughed along the slope, there is no obstruction to the flow of water and the water washes away the top soil easily. In some parts of the country, the same crop is grown year after year which spoils the chemical balance of the soil. This soil is exhausted and is easily eroded by wind or water.

Another outstanding example of faulty method of agriculture is the *shifting cultivation* practised in some areas in the north-eastern states of Arunachal Pradesh, Assam, Meghalaya, Manipur, Tripura, Mizoram as well as in Odisha. It is sporadically practised in Telangana, Andhra Pradesh, Madhya Pradesh, Chhattisgarh, Maharashtra, Kerala, Karnataka and Tamil Nadu. In this method, a piece of forest land is cleared by felling and burning of trees and crops are grown. The removal of the forest cover leads to the exposure of the soil to rains and sun which results in heavy loss of top soil, especially on the hill slopes. Thus the soil becomes unfit for cultivation and the tribes move to another piece of land after 2-3 years, returning to the earlier one after a gap of 10-15 years. In this way, the whole of the forest area is adversely affected by shifting cultivation resulting in intensive soil erosion in vast areas.

EXTENT OF SOIL EROSION IN INDIA

It has been estimated that an area of over 80 million hectares or about one-fourth of our total area is exposed to wind and water erosion out of which 40 million hectares of land has undergone serious erosion. Ironically the extent of soil erosion is increasing inspite of our efforts to check soil erosion. Experts have estimated that about 40,000 hectares of our land is permanently lost to cultivation and much larger area is rendered less productive every year due to wind and water erosion. About 21 million hectares are subject to severe wind erosion in Rajasthan and adjoining areas of Punjab, Haryana, and Gujarat (**Fig. 7.2**).

Wind erosion is a serious problem in arid and semi-arid parts of north west India. About 45 million hectares of land is subject to severe wind erosion in Rajasthan and adjoining areas of Punjab, Haryana, Gujarat and Western Uttar Pradesh (**Fig. 7.2**). It is estimated that 34 lakh tonnes of fertile soils is removed by wind every year in the districts of Jodhpur, Bikaner, Kota, Jaipur, Bharatpur, Kishangarh etc. in Rajasthan. These areas receive scanty rainfall. They are devoid of vegetation cover and have sandy soil. As such these areas are exposed to wind erosion. Faulty farming practices, failure to conserve moisture, lack of managing and over grazing make the problem of wind erosion more complicated. According to the latest estimates about 8 million tonnes of soil has been removed from every square kilometre area in desert during the last hundred years.

TABLE 7.1. Area Under Ravines in India (lakh hectares)

State	Area
Uttar Pradesh	12.30
Madhya Pradesh	6.83
Rajasthan	4.52
Gujarat	4.00
Punjab	1.20
West Bengal	1.04
Bihar	0.60
Tamil Nadu	0.60
Maharashtra	0.20

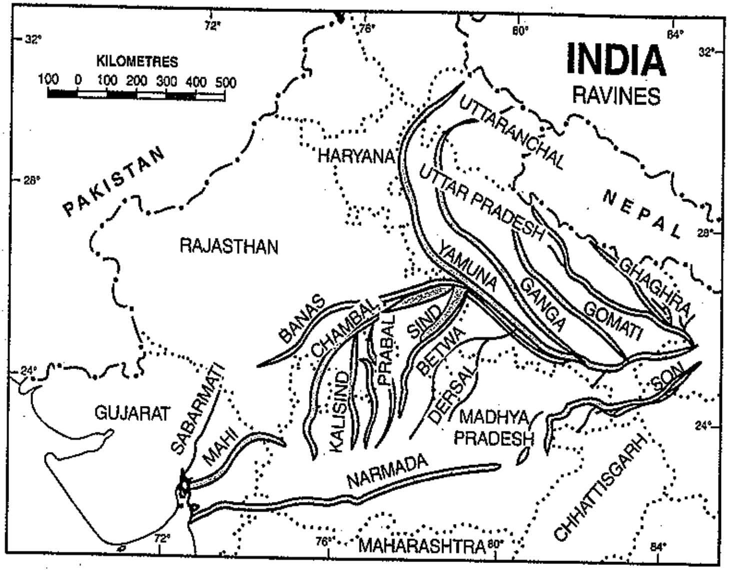

FIG. 7.3. India : Ravines

Water erosion is more active in wet areas receiving more rainfall. Steep slope, swift flow of rivers and scarce vegetation cover lead to water erosion. According to estimates by the Indian Council of Agricultural Research (ICAR), the loss due to water erosion is 53.34 million hectares annually. A working group set up by the Ministry of Home Affairs in 1971 estimated that there are 39.75 lakh hectare ravines spread in 18 states, out of which 27.65 lakh hectares (or 69.55 per cent) are in the states of Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat (**Table 7.1**). The aerial survey carried out for Chambal Development Scheme has shown that the area covered by ravines upto 4.5-6.0 metre depth is about 50,600 hectares. In Madhya Pradesh about 4 to 8 lakh hectares are affected by deep gullies and ravines along the banks of rivers Chambal and Kali Sindh. Out of this about 2.4 lakh hectares are in the districts of Gwalior, Morena and Bhind. In Uttar Pradesh the ravines are mostly along the banks of the Chambal, the Yamuna, the Gomati, Son and their tributaries (**Fig. 7.3**). Agra, Etawah and Jalaun are the worst affected districts. According to another estimate the Chambal-Yamuna badlands covering a total area of about 32 lakh hectares are the result of 1000 years of soil erosion wherein 0.25 tonnes of soil is being removed every day.

In Timil Nadu, ravines are common in South Arcot, North Arcot, Kanniyakumari, Tiruchchirapalli, Chingleput, Salem and Coimbatore districts. In West Bengal numerous gullies and ravines exist in the upper catchment areas of the Kangsabati river in Purulia district. In Bihar, river courses of the Ganga, the Gandak, the Kosi and the Son are affected by ravines.

The flood plains of the Ganga and its tributaries in Uttar Pradesh and Bihar also suffer from the problem of soil erosion caused by water. These rivers are carving deep furrows and removing fertile top soil. According to one estimate the Ganga river is transporting about 30 million tonnes of eroded material per year from the Ganga plain to the Bay of Bengal. Similarly the Brahmaputra is transporting about 10 million tonnes annually from the Brahmaputra valley to the Bay of Bengal.

The Shiwalik range has also been badly affected by gully erosion. Rivers descending from the Shiwalik hills and flowing into Punjab are locally

called ***Chos***. Erosion by ***chos*** is most marked in Hoshiarpur district of Punjab. In the 130 km of the Shiwalik, nearly a hundred streams debouch onto the plains.

The loss of soil due to *shifting agriculture* is no less pronounced. It has been estimated that more than 15 lakh hectares of forest land is cleared for shifting agriculture every year. The total area affected by shifting cultivation is estimated to be 45 lakh hectares. Some portion of this land is permanently lost to agriculture. Shifting agriculture has caused maximum soil erosion in tribal areas of Assam, Meghalaya, Tripura, Nagaland, Mizoram, Kerala, Andhra Pradesh, Odisha, Madhya Pradesh, Chhattisgarh etc. It is reported that about 207,287 hectares in Assam, 41,963 hectares in Tripura and 21,862 hectares in Manipur are under shifting cultivation. In Odisha about 33,08,502 hectares of land are subjected to shifting cultivation.

In Tamil Nadu the bad effects of misuse of land are illustrated in the Nilgiri Hills where potato is one of the main crops. Here potato cultivation is done on steep slopes, sometimes exceeding 60 per cent. This has led to intense erosion of soil and the yields of potato have gone down by about 50 per cent in spite of heavy application of fertilisers. Land steeper than 1 in 4 should not be open for cultivation but put under grasses and trees.

Coastal erosion is another form of erosion caused by constant pounding of tidal waves and currents on the sea coast. Waves and currents strike the coast with great force and break the hanging cliff rocks. The broken material is carried away by the retreating waves. Coastal erosion is quite pronounced in the season of monsoon winds and during storms and cyclones. Several coastal areas in Gujarat, Maharasthra, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh and Odisha have suffered heavily at the hands of sea erosion. Of the 560 km long coast of Kerala, about 32 km stretch consisting of sandy beaches is subject to severe sea erosion. Erosion of beaches along the Kerala coast is evidenced by uprooting of coconut trees.

Effects of Soil Erosion. The adverse effects of soil erosion are reflected in the following points :

1. Top soil is eroded which leads to loss of soil fertility and fall in agricultural productivity.
2. Flooding and leaching result in loss of mineral nutrients.
3. Ground water level is lowered and there is decrease in soil moisture.
4. Natural vegetation cover dries up and arid lands expand.
5. Frequency and intensity of floods and drought increases.
6. Rivers, canals and tanks are silted and their water holding capacity decreases.
7. The incidence and damaging power of landslides increases.
8. Economy as whole suffers a great setback.

Soil Salinity and Soil Alkalinity. Soil salinity and soil alkalinity are the results of over irrigation in canal irrigated areas. In canal irrigated areas plenty of the water is available and the farmers indulge in over irrigation of their fields. Under such conditions, the ground water level rises and saline and alkaline efflorescences consisting of salts of sodium, calcium and magnesium appear on the surface as a layer of white salt through capillary action. *Salinity* means the predominance of chlorides and sulphates of sodium, calcium and magnesium in the soils in sufficient quantity to be able to seriously interfere with the growth of most plants. ***Alkalinity*** implies the dominance of sodium salts, specially sodium carbonate. Although salts of alkali are somewhat different in their chemical properties from the salts of saline soils both soils occur in the same areas. Increasing salinity and alkalinity always indicate extension of waterlogging salt encrustation (saline efflorescence) or ***thur*** tendencies. Sandy soils are more prone to alkalinity and the loamy soils to salinity-alkalinity. Salinity and alkalinity have adverse effect on soil and reduce soil fertility. It is estimated that about 80 lakh hectares of land (2.43% of the country's total area) is affected by the problem of salinity and alkalinity. Vast tracts of canal irrigated areas in Uttar Pradesh, Punjab and Haryana; arid regions of Rajasthan, semi-arid areas of Maharashtra, Gujarat, Andhra Pradesh, Telangana and Karnataka and coastal areas of Odisha, Gujarat and West Bengal are facing this problem (**Table 7.2**). The western part of Uttar Pradesh is one of the worst sufferers at the hands of salinity and alkalinity. In some parts of Uttar

TABLE 7.2. Salinity Affected Areas in India

States/Union territories	Area (lakh hectares)
1. Uttar Pradesh	12.95
2. Punjab	12.25
3. Gujarat	12.14
4. West Bengal	8.50
5. Rajasthan	7.28
6. Maharashtra	5.34
7. Haryana	5.26
8. Karnataka	4.04
9. Odisha	4.04
10. Madhya Pradesh	2.24
11. Andra Pradesh and Telangana	0.42
12. Delhi	0.11
13. Bihar	0.04
14. Tamil Nadu	0.04

Pradesh the internal drainage is greatly restricted and the soils are charaterised by alkalinity. Some of the most fertile soils in Punjab and Haryana have been rendered useless by salinity and alkalinity. In Punjab about 6,000 to 8,000 hectares of good land is becoming barren every year due to salinisation. Although Indira Gandhi canal in Rajasthan has turned the sandy desert into a granary, it has given birth to serious problems of salinity and alkalinity. Alkali soils are met with almost all over the state of Maharashtra. In Gujarat, the area around the Gulf of Khambhat is affected by sea tides carrying silt-laden deposits. Nearly 173,530 sq km comprising estuaries of the Narmada, the Tapi, the Mahi and the Sabarmati have been damaged in this way. Portions of Dharwar districts and of Bijapur taluk are affected by what is locally known a ***karl*** soils which are saline, alkali and fairly deep and clayey. Salt lands of the Nira valley have developed due to excessive irrigation on deep black soils of the locality.

Effects of salinity and alkalinity

Soil salinity and alkalinity has many adverse effects, some important effects are as under :

(*a*) Soil fertility is reduced which results in crop failure. Cultivation is not possible on saline soils unless they are flushed out with large quantities of irrigation water to leach out the salts.

(*b*) Choice of crops is limited because some crops are sensitive to salinity and alkalinity. Only high salt tolerant crops such as cotton, rape, barley etc. and medium salt tolerant crops like wheat, rice, linseed, pulses, millets etc. can be grown.

(*c*) Quality of fodder becomes poor.

(*d*) Salinity and alkalinity create difficulties in building and road construction.

(*e*) These cause floods due to reduced infiltration, leading to crop damage in the adjoining areas.

Steps to treat salinity and alkalinity

Following steps are necessary to treat salinity and alkalinity and restore the fertility of soil.

1. Providing outlets for water to drain out excess water and lower water table. Efforts should also be made to seal all points and strips of the leakage from canals, tanks and ponds by lining them.
2. Minimising the use of water. Making judicious use of irrigation facilities.

TABLE 7.3. Area under Arid and Semi-arid conditions in India (as per cent to the total geographical area)

States	Arid	Semi-arid
Rajasthan	57.42	36.67
Gujarat	33.72	47.50
Haryana	29.32	59.77
Punjab	24.60	75.40
Maharashtra	0.42	61.17
Andhra Pradesh and Telangana	7.18	44.66
Karnataka	4.27	72.60
Jammu & Kashmir	31.13	6.22
Uttar Pradesh	—	21.73
Madhya Pradesh	—	13.38
Tamil Nadu	—	15.54
Total average	**12.13**	**29.13**

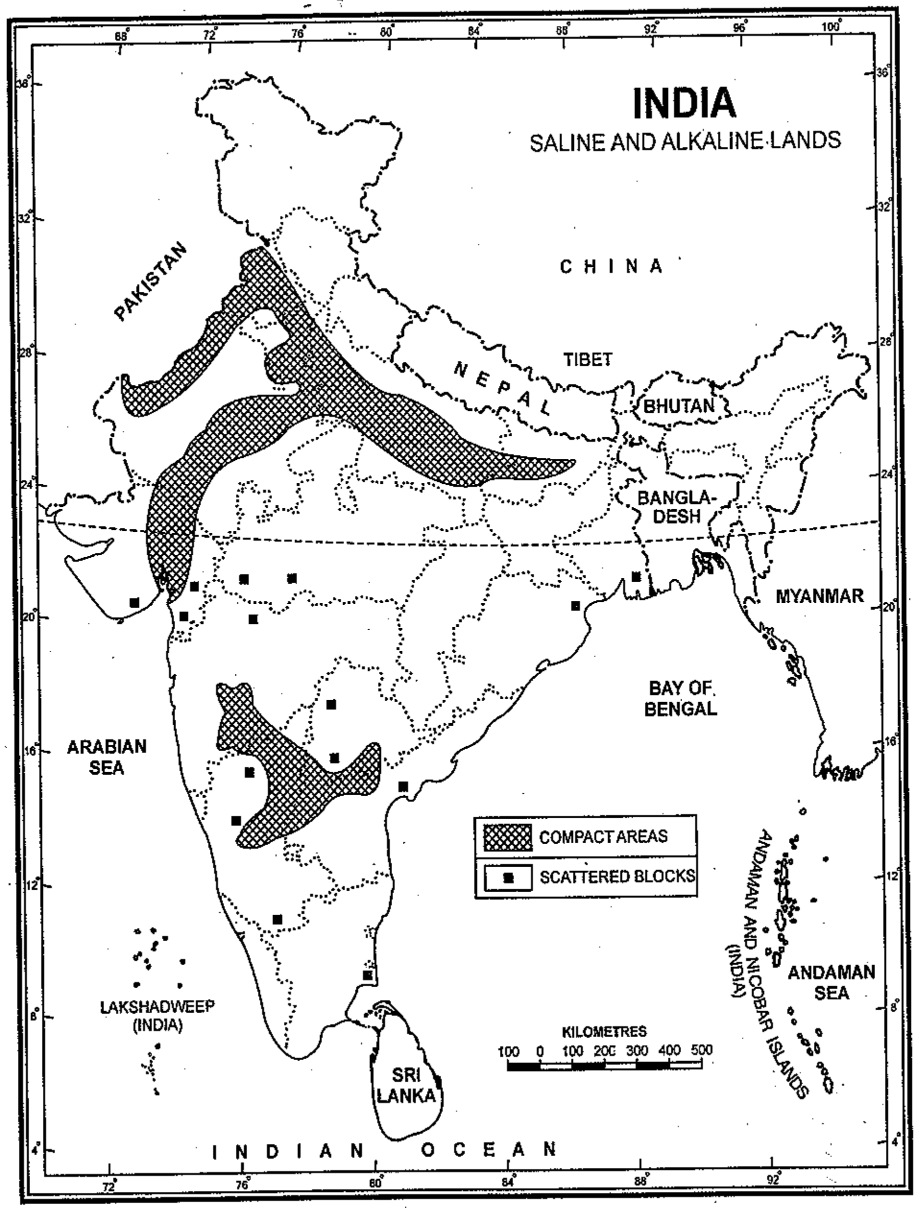

FIG. 7.4. India : Saline and Alkaline Lands

3. Planting salt tolerant vegetation and crops such as cotton, rape, barley, date palm, linseed etc. and certain grasses as fodder crops can be helpful.
4. It has been found that crop rotation involving ***dhaincha*** (green fodder)—cotton in the Deccan plateau, ***dhaincha***—rice in the Uttar Pradesh and ***dhaincha***—rice-barseem

in Punjab and Haryana have been very helpful.

5. Liberal application of gypsum in upper 15 cm thick soil to convert the alkalies into soluble compounds. Alkali can be removed by adding sulphuric acid or acid forming substances like sulphur and pyrite. Also organic residues such as rice husks and rice straw can be added to promote formation of mild acid as a result of their decomposition.
6. Flushing the salt by flooding the fields with excess water. However, this practice can lead to accumulation of saline water in the downstream area.

Desertification. Desertification can be defined as spread of desert like conditions in arid or semi-arid areas due to man's influence or climatic change. A large part of the arid and semi-arid region belonging to Rajasthan and south Punjab and Haryana and lying between the Indus and the Aravali range is affected by desert conditions. This area is characterised by scanty rainfall, sparse vegetation cover and acute scarcity of water. The Rajasthan desert is partly natural but largely man made and the fear is often expressed, quite rightly too, that the desert is spreading and that conditions within the desert are deteriorating. Desert soils suffer maximum erosion by wind. The sand carried by wind is deposited on the adjoining fertile lands whose fertility dwindles and sometimes the fertile land merges with the advancing desert. It has been estimated that the Thar Desert is advancing at an alarming rate of about 0.5 km per year. Currently about 12.13 per cent of India's total area is classed as arid and about 30 per cent area is termed as semi-arid. The highest concentration of arid land is found in Rajasthan where more than half of the total area is arid. Gujarat has about one-third of its total area as arid land. Jammu and Kashmir has cold deserts in Leh and Ladakh where the annual rainfall hardly exceeds 20 cm. Punjab and Haryana have about one-fourth of the total land characterised by arid conditions. Semi arid conditions prevail in large parts of Rajasthan, Gujarat, Punjab, Haryana, Maharashtra, Telangana, Andhra Pradesh, Karnataka, Jammu and Kashmir, Uttar Pradesh, Tamil Nadu and Madhya Pradesh (**Table 7.3**). Semi-arid conditions in north-western parts of India and in the states of Rajasthan, Punjab, Haryana etc. are created by their long distances from the sea while such conditions in the southern states like Karnataka, Telangana, Andhra Pradesh, Tamil Nadu, Maharashtra etc. are caused by the presence of the Western Ghats. These states are located in the rain shadow area of the Western Ghats.

The process of desertification is attributed to various causes of which more important are uncontrolled grazing, reckless felling of trees and growing population. Climate change have also contributed to the spread of deserts.

Desertification has several ecological implications. Some important implications are listed below.

(*i*) Drifting of sand and its accumulation on fertile agricultural land.
(*ii*) Excessive soil erosion by wind and to some extent by water.
(*iii*) Deposition of sand in rivers, lakes and other water bodies thereby decreasing their water containing capacity.
(*iv*) Lowering of water table leading to acute water shortage.
(*v*) Increase in area under wastelands.
(*vi*) Decrease in agricultural production.
(*vii*) Increase in frequency and intensity of droughts.

Measures of Controlling Desertification

(*i*) Intensive tree plantation programme should be initiated.
(*ii*) Shifting sand dunes in Bikaner, Barmer, Churu, Jaisalmer and Jhunjhunun districts of Rajasthan cover an approximate area of 74 thousand sq km. Central Arid Zone Research Institute, Jodhpur has suggested mulching them with different plant species. Mulches are put in small squares and serve as an effective physical barrier to the moving sand.
(*iii*) Grazing should be controlled and new pastures should be developed.
(*iv*) Indiscriminate felling of trees should be banned.
(*v*) Alternative sources of fuel can reduce the demand for fuelwood and save the trees from destruction hence checking the onward march of the desert.

(*vi*) Sandy and wastelands should be put to proper use by judicious planning.

Waterlogging. The flat or nearly level surfaces and saucer-like depressions make the movement of surface water sluggish leading to accumulation of rain water which in turn results in waterlogging and flooding of the soil. Waterlogged soils are soaked or saturated with water. Moreover seepage from unlined channels or canal systems also leads to waterlogging in the contiguous arable lands. It has been estimated that extent of waterlogged soils is about 12 million hectares in India; half of which lies along its coast and the other half in the inland area under existing or newly created irrigation command areas (**Fig. 7.5**).

Waterlogging is believed to be one of the chief causes of salinity. The problem of land reclamation under waterlogging conditions is a complex one and must therefore, be tackled with great care as the scheme involves huge expenditure. Proper layout of drainage schemes is the only way to overcome the menace of waterlogging. The basic methods of removing excess water from waterlogged soils are (*a*) surface drainage and (*b*) vertical drainage.

(a) Surface Drainage. Surface drainage involves the disposal of excess water over ground surface through an open drainage system with an adequate outlet. Surface drainage is helpful where (*i*) soils are deep with low infiltration rates, where (*ii*) intensity of rainfall is high, where (*iii*) terrain is level to nearly level and where (*iv*) the water table is high.

(b) Vertical Drainage. Any bore or well from which the underlying water is extracted is defined as vertical drainage. The success of vertical drainage depends upon the presence of favourable aquifer and water table for lifting the ground water on sustainable basis and the favourable quantity of water that could be re-utilised for irrigation purposes. Such conditions prevail in the Indo-Gangetic plain. In the Punjab-Haryana plain the water-table has been successfully lowered through tubewell pumping. As a consequence waterlogged saline lands could be reclaimed.

SOIL CONSERVATION

Soil conservation includes all those measures which help in protecting the soil from erosion and exhaustion. Soil erosion has been continuing over such a large part of India for such a long time that it has assumed alarming proportions. According to Prof. **S.P. Chatterjee,** "*Soil erosion is the greatest single evil to Indian agriculture and animal husbandry*". Soil is our most precious asset and no other gift of nature is so essential to human life as soil. Productive soil alone ensures prosperous agriculture, industrial development, economic betterment and a higher standard of living. A healthy agriculture is bound up with healthy soil. While emphasising the significance of conservation, **G.T. Renner** has said that conservation is defined as "the greatest good to the largest number for the longest time." According to **S.I. Kayastha,** "*With soil conservation people rise and with its destruction they fall.*" It has been estimated that about two thirds of our arable land needs conservation measures. There is, therefore, an urgent need to conserve soil for the sake of prosperity of our masses. Unfortunately, it has not attracted the attention that it deserves. Our peasantry is not fully aware of many benefits of soil conservation and *neglect of soil is like killing the hen that lays the golden eggs*. Following methods are normally adopted for conserving soil :

1. Afforestation. The best way to conserve soil is to increase area under forests. Indiscriminate felling of trees should be stopped and efforts should be made to plant trees in new areas. A minimum area of forest land for the whole country that is considered healthy for soil and water conservation is between 20 to 25 per cent but it was raised to 33 per cent in the second five year plan; the proportion being 20 per cent for the plains and 60 per cent for hilly and mountainous regions.

2. Checking Overgrazing. Overgrazing of forests and grass lands by animals, especially by goats and sheep, should be properly checked. Separate grazing grounds should be earmarked and fodder crops should be grown in larger quantities. Animals freely move about in the fields for grazing and spoil the soil by their hoofs which leads to soil erosion. This should be avoided.

3. Constructing Dams. Much of the soil erosion by river floods can be avoided by constructing dams across the rivers. This checks the speed of water and saves soil from erosion.

4. Changing Agricultural Practices. We can save lot of our valuable soil by bringing about certain

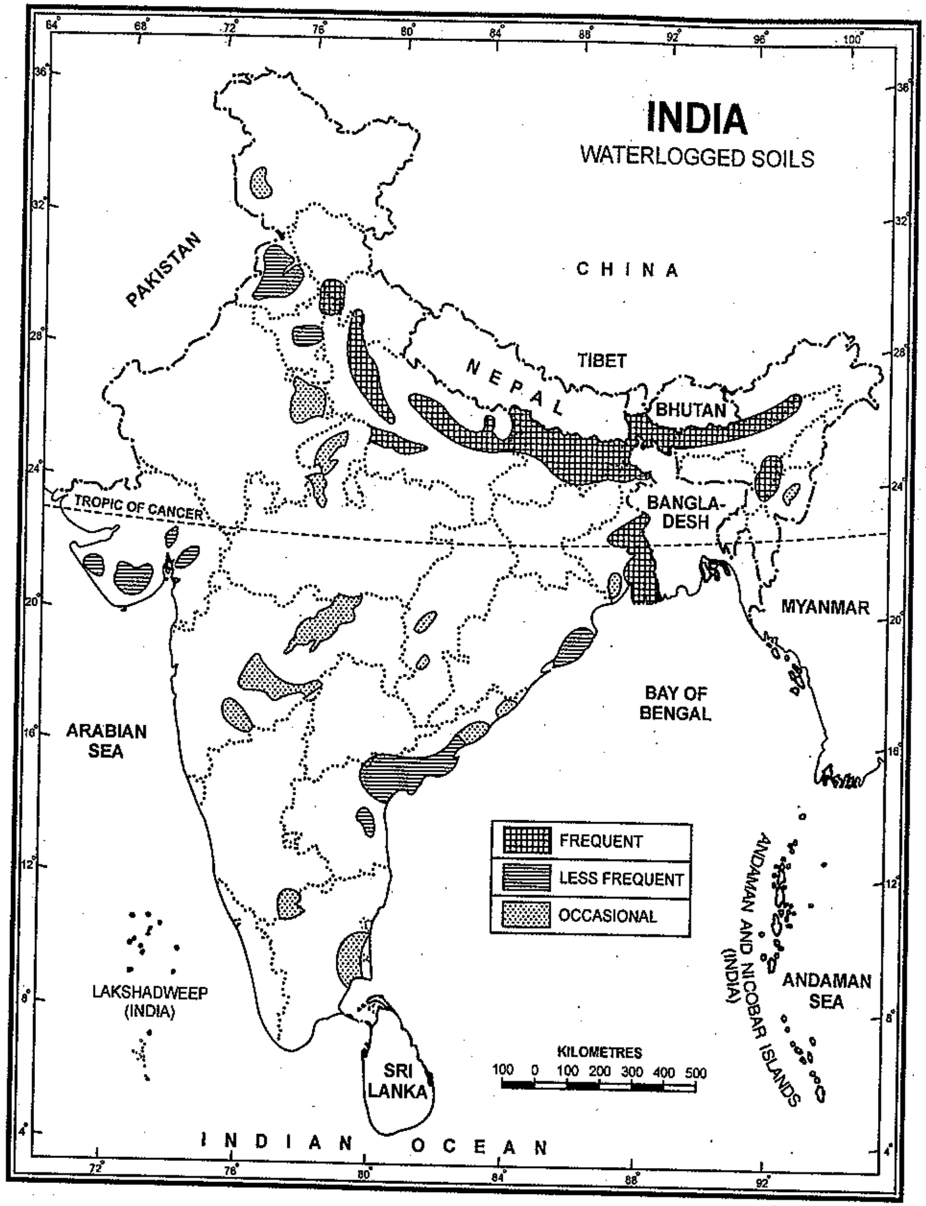

FIG. 7.5. India : Waterlogged Soils

changes in our agricultural practices. Some of the outstanding changes suggested in this context are as under :

(i) ***Crop Rotation.*** In many parts of India, a particular crop is sown in the same field year after year. This practice takes away certain elements from

the soil, making it infertile and exhausted rendering it unsuitable for that crop. *Rotation of crops is the system in which a different crop is cultivated on a piece of land each year*. This helps to conserve soil fertility as different crops make different demands on the soil. For example, potatoes require much potash but wheat requires nitrate. Thus it is best to alternate crops in the field. Legumes such as peas, beans, clover, vetch and many other plants, add nitrates to the soil by converting free nitrogen in the air into nitrogenous nodules on their roots. Thus if they are included in the crop rotation nitrogenous fertilisers can be dispensed with. By rotating different types of crops in successive years, soil fertility can be naturally maintained. For example, wheat may be cultivated in the first year, barley in the second and legumes in the third. The cycle may then be repeated. Further, there are some crops such as maize, cotton, tobacco and potato which can be classed as erosion inducing, whilst some other crops such as grass, forage crops and many legumes are erosion resisting. Small grain crops like wheat, barley, oats and rice are between these two extremes.

(ii) ***Strip Cropping.*** Crops may be cultivated in alternate strips, parallel to one another. Some strips may be allowed to lie fallow while in others different crops may be sown *e.g.*, grains, legumes, small tree crops, grass etc. Various crops ripen at different times of the year and are harvested at intervals. This ensures that at no time of the year the entire area is left bare or exposed. The tall growing crops act as wind breaks and the strips which are often parallel to the contours help in increasing water absorption by the soil by slowing down run off (**Fig. 7.6**).

(iii) ***Use of Early Maturing Varieties.*** Early maturing varieties of crops take less time to mature and thus put lesser pressure on the soil. In this way it can help in reducing the soil erosion.

(iv) ***Contour Ploughing.*** If ploughing is done at right angles to the hill slope, following the natural contours of the hill, the ridges and furrows break the flow of water down the hill. This prevents excessive soil loss as gullies are less likely to develop and also reduce run-off so that plants receive more water. Thus by growing crops in contour pattern, plants can absorb much of the rain water and erosion is minimised. When viewed from above, the field looks like a contour map (**Fig. 7.7**).

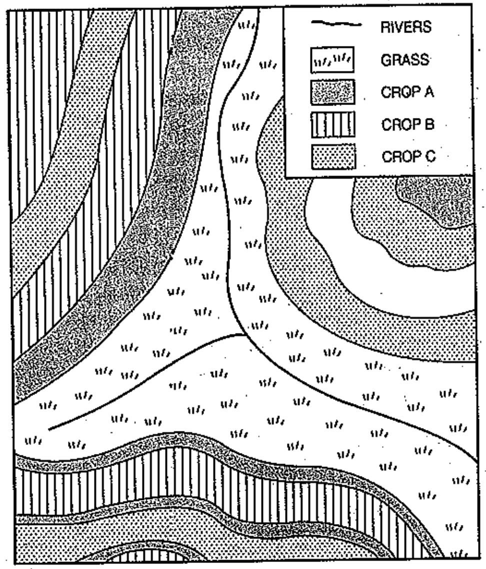

FIG. 7.6. Strip farming following the contour pattern

FIG. 7.7. Contour Ploughing

(v) ***Terracing and Contour Bunding.*** Terracing and contour bunding across the hill slopes is a very effective and one of the oldest methods of soil conservation. Hill slope is cut into a number of terraces having horizontal top and steep slopes on the back and front. Contour bunding involves the construction of banks along the contours. Terracing and contour bunding which divide the hill slope into numerous small slopes, check the flow of water, promote absorption of water by soil and save soil from erosion. Retaining walls of terraces control the flow of water and help in reducing soil erosion. Sometimes tree crops such as rubber are also planted to combat soil erosion (**Fig. 7.8**). But there is a limit to which bunding is an effective measure of soil conservation. When the slope is steeper than 8 per cent or 1 in 12, bunding becomes expensive and less effective. Nothing over 20 per cent or 1 in 5 should be terraced. Fields of a slope steeper than 15 per cent or 1 in 6 should be withdrawn from ploughing as they are not usually worth the labour of making benches very close together.

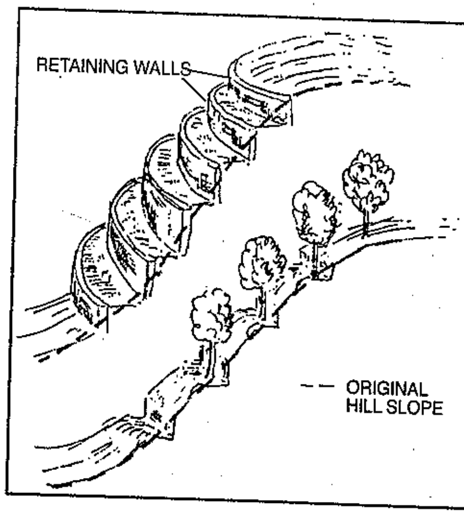

FIG. 7.8. Two ways of terracing steep hill slopes to prevent soil erosion and to produce flat-land conditions artificially.

(vi) **Checking Shifting Cultivation.** Checking and reducing shifting cultivation by persuading the tribal people to switch over to settled agriculture is a very effective method of soil conservation. This can be done by making arrangements for their resettlement which involves the provision of residential accommodation, agricultural implements, seeds, manures, cattle and reclaimed land.

(vii) **Ploughing the Land in Right Direction.** Ploughing the land in a direction pependicular to wind direction also reduces wind velocity and protects the top soil from erosion.

ACHIEVEMENTS IN SOIL CONSERVATION

Soil and water conservation measures have been adopted as one of the essential inputs for increasing agricultural output in the country right from the beginning of the First Five Year Plan. Appreciating the value of soil and the seriousness of the problem of soil erosion, the Central Government as well State Governments have taken a number of steps to conserve soil. The soil and water conservation division set up by Central Government in the Department of Agriculture and Cooperation aims at providing an overall perspective of problems like water and wind erosion, degradation through waterlogging, salinity, ravines, torrents, shifting cultivation and coastal sands.

Another scheme was sponsored by the Central Government in the Third Plan which aimed at preventing premature siltation of multi-purpose reservoirs. Scheme of Flood-Prone Rivers (FPR) was started in the Sixth Five Year Plan. Both the schemes were clubbed together during the Ninth Five Year Plan. Under the programme for the catchment management of River Valley Projects and Flood Prone Rivers, 53 catchments are covered, spread over 27 states. The total catchment area is 96.14 million hectares with Priority Area needing urgent treatment in 26 million hectares. Out of this 5.86 million hectares have been treated till 2003-04.

The *trio* of salinity-alkalinity-acidity leads to deficiency in chemical-biological nutrients and their problem has been acquiring increasing importance. Reclamation of saline and alkaline soils is a difficult task. Removal of the top soil, providing proper drainage to the waterlogged areas, avoiding seepage of water from canals, installing tube-wells in canal irrigated areas, and afforestation are some of the measures which can check the growth of unwanted salts in these soils. Application of farmyard manures, green manures, and addition of gypsum, lime, and sulphur can add to the fertility of these soils. Cultivation of salt-resistant crops like rice, barseem, barley, jowar and sugarcane has been suggested in such soils. A centrally sponsored scheme for reclamation of alkaline (usar) soils initiated in the seventh Five Year Plan is continuing in Haryana, Punjab and Uttar Pradesh. The scheme was extended

to Gujarat, Madhya Pradesh and Rajasthan during the Eighth Five Year Plan. During Ninth Plan extension of the scheme to all other states was approved where alkali soil problems exist as per scientific parameters. The scheme aims at improving physical conditions and productivity status of alkali soils for restoring optimum crop production. An area of 0.62 million hectares out of 3.5 million hectares of alkali land has been reclaimed till the end of 2003-04.

Land reclamation in the ravines spreading over 27.65 lakh hectares in Madhya Pradesh, Rajasthan, Uttar Pradesh and Gujarat is a challenging job. A ravine reclamation programme was launched in 1987-88 which was transferred to state sector in 1991-92 as per decision of the National Development Council. Major components of the ravine reclamation programme are peripheral bunding to halt any ingress of ravines, table land treatment in vicinity of upstream of the peripheral bund, afforestation, irrigation of shallow ravines and rehabilitation. About 1.266 lakh hectares of land has been treated so far.

Contour bunding and levelling have been very effective in checking soil erosion and in increasing crop yields. In Maharashtra, Karnataka, Telangana, Andhra Pradesh, Gujarat and Punjab, an increase of 25 per cent in the crop yields has been recorded as a result of contour bunding. This has also increased the water recharging capacity of wells in the adjoining areas. According to the reports of National Commission on Agriculture, the 'Kharif' and 'Rabi' crops raised in semi-arid alluvial plains of Uttar Pradesh have recorded yield increases of 35 per cent due to bunding and 60 per cent due to levelling. By bench terracing in the Kunda catchement in Nilgiris (Tamil Nadu) potato yields have gone up by 15-65 per cent.

A scheme for controlling shifting agriculture was implemented in Arunachal Pradesh and Mizoram in 1986-87. A larger scheme was launched in 1987-88 to cover nine states of Arunachal Pradesh, Assam, Meghalaya, Manipur, Tripura, Nagaland, Mizoram, Odisha and Andhra Pradesh. Till 1990-91, 26,532 families were selected for rehabilitation. The scheme involves different activities such as land development, irrigation, agriculture, horticulture, cottage industries, fisheries, social and fuel-wood forestry and minimum housing programmes. During Eighth Plan 67 thousand hectare area was treated through treatment packages. During Ninth Plan upto March 2002, 1.5 lakh hectares had been treated. The new guidelines for the scheme on the basis of new watershed to common approach has been effective from November 2000. During Tenth Plan, an area of 0.4 lakh hectares has been treated upto 2003-04.

All India Soil and Land Survey Organisation is using remote sensing technology to keep itself abreast of the latest trends.

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CHAPTER 8

Natural Hazards and Disasters

Man has been facing natural hazards and disasters since the dawn of civilisation. The earth has been undergoing various changes; both slow and catastrophic from the very beginning. It is worth understanding some of the basic terms before we make a detailed study of the natural hazards and disasters and their effects on human beings.

HAZARDS

Changes that affect humans adversely are called ***hazards***. A hazard comprises a dangerous condition or event, natural or manmade, that could cause injury, loss of life or damage to property, livelihood or environment. In other words, hazards are defined as ***"phenomena that pose a threat to people, structures or economic assets and which may cause a disaster. They could be either manmade or naturally occurring in our environment."*** (Disaster Preparedness Training Manual, Philippine National Red Cross 1954). A *natural disaster* pertains to a natural phenomenon which occurs in proximity and poses a threat to people, structures and economic assets caused by biological, geological, seismic, hydrological or meteorological conditions or processes in the natural environment.

TYPES OF HAZARDS

The list of hazards is very long and hazards can be classified in a number of ways. Generally hazards are classified depending upon their causes, mitigation strategies or their effects on societies. We shall confine ourselves to classification of disasters depending upon their causes only.

Types of Hazards depending upon their causes

Hazards could be caused by nature or man and are consequently called natural and manmade. A third type of hazards are caused both by nature and man are called ***socio-natural hazards***.

1. Natural Hazards. These are caused by the forces of nature and man has no role to play in such hazards. Following are the main examples of natural hazards :

- Earthquakes
- Volcanic eruptions
- Cyclonic storms
- Tsunamis
- Floods
- Droughts
- Landslides

2. Man-made Hazards. These are caused by undesirable activities of man. Such hazards include :

- Explosions
- Leakage of toxic waste
- Pollution of air, water and land
- Dam failures
- War and Civil Strife
- Terrorism

3. Socio-natural Hazards. These are caused by the combined effect of natural forces and misdeeds of man. For example, the frequency and intensity of floods and droughts may increase due to indiscriminate felling of trees, particularly in the catchment areas of the rivers. Storm surge hazards may be worsened by the destruction of mangroves. Although landslides are normally caused by natural forces, yet they may be caused and their frequency and impact may be aggravated as a result of building roads in mountainous areas, excavating tunnels and by mining and quarrying.

DISASTER

Extreme form of hazard leads to disaster. Disaster (French *des* meaning 'bad' and *aster* meaning 'star') is a manmade or natural event which results in widespread loss of life and property. Thus disaster is defined as "*A serious disruption of the functioning of a society, causing widespread human, material or environmental losses which exceed the ability of the affected society to cope using its own resources.*" The United Nations defines disaster as "*...the occurrence of a sudden or major misfortune which disrupts the basic fabric and normal functioning of a society (or community).* The World Bank defines disaster *as an extraordinary event of limited duration which causes serious disruption of the economy of the country.* It is an event or a series of events which gives rise to casualties and/or damage or loss of property, infrastructure, essential services or means of livelihood on a scale that is beyond the normal capacity of the affected communities to cope with unaided.

Hazards and disasters are closely related and are sometimes used as synonymous with each other. *Hazard is a threat, while disaster is an event.* The latter is a calamity or tragedy or a consequence of a hazard. *Natural hazards that cause great loss to human life and economy are known as **disasters** and **catastrophes**.* The term ***disaster*** is sometimes also used to describe a "*catastrophic situation in which the normal patterns of life (or eco-systems) have been disrupted and extraordinary emergency interventions are required to save and preserve human lives and/or the environment.*"

Classification of Disasters

Disasters are generally classified on the basis of their origin as tectonic (earthquakes, volcanoes), topographical (landslides, avalanches), meteorological (hurricanes, cyclones, tornadoes, floods, droughts), infestic (locust invasion of crops, epidemics) and human (industrial accidents, nuclear bombs).

VULNERABILITY

Hazards and disasters are unevenly distributed with respect to time and space. The terms like ***'earthquake prone'***, ***'drought prone'*** or ***'flood prone'*** areas are used to describe the distributional effect of the concerned hazards. People living in such areas are vulnerable to hazards and disasters of varied types. **Thus vulnerability is the extent to which an individual or a community or an area is exposed to the impact of a hazard.** According to National Institute of Disaster Management (formerly National Centre for Disaster Management), vulnerability is defined as the extent to which a community, structure, service or geographic ***area is likely to be damaged or disrupted by the impact of particular a hazard on account of either nature, construction and proximity to hazardous terrain or disaster prone area."*** Thus, vulnerability implies a measure of risk combined with the level of social and economic ability to cope with the resulting event in order to resist major disruption or loss. In other words, vulnerability is "***a set of prevailing or consequential conditions composed of physical, socio-economic and/or political factors which increase a community's susceptibility to calamity or which adversely affect its ability to respond to events.***"

NATURAL HAZARDS AND DISASTERS IN INDIA

Because of its subcontinental dimensions, geographical situation and behaviour of the monsoon, India is exposed to various natural hazards and disasters like drought, flood, cyclone, earthquake, etc. year after year. While all the states and union territories in the country are likely to face one or a combination of disaster situations, 27 states/union territories are more vulnerable to these disasters. Four major disasters which adversely affect different parts of the country are drought, flood, cyclone and earthquake. Only one state (West Bengal), faces all four types of disasters, seven states face three types of disasters, ten face two types of disasters and nine states face one type of disaster. It is not uncommon to experience more than one or two types of disasters affecting different parts of the country at the same time. For example, there may be flood in the Brahmaputra Valley, drought in Rajasthan and cyclonic storm in some coastal area.

Disasters occur with unfailing regularity and despite better preparedness to meet all such contingencies, the economic and social costs on account of losses caused by the natural disasters continue to mount year after year. The main hazards in India are caused by earthquakes, droughts, floods and cyclones. Since the beginning, they have been causing heavy losses of life and property forcing man to ***'learn to live'*** with natural disasters.

INDIA'S KEY VULNERABILITIES

- 55 per cent of total area is in Seismic Zones III-IV and vulnerable to earthquakes.
- 68 per cent of net sown area is vulnerable to drought.
- 40 million hectares of land is vulnerable to floods.
- 8 per cent of the total land area particularly along the eastern coast and Gujarat coast is vulnerable to tropical cyclones.
- Sub-Himalayan region and Western Ghats are vulnerable to landslides.
- Of the 7,516 km long coastline close to 5,700 km is prone to tropical cyclones and tsunamis.

The most disturbing factor is that these hazards and disasters are hitting different parts of the country with increased frequency and with greater force.

EARTHQUAKES

Earthquake is a violent tremor in the earth's crust, sending out a series of shock waves in all directions from its place of origin. If you throw a stone in a pond of still water, a series of concentric waves are produced on the surface of water. These waves spread out in all directions from the point where the stone strikes the water. Similarly, any sudden disturbance in the earth's crust may produce vibrations in the crust which travel in all directions from the point of disturbances. Earthquakes constitute one of the worst natural hazards which often turn into disaster causing widespread destruction and loss of human lives.

Earthquake Hazards in India

India has a very long history of earthquake occurrences. The most vulnerable areas according to the present seismic zone map of India are located in Himalayan and sub-Himalayan Regions, Kachchh and the Andaman and Nicobar Islands. Depending on varying degrees of seismicity, the entire country can be divided into the following seismic regions :

1. **Kashmir and Western Himalayas.** This region covers the states of Jammu and Kashmir, Himachal Pradesh and sub-mountainous areas of Punjab.
2. **Central Himalayas.** This region includes the mountainous and sub-mountainous regions of Uttarakhand, Uttar Pradesh and the sub-mountainous parts of Punjab.
3. **Northeast India.** This region comprises the whole of Indian territory to the east of northern West Bengal.
4. **Indo-Gangetic Basin and Rajasthan.** This region comprises of Rajasthan, plains of Punjab, Haryana, Uttar Pradesh and West Bengal.
5. Khambhat and Rann of Kachchh.

TABLE 8.1. Region-wise Earthquake (M > 5.0) Occurrence in India (1897–2014)

Sl. No.	Seismic Region	No. of Earthquakes of Magnitude				Return Period
		5.0–5.9	6.0–6.9	7.0–7.9	8.0 +	
1.	Kashmir & Western Himalayas	25	8	2	2	2.5–3 years
2.	Central Himalayas	68	28	4	1	1 Yr.
3.	North East India	200	128	15	4	< 4 months
4.	Indo-Gangetic Basin and Rajasthan	14	6	—	—	5 Yrs
5.	Khambhat and Rann of Kutch	4	4	1	1	20 Yrs
6.	Peninsular India	31	11	—	—	2.5–3 Yrs.
7.	Andaman & Nicobar	90	80	1	1	< 8 months

* Numbers of earthquake under category 5.0–5.9 are approximate.

6. Peninsular India including the Islands of Lakshadweep.
7. The Andaman and Nicobar Islands.

The distribution of magnitudes equal to or more than 5.0 in these regions and their average return periods are represented in the **table 8.1**.

Based on intensities of the earthquakes recorded on MM Scale the Indian Standards Institute has published a map of India showing seismic zones. Map given in **Figure 8.1** shows five Seismic zones based on MM Scale.

Zone I — Intensity V or below (Instrumental, feeble, slight, moderate, rather strong)
Zone II — Intensity VI (Strong)
Zone III — Intensity VII (Very strong)
Zone IV — Intensity VIII (Destructive)
Zone V — Intensity IX and above (Ruinous, disastrous, very disastrous, catastrophic)

According to seismologists, one part of India or the other experiences one earthquake almost everyday. But most of them are of low intensity, are harmless and go unnoticed. However, major earthquakes of higher intensity are strong enough to wreck havoc and result in great loss of life and property.

Depending upon the frequency and intensity of the earthquakes, the whole country can be divided into three broad seismological zones.

1. Himalayan Zone. The areas most prone to earthquakes in India are the fold mountain ranges of the Himalayan zone. The states of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Bihar, the Bihar-Nepal border and the north eastern states, especially Assam fall in this zone. The earthquakes in this zone are primarily due to plate tectonics. The Indian plate is pushing in the north and north-east direction at an annual rate of 5 cm subducting the Eurasian plate along the Himalayas. The Himalayas have not yet attained *isostatic equilibrium* and are rising. The region along the Himalayas where two plates meet is highly earthquake-prone. This is known as the ***zone of maximum intensity***. The absence of Nepal from the list of earthquakes shows that the whole of Himalayas are not dangerous. The Himalayas between Mount Everest and Badrinath are almost stable. This patch of tremendously huge landmass, having great heights and width rests with perfect calm and peace. The patches towards and beyond this patch are, however, very violent because of their hurried movement. Areas north-east of the arc joining Mussoorie, Shimla, Kangra, Dalhousie, Gulmarg and areas of Bihar, Assam, south of south-east Nepal, Sikkim, Bhutan, Arunachal Pradesh and western part of Nagaland, Manipur are susceptible to high magnitude earthquakes.

2. The Indo-Gangetic Zone. To the south of the Himalayan zone and running parallel to it is the Indo-Gangetic zone. Most of the earthquakes striking this zone are of moderate intensity of 6 to 6.5 on Richter scale. Therefore, this zone is called the ***zone of comparative intensity***. The earthquakes along the foothill are of medium to high intensity. However, the earthquakes of this zone are more harmful due to high density of population in this area.

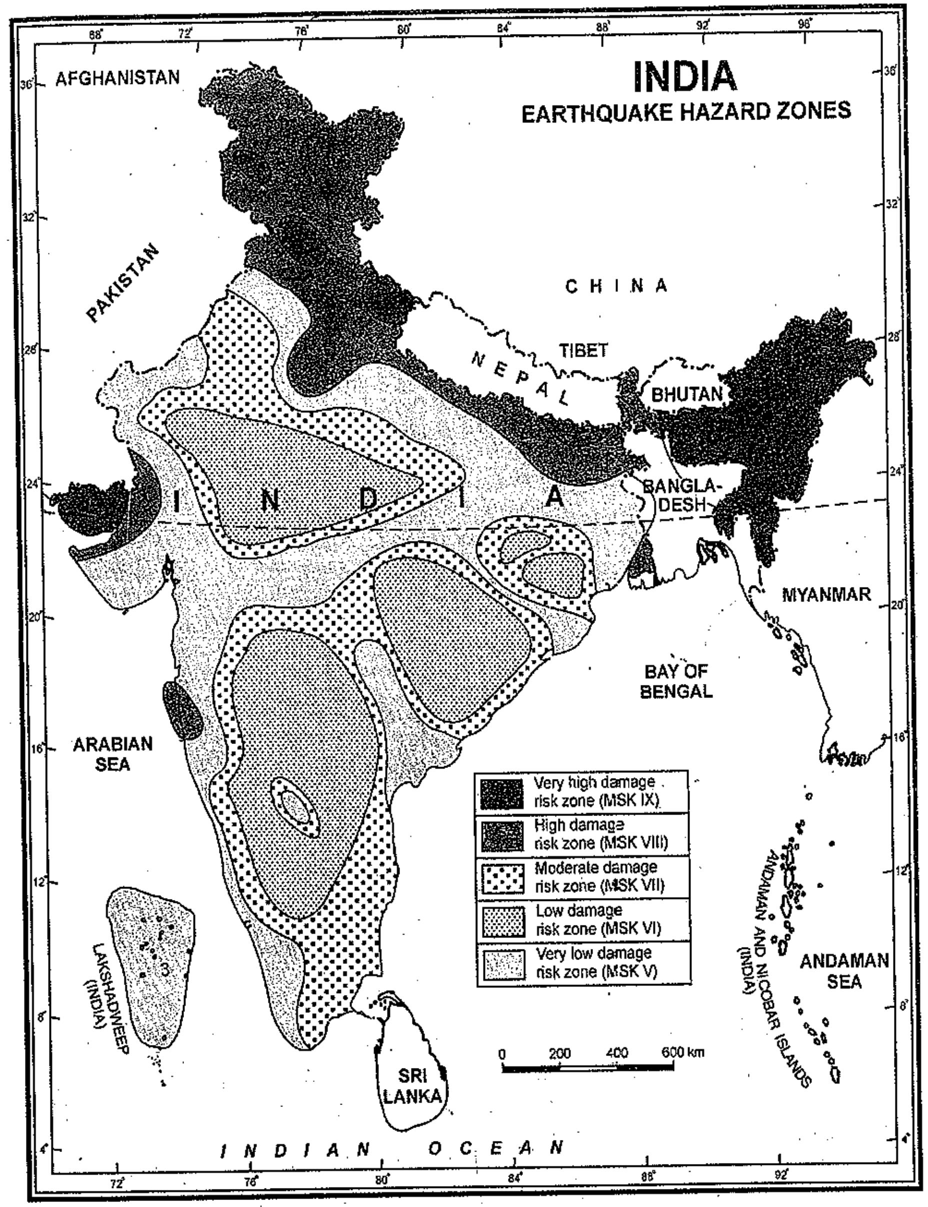


FIG. 8.1. India : Seismic Zones

3. The Peninsular Zone. The Peninsular India has presumably remained a stable landmass and only a few earthquakes have been experienced in this region. This region is, therefore, called the ***zone of minimum intensity***. But severe earthquakes of Koyna (1967), Latur (1993) and Jabalpur (1997), have raised

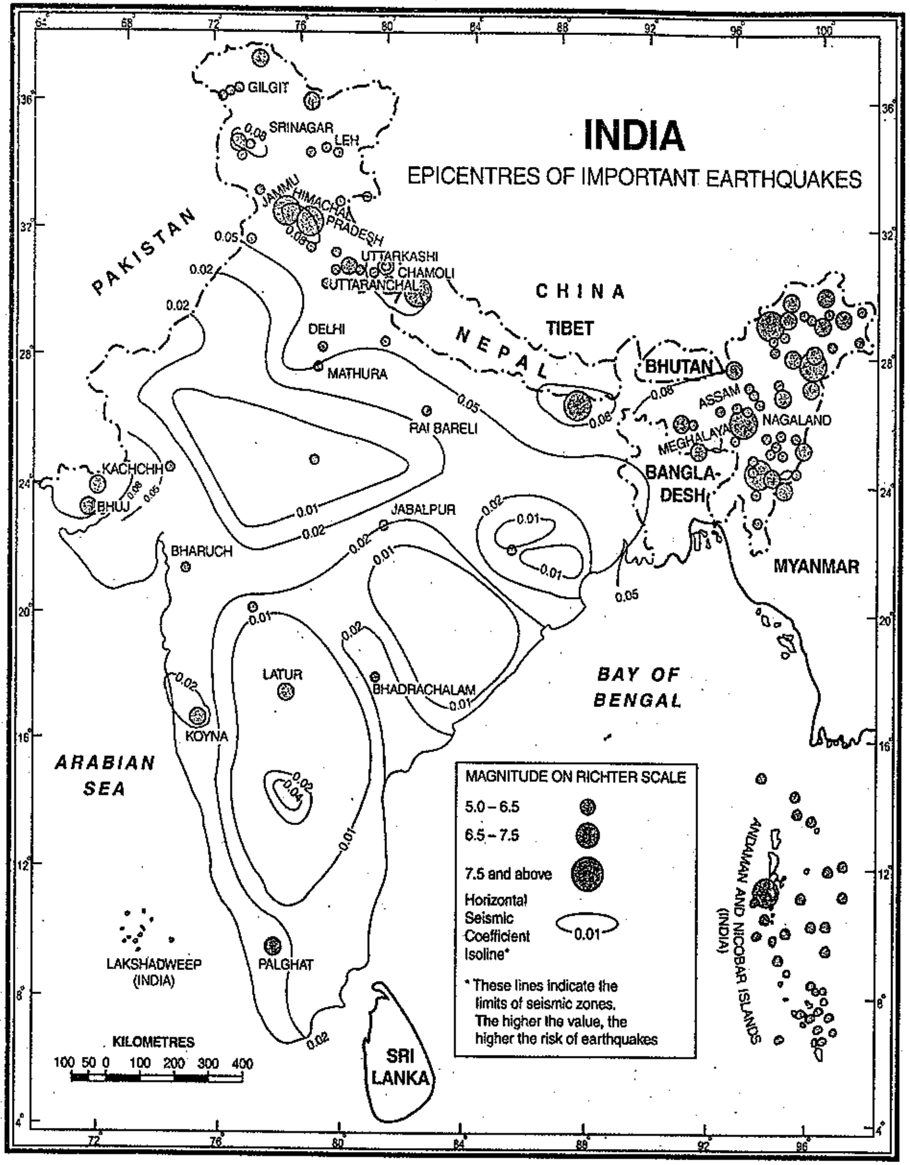


FIG. 8.2. India : Epicentres of Important Earthquakes

doubts about the seismic stability of this landmass. While the Koyna earthquake was caused due to excessive loading of water in the Shivaji Sagar reservoir formed by damming the Koyna River, the earthquake that hit Latur is supposed to be the result of plate tectonics. The northward drift of the Indian Plate had put pressure on the Tibetan Plate which caused pressure to mount at the centre of the Indian plate, leading to earthquake. The earthquake of Jabalpur also occurred under similar conditions.

Epicentres of major earthquakes (magnitude more than 5 on Richter scale) are shown in **Figure 8.2**. The country as a whole has been divided into zones by ***horizontal seismic coefficient isolines***. This coefficient varies from 0.01 to 0.08. The low horizontal seismic coefficient zone (0.01–0.02) constitutes the areas that are quite secure from earthquakes. This zone is mainly spread over extensive parts of peninsular India, Madhya Pradesh and Rajasthan areas having medium horizontal seismic coefficient (0.04–0.05) are spread over the Satluj-Ganga plain, Godavari basin of Andhra Pradesh, Ratnagiri and Raigad districts of Maharashtra and some parts of Gujarat. The areas that come under the high seismic coefficient zone are situated in Jammu and Kashmir, Himachal Pradesh, Uttarakhand, northern parts of Bihar, north-eastern states, Kachchh region of Gujarat and Andaman and Nicobar Islands. These regions are highly susceptible to earthquakes.

Earthquake Risk. The earthquake risk to a structure or system can be considered to be made up of four components as follows :

Seismic Risk =
Hazard × Exposure × Vulnerability × Location

Hazard means the occurrence of a terrifying earthquake of sufficient magnitude (hence peak intensity at the point of occurrence) capable of causing damage to the weakest manmade structures.

Exposure indicates the objects and structures made by man which are exposed to the effects of the 'hazard' and will include buildings, bridges, dams, power plants, life-line structures etc.

Vulnerability indicates the damageability of the 'exposure' under the action of the hazard, weaker constructions being more vulnerable and 'risky' than stronger ones.

Location means how far 'exposure' is situated from the location of the 'hazard', the nearer ones being in greater danger than those far away.

Hazardous Effects of Earthquakes

The hazardous effects of earthquakes do not depend only upon their magnitude and intensity alone but on so many other factors such as population, nature of rocks, type of buildings, etc. Even a weak earthquake can do great damage if it strikes a densely populated area, an area of weak structure or an area where buildings are weak. The direct and indirect disastrous effects of earthquakes include deformation of ground surface, damage and destruction to human structures such as buildings, rails, roads, dams, bridges, factories, destruction to towns and cities, loss of human and animal lives, fires, floods, landslides, etc.

Major hazards of earthquakes are briefly described as under :

1. Loss of Life and Property. There is devastating loss of life and property if the intensity of the earthquake is more than 5 on the Richter scale. Buildings, roads, railways, bridges, dams, etc., suffer severe damage when an earthquake strikes them. Several villages, towns and cities are completely ravaged. The towns of Bhuj, Bhachau, Anjar, Gandhidham, and Ratnal were completely destroyed by the earthquake which struck Bhuj on 26th January, 2001. Property worth ₹ 2,000 crore was destroyed. The maximum damage is noticed near the epicentre of the earthquake. This damage is reduced as we move away from the epicentre. An earthquake becomes a hazard or disaster only when it strikes populated area and causes unaccountable loss to life and property.

2. Topographical Changes. The main effects of earthquakes on topographical features are seen in the form of offsets along known faults, fissures, scarps, elevation and depression of coasts, etc. Earthquakes are often followed by landslides in hilly areas. Due to earthquake vibrations, the looser material at or near its maximum static stable angle may become unstable and move along the slope of hill. Cracks and fissures which occur as a result of a severe earthquake facilitate landslides. The severe earthquake which struck Uttarkashi in Uttarakhand (1991) caused many cracks and fissures in *Varunavat Parvat*. This gave birth to landslides which caused heavy damage to Uttarkashi town in the year 2003. Large masses of dry earth and rock, called ***earth avalanches***, slide over considerable distances. If wet soil slips down the hill side, a ***slump*** occurs. ***Earthflow*** is another phenomenon which is primarily restricted to ground water. The earthquake is either accompanied or succeeded by a sudden burst of water from a locality where it normally appears in springs.

3. Liquefaction. Soil liquefaction is a phenomenon where low density saturated sands of relatively uniform size inside the earth start behaving like a jelly with no strength to hold a building up, and the building just sinks or gets tilted on one side. The phenomenon of liquefaction is particularly important for dams, bridges, underground pipelines and buildings close to river banks, sea shore or large lakes. Vast tracts of plains of Uttar Pradesh and Bihar where soil is generally soft and the water table is high, offer favourable conditions for such effects. The great Bihar-Nepal earthquake of 1934 produced a belt of slumping extending from Bettiah in north-west to Purnea in the south-east (a distance of nearly 320 km), surrounding the epicentral tract, in which all buildings either tilted or sank in soft alluvium. Widespread subsidence over large area was observed. There were innumerable fissures through which large quantities of sand and water were thrown up to the surface, thereby causing large scale destruction to standing crops. The soil became totally unfit for cultivation. Rann of Kachchh also covers a vast area where large scale liquefaction of ground was observed during the Bhuj earthquake of 2001.

Pattern and Causes of Damage

Buildings. Great damage is done to buildings by the earthquakes particularly if the buildings are constructed with brick, mud or timber. Reinforced concrete buildings suffer least damage, while effected adobes and unreinforced brick buildings are severely damaged by the earthquakes. Projecting cornices, balconies, towers and arcades render the building more vulnerable.

An earthquake causes damages to the buildings by setting up oscillating (backward and forward) motion of the ground. As the part of the earth's crust affected by the earthquake oscillates, the buildings on the ground start responding to oscillation in varying degrees depending upon how these have been designed and constructed. Close to the epicentre, there is also a vertical movement. Due to oscillatory movements caused by the earthquake, the foundations of the building move with the ground, but the inertia of the rest of the building prevents it from moving instantaneously and there is a slight delay before the upper portions start moving. This delay leads to differential stresses and subsequent cracking because the roof tends to separate from the support and the walls tend to be torn apart. The force exerted on the building depends upon the movement of the ground caused by the earthquake and the weight of the building. It is axiomatic *that earthquakes do not kill—collapsed buildings do*. The Muzaffarabad earthquake in October 2005 hit Pakistan and India with a magnitude of 7.4 in Pakistan and 6.8 in India and killed over one lakh persons. Several buildings collapsed like a pack of cards. In contrast a magnitude of 7.1 earthquake in October 2004 in Hokkaido (Japan) caused only 17 injuries. The main reason for the low Japanese casualties was their seismically engineered buildings. Therefore, it is advisable to construct light weight buildings with lighter roofs in earthquake prone regions. Rapid progress in earthquake engineering has standardised techniques for earthquake resistant design of buildings in different seismic zones. India has been classified in five seismic zones based on Modified Mercalli Intensity Scale. In zones III, IV and V destruction and damage to buildings is considerable. Zone II could also have minor damage in rural buildings. but collapse of housings in this zone is not considered probable, while zone I may be taken as non damaging seismicity.

The extent of damage is dependent on a number of factors; the intensity of the earthquake, distance from the epicentre, soil condition, type of structure (mass, permissible stress, elasticity, dynamic load response and durability of materials), design of building and quality of construction.

Shape of the building has a great bearing on its resistance to earthquake risk. Geometric shapes such as square or rectangle usually perform better than buildings in the shape of L, T, U, H, +, O or a combination of these.

Damage to Transport System. Damage to transport system includes damage to highways, railways, airports, marine and river systems, water supply and sewage, fuel and oil, energy transmission and communication systems. The facilities of transport may be built either on surface or underground. The earthquake affects differently on these two types of structures. The underground structures such as oil pipelines are mainly governed by the strain in the surrounding ground caused by the propagation of earthquake waves, while the surface

structures like bridges are governed by vibrating response of the structure to earthquake ground motion. The second category of damage arises due to the blocking of road by jammed cars, fire, uprooted poles and collapsed buildings. Blocking of highways may stop various activities needed for earthquake relief and rescue.

Fire. In the event of an earthquake, short circuits, contact with live electrical wires, damage to blast furnaces and other fire related appliances are the major causes of fire.

Floods. Often earthquakes lead to distortion and displacement of the surface rocks which block the flow of a river. This causes floods in the upper course of the river. Often dams and embankments develop cracks and the course of the river lower down the dam site is flooded.

Public Health. People suffer multiple injuries and many become permanently disabled. Hazards of disease on pollution of water bodies, breakdown of sewage and sanitary pipes and other unhygenic conditions could lead to epidemics. Many people die of heart attack.

Civic Services. Civic services like water pipes, sewers, electric connections, etc. are disrupted. Fire hydrants supply lines, if vulnerable, could hamper service operations.

Economic Activities. Economic activities like agriculture, industry, trade, transport and other services may be severely affected by widespread damage to infrastructure in the event of an earthquake. It becomes one of the major causes of civic unrest.

Earthquake Safety Rules

Before an earthquake

1. Keep stock of drinking water, some foodstuffs, first-aid equipment, a crow bar, shovel, pick and rope, electric torch and some candles and a helmet for every member of the family.
2. Ensure that water heaters and other gas appliances are firmly fixed and shut off when not in use, as broken gas pipes or appliances are likely to cause fire hazards.
3. Securely fasten fixtures, refrigerators and shelves to the wall and place large and heavy objects on the lower shelf. Top heavy object should be braced or anchored.
4. Find out the location of the nearest first-aid post, Warden Post and Fire Station and approach for help if required.
5. Join the Civil Defence Organisation and train yourself and the members of your family in first-aid, rescue fire fighting etc., which will help you, your family and neighbours.
6. Conduct occasional home earthquake drills so that your family has the knowledge to avoid unnecessary injuries and panic in the event of an earthquake.
7. More responsible members of the family may be taught how to turn off electricity, gas and water at the main switches or valves.
8. Be aware of what to do in various situations so that you are prepared in the event of an earthquake, *e.g.*, at home, whilst driving a car, at work in a shop, a public theatre, cinema hall, etc.
9. Avoid the risk of an epidemic which usually follows earthquakes by using safe water and clean food.
10. Evacuate old dilapidated buildings as they are sure to timble first.

Certain other precautions, which are necessary in case of fire, should also be taken as far as possible :

1. Keep adequate water/dry sand stocked in accessible places.
2. All lofts and attics should be kept free from inflammable material.
3. Keep all inflammable stores, which are required, as much dispersed as possible.

During the earthquake

1. Do not panic. The motion is frightening, but unless it shakes something down on top of you it is harmless. The earth does not yawn open, gulp down a neighbourhood, and close up. So keep calm.

2. In the event, the safest place is an open space away from building. However, when this is not suitable do not try to run from a building during earthquake.
3. If it catches you indoors, take cover under a desk, table, bench or in doorways, halls, and against inside walls or staircase. Stay away from glass.
4. Do not use candles, matches, or other open flames, either during or after the earthquake. Put out all fires.
5. If the earthquake catches you outside, move away from buildings and utility wires. Once in the open stay there until the tremor stops.
6. Do not run through or near buildings. The greatest danger from falling debris is just outside doorways and close to outer walls.
7. If you are in moving car, stop as quickly as safety permits, but stay in the vehicle. A car is an excellent seismometer, and will jiggle on its springs during the earthquake, but it is a good place to stay until the earthquake stops.

After an earthquake

1. Keep calm, switch on the transistor radio and obey any instructions you hear on the radio.
2. Keep away from beaches and low banks of rivers. A huge wave may sweep in.
3. Expect aftershocks.
4. Turn off the water, gas and electricity.
5. Do not smoke and do not light matches or use a cigarette lighter. Do not turn on switches. There may be gas leaks or short-circuits.
6. Use a torch.
7. If there is a fire, try to put it out. If you cannot, call the fire brigade.
8. If people are seriously injured, do not move them unless they are in danger.
9. Immediately clean up any inflammable products that may have spilled (alcohol, paint, etc.)
10. If you know that people have been buried, tell the rescue teams. Do not rush and do not worsen the situation of injured persons or your own situation.
11. Avoid places where there are loose electric wires and do not touch any metal object in contact with them.
12. Do not drink water from open containers without having examined it and filtered it through a sieve, a filter or an ordinary clean cloth.
13. Eat something. You will feel better and more capable of helping others.
14. If your home is badly damaged you will have to leave it. Collect water containers, food, and ordinary and special medicines (for persons with heart complaints, diabetes, etc.).
15. Do not re-enter badly damaged buildings and do not go near damaged structures.
16. Do not walk around the streets to see what has happened. Keep clear of the streets to enable rescue vehicles to pass.

TSUNAMI

Introduction and Definition

Tsunami is derived from Japanese word *'tsu'* meaning harbour and ***'nami'*** meaning wave. According to Report of High Powered Committee on Disaster Management (2001). "Tsunami is an ocean wave produced by an event at the sea, like an earthquake, landslide or volcanic eruption" **(Fig. 8.3)**. A tsunami is not a single wave but a series of waves generated by the geological changes near or below the ocean floor. These waves may reach enormous size and have been known to travel across the oceans.

Formation of Tsunamis

(i) Undersea earthquakes

Although tsunami may be caused by landslides, volcanic eruptions or even by the impact of a large meteorite falling on the ocean, most destructive tsunamis are generated by massive undersea earthquakes, occurring at depth less than 50 km with the epicentre or fault line near or on the ocean floor. A strong undersea earthquake with magnitude greater than 7.5 on the Richter scale tilts and deforms large areas of the sea floor ranging from a few kilometres to 1000 kilometres and even more. As the sea floor is tilted or deformed by the tectonic earthquake (earthquake associated with the earth's crustal deformation), the sea water above is displaced from its equilibrium position. Waves are formed as the displaced water attempts to regain its equilibrium under the influence of gravity. It is this vertical movement of the entire water column that generates destructive tsunami waves.

The displacement of sea floor, and occurrence of an earthquake and formation of tsunamis can best be explained on the basis of plate tectonics. When two converging lithospheric plates come closer together, then heavier plate is thrust under the lighter plate and displacement of the crust takes place at the subduction zone. A fault is created and an earthquake occurs, giving rise to tsunamis.

It must be noted that a tsunami is usually not generated if the sea floor movement is horizontal. Besides, not all undersea earthquakes create tsunami, as it depends upon the nature and degree of displacement of seawater column. It is only the vertical displacement of the seawater due to abrupt, jerky movements of fault blocks on seabed that gives birth to tsunamis. Once formed, the monstrous waves soon begin their journey towards the nearest coastline, ringing the bells of doom (Fig. 8.4).

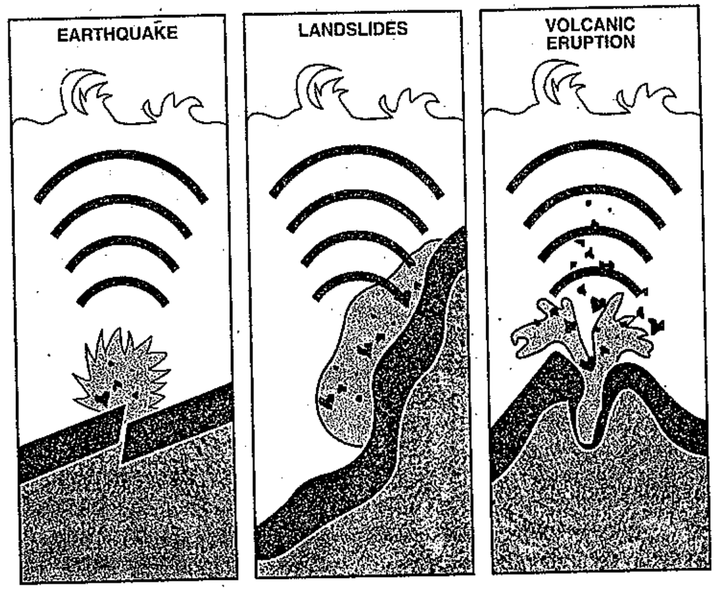


FIG 8.3. Triggering of Tsunami

(ii) Landslides

Tsunami waves are also generated by displacement of seawater resulting from landslides as well as rock falls, icefalls etc. Construction work of an airport runway along the coast of Southern France in the 1980s caused an underwater landslide. This triggered the destructive tsunami waves in the harbour of Thebes. Underwater landslides may also occur when a strong earthquake shakes the sea floor, thus forming tsunamis. These waves rapidly travel away from the source due to dissipation of energy, and create havoc in the nearby coastlines.

(iii) Volcanic Eruptions

Whenever a violent volcanic eruption takes place under the sea, it causes sudden displacement of a large volume of seawater and tsunami waves are formed. Similarly, when the roof of a volcano collapses that has a large empty magma chamber owing to continuous flow of lava, a crater sometimes as large as one kilometre in diameter is formed. As the seawater gushes into this crater, the water column of the sea is disturbed which gives rise to tsunami waves.

One of the largest and the most destructive tsunami ever recorded was generated on August 26, 1883 after the explosion and collapse of the volcano of Krakatoa in Indonesia. This explosion generated waves with a towering height of about 40 m, that wrecked havoc on the coastal areas along the Sunda Strait in both the islands of Java and Sumatra killing more than 36,000 people. It is believed that the destruction of the Minoan civilisation in Greece in 1490 B.C. was caused by tsunamis which were formed by the explosion of the volcano of Santorin in the Aegean Sea.

(iv) Meteorites and Asteroids

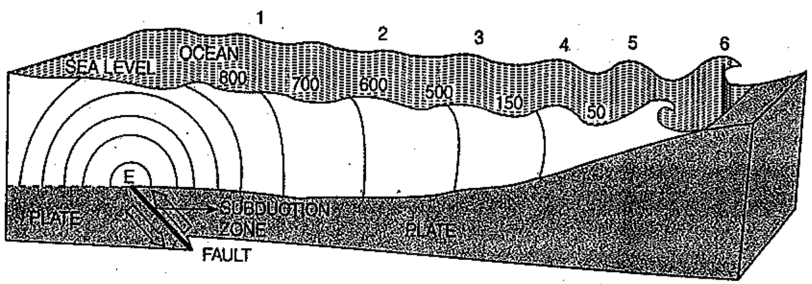
There is a potential danger of a tsunami being formed by the fall of meteorites and asteroids in the ocean. Researchers in California have developed a computer simulation depicting the ocean impact of asteroid 1950 DA, a gigantic space rock that would be very close to the earth in 2880. Although the possibility of such an impact is very remote, the computer model definitely gives the researcher an insight into the destructive power of tsunami caused by near-Earth object. Some of the meteorites have been uncomfortably close to the earth and could wreck havoc in different forms including tsunamis.

Propagation of the Tsunamis

Tsunamis consist of a series of very long waves which travel outwards on the surface of the ocean in all directions away from their place of origin. Their movement is just like ripples created by throwing a pebble into a pond of water. In deep sea the tsunamis travel at very very high speed (say 500–800 km per hour), almost as much as the speed of a jet aircraft. Their wavelength is very long which often exceeds 500–700 km. However, the amplitude of tsunamis in deep sea is very low and rarely exceeds 1 metre. Physically they propagate as long waves with speed given by

$$(\text{Water depth} \times \text{gravitation acceleration})^{1/2}$$

Since the tsunamis have very long wavelength and very low amplitude in deep ocean, they cannot be seen or detected from the air. Therefore, passengers on boats cannot feel or see the tsunami waves as the killer waves pass by underneath at high speeds. It may only appear as a gentle rise and fall of the sea. Thus tsunamis are always deceptive and are able to conceal their killing capacity in the deep water of open area. For example, the Great Sanriku tsunami, which struck Honshu in Japan on June 15, 1896 was completely undetected by fishermen as its deep water height was only about 40 cm. A monster in disguise, this tsunami transformed into huge waves when it arrived on the shore and ravaged 275 km of coastline



E : EPICENTRE OF THE EARTHQUAKE

⇖ : DIRECTION OF MOVEMENT OF PLATES

800 : SPEED OF TSUNAMI IN Kmph

1–6 : SERIES OF WAVES

FIG. 8.4. Origin and Propagation of Tsunamis

killing 28,000 people. So from the sky tsunami waves cannot be distinguished from ordinary ocean waves. But beneath, a tremendous amount of energy lurks. Since the rate at which the wave loses its energy is inversely related to its wavelength, tsunamis not only propagate at high speeds, they can also travel great transoceanic distances with limited energy losses.

As the tsunamis leave the deep water of the open ocean and travel towards the shallow water, they are transformed in two ways. Firstly their speed is reduced considerably and secondly they attain enormous height often exceeding 10 metres and occasionally may reach 30 metres. **Figure 8.4** shows the origin of tsunamis and their propagation from deep water of open sea to the coast.

Effects of Tsunamis

Tsunami pose serious danger to the inhabitants of the coastal areas. They attack the sea shore as gigantic waves, moving with great force, appearing without a warning and hitting the coastline like a water bomb. Loaded with enormous energy, the killer waves wreck havoc by flooding hundreds of metres inland, past the typical high water level. They flatten houses and wipe out villages, uproot electric poles, throw cars into swirling waters and toss boats ashore all in mad fury, and finally drag thousands of hapless victims out to sea as they recede. Large rocks weighing several hundred tonnes and other debris can be moved hundreds of metres inland by a tsunami. Tsunamis can even travel up rivers and streams that lead to the ocean.

Tsunamis in the Indian Ocean

Tsunamis have been generated in the Indian Ocean at a number of times. In 1883, eruptions from the Krakatoa fueled tsunamis which killed 36,000 people in Java and Sumatra islands of Indonesia. During the earthquake in 1880 which had its epicentre near the centre of the Bay of Bengal, tsunamis were reported. During the earthquakes of 1819 and 1845 near the Rann of Kachchh, there was rapid movement of water into the sea. Tsunamis 12 to 15 metres high were generated in the Persian Gulf by 1945 Mekran earthquake. The estimated height of waves was about 2 metres at Mumbai.

Tsunamis of 26th December 2004 in the Indian Ocean

On 26th December 2004, the Indian Ocean was hit by tsunamis which is considered to be the most catastrophic in the living memory of the inhabitants of the coastal areas of this ocean. It was caused by a severe earthquake which measured 8.9 on the Richter scale. Seismologists at Northwestern University in Illinois later upgraded the earthquake to magnitude 9.3 on Richter scale. This is perhaps the highest magnitude for any earthquake ever recorded anywhere in the world. This earthquake had its epicentre off the coast of Sumatra (Indonesia) at 3.5° north latitude and 95° east longitude. This place happens to be at the tri-junction of the Indian, Australian and Burmese (Myanmarese) plates. The earthquake was triggered by the collision of the Indian plate with Burmese plate. It occurred at the point where the Indian plate subducts below the Burmese plate due to the northward movement of the Indian plate (**Fig. 8.5**). Seismologists have noted a 15 metre slip in the vertical direction along the crack that is about 1000 km long extending upto Andaman and Nicobar Islands in the northern direction.

Damages Caused by Tsunami

This tsunami had been the most damaging in the world history. It had wrecked havoc to as many as 11 countries of south and southeast Asia and East Africa extending from Indonesia to Somalia. Hence it is rightly called the ***tragedy of international dimensions***. Various types of damages caused by the tsunami of 26th December 2004 are briefly described as under.

1. Death Toll

The tsunamis that hit the Indian Ocean on 26th Dec. 2004 claimed over 1.84 lakh lives in different countries of Asia and Africa. The soaring waves killed people of at least 40 nationalities including tourists from various countries of the world.

Table 8.2 shows that Indonesia has been the worst sufferer with death toll of over one lakh persons. Sri Lanka, India and Thailand also suffered heavy tolls. The other countries which suffered loss of life include Myanmar, Bangladesh, Maldives and the distant African countries of Somalia, Kenya, Seychelles and Tanzania.

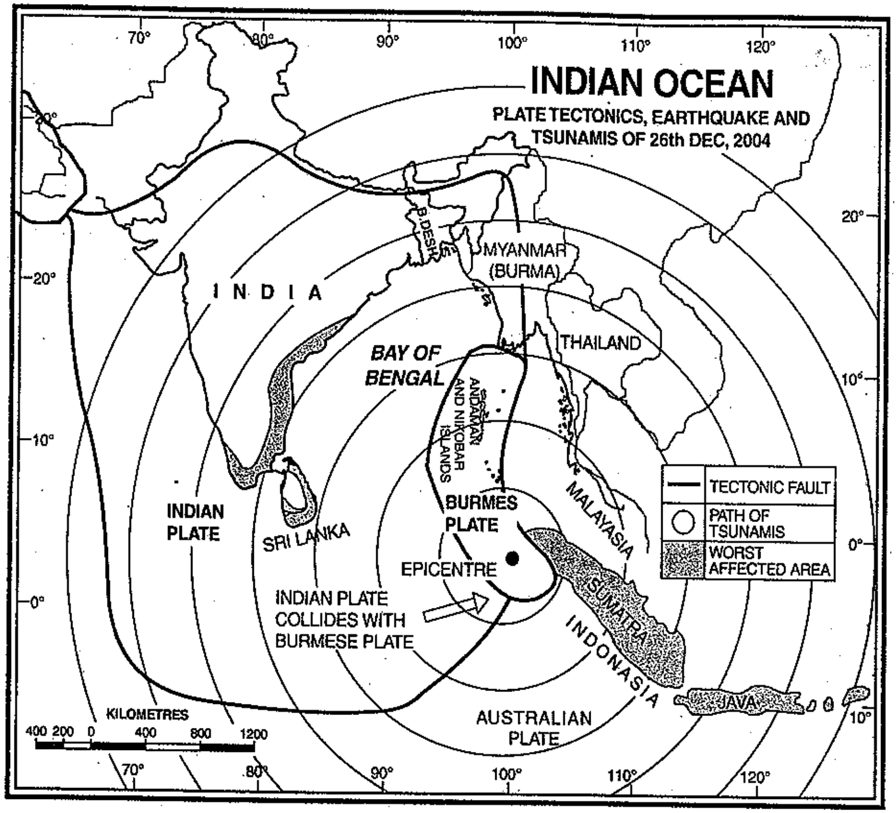


FIG. 8.5. Plate Tectonics, Earthquake and Tsunami of 26th December, 2004.

Surprisingly Malaysia suffered only a fraction of destruction despite its being located so near to the epicentre of the earthquake. This is because of the location of Sumatra which acted as buffer for Malaysia.

Besides over one million people were affected and several others were rendered homeless.

In India, the Andaman and Nicobar Islands were the closest to the epicentre of the earthquake and hence the origin of tsunamis, and were the worst sufferers. Areas like Car Nicobar, Katchal, Nancowry, Campbell Bay, Champion Island, Chowra and Teresa Island have been badly affected. In Car Nicobar, half of the total population of about 20 thousand was reportedly missing.

On the mainland of India, the main attack of tsunamis was on the coastal areas of Tamil Nadu,

TABLE 8.2. Number of Persons killed by Tsunamis

Country	Number of Dead Persons
1. Indonesia	1,13,306
2. Sri Lanka	30,196
3. India	15,160
4. Thailand	5,186
5. Other countries	20,842

Andhra Pradesh and Kerala and the union territory of Pondicherry. Of these three states, Tamil Nadu suffered the most. This was followed by Andhra Pradesh and Kerala.

The countries which reported death toll higher than India were Indonesia and Sri Lanka. In Indonesia, Sumatra and Java including Aceh Province

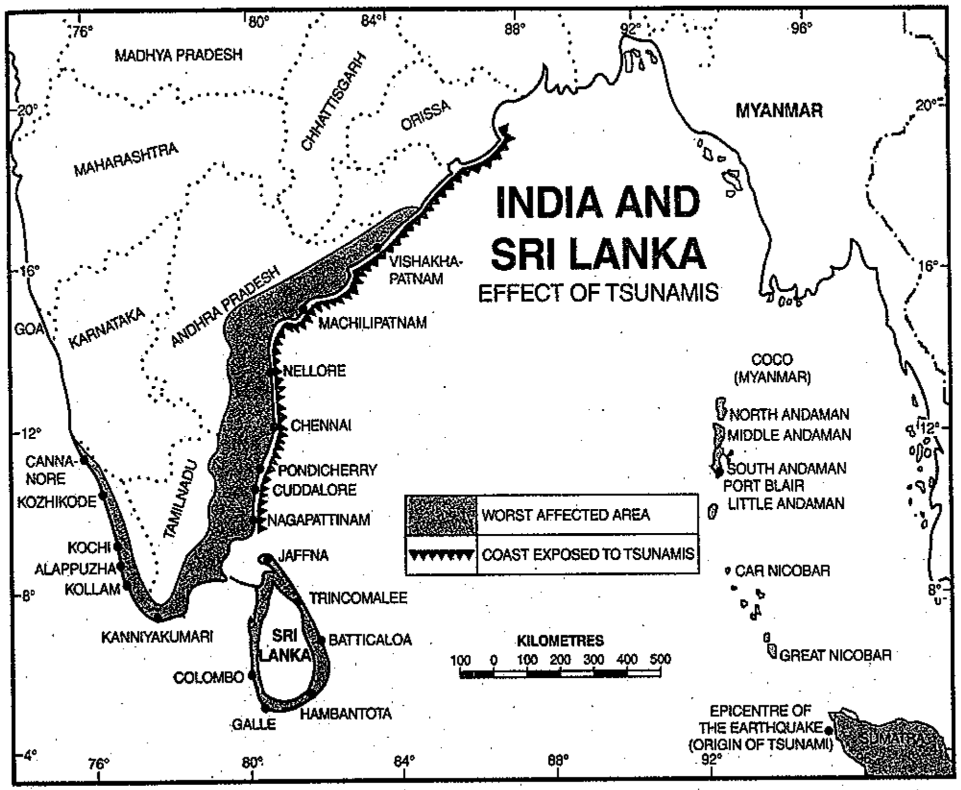


FIG. 8.6. India and Sri Lanka : Effect of Tsunamis

were the worst sufferers. In Sri Lanka, Matara, Galle, Weligma, Hambantota, Batticaloa and Colombo reported heavy casualties.

Besides a large number of tourists from Europe, North America, South America and Australia who had come to the tsunami affected countries to celebrate Christmas and New year also lost their lives.

2. Loss of Property

Property worth crores of rupees has been damaged as a result of attack by tsunamis. Infrastructural elements like houses, public buildings, transport and communication system etc. had been damaged almost beyond repair. Sea water even entered the nuclear power plant at Kalpakkam which was closed for a number of days. In Sri Lanka, rail tracks were twisted near Colombo and a train was derailed in which about 1,000 persons were killed.

According to preliminary findings of the government of India, the coastal areas of India, which include large coastal tracts of Tamil Nadu, Andhra Pradesh, Pondicherry and Kerala, have suffered financial losses of billions of rupees. The financial loss in the Andaman and Nicobar Islands was pegged at ₹ 2,500 crore (see **Table 8.3**).

TABLE 8.3. Estimates of Financial Losses in India caused by Tsunamis

State/Union Territory	Loss ₹ crores
1. Tamil Nadu	2730.70
2. Andaman and Nicobar Islands	2500.00
3. Kerala	1358.62
4. Andhra Pradesh	720.73
5. Puducherry	512.00

3. Physiographical Changes

Tsunamis of 26th December 2004 were so strong that they could bring about drastic physiographic changes in different parts of the world. Satellite pictures of the tsunami affected areas show conspicuous changes in Chennai (particularly Adyar river course) as well as Trinket Katchall and Camorta Islands of the Andaman and Nicobar. Water level in many islands had risen, number of beaches in many islands like Campbell Bay had vanished and Trinket Island was split into two. Car Nicobar, which was worst affected sank to some extent. Indira Point, the southern-most tip of the Indian Union, was almost completely washed out, shrinking the coastline inland. These islands are hardly 125 to 200 km from the origin of tsunamis and had to face the worst fury of the killing waves.

Several other physiographic changes had been reported from Indonesia, Maldives and large areas of sea bed.

4. Motion of the Earth

The US Geological Survey expressed the opinion (as expressed by Ken Herdnut) that tremendous energy released by the earthquake made the earth wobble on its axis. According to Richard Gross, a NASA geophysicist, the earthquake might have permanently accelerated the earth's rotation due to shift of mass towards the earth's centre. This had caused the planet to spin 3 microseconds or one millionth of a second faster and to tilt about 2.5 cm on its axis. In other words, day is shortened by about 3 microseconds and the north pole has shifted towards east Siberia by 2.5 cm. Besides earth's oblateness (flattering at the poles and bulging at the equator) decreased by one part in 10 billion.

5. Decline in Soil Fertility and Agricultural Production

Vast low lying coastal areas were submerged under sea water which increased the salinity of the soil and reduced agricultural production. Cuddalore and Nagapattinam districts in Tamil Nadu were the worst affected. Tests conducted on soil samples from these districts showed that sea water had seeped to a depth of about 90 cm of soil, thereby totally affecting the root zone (15–30 cm below ground). Soil profile tests showed high salinity varying from 6.8 to 9.10 pH value (neutral value for pH is 7). This is highly saline condition in which no paddy crop could be cultivated. In Nagapattinam district alone, more than 9,500 hectares of land had been rendered unfit for cultivation by increased salinity. Horticulture also suffered heavy losses. The total loss in Nagapattinam district was estimated at ₹5.2 crore. This land could be reclaimed by flushing the soil with fresh water from the Cauvery river and by administering about two metric tonnes of gypsum per hectare. This process normally takes about 3 to 4 years to show the desired results. Farmers had been advised to sow plants like cashewnut which are saline-resistant.

6. Effect on Marine Life

The killer tsunamis had badly affected the marine life of the Indian Ocean. A large section of the coral reefs of the Andaman and Nicobar Islands archipelago had been destroyed, while others suffered extensive damages. According to marine biologists, satellite pictures showed that 45 per cent of the fragile coral reefs had been destroyed. The surviving reefs were damaged by the debris washed into the sea from the islands. Experts say it would take at least 700 to 800 years for reefs to re-form. The coral reefs around the Andaman and Nicobar Islands are of fringing type *i.e.*, they lie just off the coastline. Hence they have suffered extensive damage. Some of the species that were unique to the archipelago could have become extinct.

Fishing also suffered heavy losses at the hands of the powerful tsunamis. Sea beaches along the coasts of the Indian Ocean became graveyards of the dead fishes after the tsunami swept across the ocean. Mangrove areas that acted as nursery habitats to fish and shrimp were also damaged. The breeding, feeding and other activities of large sea mammals such as whales, dolphins etc. were also adversely affected.

Marine exports from India to the tune of US $ 1.3 billion were severely hit owing to wreckage caused by tsunamis. Since hatcheries and aquaculture ponds of coastal areas from Kerala to Odisha have been adversely affected, the marine production and hence the marine exports were badly hit. Fish, prawns and shrimps form a major chunk of India's marine exports.

Tsunami Distaster Management and Mitigation

Tsunamis are so powerful oceanic waves that it is not in man's hands to control or check them. However, following few tips may be helpful if forewarning about advancing tsunamis is received.

1. Get off the beaches and head for higher ground.
2. Stay away from rivers leading into the ocean.
3. Wait for all clear as there can be several giant waves in succession.

Advance Warning about Tsunamis

The best way of escaping the fury of the killing tsunami waves is to give advance warning of impending tsunamis to the vulnerable communities. Following few tips will help the common man to apprehend the danger of tsunamis.

(*i*) If there is a major undersea earthquake, beware of the danger because tsunamis could reach the coast in a few minutes.

(*ii*) Shaking of ground is a sufficient warning for the people living in the coastal areas about the impending tsunami.

(*iii*) A perceptible rapid rise or fall in coastal water can also be taken as a forewarning about an approaching tsunami.

(*iv*) Coastal areas less than eight metres above sea level run the greatest risk of an attack by tsunamis. They should be immediately evacuated if there is danger of an approaching tsunami.

It is possible to predict the onslaught of tsunamis by studying their speed, wavelength and depth of the sea. Tsunamis often take some time to reach the sea coast from their place of origin (**Fig. 8.7**) because the wave length and speed of tsunamis is drastically reduced when they approach the shallow sea. But on reaching the coastal shallow waters, their energy is compressed and they attack the coastal population as lethal waves. Thus a correct warning a few hours before the arrival of tsunamis can save thousands of lives and property worth millions of rupees.

Tsunami Warning System in India

Unfortunately India and other Indian Ocean rim countries did not have tsunami warning system before 26th December 2004 when the deadly tsunamis hit the coasts of Indian Ocean. Had public warnings been issued about the killing tsunami waves across the Indian Ocean, thousands of lives and property worth billions of rupees could be saved as the tsunami which hit the Sumatra Island took about three hours to crash into the Indian Coast. After the catastrophe, India decided to install her own tsunami warning system at the cost of ₹125 crore rather than becoming a part of the Pacific Warning System. It was planned to install the warning system by the end of the year 2007 and was inaugurated on 15th October, 2007. The system comprises a real-time network of seismic stations, bottom pressure recorders (BPR) and the tide gauges to monitor earthquakes in the sea and tsunamis triggered by them. The centre receives the data from

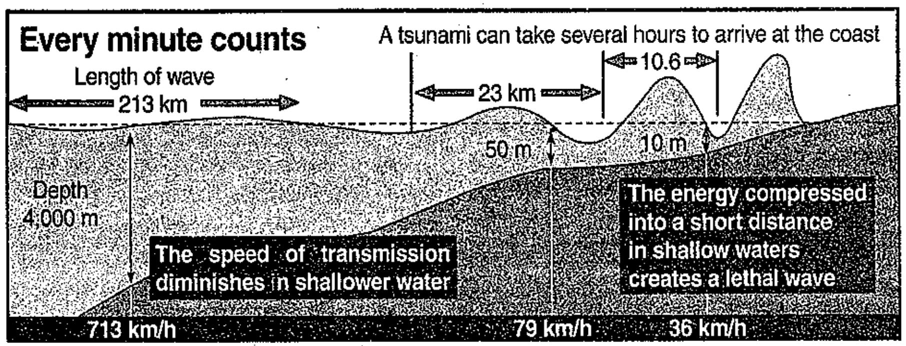


FIG. 8.7. Study of movements of Tsunamis can help in warning the people about the coming waves

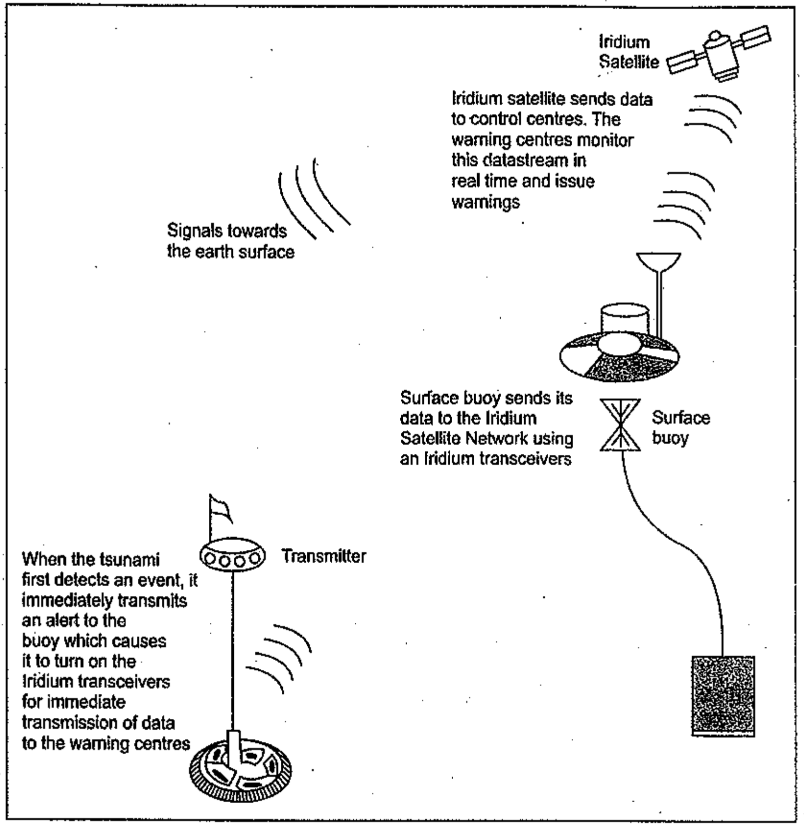


FIG. 8.8. India's Tsunami warning system.

Source : NOAA Centre for Tsunami Research.

the seismic network of the Indian Meteorological Department and other international set ups.

The system can detect earthquakes above 6 magnitude occurring the Indian Ocean in less than 20 minutes and alert agencies within 13 minutes. This is done with the help of the BPRs—the key sensors that confirm the triggering of the tsunami. Six BPRs, have been installed in all out of which four are in Bay of Bengal and two are in the Arabian Sea. The system was successfully tested during the 8.4 magnitude earthquake that hit Indonesia on September 12, 2007.

The centre generates and disseminates timely advisories to the control room of the Home Ministry which issues an alert to the public. To warn the ministry, a satellite based network for disaster management support has been established. This enables the centre to also issue alerts to the state emergency operations centres. The messages are to be sent by telephone, fax, SMS and e-mails to the authorised officials.

HOW INDIA'S TSUNAMI WARNING SYSTEM WORKS

- The system comprises a network of real-time seismic stations and bottom pressure recorders (BPRs) installed in deep sea to detect disturbances.
- It senses all tremors in the Indian Ocean measuring over 6 on Richter scale in less than 20 minutes.
- The system can sound an alert 13 minutes after an undersea quake.
- After equipment sends data to the early warning centre, a computer generates alerts.

It has been acclaimed as the ***"most modern"*** tsunami warning system in the word by **Peter Koltermann**, the head of the tsunami co-ordination unit intergovernmental oceanographic commission, UNESCO.

Unusual Animal Behaviour and Tsunamis

As in case of earthquakes, animals start behaving in unusual manner, before tsunamis actually strike the coast. At the time of catastrophic tsunamis which wrecked havoc in Indian Ocean on 26th December 2004, elephants in Thailand started wailing. They soon calmed down, but started wailing again about an hour later. This time they could not be comforted despite their ***mahauts***' efforts. The elephants just kept running for the hill. The elephants that were not working, broke their hefty chains. Soon the area was attacked by devastating tsunamis caused by the earthquake (8.9 on Richter scale) of Sumatra.

Abnormal behaviour of birds and animals was also observed in the coastal belt of Tamil Nadu (the worst hit area in India). Animals in forests were feeling restless. Birds stopped crying and there was unusual silence. About two months before the tsunamis struck the Indian coast, fishermen of Puducherry found fish with reddish tails, called ***Red Bait***, in their trawler nets. The sighting of this fish had always preceded a natural calamity. Catches of similar type in 1977, 1979 and 1996 were followed by major cyclones. It is a fishermen's instinct that Red Bait portends disaster and it has often come true. According to Central Marine Fisheries Research Institute (CMFRI), the Red Bait (measuring about 12 cm when fully grown and is edible) is a deep water fish which surfaces during 'upwelling' of water (a phenomenon of water at the bottom coming-up). This phenomenon is more pronounced on the Western Coast of India. But this time upwelling happened on the East Coast and that too during the non-upwelling season. Still CMFRI was not alarmed, since unlike cyclones, tsunami was completely unknown. Some of the other instances of abnormal behaviour of animals and birds noticed on that fateful day were as under.

- Crows flew into CMFRI's fish hatchery in Chennai and didn't budge.
- Cows on the Chennai beach ran like mad away from the coast.
- At Point Calimere Wildlife Sanctuary, black bucks and deer fled towards higher ground.

Vegetation. Impact of tsunamis can be considerably reduced by growing sea coast vegetation. Sea vegetation can be effective protection if the vegetation cover along the coast exceeds 70 per cent of the area. Unfortunately most of the natural vegetation has been destroyed for obtaining fodder and fuel. In Tamil Nadu only 110 km stretch out of a total coastal length of 1,076 km has sufficient vegetation cover.

Structural Protection. Structures like walls, ridges etc. can act as protective devices to some extent. Tamil Nadu government has proposed to construct a sea wall along the entire 1,076 km long coastline from Chennai to Kanniyakumari. But it will have its own financial and ecological limitations.

Although tsunamis constitute a natural tragedy and man has hardly any control on such a powerful natural phenomenon yet man's own misdeeds have made the situation very dangerous and helped in aggravating the fury of tsunamis. For example, no construction is allowed within 500 metres of the coast. There is legal obligation in India to leave this stretch of land vacant but all sorts of constructions residential, commercial, recreational etc.) is carried on without caring for the law. People living in this belt are most vulnerable to tsunamis and other sea related hazards.

Mining of sand and other minerals from the sea, as is done in Kanniyakumari, makes the concerned area highly vulnerable to tsunamis. The sand deposited on the sea coast absorbes much energy of the waves, and saves much of the coastal areas from their fury. There is urgent need to check unwanted construction and mining in ecologically sensitive coastal areas.

DROUGHTS

Introduction and Definition

Drought is a temporary reduction in water or moisture availability significantly below the normal or expected amount for a specific period. According to High Powered Committee on Disaster Management Report, "Any lack of water to satisfy the normal needs of agriculture, livestock, industry or human population may be termed as a drought." This condition occurs either due to inadequacy of rainfall, or lack of irrigation facilities, under-exploitation or deficient availability of water for meeting the normal crop requirements in the context of the agro-climatic conditions prevailing in any particular area. This has been scientifically computed as Moisture Index (MI). Drought, in this context, can be defined as adverse MI or adverse water balance which may be attributable not only to a prolonged dry spell due to lack of sufficient rainfall but also due to such other factors as excessive evapo-transpiration losses, high temperature, low soil holding capacity, etc. The inadequacy is with reference to the prevailing agro-climatic conditions in any particular area. Therefore, there is a drought in Jaisalmer (Average rainfall 200 mm) if rainfall is not sufficient to grow grass and paltry coarse-grains, whereas in Bolangir or Koraput (Odisha-rainfall above 1000 mm) there is a drought if there is not enough rainfall for bringing the paddy crop to maturity.

Drought is a distress situation caused by lack of rainfall. The failure of rains may be reviewed from two aspects. Firstly, the rainfall may be insufficient. Secondly it may be sufficient for the region as a whole but with wide gap, separating two wet spells. Thus both the amount as well as time of rainfall are important. In other words, drought is a relative phenomenon. Therefore, the amount of rainfall is not that important as its effectiveness.

Types of Drought

Following main types of drought may be recognised.

1. Meteorological Drought

It describes a situation where there is a reduction in rainfall for a specific period (days, months, seasons or year) below a specific amount (long term average for a specific time). The India Meteorological Department (IMD) has defined drought as a situation occurring in any area when the mean annual rainfall is less than 75% of the normal rainfall. IMD has further classified droughts into two broad categories *viz.* a ***severe drought*** when the deficiency of rainfall exceeds 50% of the normal rainfall and ***moderate drought*** when the deficiency of rainfall is between 25 and 50% of the normal rainfall.

It is worth noting here that the effectiveness of rainfall is more important then the amount of rainfall so far as meteorological drought is concerned. On an average India receives 118 cm annual rainfall which is considered to be highest anywhere in the world for a country of comparable size. But the uncertain, unreliable and erratic nature of rainfall by south-west monsoons creates drought conditions in different parts of the country. The major causes of meteorological drought may be summed up as under :

(*i*) Lean monsoons and below average rainfall due to absence of depressions over India.

(*ii*) Late onset or early withdrawal of monsoons.

(*iii*) Prolonged breaks in monsoon.

(*iv*) Re-establishment of southern branch of jet stream.

2. Hydrological Drought

Hydrological drought is associated with reduction of water. A meteorological drought often leads to hydrological drought. Generally it takes two successive meteorological droughts before the hydrological drought sets in. There are two types of hydrological droughts *viz.*, (*i*) surface water drought and (*ii*) ground water drought.

(*i*) ***Surface-water Drought.*** It is concerned with drying up of surface water resources such as rivers, streams, lakes, ponds, tanks, reservoirs, etc. There are many processes, besides meteorological drought, which lead to surface water drought. Large scale deforestation is the main cause of surface water drought. Some other unwanted human activities have led to the enhancement of flood/drought duo. Important among them are ecologically hazardous mining, indiscriminate road construction, and spread of non-terraced agriculture. In the Doon valley limestone quarrying has drastically changed the surface water flow in the valley turning several perennial rivers into carriers of monsoon floods which go dry after the monsoon.

(*ii*) ***Ground-water Drought.*** Ground-water drought is associated with the fall in the ground water level. This happens due to excessive pumping of ground water without compensatory replenishment and creates more or less irreversible ground water drought even in normal rainfall conditions. Ground water replenishment depends upon the availability of surface water obtained from rainfall and nature of soil. The Northern Plain of India has soft and porous

alluvial soils. These soils permit percolation of water and help in ground water replenishment. In contrast, the peninsular plateau area is made up of hard and impervious rocks which hinder the process of ground water replenishment.

3. Agricultural Drought

Agricultural drought is concerned with the impact of meteorological/hydrological drought on crop yields. When soil moisture and rainfall conditions are not adequate enough to support a healthy crop growth to maturity thereby causing extreme moisture stress and wilting of major crop area, it leads to agricultural drought. Agricultural drought may occur even when there is no meteorological drought and *vice-versa*. It is worth noting that agricultural drought is a relative category, depending upon the value of plant and soil. What could be a drought condition for the cultivation of rice, could well be a suitable condition for wheat and a condition of excess soil moisture for dry crops like bajra or jowar. Thus the choice of crops evolve according to variations of climatic and soil conditions. The indigenous dry-crops prove very high-yielding when there is optimum use of water. However, under extreme condition of soil water drought, no plant can survive and this condition is termed as ***desertification.***

With the onset of green revolution in India in 1960s, High Yielding Varieties (HYV) of seeds have replaced the traditional drought resisting seeds. The use of fertilisers has also increased the water requirements of different crops. The agriculture based on the Green Revolution technology is precariously dependent on irrigation and any delay in supply of water will cause serious agricultural drought. It has been found that the organic matter content of HYV seeds is quite less. Organic matter input to soil increases its water holding capacity and soils rich in organic content don't dry quickly. Hence the use of HYV seeds has increased the risk of agricultural drought to a great extent. Recent studies have revealed that with the addition of manure and organic fertiliser, the water retentivity in the soil increases by 2 to 5 times.

Change in cropping pattern, particularly with the introduction of Green Revolution technology, has also led to soil water drought. The indigenous cropping pattern was in tune with the agroclimatic conditions of the concerned region. With the introduction of an alien cropping pattern, more water demanding crops have gained importance which has led to soil water drought. For example, rice cultivation was practically unknown in Punjab, Haryana and Western Uttar Pradesh before Green Revolution and this region is not suitable for rice cultivation considering the amount of rainfall received by this region. The area receives an average annual rainfall from 50 to 75 cm whereas minimum amount of rainfall for any successful cultivation of rice is 100 cm. This change in the cropping pattern has put heavy strain on meagre water resources leading to acute occasional droughts.

In the drought affected areas of Maharashtra, Karnataka and Andhra Pradesh there is a change in the cropping pattern in which cash crops are given more importance than the traditional crops. Thus while the staple crops are denied water, cash crops like sugarcane and grapes are given priority with respect to irrigation. This leads to a condition of soil water drought which is created not by absolute scarcity of water but by preferential diversion of limited water resources.

4. Soil Moisture Drought

This is a situation of inadequate soil moisture particularly in rainfed areas which may not support crop growth. This happens in the event of a meteorological drought when the water supply to soil is less and water loss by evaporation is more.

5. Socio-Economic Drought

It reflects the reduction of availability of food and income loss on account of crop failures endangering food and social security of the people in the affected areas.

6. Famine

A famine occurs when large scale collapse of access to food occurs which, without intervention, can lead to mass starvation.

7. Ecological Drought

Ecological drought takes place when the productivity of a natural eco-system falls significantly as a consequence of distress induced environmental damage.

Causes of Droughts

Droughts in India occur in the event of a weak south-west monsoon. A weak monsoon results in deficient rainfall and droughts occur. Droughts also occur due to late arrival or early withdrawal of the monsoons. Prolonged breaks in the monsoon during rainy season also result in droughts. Although a drought may occur at any time and in any part of the country, most of the drought prone areas are those having marginal rainfall and high variability of rainfall.

Following are indications of a drought with respect to monsoon rainfall.

TABLE 8.4. Rainfall Vagaries and Drought Conditions

1. Deficient rainfall	A drought occurs when the rainfall is less than 75% of the normal.
2. Delay in onset	Maximum of three weeks from the normal date of arrived for a given region
3. Timely onset and sudden break	A maximum break of two weeks after the timely onset of the monsoon
4. Early withdrawal	A drought occurs when the monsoons withdraw from north-west India by the last week of August

Effects of Droughts

Droughts have a wide range of effects on the masses in a developing country like India. The impact of droughts is specifically conspicuous in view of the tropical monsoon character of the country. Rainfall by the south-west monsoon is notorious for its vagaries. The impact of droughts in India can be summed up under the following headings :

***(i)* Physical Impact.** Meteorological drought adversely affects the recharge of soil moisture, surface runoff and ground water table. Soils dry up, surface runoff is reduced and ground water level is lowered. Rivers, lakes, ponds and reservoirs tend to dry up, wells and tube-wells are rendered unserviceable due to lowering of the ground water table.

(ii)* Impact on Agriculture.** Indian agriculture still largely depends upon monsoon rainfall where about two-thirds of the arable land lacks irrigation facilities and is termed as ***rainfed. The effect is manifested in the shortfalls of agricultural production in drought years. History is replete with examples of serious shortfall in cultivated areas and drop in agricultural productivity. Severe shortage of foodgrains had been felt and the country had to resort to import of foodgrains to save the poor people from hunger and starvation. However, India has been able to build a buffer stock of foodgrains and threat from droughts is not as serious as it used to be before the Green Revolution.

It is worth mentioning here that the shortfall in agricultural production may be the direct impact of meteorological droughts but the succeeding hydrological and agricultural droughts have a long range and far reaching impact on agriculture. This impact may be in the form of changes in the cropping patterns and impoverishment on cattle.

***(iii)* Social and Economic Impact.** Social and economic impact of a drought is more severe than the physical and agricultural impacts. A drought is almost invariably associated with famine which has its own social and economic consequences. The impact of drought manifests itself in the following sequence :

1. Decline in cultivated area and fall in agricultural production (including crops and milk).
2. Fall in employment in agricultural sector.
3. Fall in purchasing power.
4. Scarcity of drinking water, foodgrains and fodder.
5. Rise in inflation rate.
6. Distress sale of cattle and loss of cattle life.
7. Low intake of food and widespread malnutrition.
8. Ill health and spread of diseases like diarrhoea, dysentery, cholera and opthalmia caused by malnutrition, hunger and starvation.
9. Distress sale and mortgage of land, jewellery and personal property.
10. Migration of people from drought hit areas to other areas in search of livelihood and food.

11. Death due to malnutrition/starvation/diseases.
12. Slowing down of secondary and tertiary activities due to fall in agricultural production and decline in purchasing power.
13. Low morale of the people.
14. Social stress and tension, disruption of social institutions and increase in social crime.
15. Growth of fatalism and belief in supernatural powers and superstitions.

The greatest impact of a drought is seen on the weaker sections of society. These include landless labourers, small and marginal farmers as well as artisans like weavers. Such people live in hand to mouth economy and do not have enough stock to sustain in the event of a drought. Whatever little stock they have, it is quickly exhausted and they are compelled to go in for distress sale or mortgage their belongings to rich landlords. Thus whereas a drought situation brings miseries and sufferings for the poor people, the rich people take undue advantage of the situation and exploit the poor people. Often the poor becomes poorer and the rich becomes richer in a drought situation. A series of bad harvest plunges the small and marginal farmers in a vicious circle of poverty making them landless and penniless. The money-lender charges high rates of interest and the inability of the farmers to repay the loan compells them to forfeit their mortgaged property. In extreme cases, the farmers tend to commit suicide. Cases of suicide by farmers in Andhra Pradesh, Telangana, Karnataka, Odisha, Maharashtra and even in agriculturally rich states of Punjab and Haryana have been reported from time to time.

Drought Prone Areas

A drought prone area is defined as one in which the probability of a drought year is greater than 20 per cent. A chronic drought prone area is one in which the probability of a drought year is greater than 40 per cent. A drought year occurs when less than 75 per cent of the normal rainfall is received.

In India, the hard core of recurring drought affects 16 per cent of the total area and 12 per cent of the population, although the total average drought prone area may be as much as 10 lakh sq km or about one third of the total land area of the country. The areas regularly haunted by droughts are those receiving low (generally below 75 cm annually) and highly unreliable (variability over 40 per cent) rainfall and with inadequate irrigation facilities. In all 77 districts receiving less than 75 cm of rainfall per annum are drought prone. This accounts for 34 per cent of the net sown area. In addition, there are 22 districts in Maharasthra, Gujarat, Madhya Pradesh, Karnataka, Rajasthan and Uttar Pradesh accounting for 9 per cent of the cultivated area of the country which receives 75 to 85 cm of rainfall per annum. This rainfall is of doubtful efficacy and as such these districts should also be considered vulnerable to drought. However, the severest droughts have occurred in comparatively wet areas such as West Bengal, Bihar and Odisha where rainfall is normally plentiful enough to allow high density of population and where failure of rainfall can affect millions of people.

There are some well defined tracts of drought which are briefly described as under (**Fig. 8.9**).

(*a*) The desert and semi-desert region covering about 6 lakh sq km. It is more or less a rectangle formed by lines from Ahmedabad to Kanpur on one side and from Kanpur to Jalandhar on the other. Some areas in this region are without irrigation and comprise the worst famine tracts of the country.

(*b*) The dry region lying in the leeside of the Western Ghats upto a width of 300 km stretching eastwards up to 100 km from the East Coast and reaching right upto the southern tip of the peninsula. It covers an area of about 3.7 lakh sq km.

(*c*) Outside the above mentioned two major regions, there are isolated pockets which experience frequent droughts and are termed as drought prone areas. They are (*i*) Coimbatore and Nellai Kottabomman districts in Tamil Nadu; (*ii*) Saurashtra and Kachchh regions; (*iii*) Jhansi, Lalitpur, Banda, Mirzapur, Pilibhit, Kheri and Bahraich districts of Uttar Pradesh; (*iv*) Palamau plateau of Jharkhand; (*v*) Purulia district of West Bengal and (*vi*) Kalahandi region of Odisha, (*vii*) Large parts of Uttarakhand, and (*viii*) Jammu and Uddampur in Jammu and Kashmir. These scattered pockets account for about one lakh sq km.

Frequency of Droughts

Frequency of droughts refers to the number times droughts occur in a given duration of time. Different

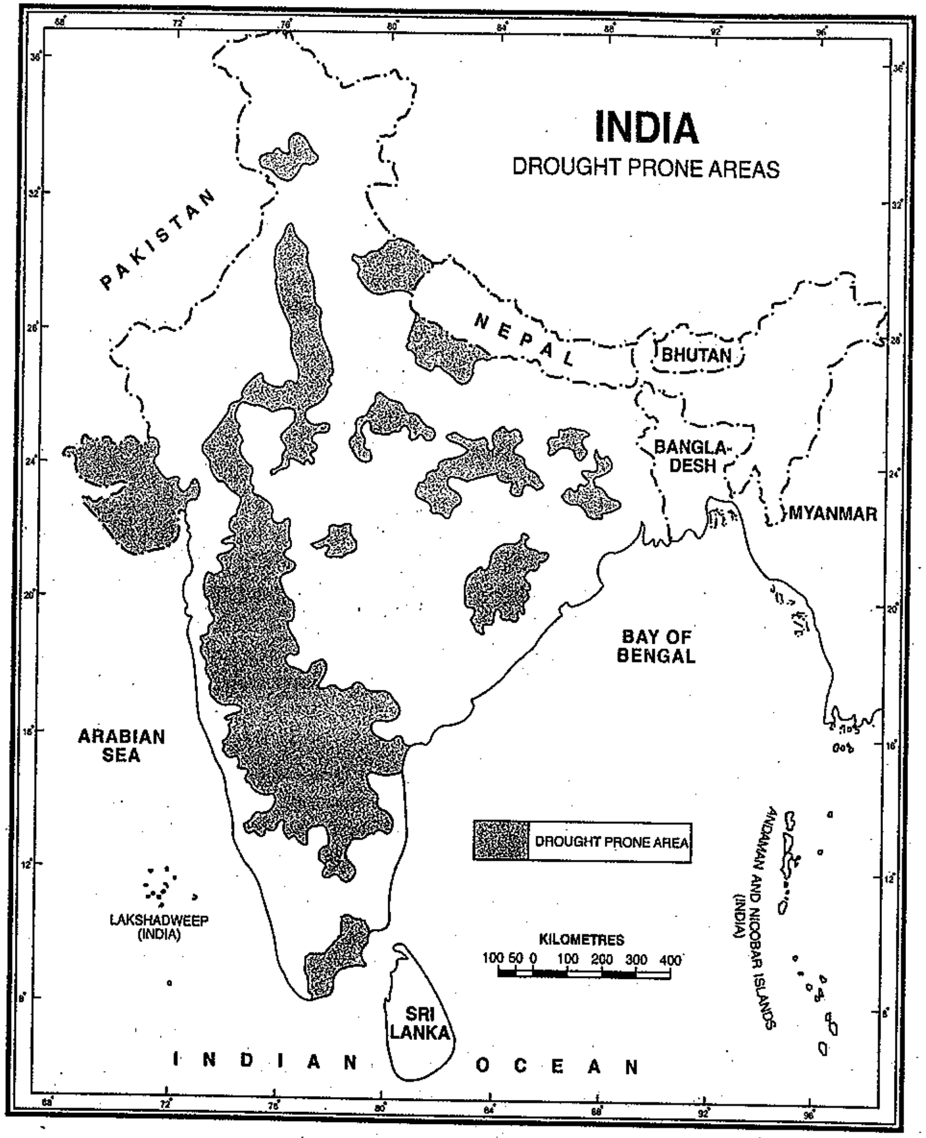


FIG. 8.9. India : Drought Prone Areas

parts of the country experience different frequencies of droughts depending on the amount of rainfall, variability of rainfall and water requirements. **Table 8.5** shows that areas with higher rainfall are less prone to droughts while the arid and semi-arid regions suffer from frequent droughts.

Drought Management

Among the various natural disasters the one which has received the greatest attention is the occurrence of drought. A drought often leads to total loss of crops or sharp drop in the production of foodgrains and creates conditions of famine. History

TABLE 8.5. Frequency of droughts in India

Meteorological sub-divisions	Recurrence of the period of highly deficient rainfall
1. Assam	Very rare, once in 15 years
2. West Bengal, Chhatisgarh, Bihar, Madhya Pradesh, Coastal Andhra Pradesh, Maharashtra, Konkan, Kerala, Odisha	Once in 5 years
3. South interior Karnataka, Eastern Uttar Pradesh, Vidarbha	Once in 4 years
4. Gujarat, Eastern Rajasthan, Western Uttar Pradesh, Tamil Nadu, Kashmir, Rayalseema, Telangana	Once in 3 years
5. Western Rajasthan	Once in 2.5 years

Source : India Meteorological Department.

is replete with great famines in the country and the strategies adopted to face the challenges. Drought is a slow onset natural hazard and offers sufficient time and opportunity to mitigate its impact. The first systematic attempt at famine relief measures could be traced to Great Famine or the Orissa Famine of 1866. The first Famine Commission was appointed by the then Government of India under the Chairmanship of Sir George Cambell. The second step was the appointment of a Famine Commission in 1880 following the famines of 1873 and 1876-78. Following the recommendations of the Famine Commission, the administration decided to promulgate Famine Codes from 1883 onwards which ushered in the modern policy of relief administration.

Moving from Drought Relief to Drought Management. After Independence, India experienced major droughts in the years 1965-67, 1972-73, 1979-80 and 1985-88. The analysis of India's drought response efforts reveals that the pre-1987 efforts to mitigate droughts were primarily focused to intervene at later stages, particularly at the socio-economic drought stage. The approach was to deal with ultimate consequences of the drought thus preventing the deterioration drought leading to famine conditions, essentially providing employment opportunities to the affected population through relief projects and distribution of foodgrains through public distribution system (PDS). The contingent drought relief expenditure imposed a serious strain on public finances as huge amounts had to be divested from development for undertaking relief projects. Analysis of the drought relief expenditure incurred by the Rajasthan Government in 1980s reveals that the drought relief outlays exceeded development outlays.

By incorporating contingency crop planning with drought response efforts through relief approaches acquired the status of Drought Management Strategies in early 1970s. The drought management approach differed from drought relief approach with regard to objectives, reliance of early warning indicators and timing of public intervention. The objective of relief approach was to protect entitlements of the affected population by ensuring physical and economic access to food through relief projects and public distribution system of foodgrains. As against this, the drought management approach aimed at ensuring entitlement to produce food so as to obviate the need for taking up ***ad hoc*** relief projects. While drought relief approach relied on socio-economic indicators like crop production data, price rise, migration of the people and increased rate of petty crimes, etc., for drought declaration and intervention, drought management approach relied on hydro-agro indicators like rainfall, water level reservoirs and progress of cropping pattern to detect early signs of developing drought situation. While drought relief approach enabled the government to intervene only in the month of November/December when the rainy season is over and the kharif crops have been harvested, the drought management approach enabled the government to intervene in the monsoon season itself.

According to report of the High Powered Committee on Disaster Management (2002), "Drought management is generally by focus on employment generation, water conservation and power supply, standing crop saving and public distribution supplies of essential commodities". However, drought management may conveniently be discussed under the following heads.

1. Drought Prone Area Programmes (DPAP)

This programme was initiated in 1974. The intention was to change DPAP from a relief and employment oriented programme into one aimed at 'drought proofing' through adoption of an integrated area development approach which sought to mitigate the impact of future droughts by stabilizing both production and employment. The programme was conceived as a long term measure for restoration of ecological balance by conserving, developing and harvesting land, water, livestock and human resources. The objectives of the programme are :

(*i*) To minimise the adverse effects of drought on production of crops and livestock and productivity of land, water and human resources through integrated development of the natural resource base of the area and adoption of appropriate technologies.

(*ii*) To conserve, develop and harness land, water and other natural resources including rainfall for restoration of ecological balance in the long run.

DPAP is under implementation in 629 blocks of 96 districts in 13 states. The total area covered under this programme is about 5.54 lakh sq km.

2. Establishment of Crop-weather Watch Group

This watch group was set up during 1979 drought by the Ministry of Agriculture. It consists of representatives from the Department of Agriculture, India Meteorology Department, Indian Council of Agricultural Research, Ministry of Information and Broadcasting, and others. A two pronged strategy was adopted which focused on curative and preventive measures. They were to provide weekly reports of rainfall, agricultural operations, employment and other activities for occurrences affected by drought. The twelve-point programme was created to avert ***Trikal* (*Akal, Jalkal, Tinka*)**, which means to take care of food, water, and fodder. Although drought affected 240 districts and 220 million people, the severity was not widely felt and no starvation deaths were reported because of the buffer stocks of food grains available with the government.

3. Integrated Watershed Management

Integrated watershed management as a preventive measure plays a key role in moderating drought conditions. This approach ensures planning on the basis of the total available water resources, conjunctive use of surface and groundwater, allocating priority for rational use of water and also the preparation of a coordinated plan. Thus, watershed management hold the promise of conservation of land and water resources and their optimal utilization in reality. Under the National Watershed Programme for Rainfed Areas, a large number of watersheds have been established in different rainfed regions of the country.

FLOODS

Definition and Introduction

Flood is a state of high water level along a river channel or on coast that leads to inundation of land which is normally submerged. Flood is an important component of hydrological cycle of a drainage basin. As a matter of fact droughts and floods are two extreme ends of the hydrological cycle. While droughts occur due to failure of rainfall caused by the southwest monsoons, floods occur in the event of excessive rainfall. Flood is a natural hazard which occurs in response to heavy rainfall and it *becomes a disaster when it inflicts heavy loss to life and property.*

Causes of Floods

Floods are generally caused by one or more unfavourable meteorological and physical factors. A combination of unfavourable meteorological and physical factors working together leads to a serious flood situation resulting in a disaster. In recent times, the impact of meteorological and physical factors has been accentuated by unwanted human activities. Following are the major causes of floods in India.

A. ***Meteorological Factors***

1. Heavy Rainfall
2. Tropical Cyclones
3. Cloud Burst

B. ***Physical Factors***

1. Large Catchment Area
2. Inadequate Drainage Arrangement

C. ***Human Factors***

1. Deforestation
2. Siltation
3. Faulty Agricultural Practices
4. Faulty Irrigation Practices
5. Bursting of Dams
6. Accelerated Urbanisation

Effects of Floods

Floods have multipronged effects on human life. A more frightening fact is that floods are becoming more damaging as their frequency, intensity and magnitude increases with the passage of time. The most damaging effect of floods is the colossal loss of life and property. The other losses include damage to crops, cattle loss, break down of communication, dislocation of transport system and disruption of essential services.

Earlier the impact of floods was not as intense and widespread as it is now. There are several reasons for this deteriorating condition. Floods are becoming more frequent and furious due to ecological degradation such as deforestation. Moreover, the population in India is increasing at a rapid pace and even the areas prone to floods, such as flood plains and even river beds are inhabited by the people. The principle '*where a river has the right of way stay out of its way*' is not followed by the people who have little option in setting themselves or locating industrial projects. In fact floods cause more damage than any other single disaster. India is the most flood affected country in the world next only to Bangladesh. About 20 per cent of the global deaths caused by floods in the world are in India. Bangladesh accounts for about 5 per cent of the total. The most severely affected are generally the poor people because they live on the periphery of human habitat. **Table 8.6** gives an idea of flood damages in India.

TABLE 8.6. Annual Average Flood Damages (based on data from 1953 onwards)

Damage Head	Magnitude
1. Land area affected	7.56 million hectare
2. Population affected	32.03 million
3. Human lives lost	1,504 number
4. Livestock lost	96,713
5. Houses damaged	11,683 (₹ 136.615 crore)
6. Crop damaged	₹ 460.07 crore
7. Public utilities damaged	₹ 377.248 crore
Total Losses	**₹ 982.126 crore**

Source : Manual on Natural Disaster Management in India, NDM Division (2001), p. 29.

Flood Prone Areas

The Rashtriya Barh Ayog (RBA) or National Commission on Floods, set up by the Government of India in 1976, provided statistical evidence of flood problem in the country. The commission took the maximum area affected by floods in a state in any one year, as its flood prone area and added up the flood prone areas of all the states to get the flood prone area of the country. This proved to be erroneous method as it underestimates the severity of the problem. This is due to the fact that there is no guarantee that floods in any year will affect only those areas which were affected during the maximum flood year. On several occasions, flood waters have inundated areas which were never flooded before. Yet the commission found that the country's flood prone area increased from 25 mha in 1960s to 34 mha in 1978. At present 40 mha or one eighths of the total land area of the country is assessed to be flood-prone. This shows that there has been a rapid increase in he flood-prone area of the country. A glance at **Fig. 8.10** will show how the flood prone areas are distributed. It is estimated that over three-fourths of the total damage done to crops and property is in the plains of Northern India comprising of Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal and Assam. The geographical distribution of flood prone areas in India is as under :

The Ganga River Region

In Uttar Pradesh and Bihar, the mighty Ganga receives a large number of tributaries such as the Gomati, the Ghaghra, the Gandak and the Kosi from the left bank as well as the Yamuna and the Son from the right bank. This brings huge quantities of water to these areas both from the Himalayan region and from the Peninsular India resulting in devastating floods. River Kosi often shifts its course flooding new areas and converting once fertile areas into wasteland. The Kosi which means ***kosna*** (curse), brings flood fury to

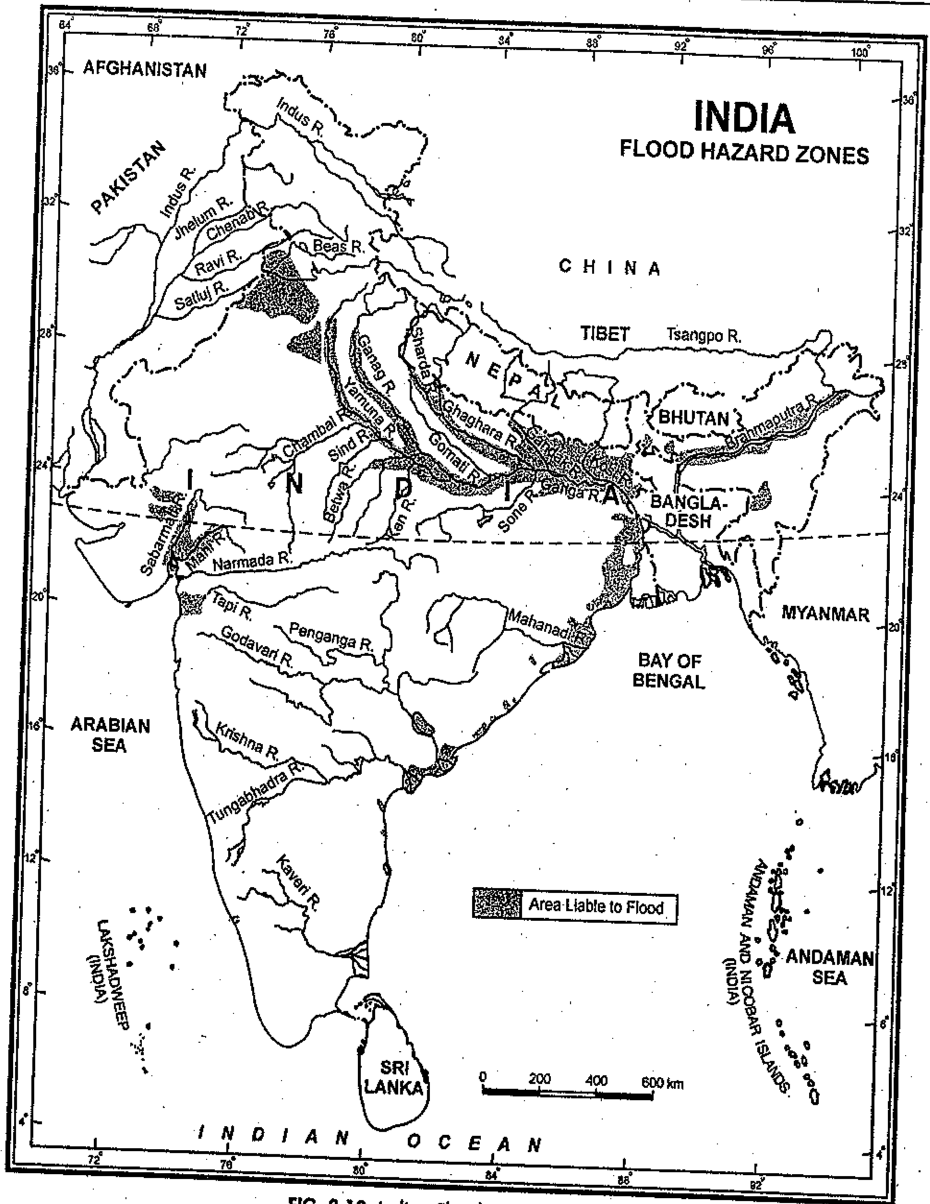


FIG. 8.10. India : Flood Hazard Zones

vast area every year and is living upto its name. The Yamuna is an important right bank tributary of the Ganga and floods large areas in Uttar Pradesh and Haryana. The Chambal and the Betwa meet the Yamuna and add to the flooding capacity of the Yamuna.

In *Uttar Pradesh* floods are frequent in the eastern districts, mainly due to spilling of the Rapti,

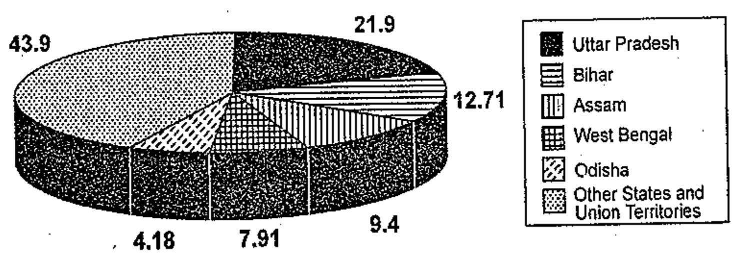


FIG. 8.11. Flood Prone Areas in India (%)

the Sharda, the Ghaghra and the Gandak. The problem of drainage congestion exists in the western parts of Uttar Pradesh, particularly in Agra, Mathura and Meerut districts. Erosion is experienced in some places on the left bank of the Ganga and on the right banks of the Ghaghra and the Gandak.

In *Bihar* the floods are largely confined to the northern part of the state where occurrence of floods is almost an annual feature. The rivers such as the Burhi Gandak, the Bhagmati and the Kamala and other smaller rivers of the Adhwara Group, the Kosi in the lower reaches and the Mahananda spill over their banks causing considerable damage to crops and dislocation of traffic.

Uttar Pradesh and Bihar are the worst flood affected states and account for over one-third of the flood prone area of the country.

In *West Bengal* the southern and central parts are flooded by the Mahananda, the Bhagirathi, the Ajoy, the Damodar etc. due to an inadequate capacity of river channels and tidal effect. There are occasional floods caused by the Damodar river even after the construction of four dams and a barrage under the Damodar Valley Project. In 1956, about 25,000 sq km of area was flooded in Southern districts of West Bengal by this river. The Ganga delta is often flooded. There is also the problem of erosion of banks of some of the rivers and on left and right banks of the Ganga upstream and downstream respectively of the Farakka Barrage.

Cloudburst and Floods in Uttarakhand

The torrential rainfall caused by a cloudburst on June 16, 2013 led to a flood situation which was never experienced in the meteorological history of the state of Uttarakhand. Districts of Uttarkashi and Rudraprayag were the most affected areas where 479 mm rainfall was recorded in a short span of just three hours. The Himalayan tributaries of the Ganga like Alaknanda, Mandakini, Bhagirathi, Kali Ganga, Gauri Ganga were in spate. According to National Disaster Management Authority (NDMA), these floods left about 15,000 dead, 436 injured and 1800 missing. As many as 1,07,670 people had to be evacuated from the flooded areas and were taken to be safer places. Moreover, 2,232 houses, 154 bridges and 1520 roads were damaged. The flooding was so fierce and disastrous and the loss of life and property was so colossal that it was named as ***Himalayan Tsunami.***

Natural or Manmade Disaster?

Like all other weather events, cloudbursts and the consequent floods are natural phenomena as these area caused by unusual behaviour of monsoon winds. The abnormally higher amount of rainfall (more than 400 per cent) in Uttarakhand was caused by fusion of westerlies with monsoon at cloud system. The westerlies reached the Himalayan states via Afghanistan to collide with the monsoon, triggering deadly rains. Besides the rain water, a huge quantity of water was probably released from melting of ice and glacious due to high temperature during the months of May and June. The water not only filled up the lakes and rivers but also caused breaching of moraine dammed lakes in the upper reaches of the Himalayas.

Although cloudburst, heavy rainfall and devastating flood are primarily natural phenomena, several environmentalists term this as a ***man-made*** *disaster*. Unwanted human activities leading to environmental changes have aggravated the problem and reduced the natural defense system. In the last few decades the region has witnessed large scale demographic changes in the form of growth and composition of population, rapid urbanisation, deforestation and expansion of roads. The Uttarakhand Himalayas have undergone large scale slope destablization, particularly along the roads where widening of roads was in progress. Unabated expansion of hydroelectric power stations and rapidly increasing tourism, particularly pilgrimage, are some of the reasons of unprecedented devastations. Mindless illegal construction of resorts, hotels, guest houses and roads has been undertaken in this ecologically fragile region. Buildings have been constructed over flood ways, old drains and streams blocking the natural pathway of water. Human greed has forgotten the fact that these ecologically fragile mountainous areas have limited carrying capacity which should not be exceeded at any cost.

It is estimated that as many as 70 hydal projects in three major river basins *viz*. Alaknanda, Mandakini and Bhagirathi have been proposed to be constructed. Of them, 23 are mega projects (more than 100 MW) 22 medium (10-100 MW) and 25 small (less than 10 MW). Hydroelectric projects require large scale blasting of hills to build dams and tunnels, disturbing the rock structure, which starts rolling down once the top soil is uprooted by rains. The muck fills the river bed and flows down with water, intensifying the river's rage. Huge diversion of forest cover for these dams also reduces the capacity of the local ecology to retain rain water. Further 640.25 kilometres of natural flow of the rivers, about half the length of major rivers the region, is diverted. This leads to catastrophic floods when the rives tend flow in their natural courses.

The anthropogenic factors have led to the increased frequency and severely of floods in the whole of the Himalayan region. For example, Uttarkashi had just one flash flood between 1978 and 2005 but bad to suffer from four major flash floods between 2005 and 2013.

Glacial Lakes Outburst Flood (GLOF). A glacial lake is a water mass existing in a sufficient amount and extending with a free surface in, under, beside and/or in front of a glacier and originating from glacier activities and/or retreating process of a glacier. Triggering events for an outburst can be moraine failures induced by an earthquake, by increase of permafrost (permanently frozen ground) and increased water pressure, or a rock or snow avalanche slumping into the lake causing an overflow.

The mechanism that triggers floods from glacial lakes depends on the nature of the damming materials, the position of the lake volume of water, nature and position of the mother glacier, physical and topographical condition and physical conditions of the surrounding areas. The important chain reaction in this context is the danger from avalanches, debris flows, rock fall or landslides reaching the lake and provoking a lake outburst.

Since the beginning of the 19th century, the number of glacial lake outburst floods (GLOFs) has increased in the Himalayas. It is estimated that there are about 20,000 glacial lakes in the Himalayas which have been formed by melting of glaciers, perhaps due to global warming. Of these, over 200 glacial lakes have the potential of causing catastrophic outburst floods. This fact has been established by the International Centre for Integrated Mountain Development (ICIMOD) at Kathmandu which used satellites-based geographical information system (GIS) and high resolution remote sensing technology to locate these glacial lakes in the Himalayas. According to a recent study by ICIMOD as many as 20 glacial lakes in Nepal, and 24 in Bhutan have become potentially dangerous as a result of climate change. In India, there are 14 lakes in the Tista river basin and 16 in Himachal Pradesh. Nepal and Bhutan are among the first countries in the world to make glacial outburst floods a national priority. But in India, information on basic glaciology and more specifically the threat from GLOF is scatter and of little value. The main reason for such a situation is that such lakes are situated in remote and inaccessible areas and findings of remote sensing and GIS to be cross checked on the basis of ground studies is difficult. However, a report compiled by scientists at Delhi University for the Ministry of Environment and Forests in 2008 showed the existence of 366 glacial lakes in Sikkim's Tista basin; which is much more than reported by ICIMOD.

The most significant chain reaction in connection with GLOF is the danger from avalanches, debris

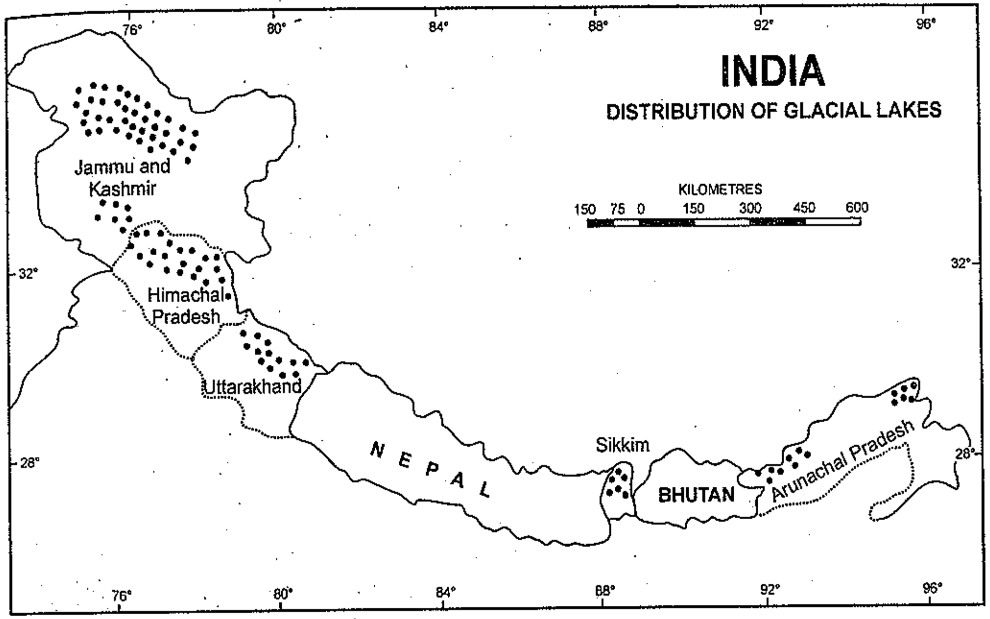


FIG. 8.12. India : Glacial Lakes in the Himalayas

flow, rock fall or landslides reaching the lake and thus provoking the lake outburst. Only Moraine Dammed Lakes, Ice Dammed Lakes and Ice-cored Dammed Lakes are considered to be vulnerable from the GLOF point of view. Breaching and instantaneous discharge of water from glacial lakes can cause flash floods which are big enough to create enormous damage in the downstream areas. Such floods pose severe geomorphological hazards and can wreak havoc on all manmade structures located along their path. Huge damage created during GLOF events is associated with large amounts of debris that accompany the flood waters. GLOF evens have resulted in a large number of deaths as well as destruction to houses, bridges, agricultural, fields, roads, etc. Such damages are almost unrecoverable and can take place at long distances from the outburst source.

GLOFs are like ticking time bombs which are capable of releasing billions of cubic metres of glacial water, in a few hours or even in a matter of a few minutes and virtually without warning to those living downstream. Unfortunately, the danger from GLOFs is increasing due to increase in size and number of glacial lakes resulting from global warming.

Researchers, till the catastrophic flood of 16-17 June, 2013 in Kedarnath, were of the opinion that this area is not prone to GLOFs. However, heavy downpour on June 16, 2013 rapidly filled up Chorabari Tal, a glacial lake less than 4 km upstream from Kedarnath and continued heavy rainfall next morning caused lake to overflow and possibly burst out from its loosely packed rim of moraines. This event re-inforced the already serious situation and destroyed almost whole of Kedarnath town and several other areas downstream.

Mitigation

1. Damages by cloudburst or GLOFs can be considerably reduced by forecasts and early warning system. It appears that warnings issued by India Meteorological Department were not taken seriously and the precious warning time was not used.
2. Large areas of the Himalayas are at the risk natural hazards like intense rainfall, earthquakes, landslides, avalanches, GLOFs etc. Mapping and monitoring of said areas is of paramount importance.

3. Principles of hydro-ecology and engineering should be strictly followed in planning and designing of infrastructure and disaster preparedness. Huge damage in Uttarakhand in June, 2013 is partly attributed to large scale illegal construction of buildings in the river beds and other flood prone areas.
4. Comprehensive reports of the entire Himalayan region for better planning and management are urgently needed.
5. Periodic review of water level in the glacial lakes, lake overflows, movement of moraines, activation of dormant river channels, etc. can go a long way to reduce the impact of natural hazards like GLOFs.

The Bhrahmaputra River Region

In the Brahmaputra basin, floods are almost an annual feature. The main cause of floods here is heavy rainfall amounting to over 250 cm during the rainy season. Large amount of silt is deposited here by the Brahmaputra and its tributaries which makes the river channel shallow and its capacity to carry large amount of water is reduced. This results in flooding of vast areas in and around the valley. Earthquakes, which occur at freq·ant intervals, cause change in the level of river cou.se and the flow of water in the river is obstructed. This leads to inundation of large areas in this region. Landslides are very common here. Huge rock material falling as a result of landslides acts as a temporary dam across the river and vast area is submerged under water. Later it gives way under the pressure of water and floods large area downstream. The Assam Valley is considered to be one of the worst flood-affected areas of India. The main causes of floods in the Brahmaputra river system can be summed up as under :

(*i*) There are 34 major tributary rivers of the Brahmaputra. These bring huge quantities of water and silt which cause floods.

(*ii*) Very heavy rainfall exceeding 250 cm per annum.

(*iii*) Narrowness of the Brahmaputra valley with a maximum width of about 81 km surrounded by hills.

(*iv*) Heavy deposit of silt has raised the river bed considerably which has reduced the water accommodating capacity of the river.

(*v*) Occasional earthquakes, such as those of 1897, 1930, 1950 and 1984 have brought about changes in the course of the river.

(*vi*) Very high population pressure, primarily due to migration from Bangladesh and some other Indian states has forced people to live in the flood prone area.

According to the reports of the Assam government, all the districts of the Brahmaputra valley are inundated almost every year.

Though most of the flood affected areas in Assam are rural in character, yet some urban areas are also affected by floods each year. The worst flood affected area of the Brahmaputra valley is the world's largest river island, Majuli. The urban areas of Assam, namely Dhubri, Guwahati, Dibrugarh, Tezpur etc. ate frequently flooded. It has been estimated that an area of 30 lakh hectares out of 78 lakh hectares *i.e.*, about 45 per cent of Assam's total area is flood prone.

The North West Rivers Region

The flood problem in this region is less serious as compared to the one prevailing in the Ganga and the Brahmaputra river regions. The major problem is that of inadequate surface drainage which causes inundation and waterlogging over vast areas. In the Punjab-Haryana plain rain water in the waterlogged and poorly drained areas inundate large parts. Major and minor rivers like the Satluj, the Beas, the Ghaggar and the Markanda are in spate during the rainy season and bring flood havoc to vast areas.

In *Punjab* floods are an annual feature though intense floods are experienced at an interval of 4-5 years. The main reason of floods in Punjab is obstruction of poor natural drainage by man made features. Some of the major canals (the Bhakra System) do not follow the natural flow and create obstacles. Secondly, National Highway No. 1 and the main railway line run almost perpendicular to the natural flow. Cultivation of area near river banks and construction activities in low lying areas, especially in cities like Ludhiana, Patiala, etc.

have together created obstacles in the natural flow of water.

The state of *Haryana* experiences severe flood once in a decade. The saucer shaped topography of the state does not permit free flow of surface runoff and even a moderate rainfall can cause floods. Sometimes, floods are caused by the Ghaggar river also. This river used to disappear in the sands of Rajasthan after flowing through Punjab and Haryana. In recent years, besides flooding Punjab and Haryana areas, it has become active in Rajasthan territory also, occasionally submerging large areas.

In the north-western river basin covering Jammu and Kashmir and Himachal Pradesh, the Satluj, the Beas, the Ravi and the Chenab often flood large areas. Floods occur periodically in Jhelum and its tributaries in the Kashmir Valley causing a rise in level of the Wular Lake thereby submerging marginal areas of the lakes and sometimes threatening Srinagar and other areas along the river banks. Similarly the Chenab and its tributaries like Tawi are often in spate endangering several densely populated areas in Jammu and Akhnoor.

The Central India and the Deccan Region

The southern states of Andhra Pradesh, Telangana, Karnataka, Tamil Nadu, Odisha, Jharkhand, Chhattisgarh, Maharashtra, the state of Gujarat and parts of Madhya Pradesh are included in this region. The floods do not pose a serious problem in this region because most of the rivers have well defined and stable courses. However, the deltas of the Mahanadi, the Godavari, the Krishna and the Cauvery suffer from occasional floods owing to the large scale silting and the consequent change in the river courses. Indiscriminate felling of trees in the catchment areas of major rivers has complicated the flood problem. High tide at the time of flood aggravates the flood situation. Lower courses of the Narmada and the Tapi in Gujarat are also prone to floods.

The small rivers of *Kerala*, originating in the Western Ghats and flowing to the Arabian sea, cause considerable damage when in spate.

The above description of flood prone areas reveals that one or other part of the country is affected by floods and flooding is almost an annual phenomenon.

FLOOD DISASTER MANAGEMENT

Flood disaster management implies not letting the excess runoff water flow suddenly and intensively in the drainage network. After the unprecedented floods of 1954, flood management works were taken up in a planned manner by the State Governments. The main thrust of managing floods in different river basins was to modify the floods through specific structural measures such as reservoirs, embankments, channel improvement, town protection and river training works. The various measures adopted for flood mitigation may be categorised into two groups *viz.*, structural and non-structural. The main steps for flood disaster management are briefly discussed below.

(1) Flood Forecasting

Flood forecasting involves giving prior information regarding the occurrence of floods. This is essential and is extremely useful for taking timely action to prevent loss of human lives, livestock and movable property. The Central Water Commission (CWC) started flood forecasting in November 1958 when the first forecasting station was established at Old Railway Bridge, Delhi. Since then it has been extended to cover almost all the major inter-state flood prone rivers of the country. At present there are 175 flood forecasting stations on various rivers in the country which includes 147 river level forecasting and 28 inflow forecasting stations spread over nine major river basins.

These centres issue daily-flood forecasts and warnings throughout the flood season from May to October. For achieving greater accuracy, the Central Water Commission recently established a procedure of carrying out a self-analysis and appraisal of the forecasting network at the end of the monsoon season.

Flood forecasting involves the following four main activities :

(*i*) Observation and collection of hydrological and hydro-meteorological data;

(*ii*) Transmission of data to forecasting centres;

(*iii*) Analysis of data and formulation of forecast; and

(*iv*) Dissemination of forecast.

On an average, 7,500 forecasts at various places in the country are issued during the monsoon season every year with over 98 per cent accuracy. A forecast is considered accurate if forecast water level is within ±15 cm of actual water level and the inflow forecast (*i.e.*, discharge) is within ± 20% of actual discharge.

A Memorandum of Understanding was signed by India and Nepal in 1988 according to which 45 Hydrological and Hydro-meteorological Stations were to be set up in India and Nepal for issuing flood forecasts to benefit both the countries.

A Memorandum of Understand with China has also been signed according to which China provides hydrological information with respect to Brahmaputra and Satluj rivers during the monsoon season. The MoU is renewed from time to time for regular flow of information. This information is utilised in the formation of flood forecasts by the Central Water Commission.

Bulletins are also updated on CWC Website www.cwc.nic.in for wider publicity among user agencies during flood season.

Forecast Bulletins

Flood forecasts and warning which are formulated by various flood forecasting centres are supplied in the form of "DAILY WATER LEVEL AND FLOOD FORECAST BULLETINS" to concerned Civil and Engineering Authorities on Wireless/Telephone/by Special messenger/Priority Telegrams, depending upon the urgency and available mode of communication media.

Control Rooms

Generally, the State Governments set up "Central Control Rooms" at State and District Headquarters which receive these forecasts and disseminate the warning to the affected areas and organise relief as well as rescue operations. The forecasting centres also send the forecasts to the "ALL INDIA RADIO" stations, "DOORDARSHAN" and the local "NEWSPAPER" for wider publicity.

On receipt of "Fresh Information" a revised forecast is issued, if the situation warrants. During high flood stages the "Control Room" of the forecasting centre works round the clock and keeps informed the flood fighting agencies about the latest river position. They work in close collaboration.

2. Reduction of Runoff

Reduction of runoff is one of the very effective methods of flood disaster management. Runoff can be reduced by inducing and increasing infiltration of the surface water into the ground in the catchment area. This can be done by large scale afforestation particularly in the catchment area. Afforestation helps in reduction of runoff in the following ways :

(*i*) The canopy of the forest cover intercepts the falling raindrops and the roots, the leaf litter and humus are capable of holding water.

(*ii*) Together these encourage infiltration and reduce runoff.

(*iii*) Runoff reduction helps in reducing soil erosion which leads to reduced sediment load of the streams.

(*iv*) Reduction in stream sediment load reduces siltation and helps in maintaining the water accommodating capacity of the rivers.

In the Indo-Gangetic plain, the runoff can be reduced by artificially inducing infiltration by digging wells along the beds of ephermal channels. A series of dug wells helps in storing and channelising the surface water. There is vast scope of using this method in the Northern Plain of India due to soft soil and vastness of aquifers.

3. Reducing Flood Peaks by Volume Reduction (Constructing Dams and Detention Basins)

The flood peaks can be reduced by construction of dams and detention basins. Dams have the capacity of holding huge quantity of water during the flood period and help in reducing flood peak volume of water. Water stored in reservoirs created by constructing dams can be allowed to flow down the stream under controlled conditions depending upon the accommodating capacity of the river downstream the dam. A number of reservoir projects have been completed in India since the launching of the National Flood Control Programme in 1954. These dams have helped in mitigating flood-peak in the down stream reaches. Notable among these are Tilaiya, Konar, Maithon and Panchet Hill dams in the Damodar Valley System, Bhakra Dam on the Satluj, Hirakud Dam on the Mahanadi, Pong Dam on the Beas, Nagarjun Sagar and Tunghbhadra on the Krishna and

Ukai Dam on the Tapi. All these dams have afforded reasonable degree of protection to about 13.64 lakh hectares of land.

Apart from dams as described above ponds, tanks and surface storage structures also check flood and help in harvesting water for dry seasons. Other types of detention basins include natural depressions such as marshes in plains and old quarries and mines.

4. Reducing Flood Levels

Flood levels can be reducing in the following ways.

(*i*) **Stream Channelisation.** A close network of canals reduces flood hazard to a great extent because flood water flowing in the river can be diverted to canals. Canals serve as temporary storage and hold water as its flood waves move downstream. Thus they help in reducing the severity of the flood.

(*ii*) **Channel Improvement.** Channel improvement is done by deepening, widening, straightening, lining and cleaning out of vegetation and debris from the river channel. These changes in the river channel increase the flood conveyance capacity of the river. Channel improvement is supplemented by bank stabilisation by constructing ripraps, dykes or spurs and planting deep root trees on embankments. In a meandering river, meander loops impede drainage and retard disposal of flood water. Whenever, the river meanders become extremely sharp, they can be straightened by artificially cutting individual or a series of bends. This method can be applied to the meandering courses of the rivers like the Gandak, the Gomati, the Rapti, the Kosi, etc.

(*iii*) **Flood Diversion.** Flood diversion is the process of diverting the flood water in marshes, lakes, the depressions and spreading it thinly over paddy fields and desert drylands. One such scheme is the Ghaggar Diversion Scheme which diverts 340 cumecs (cubic metres per second) of water before its entry into Rajasthan into the depressions and the areas between the sand dunes. In this way, discharge of water in the Ghaggar river is kept within the safe limits during the flood period.

5. Protection against Inundation (Construction of Embankments)

Building of embankments was considered to be the only way of controlling floods in 1940s. It is still considered to be one of the very effective devices against inundation of the inhabited areas and agricultural land. Construction of embankments has been taken up on a large scale in India. Between 1954 and 1978, 10,821 km long embankments had been built. By March 2000, more than 33,630 km of new embankments had been constructed. Most of the embankments have been constructed in north India where the Brahmaputra valley of Assam, northern parts of Bihar, Uttar Pradesh (Ganga, Yamuna and Ghaghara) and Punjab (Satluj, Beas and Ravi) are the main beneficiaries. In south India, embankments have been constructed mainly in the deltaic parts of the Mahanadi, the Godavari, the Krishna and along the banks of Penneru (**Fig. 8.13**).

As mentioned earlier, the Brahmaputra valley in Assam is the most frequently and severely flooded part of India. As such it is also the most heavily embanked part of the country. About one third of the total embankments of India have been constructed in Assam alone. The largest construction of embankments has taken place along the Brahmaputra river itself. Efforts have been made to control floods in the Brahmaputra river by constructing embankments at several places. At present the total length of embankments along the Brahmaputra is 934 km and 2,400 km on its various tributaries. These embankments provide protection to an area of 13.27 lakh hectares out of a total flood-prone area of 30 lakh hectares.

Next to Assam, Bihar is the most heavily embanked state, About 20 per cent of the total embankments of India have been constructed in Bihar. With the increase in flood prone area over the years from 2.5 million hectares in 1952 to 6.89 million hectares in 1994, the length of embankments has also grown from 160 km in 1952 to 3,465 km in 1998 *i.e.*, an increase of almost 22 times. The Kosi, and the Burhi Gandak are the most heavily embanked rivers. The Gandak, the Bhagmati, the Son and the Mahananda also have long stretches of embankments. These embankments have provided considerable protection to large areas particularly in north Bihar.

However, there are severe limitations of embankments as a flood control device. As a matter of fact, they are not so much a method of flood control as flood transfer. Embankments may protect the neighbouring areas but they often cause floods in

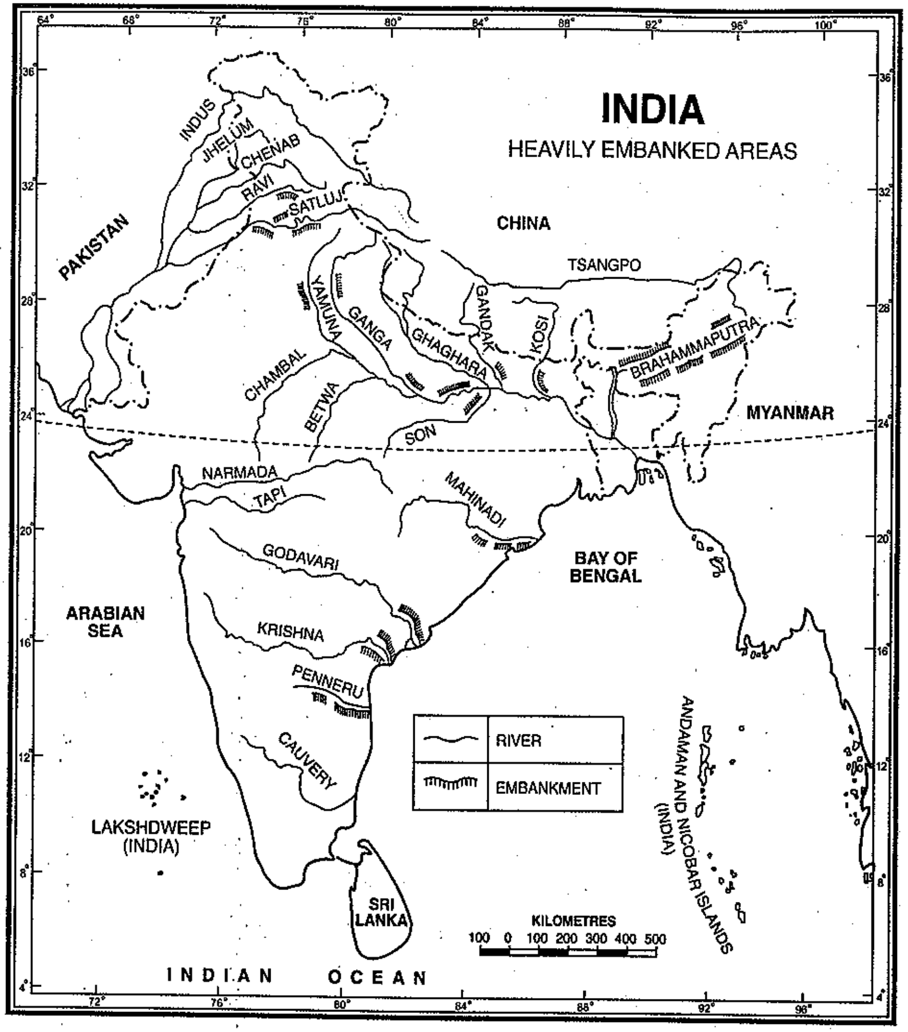


FIG. 8.13. India : Heavily Embanked Areas

the downstream areas. In the event of high flood levels, the embankments may develop breaches and floods cause heavy damage to life and property in the low lying areas near the embankments. Construction of embankments puts limits to the river channel. The sediment which was to be deposited in a much wider area in the absence of embankments, is deposited in the limited river channel. Thus the river bed rises at an accelerated rate and consequently the flood water level rises. Under such circumstances the flood water may overflow the embankments or there may be breaches in the embankments due to intense hydraulic pressure. Under both the circumstances, the flood situation takes a serious turn and causes untold miseries to the people living in the neighbouring areas. Thus whereas constructing embankments is a very useful method of flood control it can lead to a very serious flood situation. The *Rashtriya Barh Ayog*

report states. "Embankments are not a feasible measure of flood protection in cases where the country runoff draining into the river is so large as to inundate appreciatively the area protected by the embankments from river spills, during periods when the river is running at high flood stages."

6. Flood Plain Zoning (FPZ)

Flood plain zoning is another very effective method of flood management. It is based on information regarding flood plains, particularly the identification of floodways in relation to land use. Detailed maps of flood prone areas are prepared after a thorough study of flood cycles. Some areas are more prone to floods than the others. Different zones are identified and demarcated. After that necessary control is exercised with respect to land use.

Recognising the significance of FPZ as an effective device upon flood control, the Central Flood Control Board mooted the idea in 1957 to demarcate flood zones to prevent indiscriminate settlement in flood plains. The increasing trend in flood damages was observed in India even during the 1970s and the State Governments were requested to give due attention to development of flood plains in a regulated manner. A model bill on Flood Plain Zoning was circulated to State Governments as early as 1975 with a request to enact suitable legislation for restricting the encroachment of flood plains and for their development in a regulated manner. The main features of the model bill were :

(*a*) flood zoning authority,

(*b*) delineation of flood plain,

(*c*) notification of limits of flood plains,

(*d*) restrictions on use of flood plains,

(*e*) compensation, and

(*f*) power to remove constructions after prohibition.

FLOOD CONTROL PROGRAMMES AND POLICY

After devastating floods in 1954, the Government of India announced a National Flood Management Programme. The programme was divided into three phases—immediate, short term and long term.

(*a*) **Immediate phase** extending over a period of 2 years was adopted for intensive collection of data and execution of emergent flood protection measures.

(*b*) **Short term measure** covering next 4 to 5 years, included construction of spurs and embankments at selected sites.

(*c*) **Long term measures** included the construction of storages, reservoirs on rivers/tributaries and additional embankments.

It has been estimated that out of 40 million hectares of flood prone area only 32 million hectares can be provided with reasonable degree of flood protection by structural measures.

Since the launching of the National Programme of Flood Management in 1954, 45 million hectares of land has been provided with a reasonable degree of protection against floods by construction of embankments, drainage channels, town protection works and by raising villages.

Post Flood Management

Post flood management includes the following :

1. Speedy restoration of transport system particularly roads and railways and postal services.
2. Supply of safe drinking water to the affected areas either by tankers or by fire tenders.
3. Repair of power, telephone and sewerage lines.
4. Proper arrangement for supply of food, shelter and clothing to affected people.
5. Adequate supply of necessities of life.
6. Constitution of a survey team to assess the loss and compensation to be given to the affected people.
7. Assistance for repair/rebuilding of private properties.
8. Desilting and dewatering of inundated areas.
9. Taking up appropriate measures according to Contingency Plan for agricultural sector.

TROPICAL CYCLONES

The World Meteorological Organisation (WMO) uses the term *"Tropical Cyclone"* to cover weather systems in which winds exceed 'gale force' (minimum of 34 knots or 63 kph). Over warm water in the tropical ocean, little away from the equator within the belt of 30°N and 30°S, the occurrence of tropical cyclones is almost a worldwide phenomenon. However, their characteristics like frequency, intensity and coastal impact vary from region to region. Tropical cyclones are the most destructive of the seasonally recurring rapid onset natural hazards. Between 80 and 100 tropical cyclones occur around the world each year. But these have been the deadliest when crossing the coast bordering the north Bay of Bengal (coastal areas of Tamil Nadu, Andhra Pradesh, Odisha, West Bengal and Bangladesh) mainly because of serious storm surge problem in this area.

Characteristics and Destructive Power of Tropical Cyclones

Tropical cyclones are characterised by destructive winds, storm surges and exceptional levels of rainfall, which may cause flooding. Wind speeds upto 200 km/h, rainfall of upto.50 cm/day for several consecutive days and storm surges of 7 m high are not uncommon. A mature cyclone releases energy equivalent to that of 100 hydrogen bombs. Cyclone is a heat engine whose heater is the oceanic water. The released heat after condensation converts into kinetic energy for the cyclone. Yet it is described as a poor heat engine since it converts only 3% of the heat generated into kinetic energy.

Destructive Winds

The strong winds that blow counter-clockwise in the Northern Hemisphere, while spiralling inward and increasing toward the cyclone centre are highly destructive. Wind speeds progressively increase towards the core. As the eye arrives, winds decrease to become almost calm but rise again just as quickly as the eye passes and are replaced by hurricane force winds from a direction nearly the reverse of those previously blowing.

Wind speeds greater than 120 kmph are characteristic of severe cyclonic storms with a core of hurricane winds. All physical structures are vulnerable to the extreme pressures exerted by winds and thus collapse or are damaged. Wind speeds of cyclonic storms have been incorporated into the building code for coastal areas.

Damages due to wind are not confined to the coastal areas only. Damage can occur well in the interior. For example, a number of structures around Vijayawada (which is about 100 km from the coast) were damaged in a cyclone. Almost the whole east coast of India from Tamil Nadu to West Bengal is vulnerable to wind hazard. The coasts of Kachchh and Kathiawar in Gujarat are also highly vulnerable to wind hazard. Such wind hazards are mostly associated with tropical cyclones. High wind velocity of 50 m/s is not uncommon in these coastal regions.

Storm Surges

One of the peculiar characteristics and having a very high damage potential is storm surge. Storm surges are an abnormal rise of seawater due to tropical cyclone and are greatly amplified where the coastal water is shallow, in the estuarian region and where the shape of the coast is like a funnel.

The major factors include

- A fall in the atmospheric pressure over the sea surface
- The effect of wind
- The influence of the sea bed
- A funnelling effect
- The angle and speed at which the storm approaches the coast
- The tides.

The coastal areas of north Bay of Bengal satisfy most of the above mentioned criteria and the storm surge gets enormously amplified there. Due to several favourable factors in these areas, the world's highest storm surge of 41 feet (over 13 metres) was reported from the area in 1876 near Bakerganj. Cyclonic storms are sometimes accompanied by tidal waves with heights of five metres and sometimes hit 20 km inland with wind speed of 150 kmph.

The low-pressure area or "eye" of the cyclone allows the sea level to rise. The high-speed winds surrounding the "eye" drive more water over this rise. The sloping bed of the sea and contours off the shoreline add further to the height. A further contribution to the height of the storm surge is added if the cyclone arrives at high-tide time.

Storm surges are not waves though they may look like them. A storm surge is a mass of water,

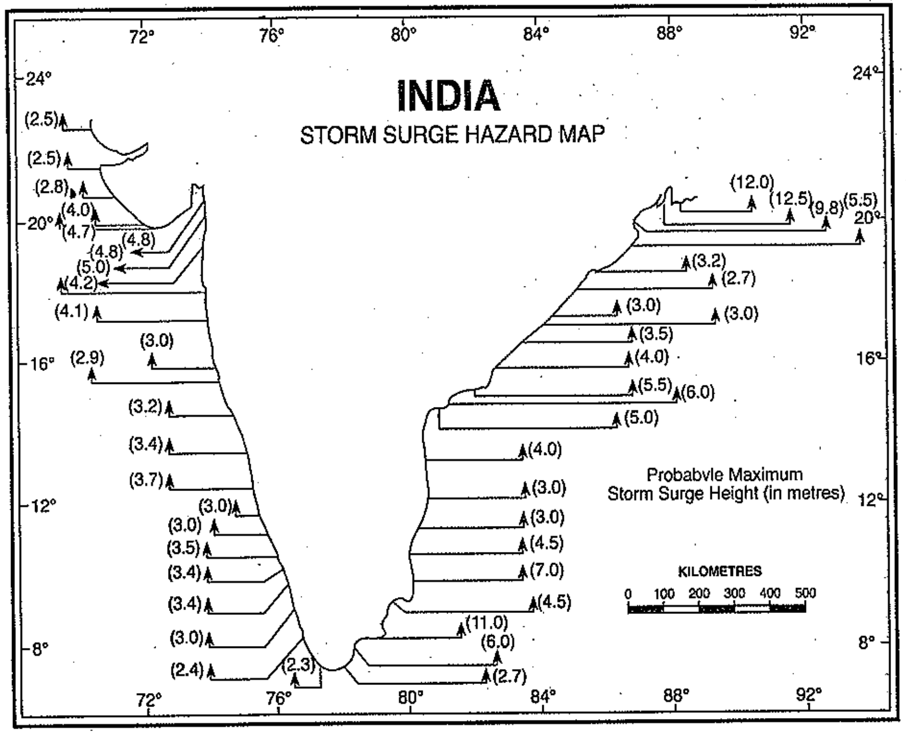


FIG. 8.14. India : Storm Surge Hazard Map

which will submerge everything in its path, till it recedes back into the sea. It moves at the same speed as that of the cyclone. It travels upto the point where the ground height is equal to the height of the surge. The period of submergence of the land may be as long as 45 minutes or more depending on the depth it reaches inland. Map in **Fig. 8.14** shows that the entire coast of India is influenced by storm surges caused by cyclones and tides.

As the leading edge of the surge crashes against the coastline and the water continues to travel inland there will be surface waves created which criss-cross each other and carry much under water turbulence. The destruction caused by the surge is tremendous. Houses are the worst affected. First the speed of the surge places great stress on the walls. The turbulence and currents created destroy the foundations of the structure. The debris like uprooted trees, fences and parts of broken houses act as battering rams, which cause further damage. The sand and gravel carried by the fast moving currents at the bottom of the surge can cause sand papering action on the foundations. The huge volume of water can cause such pressure differences that the house "floats" and once the house is lifted from the foundations water enters the structure and causes collapse of the building.

Damage occur to every kind of assets built above the ground level due to the above characteristics and crops get affected very badly.

Exceptional rainfall occurrences

The world's highest rainfall spread over one or two days has occurred during tropical cyclones. The very high specific humidity condenses into exceptionally large raindrops and giant cumulus clouds, resulting in high precipitation rates. When a cyclone makes landfall, the rain rapidly saturates the catchment areas and the rapid runoff may extensively flood the usual water sources or create new ones.

Rainfall is generally very heavy and spreads over a large area thus leading to excessive amount of water, which leads to flooding. The size of drops, in a rainfall, increases with increase in rainfall intensity. Soil erosion results on a large scale as raindrops strike the ground with energies substantially greater than those in ordinary rainfall. The heavy rains waterlog the ground and cause softening of the earth due to soaking. This contributes to weakening of tank embankments, the leaning over of utility poles or collapse of pole type structures.

TROPICAL CYCLONES IN INDIA

With about 6 per cent of the world wide cyclones, the Indian subcontinent is one of the worst cyclone affected areas of the world. About 8 per cent of the total land area, particularly along the eastern coast and Gujarat coast is vulnerable to tropical cyclones. In fact, Indian ocean is one of six major cyclone prone regions of the world. On an average, about 5-6 tropical cyclones are formed in the Bay of Bengal and the Arabian Sea every year, out of which 2 or 3 may be severe. More cyclones form in the Bay of Bengal than in the Arabian Sea. As such, the eastern coast is more prone to cyclones and about 80 per cent of the total cyclones generated in the Indian Ocean strike the east coast of India. There are two definite seasons of tropical cyclones in the North Indian Ocean. One is from May to June and the other from mid-September to mid-December. May, June, October and November are known for ***severe storms***. The entire east coast from Odisha to Tamil Nadu is vulnerable to cyclones with varying frequency and intensity. Along the west coast, the Gujarat and Maharashtra coasts are more vulnerable as compared to the southern part. Most of the cyclones have their origin between 10°N and 15°N during the monsoon season. Almost all storms in the Bay of Bengal have their genesis between 16°N and 21°N and west of 92°E in June. By July, the Bay storms form north of 18°N and west of 90°E. It is also noteworthy that most July storms move along a westerly track. They are generally confined to the region between 20°N and 25°N and recurvature to the Himalayan foothills is comparatively rare. **Figure 8.15** shows the direction and seasonal distribution of cyclonic storms as well as the areas affected by the cyclonic storms. The frequency of cyclones and severe cyclones in the Bay of Bengal and the Arabian Sea during the period from 1897 to 2014 is shown in **Table 8.7.**

TABLE 8.7. Frequency of Tropical Cyclones (1897-2014)

Month	Bay of Bengal		Arabian Sea	
	Cyclonic storm	Severe cyclonic storm	Cyclonic storm	Severe cyclonic storm
January	4	2	2	0
February	0	1	0	0
March	2	3	0	0
April	11	11	2	4
May	15	34	4	15
June	33	6	6	12
July	33	7	3	0
August	27	3	2	0
September	24	15	5	3
October	44	35	14	11
November	40	54	6	21
December	23	20	5	2
Total	256	191	49	68

Source **:** India Meteorological Department, New Delhi.

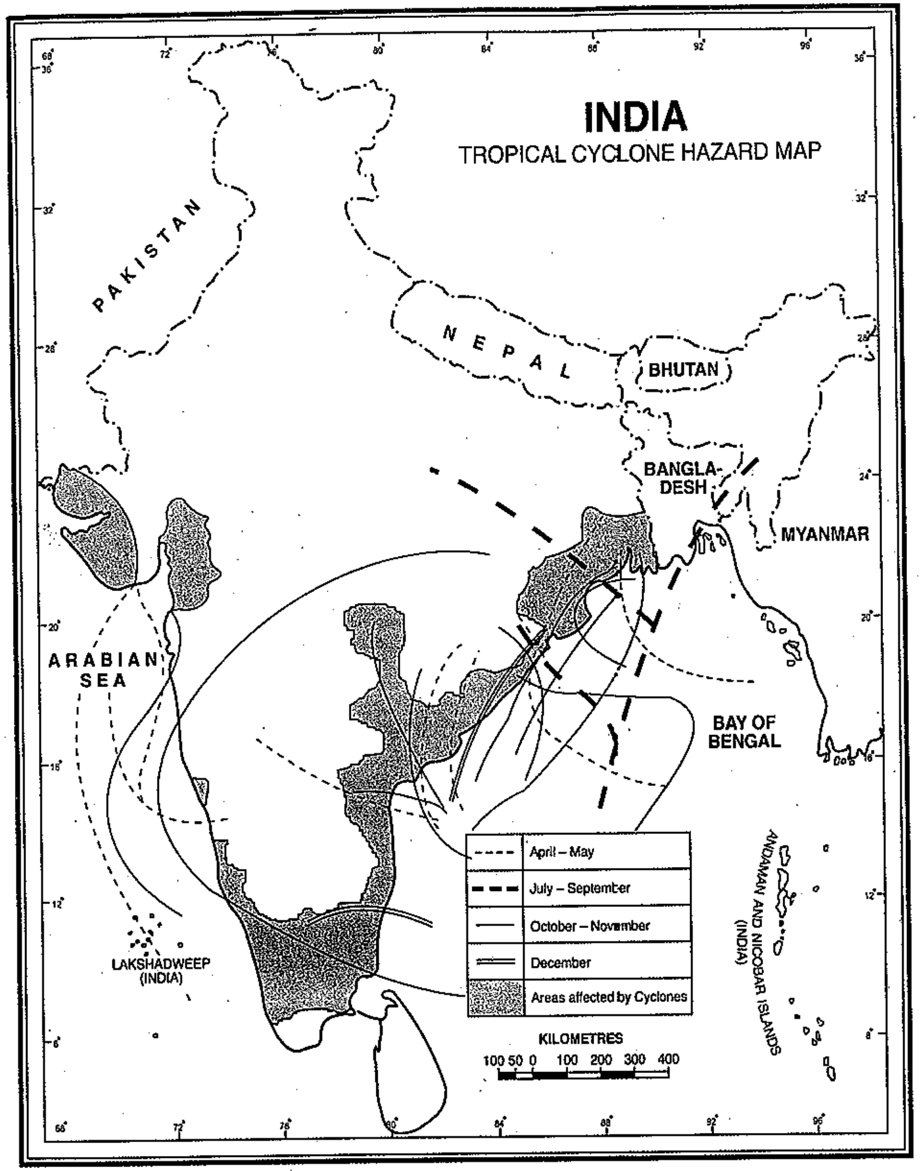


FIG. 8.15. India : Tropical Cyclone Hazard Map

The distructive effect of cyclonic storms is confined to coastal districts, maximum destruction being within 100 km from the centre of the cyclones and on the right of the storm track. Principal dangers from a cyclone are : (*i*) Gales and strong winds, (*ii*) Torrential rain, and (*iii*) High tidal waves (also known as 'Storm surges'). Most casualties are caused by coastal inundation by tidal waves and storm surges. Maximum penetration of severe storm surges varies from 10 to 20 km inland from the coast. Heavy rainfall and floods come next in order of devastation. They are often responsible for much loss of life and damage to property. Death and destruction purely due to winds are relatively less. The collapse of buildings, falling trees, flying debris, electrocution, rain and aircraft accidents and disease from contaminated food and water in the post-cyclone period also contribute to loss of life and destruction of property. **Table 8.8** gives a chronological account of the devastating effects of some severe cyclonic storms in India. This table and **Figure 8.15** bring us to the conclusion that the states of Andhra Pradesh, Odisha on the east coast and Gujarat on the west coast of India are extremely vulnerable to tropical cyclones. These three states deserve a brief description with respect to their vulnerability to the tropical cyclones.

Andhra Pradesh. Andhra Pradesh has a long coast line of 1,030 km from Srikakulam in the north to Nellore in the south along the east coast of India and bordering the Bay of Bengal. Nine coastal districts of Srikakulam, Vizianagram, Vishakhapatanam, East Godavari, West Godavari, Krishna, Guntur, Prakasam and, Nellore are highly vulnerable to tropical cyclones. This state has a very long history of cyclones and has experienced 71 cyclones from 1892 to 2014. The geographical set up of the state particularly makes it most vulnerable to tropical cyclones. The terrain is sloping generally from west to east and most of the area is plain except for portions of the northern districts. The Geographical location of India and the position of Andhra Pradesh between latitudes 13° north to 19° north with Bay of Bengal in the east is also a major contributing factor for the predicament nature has placed the state in.

TABLE 8.8. Some Severe Cyclones in India

Location	Date	Damages
Bengal	Oct., 1847	75,000 people and 6,000 cattle killed. Damage to property and communication system.
Bengal	Oct., 1874	80,000 people killed, heavy loss to property and communication disrupted.
Andhra Coast	Nov., 1946	750 people and 30,000 cattle lost life. Damage to property and roads also reported.
Tamil Nadu	Dec., 1972	80 people and 150 cattle killed and communication disrupted.
Bengal	Sept., 1976	10 people and 40,000 cattle lost life. Damage to property including communication
Andhra Coast	Nov., 1977	8547 people and 40,000 cattle lost life. Communication disrupted heavy loss to property.
Tamil Nadu	May, 1979	700 people and 3,00,000 cattle lost life. Communication disrupted
Odisha	Sept., 1985	84 people and 2,600 cattle lost life. Land damaged.
Andhra Coast	Nov., 1987	50 people and 25,800 cattle lost life, 8,400 houses destroyed, roads and other communication disrupted.
Odisha	June, 1989	61 people and 27,000 cattle lost life, 145,000 houses destroyed, communication disrupted.
Andhra Coast	May, 1990	928 human lives lost, 14,000 houses damaged.
Tamil Nadu	Nov., 1991	185 people and 540 cattle dead. Property including roads worth ₹300 crore damaged.
West Bengal	April, 1993	Over 100 casualties, communication system including roads disrupted and damaged.
West Bengal	Nov., 1994	More than a thousand houses damaged in 26 villages, damage to lakes and fisheries, disrupted all communication.
Andhra Coast	Oct., 1996	1,057 casualties, 647,000 houses damaged, road network completely damaged.
Andhra Coast	June, 1996	2,000 killed, 900 went missing near Kakinada.
Gujarat	June, 1998	3,500 casualties, 2.0 lakh houses damaged.
Odisha	Oct., 1999	10,086 casualities, 21.6 lakh houses damaged, 1.3 million displaced.
Odisha and Andhra Pradesh	Oct. 2013	30 dead, 8 million affected.

The entire coastline of Andhra Pradesh is likely to be visited annually by one or two cyclonic storms on an average, most probably during May, October and November. These storms are sometimes accompanied by tidal waves as high as 5 metres or even more. If the land is flat as in the case with the deltas of Krishna and Godavari, the storms can hit 20 km inland, wind speeds exceeding 150 kmph along with heavy rains of the order of 30-50 cm in 24 hours, overflowing rivers and rivulets, inundating vast areas and causing heavy damage to life and property.

The coast of Andhra Pradesh is dotted by more than 2,500 villages having a population of over six million. The people living in the belt of 20 km from the coast are generally comprising of fishermen and weaker sections and the majority have thatched type houses which are very vulnerable to strong cyclonic storms. There are very few permanent buildings by way of temples, churches, and schools. Under such circumstances, the ability of people to cope with disasters is *ad hoc* based only on the experience of those in the community who may have faced a similar disaster in the past.

Odisha. Like Andhra Pradesh, its neighbouring state Odisha is also vulnerable to tropical cyclones. In the recent years, Odisha has been hit by tropical cyclones in 1985 and 1989. The latest was the **'Super Cyclone of Odisha** which hit the state on 29th October 1999. It was the most devastating cyclone in the living memory of Odisha. This cyclone left the state in a virtual paralysis with its communication system and infrastructure totally wrecked. It severely affected more than 13 million people in 97 blocks, 28 urban local bodies in 12 districts including the state capital Bhubaneshwar and the old city of Cuttack. Overnight, the state seemed to have slipped into stone age. The agriculturally rich districts of Khurda, Puri, Cuttack, Jagatsinghpur, Kendrapara were devastated due to storm while districts like Jajpur, Bhadrak, Keonjhar, Balasore and Mayurbhanj were severely affected by unprecedented flood.

According to Meteorologists, it was the strongest cyclone in India's memory. It was a cyclone of catastrophic intensity with sea waves upto 7 metre high, which had rushed in and at places, travelled upto 15 km inland. Bhubaneshwar gets no more than an average of 1,200 mm of rainfall annually, but on that fateful day, the city received incessant rainfall of 426 mm.

Cyclone Phailin. A severe cyclone hit the Odisha coast on the night of October 12, 2013 affecting vast coastal areas of Odisha and Andhra Pradesh. It was the second deadliest cyclone to hit the eastern coast of India, next only to the Super Cyclone of Odisha which hit the Odisha coast in October, 1999. Thus it was the strongest cyclone in a span of 14 years. It caused massive damage in the districts of Ganjam, Gajapati, Khurda, Puri and Jagatsinghpur. Districts of Balasore, Nayagarh, Keonjhour, Kendrapara, Jajpur, Kandhamal, Cuttack, Karaput, Nabaranghur and Bhadrak were also affected. As many as 1,45,014 villages and more than 3.75 lakh houses were destroyed. Paddy crop worth ₹ 2,400 crores over 6.2 lakh hectares of land was also destroyed. In addition, the cyclone caused heavy damage to large parts of Coastal Andhra Pradesh. With wind speed varying from 210 to 240 kmph, this cyclone was rated at number 4 on Saffir-Simpson scale as against number 5 given to Super Cyclone of 1999.

However, the redeeming factor was that the death toll was limited to 30 only. This unique feat was accomplished by virtue of combined efforts of India Meteorological Department (IMD), National Disaster Management Authority (NDMA), Army, IAF Navy and NGOs. IMD tracked Phailin from the time it formed on October 8, 2013 and gave advance warning of implending cyclone. This gave sufficient time to government machinery for taking safety measures and about one million people were evacuated and taken to safer places. Cyclone warnings issued on radio, TV and via loudspeakers played a crucial role in public awareness and helped the concerned authorities to take timely action in the right direction.

Gujarat. The state of Gujarat is the worst sufferer at the hands of cyclones on the west coast of India. According to vulnerability Altas of India, Kachchh, Jamnagar, Porbandar, Junagadh, Ameri and Bhavnagar districts lie in the **Very High Damage** zone for wind and cyclone hazards. Data collected for storm winds and cyclones crossing inland between 1877 and 1991 indicate that Jamnagar, Porbandar and Junagadh districts have faced severe cyclone storms four times, Kachchh has faced it 2 times and other coastal districts 3 times. In recent times, Gujarat was hit by a severe cyclone on 9th June 1998. This was caused by an unusual phenomenon when a low-pressure depression was created on the western side of the country. This gave rise to strong winds taking the shape of cyclone in the Arabian Sea. This cyclone hit the coastal areas of Gujarat. Strong winds of this a cyclone reached a peak of 235 km per hour. The worst affected area was the Kachchh district as it lay directly on the movement track of the cyclone. The death toll was abnormally high due to very high migrant labour population working in the salt pans and the port area and staying in temporary structures. The physical damage felt due to the cyclone was accentuated more in the rural areas. The urban areas, with closely packed structures having permanent flat roofs, channeled high velocity winds along roads and other open space corridors.

Typically, rural structures with (*i*) unburnt brick walls sloping or flat roofs, (*ii*) stone walls with sloping or flat roofs, and (*iii*) light structures made of wood, GI sheets and bamboo are highly vulnerable to high wind velocity, exceeding 180 kmph. In the district of Jamnagar 50% of the structures in the rural areas belong to the first and the second categories mentioned here. Kachchh is still worse off where over 70% of the structures belong to the first and second categories. The estimated damages caused by this cyclone were 3,500 dead, 20,000 families affected and 200,000 houses damaged.

MAIN MITIGATION STRATEGIES

1. Cyclone Shelters

One of the most successful means of reducing loss of human lives during cyclones is the provision of cyclone shelters. In densely populated coastal areas, where large scale evacuation is not always feasible, community buildings and buildings used for gathering of large number of persons, like schools, *dharamshalas*, hospitals, prayer halls, etc. can be used as cyclone shelters. These buildings can be so designed, as to provide a blank facade, with a minimum of apertures in the direction of the prevailing winds. The shorter side of the building should face the storm. Alternately these buildings can be designed on a circular/ellipsoidal plan, so as to impart least wind resistance. Earth berms and green belts can be used in front of these buildings to reduce the impact of the storm. These shelters should be located in relatively elevated areas with provision for community kitchen, water supply and sanitation.

Another alternative, though expensive, is to have individual cyclone shelters attached to dwelling units. The shelter is fabricated in concrete and steel and designed for installation on flat ground adjacent to the house. The shelter is installed 4 feet in the ground, the soil from the excavation is placed around the shelter to help increase the shelter's effectiveness in protecting its occupants. The cyclone relief shelter can take care of population ranging from 50 to 300 people (men, women and children). Several multi-purpose cyclone shelters have been built in vulnerable areas of coastal Odisha, particularly after the super cyclone of 1999.

2. Engineered Structures

Cyclone proof structures which can withstand the force of winds and torrential rains can be of several types. Such facility is generally lacking due to widespread poverty of the people living in coastal areas. However, following precautions can be taken :

(*i*) Kachha house with thatched roofs should be avoided in coastal areas. Instead, loans should be given to vulnerable people for constructing cyclone proof houses and proper guidance should be given to them. As far as possible, houses should be constructed on stilts or on earth mound.

(*ii*) Houses can be strengthened to resist wind and flood damage. All elements holding the structures need to be properly anchored to resist the uplift or flaying off of the objects. For example, avoid large overhangs for roofs and projections should be tied down. Trees planted in a row can act as a shield, because such a provision reduces the energy of the cyclones.

3. Flood Management

Cyclones are accompanied with torrential rainfall which causes flooding of widespread areas. Therefore, flood mitigation measures (as mentioned earlier in the chapter) should also be taken.

4. Coastal Shelter Belts

Rows of strong rooted trees with needle like leaves are planted in the direction facing the wind. The trees in first few rows are provided fenced support to save them from being uprooted. These shelter belts can be grown all over the coastal area. Tidal forest trees and other hardwood trees are also recommended. Shelter belts grown along the coastline is a powerful tool to mitigate the impact of strong cyclonic winds. They also help in checking the soil erosion and inward sand drift, thereby protecting cultivated fields, houses and homesteads near the coast.

CYCLONE WARNING

Giving advance warning about a coming cyclone is one of the most effective methods of reducing the disastrous effects of cyclones. India Meteorological Department is the pioneer institute which issues such warnings.

A cyclone warning division has been set up in New Delhi to coordinate and supervise the totality of cyclone warning programmes in the country.

Cyclone Tracking

Cyclone tracking in India is done with the help of the following :

(*i*) Regular observations from weather network of surface and upper air observing stations

(*ii*) Reports from ships

(*iii*) Cyclone detection Radars

(*iv*) Satellites

(*v*) Reports from commercial aircrafts

Communication Network (Dissemination of Cyclone Warnings)

Cyclone warnings are communicated to Crisis Managers and other concerned organizations by high priority telegrams, telex, telephones and Police wireless. Cyclone warnings are provided by the IMD from the Area Cyclone Warning Centres (ACWCs) at Kolkata, Chennai and Mumbai and Cyclone Warning Centres (CWCs) at Vishakhapatnam, Bhubaneswar and Ahmedabad. Cyclone warning bulletins for All India Radio/Doordarshan, and cyclone advisories for the north Indian Ocean to Bangladesh, Myanmar, India, Maldives, Pakistan, Sri Lanka and Thailand are being issued from Meteorological Office in New Delhi. This office also issues tropical cyclone advisories for the tropical cyclones in the south west Indian ocean to Mauritius. There is also a Satellite based communication system called the Cyclone Warning Dissemination Systems (CWDS) for transmission of warnings. There are 250 such cyclone-warning sets installed in the cyclone prone areas of east and west coast. The general public, the coastal residents and fishermen, are also warned through the Government machinery and broadcast of warnings through AIR and Television.

Recently India Meteorological Department has developed a system known as ***"Disaster Warning System" (DWS)*** to transmit cyclone warning bulletins through INSAT-DWS to the recipients.

Post Disaster Assistance

Post disaster assistance is very essential for rescue and rehabilitation of the people in distress. It includes the following.

- Evacuation
- Emergency shelter
- Search and rescue
- Medical assistance
- Provision of short term food and water
- Water purification
- Epidemiological surveillance
- Provision of temporary lodging
- Reopening of roads
- Re-establishment of communications networks and contact with remote areas
- Debris clearance
- Disaster assessment
- Provision of seeds for replanting

LOCAL SEVERE STORMS

Local severe storms are small scale disturbances which are formed due to strong connective motions in a moist and unstable atmosphere and originate from well grown cumulonimbus clouds. The destructive effects of local severe storms are thunderstorms, strong winds, hail storms, lightening, heavy rains and tornadoes

Thunderstorms

Thunderstorms are a meso scale phenomena covering an area of tens to hundreds of square kilometres and lasting a few minutes to a few hours. They occur when there is instability in the atmosphere under adequate moisture conditions and a mechanism exists to release the instability. Thunderstorms constitute an important form of local severe storms which cause considerable damage to life and property every year. They occur over all parts of India and there is no month when one part or the other of the country is not affected by thunderstorms. The period of least thunderstorm activity is December to March. However, the most widespread thunderstorm activity all over the country occurs during the hot weather period from middle of March to middle of June. This is also known as the ***pre-monsoon period***. The main regions of the pre-monsoon thunderstorm activity are (*i*) Northeast India (*ii*) Northwest India, (*iii*) Central parts of the country and (*iv*) Southwest Peninsula. The maximum activity is during March-September in northeast India while it is April-May and October-November in southwest peninsula. Severe thunderstorms occur generally during the afternoon and evening hours, **Figure 8.16** shows the average annual frequency of thunderstorms.

Thunderstorms of West Bengal. Chhotanagpur plateau of Jharkhand and northeast India during March-June are often accompanied by violent destructive squalls reaching 100 km per hour. They are known as ***'Norwesters'*** in meteorological language in India as their modal direction is from northwest. They are also called ***'Kalbaisakhis*** which means *evil or black storms of month of Vaisakh*. They cause widespread damage to crops and kill cattle and at times, people too. During March-June the thunderstorms of northwestern and central India are often preceded by dust storms. There are thundersqualls which raise walls of dust and sand rendering visibility to practically nil and are locally known as ***'andhis'*** (blinding storms). Significant duststorm activity begins in April and reaches maximum in June.

During the post-monsoon (October and November) period thunderstorms occur in association with cyclonic storms and depressions mostly over peninsular India.

Basic parameters leading to the development of thunderstorm are observed through conventional synoptic surface and upper air meteorological observations. Frequency of their observation varies from two to six over the surface and two to four over upper air. Hourly observations are taken in some selected areas and are used for forecasting severe thunderstorms. The most reliable tracking of severe storms is through radar surveillance. As soon as the thunderstorm cells or squall lines are observed on the radar screen, their speed and direction of movements can be measured by marking their progress over the radar screen. Indications are also available on the radar screen regarding the severity of the thunderstorm and its potential for producing rain and hail. Such information is used for forecasting local severe storms. Cloud observations from geostationary satellites and polar orbiting satellites are useful in demarcating broadly the areas of potential for the convective development where severe storms may occur.

At present there is provision for issuing warnings based on certain known facts for high speed wind, hail and heavy rain associated with the thunderstorms generally 24 hours in advance to the warnees listed with different meteorological offices in the country. In addition, such warnings are issued on radio, television and other news media from different meteorological offices in India.

Hailstorms

Hail is precipitation in the form of ice pellets. Thunderstorms producing hail are known as ***hailstorms***. The size of hailstorms may vary from less than a centimetre to about 5 cm or even more in diameter. Hail is the product of violent convection, formed in a cumulonimbus (Cb) cloud. A storm starts its life as an ice crystal. It grows progressively as it

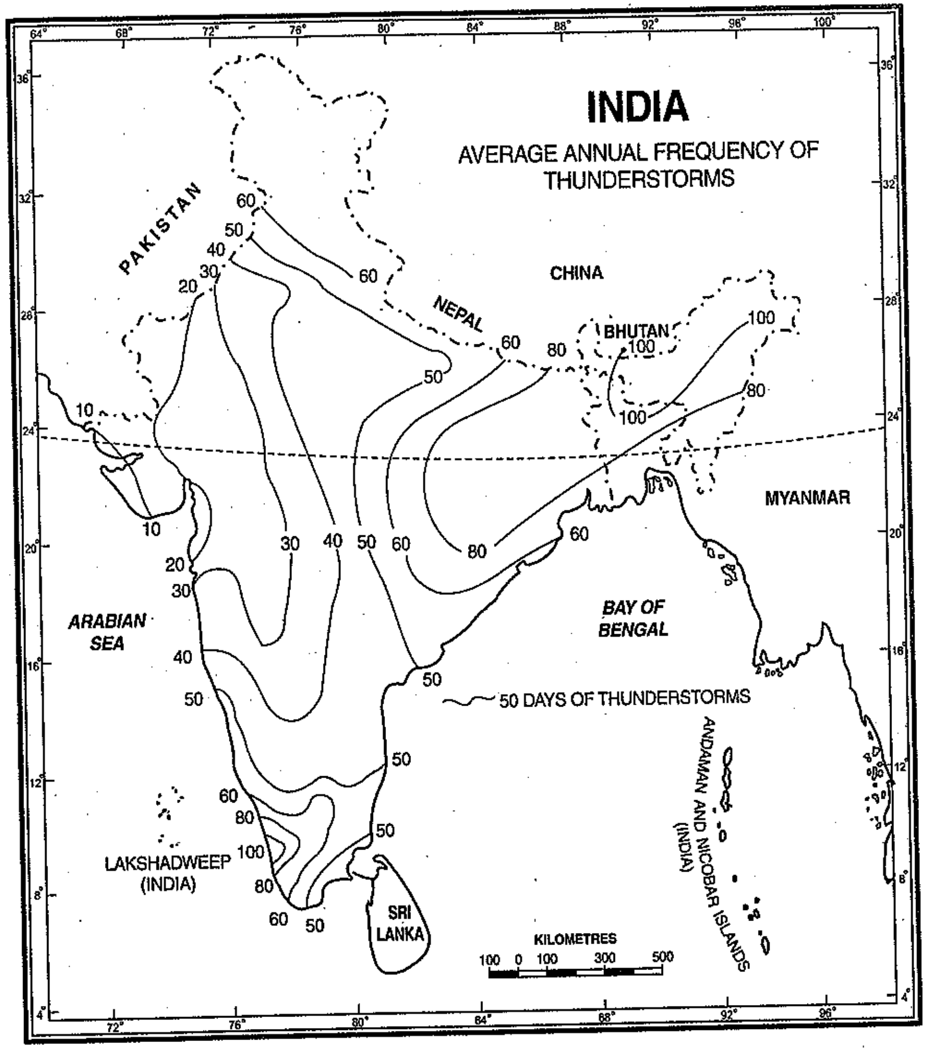


FIG. 8.16. Average Annual Frequency of Thunderstorms

comes into contact with ice crystal and water droplets alternately in up and down currents in the Cb cell. This is evident from the study of its structure. A cut section of a hailstone resembles an onion with alternate layers of glaze ice and opaque rim. The glaze ice layers of the hailstone are formed during its downward journey in the region of super-cooled water while the opaque rim layers form at higher levels where smaller drops predominate. Once the hailstones become too large to be supported by the vertical updrafts, they start falling on the ground. They fall with great speed which is often accentuated by the squall. Sometimes the hailstones attain large size (as large as a golf ball) and cause heavy damage to crops, property and life. Hail is a grave hazard to aircraft in flight.

During the period from March to May thunderstorms over northern India, particularly the submountain areas are accompanied by hail. Hailstorms also occur in association with western disturbances during the winter months from December to February. However, hail is rare in the southwest monsoon period. The annual frequency of hail is the highest in extreme northeast of the Brahmaputra valley with nearly 15 occasions. The other high incidence areas are Tripura, Dumka and Pakaur (Santhal Parganas) of Jharkhand, West Bengal and submontane regions of Uttarakhand. However, no region is free from hail.

Tornado

Tornadoes are extremely severe vortices of very small dimensions occurring in association with intense and large cumulonimbus (Cb) clouds or cyclonic storms. They comprise the most destructive meso-scale convective phenomena which builds up in thunderstorm. The visible symptom of a tornado is a small funnel extending down from a Cb cloud with winds reaching several hundred kilometres per hour, revolving tightly around the core. Actual records of wind speed are not available because anemometers cannot withstand such high speeds. From the sound etc. is presumed that the speed of the wind in a tornado may exceed the speed of sound. Wind speeds of as high as 400 to 500 kmph are not uncommon. Tornadoes travel along narrow paths with lengths from a few km to 100 km or more. The width of the path is small, ranging from 30 to 100 metres. The diameter of the funnel touching the ground may vary from less than a metre to a few tens or hundreds of metres. The entire disturbance moves at speed varying between 100 to 150 kmph.

In view of their severe intensity, tornadoes have high potential for destruction. They cause immense damage and devastation to life and property. Because of vortex, they suck everything in their path. They are also known as ***"twisters"***. The pressure may be lower by 10% inside the vortex than at the periphery. Hence, when the funnel passes over, buildings seem to explode. The debris and even persons may be sucked and carried aloft by the tornado. On 24th March, 1998, tornadoes claimed 200 lives in West Bengal and Odisha. Tornadoes occurring over sea suck water up to the base of the mother cloud. The cloud becomes linked with water body and the phenomena is termed as ***'water spout'***.

The most probable regions of tornado occurrence in India are Assam and adjoining states, West Bengal, Odisha, the Ganga plain, Punjab and Haryana.

Considering the random occurrence of tornadoes, their short life period and very low frequency in India (1 to 2 per year), the warning services for tornadoes are not seriously attempted as yet. In fact, advance warning of tornadoes is a difficult task. The radar comes in quite handy for tornado monitoring and warning. Unless the warning of tornado occurrence is disseminated to public at large, due to its short life, adequate steps cannot be taken by public to get away from the path of tornado. Various state governments in the target region have promulgated building laws which specify design of houses capable of withstanding tornado fury.

Cloudburst

Cloudburst is andher extreme natural hazard which causes large scale loss of life and property within a span of a few minutes.

WHAT IS A CLOUDBURST ?

A cloudburst refers to a sudden downpour within a radius of a few kilometres. The area affected by a cloudburst typically does not exceed 20-30 sq km. The downpour does not last more than a few minutes but is capable of causing heavy loss of life and property and leading to untold miseries to human beings, animals etc. Over 100 mm of rain in an hour is the basic criteria for a cloud to be called a ***cloudburst***.

Highly concentrated rainfall over a limited area in a short duration of time is the main criteria for any weather event to be termed as cloudburst. Following are some of the major events of heavy rainfall over a limited area in a short duration of time.

Area/Place	Date	Amount and duration of rainfall
Uttarkashi and Rudraprayag	June 16-17, 2013	479 mm in three hours
Leh	August 2,1010	250 mm in one hour
Mumbai	July 26, 2005	1448 mm in 10 hours

Source : India Meteorological Department.

Meteorologists believe that cloudbursts occur due to rapid lifting of clouds by the steep orography of the region. The clouds get vertically lifted. Such clouds are generally called ***connective clouds*** which can extent upto 15 kilometres in the air above the ground. This process is called the ***"cumulonimbus connection condition"*** which results in formation of towering vertical dense clouds. The lifting is generally dynamic which causes thermodynamic instability resulting in rapid condensation and highly concentrated heavy downpours.

HOW A CLOUDBURST COMES INTO BEING ?

1. Warm and humid air is pushed up along the mountain slope.
2. The air mass keeps rising and forms large thunder clouds.
3. Lack of upper-level wind prevents dissipation of the thunder clouds.
4. Concentrated localised rainfall occurs.

Further, it is believed that in the Himalayan region, the clouds which are being lifted up at a fast rate are also accompanied by soil moistened by earlier precipitation. This moistened soil acts as an additional source of moisture and might also have an important role in the frequent cloudbursts in the Himalayan region. Cloudbursts are more frequent in the monsoon season.

The above discussion and table 8.9 make it clear that most cloudbursts occur in the Himalayan region.

TABLE 8.9. Major Cloudburst in India since 1988

Date	Place/Area	Extent of Loss
December 29, 1988	Kinaur district of Himachal Pradesh	35 persons dead and hundreds of houses destroyed.
August 15, 1997	Chirgaon in Shimla district of Himachal Pradesh	1,560 people killed.
August 17, 1998	Malpha village in Kumaon division of Uttarakhand	250 people, including 60 Kailash Mansarover pilgrims in Kali valley were killed.
August 22, 2000	Kinaur (Himachal Pradesh)	200 people killed due to heavy flooding in the Satluj river.
July 29, 2001	Baijnath in Kangra district	10 persons killed.
July 16, 2003	Shilagarh in Gursa area of Kullu (Himachal Pradesh)	40 persons killed
August 8, 2003	Kullu and Shimla	100 dead
July 6, 2004	Alaknanda river basin Uttarakhand	17 killed, 28 injured and more than 5000 pilgrims stranded near Baridanath shrine area in Chamoli district.
August 16, 2007	Bhavi village in Ghanvi, Himachal Pradesh	52 people dead.
August 7, 2009	Nachni area near Munsigari in Pithorgarh district of Uttarakhand	37 people dead
August 6, 2010	Leh town of Ladakh region in Jammu and Kashmir	Series of cloudbursts left over 1,000 persons dead and over 400 injured.
July 20, 2011	Upper Manali, Himachal Pradesh	2 dead and 22 missing.
September 14, 2012	Rudraprayag, Uttarakhand	39 people dead
June, 16, 2013	Uttarkashi, Uttarakhand	15,000 dead, 436 injured, 1,800 missing.
July 31, 2014	Tehri, Uttarakhand	Several people died and many houses flattened.

Source : (*i*) IMD, (*ii*) Science Reporter, August, 2013, p. 17.

But that does not mean that other parts of the country are free from the fury of cloudbursts. Western ghats, western coastal areas, central and western India are also prone to cloudburst. In these areas, cloudbursts occur rarely but they strike with tremendous force and heavy downpour in a short duration of time. For example cloudburst in Musi river (a tributary of the Krishna river) in 1908 claimed 15,000 lives and destroyed 80,000 houses in Hyderabad. Cloudburst in 1979 was responsible for breaching the Machu dam following incessant rain which resulted in heavy flooding of the downstream area. Morvi town was almost completely destroyed.

On July 26, 2005, Mumbai received 1,448 mm of rain in 10 hours by a cloudburst; throwing entire life of the city out of gear. According to India Meteorological Department, Mumbai had never experienced such high rainfall in such a short duration for about 500 years and it may not happen in the coming 200 years.

Heat and Cold Waves

Heat and cold waves are extremes of high and low temperatures above and below normal temperature respectively. These weather associated conditions can also be categorised as disasters since many deaths occur due to them. Poor and weaker sections of society are particularly prone to heat and cold waves as they cannot afford to ensure protection against extreme heat and cold. Human body is acclimatised to a particular limit of temperature. Long exposure to extremes of cold or heat may lead to severe thermal strain and ultimately to death. This needs monitoring of daily maximum temperature in summer and daily minimum temperature in winter. In the summer season (March to July) normal temperatures over most parts of India are very high. Any abnormal increase in maximum temperature during day leads to disastrous consequences. Two to three heat waves are experienced in India during the summer season. Widespread heat waves normally occupy about 10 per cent of the Indian landmass. Generally they develop over northwest India and extend towards east and south.

Cold waves are experienced in winter season (November to March). Most of the cold waves occur in north west India and are associated with western disturbances. No absolute criteria can be laid down in respect to cold waves. They have to be defined with respect to the normal minimum temperatures experienced over a given area. Minimum temperatures 6 to 7°C below normal are considered as moderate cold waves and those of 8°C and more as **'severe cold waves'**. Generally the cold wave start over north-west India and gradually spread eastwards and southwards, at times as far east as West Bengal and as far south as Telangana. Each winter, two to three cold waves may be experienced.

LANDSLIDES

Introduction and Definition

Landslide is a rapid movement of rock, soil, and vegetation down the slope under the influence of gravity. Landslides are generally sudden and sporadic. An earthquake and heavy rainfall may cause large landslides in mountainous areas. Wherever mountain slopes are steep, there is a possibility of large disasterous landslides. They can also result when the base of a slope is oversteepened by excavation or river erosion. Man breaks rocks for constructing roads, railways, buildings, tunnels etc. In such cases rocks become loose and landslides occur. Mining activity by man is also responsible for landslides.

Landslides are very common along the steep slopes of the Himalayas, the Western Ghats and along the river valleys. **Natural removal of soil and rock from slopes is known as mass wasting.** Landslide as a hazard has long been recognised by the people living in the mountains. It becomes specially dangerous when there is heavy rainfall or snowfall on the steep hill sides which makes the rocks to slip and break.

The extent of landslides depends on the steepness of the slope, the bedding plane of rocks, the amount of vegetation cover and the extent of folding and faulting of the rocks. It is the rocks that break and carry with it the soil and debris. A major cause which triggers off the landslide is the weight of the overlying material and the presence of a lubricating material like water, this is known as ***solifluction.*** Freezing and thawing of the rocks on mountain slopes cause them to break and roll down the slopes. The over bearing weight of snow or ice or water which has seeped into the soft permeable rocks also lead to

A Checklist of Causes of Landslides

1.	***Ground Causes***
	1. Weak, sensitivity, or weathered materials
	2. Adverse ground structure (joints, fissures etc.)
	3. Physical property variation (permeability, plasticity etc.)
2.	***Morphological Causes***
	1. Ground uplift (volcanic, tectonic etc.)
	2. Erosion (wind, water)
	3. Scour
	4. Deposition loading in the slope crest
	5. Vegetation removal (by forest fire, drought etc.)
3.	***Physical Causes***
	1. Prolonged precipitation
	2. Rapid draw-down
	3. Earthquake
	4. Volcanic eruption
	5. Thawing
	6. Shrink and swell
	7. Artesian pressure
4.	***Man-made Causes***
	1. Excavation (particularly at the toe of slope)
	2. Loading of slope crest
	3. Draw-down (of reservoir)
	4. Deforestation
	5. Irrigation
	6. Mining
	7. Artificial vibrations
	8. Water Impoundment and leakage from utilities.

Source : Manual on Natural Disaster Management in India (2001), National Centre for Disaster Management, p. 63.

slipping and breakage of hill slopes. Near the sea coast, such as the Kanara coast, cliffs are eroded at the base by sea waves and the rocks jutting out on top break off and fall. Landslides occur frequently during the rains. Deforestation as a result of felling of trees for timber and removal of vegetation cover for development activities are also responsible for soil erosion and destabilization of slopes. It is estimated that the construction of just one kilometre long road requires removal of 40,000 to 80,000 cubic metres of debris, which slide down the slopes, killing vegetation and choaking mountain streams.

From the above discussion, it can be concluded that landslides can be caused by poor ground conditions, geomorphic phenomena, natural physical forces and quite often due to heavy spells of rainfall coupled with impeded drainage.

Onset-Type and Warning. Generally speaking, landslides occur gradually but often they occur without warning. They may take place in combination with earthquakes, floods and volcanoes. It is difficult to predict the actual occurrence of landslides. The areas of high risk can be determined by using information on geology, hydrology, vegetation cover, post occurrence and consequences in the region.

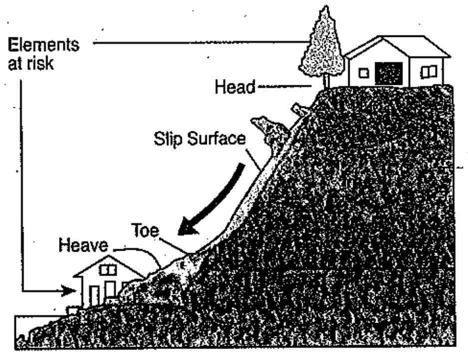


FIG. 8.17. Landslides : Elements at Risk

Elements at Risk. The most common elements at risk are the settlements built on the steep slopes, at the toe, and at the mouths of streams emerging from the mountain valley (**Fig. 8.17**). Buildings constructed without appropriate foundation for a given soil and in sloppy areas are also at risk. Roads, communication lines, and buried utilities are also at risk.

Landslide Vulnerability Zones

Following landslide vulnerability zones are recognised in India :

(i) **Very High Vulnerability Zone.** This zone includes young mountains of the Himalayas, Andaman and Nicobar, steep and rainy slopes of the Western Ghats and Nilgiris, the north-eastern regions

and areas of intense human activities particularly those related to construction of roads, dams etc.

(ii) **High Vulnerability Zone.** These areas have geographical conditions similar to those areas which have very high vulnerability. The only difference is that the intensity and frequency of landslides is less as compared to areas of very high vulnerability. All the Himalayan States and the States from the north-eastern region except the plains of Assam are included in the high vulnerability zones.

(iii) **Moderate to Low Vulnerability Zone.** These include areas which receive less precipitation such as Trans-Himalayan areas of Laddakh and Spiti, Aravalli hills, rainstorm areas of the Western and Eastern Ghats and Deccan plateau, Landslides due to mining and subsidence are most common in states like Jharkhand, Odisha, Chhattisgarh, Madhya Pradesh, Maharashtra, Andhra Pradesh, Telangana, Karnataka, Tamil Nadu, Goa and Kerala.

(iv) **Other Areas.** The remaining parts of the country especially states like Rajasthan, Haryana, Uttar Pradesh, Bihar, West Bengal (except district Darjeeling), Assam (except district Karbi Anglong) and Coastal regions of the southern States are safe as far as landslides are concerned.

Consequences of landslides

Landslides have serious consequences at the local level. They obstruct the flow of water in the river and cause flash floods. There are frequent floods in the upper courses of the rivers like the Ganga and the Brahmaputra due to landslides. When the mass of landslides falls on roads and railway tracks, it creates hindrance and rail traffic.

Landslide Zonation Mapping is a modern method to identify landslide prone areas and has been in use in India since 1980s. Figure 8.18 shows the landslide prone areas in India.

Casualties. Casualties depend upon the place and time of occurrence of the landslides. Maximum casualties occur in densely populated areas down the slope.

Typical effects of some of the landslides in the recent past are described below :

Landslides in the Hills. Hilly regions of India are most vulnerable to landslide hazards. In fact, landslides are almost an annual and recurring phenomenon in the hilly areas. In the mountainous region there is a closely established link between rainfall, landslides and floods. Hilly areas especially

TABLE 8.10. Major Landslides and their effects

Date/Year	Location	Effects
1993	Ratighat (Uttarakhand)	Nainital hill area remained cut off for about a week. It took five days to clear the debris.
1993	Nilgiri Hills (Tamil Nadu)	Forty people died, over 600 families shifted to safer places. Roads and houses destroyed.
August 12-18, 1998	Malpa (Uttarakhand)	Entire village was washed away. About 384 persons including 60 pilgrims going to Lake Mansarovar were killed.
Sept. 24 to Oct. 10, 2003	Uttarkashi (Uttarakhand)	Boulders from Varunavat Parvat razed several parts of the Uttarkashi town. Landslides affected 362 families and nearly 3,000 people were evacuated. Several portions of the national highway leading to Gangotri were damaged.
July 6, 2004	Badrinath (Uttarakhand)	Landslide blocked the pilgrimage route to Badrinath. Over 2,000 pilgrimage were stranded in the hills near Badrinath. Nearly 1,000 shopkeepers and 2,500 villagers were trapped and remained cut off for 3 days. Roads were blocked. Massive rescue work had to be launched.
June 16, 2013	Uttarakhand	Floods and landslides caused by heavy rains resulted in untold damage to life as property.
July 30, 2014	Malin village 80 km north of Pune	The whole village burried in the debris. More than hundred people feared dead.

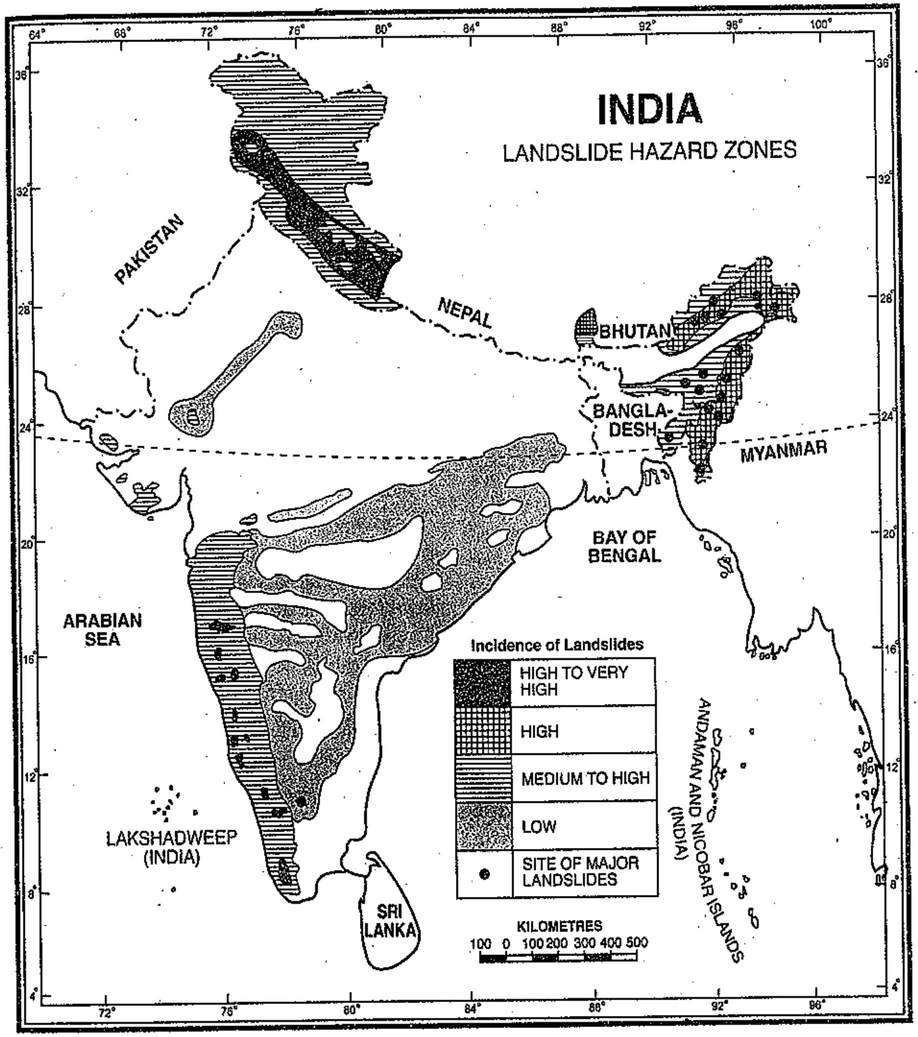


FIG. 8.18. India : Landslide Hazard Zones

in Jammu and Kashmir, Himachal Pradesh, Uttarakhand and Arunachal Pradesh have been experiencing landslides caused by incessant rainfall for many years now.

Landslides in Uttarakhand. Report of The Central team on landslides in hill areas of Uttar Pradesh (now a separate state of Uttarakhand) during 1998 indicates the damages caused due to hailstorms, heavy rains and the resulting crop damage in the state during the months of May to September 1998. The report observes that the Himalayan ecology is extremely fragile and falls under the Seismic Zone V. The main causes for landslides have been unplanned and unscientific development activities in the hilly areas, mindless and indiscriminate felling of trees, urbanisation, etc. which have caused ecological imbalances in the Himalayas. Increasing pressure of human and animal needs, rapid denudation, biotic interference etc., have further aggravated the problem of soil erosion, avalanches, flash floods etc. The damages are caused by nature and induced by human activities.

Every year, the landslides in the region kill dozens of people and cause widespread damage to several villages such that they have become totally unfit for habitation. The landslides have caused havoc and the terraced fields have been destroyed that cannot be renovated or made productive again. The road network remains closed for long periods causing indescribable hardships to the villagers who get their home supplies and provisions from the neighbouring areas. The water course is also disrupted due to landslides as they are breached from several places and are choked by debris. More so, the water channels are affected from the uphill side due to which the villagers are devoid of water for irrigation purpose. This adversely affects agricultural production.

Main Mitigation Strategies

- **Hazard Mapping.** It locates areas prone to slope failure. This helps in identifying areas prone to landslides and avoidance of areas for building settlements.
- **Land Use.** This pertains to preservation of vegetal cover. Denuded path slopes provoke landslides and must be reforested with suitable tree species. Due care must be taken to avoid blockage of natural drainage while constructing roads, buildings and canals.
- **Retaining Walls.** These are built along the road sides to stop debris from slipping. Such retaining walls have also been constructed along the Konkan railway line.
- **Surface Drainage Control Works.** The surface drainage control works are implemented to control the movement of landslides accompanied by infiltration of rain water and spring flows.
- **Engineered Structures.** Buildings and other engineered structures with strong foundations are in a better position to withstand the ground movement forces. Underground installations such as pipes and cables should be made flexible to move in order to withstand forces caused by the landslides.
- **Increasing Vegetation Cover.** This is the cheapest and the most effective way of arresting landslides. This helps in binding the top layer of the soil with layers below, while preventing excessive run-off and soil erosion.

AVALANCHES

Introduction and Definition

The term avalanche generally denotes the descent of material down a mountain slope, but specifically meaning the hurtling down a mountain slope of mass of snow, compounded with ice and rock.

In winter, avalanches are caused when fresh snow falls and slips off the snow surface. In spring, they are produced when partly thawed snow rolls down mountain slopes. Along the way these masses increase in size and acquire a dangerous momentum. Avalanches also occur when edges of glaciers in high mountains break off.

Avalanches are commonly subdivided according to the material involved.

Snow avalanches occur in predictable locations in snowy mountains and create distinctive ground features as they move down the mountain side.

Debris avalanches involve the rapid downslope movement of sediment.

Rock avalanches are very rapid downslope movements of bedrock which become shattered during movement. These avalanches sometimes achieve velocities as high as 400 kmph. They can travel tens of kilometres from their source, sometimes with devastating effects on human life.

Damages by Avalanches

Generally speaking, avalanches cause the following damages :

(*i*) Roads are damaged by snow of the avalanches.

(*ii*) Traffic is blocked when an avalanches falls on a road.

(*iii*) Road structures such as retaining wells are overturned.

(*iv*) Structures coming in the way of an avalanche are damaged.

Preventive Measures

(*i*) Afforestation of avalanche prone area.

(*ii*) Trapping the avalanche by control measures.

(*iii*) Disposing the avalanche potential snow packs by artificial triggering

(*iv*) Predicting the occurrence of avalanches through stability analysis and issuing warning about impending avalanche.

(*v*) Guiding the residents about the emergency evacuation shelters.

Avalanche Prone Areas in India

The higher reaches of the Himalayan region are prone to attack by avalanches. The snowy region of the Western Himalayas is particularly prone to avalanches. It includes higher areas in Jammu and Kashmir, Himachal Pradesh and Uttarakhand. The details are as under :

1. Jammu and Kashmir – Higher reaches of Kashmir and Gurez valleys, Kargil and Ladakh and some of the major roads.
2. Himachal Pradesh – Chamba, Kullu-Spiti and Kinnaur are vulnerable areas.
3. Uttarakhand – Parts of Tehri Garhwal and Chamoli districts are vulnerable areas.

Snow Avalanche Zones

There are three types of snow avalanche zones :

1. **Red Zone.** The most dangerous zone where snow avalanches are most frequent and have an impact pressure of more than 3 tonnes per square metre.
2. **Blue Zone.** Where the avalanche force is less than 3 tonnes per square metre and where living and other activities may be permitted with connection of safe designs but such areas may have to be vacated on warning.
3. **Yellow Zone.** Where snow avalanches occur only occasionally.

Avalanche Disaster in India

As mentioned earlier, most avalanche disasters in India take place in the west Himalayan region particularly in Jammu and Kashmir and Himachal Pradesh (see **Table 8.11**).

Avalanche Control Measures

Types of Control Measures. There are two types of control measures *viz.* (*i*) hardware, and (*ii*) software.

(*i*) ***Hardware measures*** are meant for preventing avalanches or for blocking or deflecting avalanches with protective structures.

(*ii*) ***Software measures*** provide safety by eliminating the probability of avalanches by removing

TABLE 8.11. Avalanche Disaster in India

Location	Year	Damage
Himachal Pradesh	March, 1978	30 people killed, road and property damaged.
Lahul & Spiti	March, 1979	237 people killed. Communication lines disrupted.
Jammu & Kashmir	Dec. 1982	100 people killed. Communication lines disrupted
Ladakh	Dec. 1984	27 soldiers killed under avalanches generated by artillery fire.
Jammu & Kashmir	March, 1988	70 people killed. Communication lines disrupted
Himachal Pradesh	March, 1991	Tinku avalanche takes place every year 4-5 times Jan-March, road was blocked for 40 days in 1991.
Himachal Pradesh	Sept. 1995	Due to avalanche, huge chunk of debris came down which later melted into a flood.

Source : Manual on Natural Disaster Management in India. National Centre for Disaster Management (2001), p. 75.

snow deposits on slope with blasting and by predicting the occurrence of avalanches and recommending evacuation from hazardous areas.

Avalanche Control Structures

Two major types of avalanche control structures are (*a*) Prevention Structures and (*b*) Prediction structures.

(*a*) **Prevention Structures.** These structures are meant for preventing the occurrence of avalanches. Following are the major preventive structures.

(*i*) ***Avalanches Prevention Forest.*** These prevent the movement of avalanches by the resistance of tree trunks and branches, increase the stability of snow cover by uniformly distributing it and control quick changes in snow cover.

(*ii*) ***Stepped Terraces.*** Theses help in stabilising the snow cover. Stepped terraces are easy to construct but are not effective in controlling surface layer avalanches.

(*iii*) ***Avalanche Control Piles.*** Avalanche Control Piles are assemblies of single piles driven into slopes in avalanche zones to control surface layer avalanches. Spacing of piles depends upon the type of snow or topographical features. The average spacing is about 5 metres.

(*iv*) ***Avalanche Control Fence.*** Avalanche Control Fence is installed on slopes of avalanche zones to prevent full depth or surface layer avalanches.

(*v*) ***Suspended Fences.*** Suspended fences are used in steep slopes or in areas where foundations cannot be properly installed because of poor ground conditions. These are useful in small area.

(*vi*) ***Snow Cornice Control Structures.*** These structures are installed at tops of mountain areas to prevent the development of snow cornices that can cause avalanches.

(*b*) **Protection Structures.** These structures are installed in the path of the avalanche or in snow deposit areas to change direction of flow of avalanches, to reduce their energy to block their flow or to allow their passage. Following are the main protective structures.

(*i*) ***Protective Fences.*** These are installed to block the avalanches and their action is similar to that of retaining walls. They are normally constructed of steel and are used mainly for blocking small avalanches.

(*ii*) ***Retaining Walls.*** Retaining walls are normally installed in snow deposit areas to block the flow of avalanches before they reach the roadside. These walls need a pocket large enough to store snow deposited by avalanches and are not very effective unless they are installed on gentle slopes of 20 degrees or less.

(*iii*) ***Deflecting Structure.*** As the name indicates, these structures are installed to deflect the flow of an avalanche. This is done particularly to avoid interference of the avalanche in road traffic.

(*iv*) ***Snow sheds.*** Snow shed is a roofed structure installed over a road to allow the flow of an avalanche over the roof. This is most reliable of the various avalanche protection structures.

(*v*) ***Retarding Structure.*** These are structures to reduce the flow velocity or the scale of the avalanches. There are various types such as earth mounds, retarding piles, grating crib work and retarding fences.

Other Control Measures. Apart from the above mentioned measures, there are other control measures which are briefly described as under.

(*i*) ***Prediction and Forecasting.*** Prediction and forecasting is a very effective method of reducing the risk from avalanches can not only prevent avalanche disasters but can also make it efficiently dispose off dangerous snow deposits and cornices.

(*ii*) ***Disposal of Avalanches Potential Snow Packs.*** Methods that dispose of snow packs on hazardous slopes include hard labour, mechanical methods that use blasting powder. In general, small avalanches are usually disposed of by blasting.

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CHAPTER

Environment

INTRODUCTION

The word environment has been derived from the French word *Environir* which means '*to surround*'. Thus environment refers to the sum total of conditions which surround man at a given point of space and time. It is a composite term for the conditions in which organisms live. It includes both biotic and abiotic substances. In other words, environment is the totality of all physical, social, and biological factors, individually as well as collectively, that comprise the natural and man made surroundings.

Considering its basic structure, environment may be divided into two broad types *viz.* physical environment and biotic environment. Physical environment is subdivided into three broad categories *viz.*, (*i*) solid, (*ii*) liquid and (*iii*) gas which represent three basic realms of the earth known as the ***lithosphere***, the ***hydrosphere*** and the ***atmosphere.*** The biotic component of environment consists of plants and animals including man as an important factor. Of all the organisms, man is the most intelligent, skilled and civilized creature. He is both the creator and the moulder of his environment. With his tremendous scientific and technological advancement, man has to a large extent, succeeded in controlling and dominating nature. In this process, he has interfered with nature and disrupted his biotic and abiotic environments.

Pollution. The word pollution has been taken from the Latin word *Pollutionem*, meaning defilement from polluere, to soil or defile (make dirty). Later on Oxford English Dictionary used the word *pollute* with reference to physical contamination of terrestrial or aquatic environments in the nineteenth century. In the twentieth century the word pollution was used with reference to contamination of water, soil and air. According to the report of the Environment Pollution Panel of the **U.S. President's Science Advisory Committee** (1965), environmental pollution may be defined as the unfavourable alteration of our surroundings, wholly or largely as a byproduct of man's actions, through direct or indirect effects, of changes in energy patterns, radiation levels, chemical and physical constitution and abundance of organisms. **R.F. Dasmann** (1975) has defined pollution as *"the accummulation of substances, or forms of energy, in the environment in the quantities, or at rates of flow, which exceed*

capacity of ecosystems to either neutralize or desperse them to harmless levels". In simple words, pollution is an undesirable change in the physical, chemical or biological characteristics of our air, land and water that may or will harmfully affect human life or that of desirable species, our industrial processes, living conditions and cultural assets or deteriorate our raw material resources.

Pollutant. According to **Sir Fedrick Warner**, "A substance is normally considered to be a pollutant if it adversely alters the environment by changing the growth rate of species, interferes with the food chain, is toxic or interferes with the health, comfort, amenities or property values of people." Pollutants may be solids, liquids as well as gases. The solid particulate pollutants include aerosols, industrial wastes, such as lead, mercury, asbestos, etc. The liquid pollutants are dissolved solids, ammonia, urea, nitrates, chlorides, fluorides, carbonates, insecticides and pesticides—all in dissolved form, oil and greases, etc. The major gaseous pollutants are carbon dioxide, sulphur dioxide, nitrogen oxide, etc.

ENVIRONMENTAL POLLUTION IN INDIA

There has been large scale pollution of the natural environment in India, especially after Independence, as a result of unprecedented urbanization and industrialization. The most important source of pollution in India is its fast growing population. Most parts of India are now crowded with people resulting in large scale consumption of resources and creation of wastes. Pollution problems increase almost in proportion to the increase in population because the pollutants and wastes also increase proportionately. In India, the problem of environmental pollution is further complicated by widespread poverty of the masses. A large proportion of Indian population lives below the poverty line in slum areas without basic civic amenities. In fact, *poverty and underdevelopment are India's prime pollution problems which are roots of the major ecological imbalances and poor quality of human environment in the country.*

AIR POLLUTION

Air is a mixture of several gases. The main gases are nitrogen (78.09%) for forming products such as, fertilizers for plants and for making the air inert, oxygen (20.95%) for breathing and carbon dioxide (0.03%) for photosynthesis. Some other gases like argon, neon, helium, krypton, hydrogen, ozone, zenon and methane are also present. Besides, water vapour and dust particles make their presence felt in one way or the other.

Air is most essential for all types of life in the biosphere because it helps in breathing. *Man can live without food for a few weeks, without water for a few days but he cannot live without air even for a few minutes.* A person breathes 22,000 times a day inhaling about 16 kg of air. It is mostly the oxygen which is consumed while carbon dioxide is released during the breathing process. **Table 9.1** gives the composition of respiratory act.

TABLE 9.1. Composition of Respiratory Air

Name of the gas	Volume %of	
	Inhaled air	Exhaled air
Oxygen	20.95	16.4
Nitrogen	79.01	79.5
Carbon dioxide	0.04	4.1

The atmospheric air is recognised as clean when there are no drastic variations in its natural composition and it is devoid of any solid particulate matter. It must be borne in mind that we cannot find clean or pure air in any part of the world because it is constantly being polluted both by nature and man. When we breath, not only oxygen but some other gases such as sulphur dioxide, hydrogen sulphide, carbon monoxide, dust particles, emissions from volcanoes, etc. also enter our respiratory system. Thus air becomes polluted when its normal composition is disturbed either by nature or by man or by both. **World Health Organisation** (WHO) has defined air pollution as limited to situation in which the outdoor ambient atmosphere contains materials in concentration which are harmful to man and his surrounding environment. In simple words air pollution refers to the injection into the atmosphere of gases, liquids and solid particles detrimental to human health. Air pollution knows no political boundaries, it is a global phenomena.

Air Pollutants

Air pollutants are classified as primary or secondary based on their characteristics while they are emitted and physical/chemical changes they undergo while in the atmosphere. The pollutants emitted into the atmospheric directly from the identifiable sources that remain scattered in the atmosphere in the same chemical form as at the time of emission from source are known as ***primary pollutants***. The pollutants which undergo chemical changes in the atmosphere as a result of reactions among two or more pollutants are called ***secondary pollutants***. The pollutants like sulphur dioxide, nitrogen dioxide and particulates are recognised as primary pollutants while several other air pollutants are categorised as secondary pollutants.

Normally speaking, urban air is more polluted than rural air. The routine pollutants in urban air include sulphur dioxide, nitrogen oxides and suspended particulate matter. Besides, there is a severe threat from a range of other air toxins such as carbon monoxide, small particulate emissions, lead, benzene, polycyclic aromatic hydrocarbons (PAH) and ozone. A brief description of various air pollutants commonly found in the urban atmosphere is given below :

1. Sulphur dioxide (SO_2) : Critical Pollutant. Sulphur dioxide is generated from natural resources such as the bacterial decomposition of sulphurs in the soil from the oxidation of hydrogen sulphide produced by the decay of organic matter, from volcanoes, etc. The anthropogenic sources of sulphur dioxide emission arise mainly from combustion of fuels because of trace amount of inorganic and organic sulphur contained in the fossil fuels and ores. It has been estimated that about one-third of the sulphur dioxide emission in the atmosphere arises from the activities of man, chiefly the combustion of fossil fuels. Significant quantities of sulphur dioxide are emitted by oil refineries, automobiles, thermal power plants, acid plants, smelters, incinerators, etc.

Studies conducted by Central Pollution Control Board, indicate that Sulphur Dioxide concentrations in percentage of locations are limited to low and moderate category though fluctuating over the years from 2001 to 2010 (**Fig. 9.1**).

2. Nitrogen Oxide (NO_2) : Killer Gas. Generally recognised as sum of nitric oxide (NO) and nitrogen dioxide (NO_2), it is a reddish brown corrosive gas. The automobile exhaust is one of the largest sources of NO_2 emission in the ambient air, as these are formed during combustion as a result of oxidation of atmospheric nitrogen and organic nitrogen. The significant concentration of nitrogen oxides in gaseous emissions occurs from the industrial emissions where nitric acid is produced or is used in chemical reactions. The residence time of NO_2 in the atmosphere is about a few days and is scavenged from the atmosphere through formation of nitric acid, nitrites or nitrates and through their dry dissociation.

Figure 9.2 shows that NO_2 concentrations showed a reduction in low category and increase in moderate, high and critical categories. These trends are clear indicators of an increase in pollution levels with respect to NO_2. High concentration of NO_2 is a major concern of air pollution. In addition to being a pollutant by itself it also aids formation of yet another deadly gas—ozone. Studies show that NO_2 peaks coincide with traffic peaks.

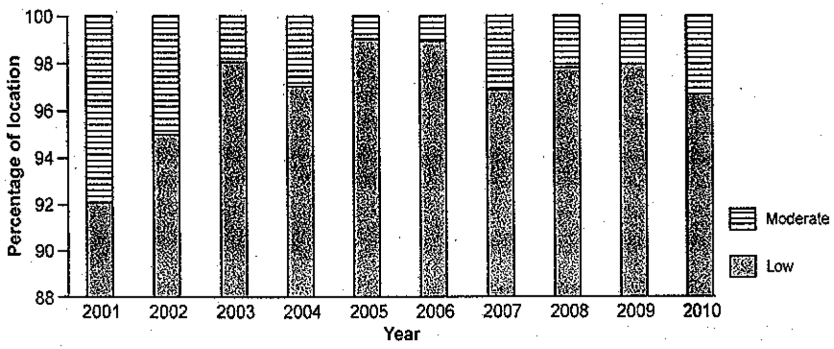

FIG. 9.1. Yearly trends of Sulphur Dioxide in locations (Residential/industrial/rural/other areas)

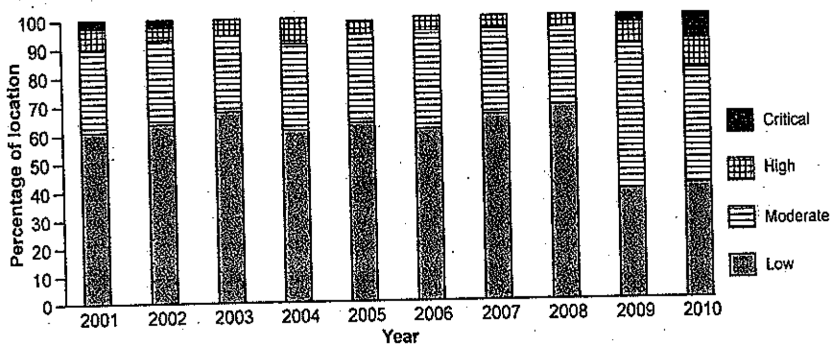

FIG. 9.2. Yearly trends of NO_2 concentration in the air from 2001 to 2010

The steady upward trend of annual NO_2 levels in Mumbai, Delhi and Chennai indicates that the problem is going to take serious turn in the near future.

Though annual mean concentrations of NO_2 in most cities are still within the limits of tolerance, maximum levels in several cities are well above the permissible limits. Gajrala in Uttar Pradesh, Ludhiana, Jalandhar and Patiala in Punjab, Parwanoo in Himachal, Kottayam in Kerala, Pondicherry, Mysore in Karnataka, Haora in West Bengal, Dhanbad, Sindri and Jharia in Jharkhand, Ahmedabad, Surat, Vapi, Rajkot and Ankleshwer in Gujarat, Nagda and Jabalpur in Madhya Pradesh, Jaipur, Alwar and Kota in Rajasthan are some of the towns and cities where NO_2 concentration is already well beyond the standard or it is increasing rapidly.

3. Particulate Matter (P.M.). The particulate matter refers to the solid or liquid particles in its form of dust fumes, mist or smoke and originated either by dispersion of particles from breakdown of solid bulk material or condensation originated, built up from molecular dimension after heating or cooling. The particles have several physico-chemical properties such as size, mass, volume, settling velocity, chemical aerodynamics and optical properties. These properties of the particles play a vital role in atmospheric processes. The size, density and shape of the particles are of prime importance because these factors not only influence their cleansing rate from the environment, but also their effects. The particle size is one of the most important physical characteristics of air borne particulate matter because it controls the residence time of particles in the ambient air. The size of particles may vary from 0.002 μm, (micron) to 500 μm (one micron is equal to one millionth of a metre). Particles larger than 50 μm can be seen with naked eye. Following two types of particulates are recognised depending upon their size.

(i) Suspended Particle Matter (SPM). Particles with size less than 100 μm are very small particles and tend to remain suspended in the atmosphere for a long period of time. Hence, they are known as ***suspended particulate matter (SPM)***. In other words, SPM can be defined as solid and liquid particles in the air that are small enough not to settle down onto the earth's surface under the influence of gravity. The main contributors of SPM in ambient air are dust from different sources like conduction activities, open fields, mining, stone crushers etc. and from industrial sources such as thermal power plants and smelters.

(ii) Respirable Suspended Particulate Matter (RSPM). Respirable Suspended Particulate Matter (RSPM or PM_{10}) are the particulates having diameter less than 10 μm. These are very small particles. As such they can be inhaled and may enter deep into the respiratory tract and pulmonary system of human beings. The sources of RSPM include road dust, wind blown dust and the dust from agriculture, construction and combustion processes. **Figure 9.3** shows that more than half the locations in India are critical with respect to PM_{10} concentration in the air. The number of locations with high and moderate concentrations has also risen and locations with low concentrations are negligibly small.

4. Carbon Monoxide (CO). Incomplete combustion of carbon results in the production of carbon monoxide (CO). The anthropogenic sources of

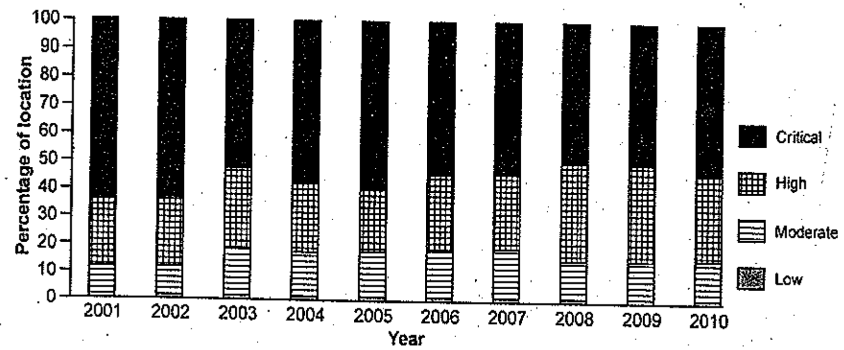

FIG. 9.3. Percentage of locations with low, moderate high and critical concentration of PM_{10} from 2001 to 2010.

CO are motor vehicles, coal combustion, fuel oil combustion, industrial processes, solid waste disposal and refuse burning. In motor vehicles air-to-fuel ratio has a direct impact on carbon monoxide emissions. At lower air-to-fuel ratio, carbon monoxide emissions are increased due to incomplete combustion in low presence of oxygen.

In urban areas, carbon monoxide concentration follows a diurnal pattern, which depends on traffic volume and speed. Generally CO concentrations reach to a maximum in the early morning hours due to peak early morning traffic and then fall to low level during the day. A second peak of CO concentration is usually observed corresponding to the late afternoon traffic period, and decrease to low levels during the night.

The residence time of CO in the atmosphere is about three years, The anthropogenic sources of carbon monoxide have been continuously increasing during the last few years in most of the urban areas.

5. Photochemical Oxidants. These are mainly the result of secondary reactions in the atmosphere and are not directly attributed to nature. *Ozone* is the main photochemical oxidant and its formation is normally attributed to nitrogen dioxide photolytic cycle. Ozone is formed through dissociation of nitrogen oxides (NO_2) by sunlight to yield the oxygen atoms, which then react with molecular oxygen to produce ozone molecule. The presence of reactive hydrocarbon allows ozone to accumulate at higher than steady levels.

The meteorological factor important in formation and transport of ozone in the lower troposphere are degree of atmospheric stability, wind speed and direction, intensity and wave length of sunlight and synoptic weather condition. Ozone produced near pollutant sources/areas can be transported over long distances. A result of such reactions produce photochemical smog which is characterised by grayish haze during period of excessively high ground level pollution.

Peroxyacyl nitrate (PAN) is phytotoxic pollutant obstructing visibility. PAN is relatively stable in upper troposphere and can travel over long distances. Upon mixing with lower tropospheric air, PAN can thermally dissociate and release NO_2.

6. Organics in Ambient Air. Hydrocarbons and Polynuclear aromatic hydrocarbons, Benzene and volatile organic compounds are the chief organics in ambient air.

(i) Hydrocarbons and Polynuclear- aromatic hydrocarbons (PAH). The ambient hydrocarbon composition includes the unburned hydrocarbon from fuels such as gasoline, species formed during combustion and natural hydrocarbons emitted by vegetation. The major anthropogenic sources of hydrocarbons are partially burned gasoline from vehicular sources and interior emissions. Gasoline evaporation and solvent evaporation also account for emission of hydrocarbons. Industrial sources of hydrocarbons include chemical manufacturing facilities, petroleum refineries and metallurgical operations.

Polynuclear aromatic hydrocarbons (PAHs) are homologs of benzene. The sources of PAHs are heat generation using coal, refuse burning, motor vehicles, industries such as steel and coke manufacturing and carbon-black manufacturing.

The residence time of hydrocarbons in the atmosphere is about three years. Many of the hydrocarbons are oxidised and several are converted to other organic compounds in the presence of nitrogen oxides. Ultimately the hydrocarbons may be converted to particulates and scavenged from the atmosphere.

(ii) Benzene. Benzene is produced during the distillation of crude petroleum and forms a significant component of gasoline. Transport vehicles comprise the major source of benzene emissions. Other sources of benzene emission are chemical manufacturing, coke ovens, petroleum refineries, etc. It is estimated that emissions of benzene from motor vehicle operation are substantial and benzene comprises about 4% of automobile exhaust emission and approximately 1% of fuel evaporative emissions. The urban areas have higher concentration of benzene.

(iii) Volatile Organic Compounds (VOC). The organic compounds which evaporate easily are recognised together as volatile organic compounds. Technically such compounds are defined as organic compounds with a vapour pressure of 1300 pascals (about 1% atmospheric pressure at sea level). These compounds may include several aromatic hydrocarbons and are included into the common category because of their similar physical behaviour in the atmosphere. Volatile organic compounds emerge as evaporative emissions during handling, storage and use as part of unburnt or partially burnt hydrocarbon mostly along with exhaust gases from vehicles. The volatile organic compounds (VOC) are emitted to the atmosphere from transport, use of industrial solvents and for domestic purposes. These compounds are scavenged with condensation along with water vapcurs, absorption on surfaces or on particles. Some outstanding examples of volatile organic compounds are aldehydes, ketones, organic acids, alcohols, furans, etc.

TABLE 9.2. Typical Sources of some Air Pollutants in Ambient Air

Sl. No.	Air Pollutants	Major Sources
1.	Sulphur Dioxide (SO_2)	Fuel combustion, power station, industrial processes, chemical processes, diesel vehicles, solid waste disposal, smelters.
2.	Nitrogen Oxide (NO_x)	Transport (road, rail, passenger and commercial), fuel combustion, power stations, industrial boilers, chemical processes, waste incinerators, smelters.
3.	Particulate Matter (SPM, RSPM-PM_{10}, RSPM-$PM_{2.5}$)	Fuel combustion, power stations, construction activities, industrial processes, diesel vehicle exhaust, re-suspended road dust, domestic refuse burning, domestic wood.
4.	Carbon Monoxide (CO)	Transport, combustion, industrial processes, solid waste disposal, refuse burning.
5.	Ozone (O_3)	Secondary pollutants formed during photochemical reaction.
6.	Organic compounds	Transport, oil based fuel combustion sources, chemical processes, solvent use, waste incinerators, vaporization of fuel.
	Benzene	Petrol combustion products, petrol filling stations, chemical process.
	Polynuclear aromatic hydrocarbons (PAH)	Fuel combustion, industrial emission.
	Volatile organic compounds (VOC)	Transport, solvents (especially used in industrial and domestic sector).
7.	Trace metals	Fuel combustion, chemical process, transport, metal production and finishing operation, product manufacture.
	Lead (Pb)	Lead additives in gasoline, soil originated particles.
	Cadmium (Cd)	Fuel combustion, metal production process, transport.

Source : Air Quality Status and Trends in India (2000), Central Pollution Control Board, pp. 17-18.

7. *Trace Metals in Ambient Air.* Various metals are found in the ambient air in trace and ultra trace concentrations. These include lead, cadmium, zinc, nickel, iron, chromium, etc. They are briefly described as under :

Lead. The airborne soil is the primary source of atmospheric lead. Smelter and refinery processes, as well as incineration of lead containing waste are major point sources of lead. *One of the most important source of lead is release of lead compounds from motor transport using* lead gasoline containing tetra-ethyl or tetra methyl lead. It is estimated that about 75% of lead is emitted into the atmosphere in the form of particles less than 1 μm in size which can stay in atmosphere for long time. Approximately 70-80% lead which is added to the leaded gasoline for increasing its octane number is discharged into the atmosphere. Other major sources of lead emission are burning of lead containing products like paints, batteries, plastics, combustion of coal and oil.

Sources of ***chromium*** include metallurgical and chemical industries, products employing chromate compound, cement and asbestos. Sources of ***zinc*** include zinc refineries, manufacturing of brass, zinc and galvanising process. Sources of ***cadmium*** include metal industries engaged in extraction, refining, electroplating and welding of cadmium material. It is also emitted as byproduct of refining laced zinc and copper. It is estimated that about 76% of all anthropogenic cadmium emissions come from non-ferrous metal industries, Sources of ***nickel*** include metallurgical plants using nickel, engines burning fuels containing nickel additives, burning of coal and oil, nickel plating facilities and incineration of nickel products. Sources of ***iron*** in ambient air include iron and steel plants, fly ash from combustion of coal and fuel oil, municipal waste incineration and use of welding rods.

Different pollutants in ambient air originate from different sources. Most sources of pollutants are associated with transport or industries and have different effects in different parts of the country. **Table 9.2** gives a brief summary of typical sources of some air pollutants in ambient air.

The areal distribution of three major pollutants (SO_2, NO_2 and PM_{10} is given in **table 9.3**. This table shows that Jharkhand had the maximum concentration of SO_2 (23 $\mu g/m^3$) followed by Maharashtra (17 $\mu g/m^3$). With respect to NO_2, West Bengal had the maximum annual concentration (64 $\mu g/m^3$) followed by Delhi (55 $\mu g/m^3$). With respect to PM_{10}, Delhi had the maximum annual average concentration (261 $\mu g/m^3$) followed by Jharkhand (193 $\mu g/m^3$).

Effects of Air Pollutants

Air pollutants have varied effects on human life, the most important being their effects on human health. Their other effects are on materials, and vegetation. A brief description of effects of various air pollutants on health is given as under :

1. Health Effects Associated with Air Pollutants

Air pollutants have serious adverse effect on human health. People living in urban and industrial areas are particularly prone to varied types of diseases due to air pollution.

I. *Health Effects of Sulphur Dioxide (SO_2).* Human beings chronically exposed to SO_2 have higher incidence of cough, shortness of breath, bronchitis, colds of long duration and fatigue. Most of the SO_2 in the atmosphere is converted to sulphate salts, which are removed by sedimentation or by washout alongwith precipitation thereby making rain water acidic due to sulphuric acid formation. The most common acute exposure to SO_2 at concentration > = 0.4 ppm (parts per million) is induction of asthmatics after exposure lasting only 5 minutes. Increased prevalence of cough in children with intermittent exposure to SO_2 levels of 1.0 ppm is observed.

II. *Health Effects of Nitrogen Dioxide (NO_2).* The oxides of nitrogen are toxic gases which enter the human body during breathing. High concentration of NO_2 may increase susceptibility to respiratory pathogens and also increases risk of acute respiratory diseases like bronchitis, chronic fibrosis, emphysema and bronchopneumonia. NO_2 exposure can cause decrement in lung functions. It has been established that continuous exposure with as little as 0.1 ppm NO_2 in air over a period of one to three years increases incidence of bronchitis, sedema, emphysema, oedema and adversely affects the performance of lungs. US study by Hasselblad *et al.*

(1992) indicate that repeated NO_2 exposure increases respiratory illness in children. The epidemiological studies suggest that an increase of 30 $\mu g/m^3$ in NO_2 levels results in about 20 per cent increase in

TABLE 9.3. Annual Average Concentration of Criteria Pollutants in States
(residential/industrial/rural/other and sensitive areas)

States & Union Territories	SO_2		NO_2		PM_{10}	
	Annual average ($\mu g/m^3$)	Standard deviation	Annual average ($\mu g/m^3$)	Standard deviation	Annual average ($\mu g/m^3$)	Standard deviation
Andhra Pradesh	5	2	17	4	73	24
Assam	7	1	15	2	76	51
Bihar	5	2	26	9	118	80*
Chandigarh	2	0	16	7	92	56
Chhattisgarh	11	1	22	2	107	14
Dadra & Nagar Haveli	7	0	18	1	39	27
Daman & Diu	7	0	18	1	35	21
Delhi	5	2	55	13	261	130*
Goa	14	15	18	10	68	36
Gujarat	15	3	23	3	89	15
Haryana	14	4	23	6	171	73*
Himachal Pradesh	3	1	15	4	88	39
Jammu & Kashmir	5	2	13	4	105	41
Jharkhand	23	3	39	4	193	67*
Karnataka	10	6	22	5	70	35
Kerala	4	1	13	3	42	16
Madhya Pradesh	11	6	17	6	137	57
Maharashtra	17	7	31	11	101	40
Meghalaya	2	1	10	4	101	15
Mizoram	2	0	6	1	42	10
Nagaland	2	0	6	2	68	42
Odisha	5	1	18	3	86	25
Punjab	11	2	27	5	187	37
Puducherry	6	2	13	3	38	12
Rajasthan	7	2	29	6	168	99*
Tamil Nadu	9	3	20	8	70	39
Uttar Pradesh	12	6	30	11	181	111*
Uttarakhand	—	—	—	—	169	36
West Bengal	10	4	64*	19	110	70

N.B. '—' inadequate data, *-exceeding NAAQS. Data of monitoring stations with monitoring days greater than or equal to 50 has been considered.

Source : National Ambient Air Quality Status and Trends in India 2010, Central Pollution Control Board, p. 24.

respiratory illness and diseases. Continuous exposure with more than 2.0 ppm NO_2 may cause extensive morphological alteration, lung dispensability and permanent changes in the lung (bronchiolitis).

III. ***Health Effects of Particulate Matter.*** The particles may influence the human body on setting and cause external effects *e.g.*, effects on skin. However, certain groups of particles pass into the blood stream on being inhaled and act as systematic poison. The effect of irritant particles in respiratory tract depends upon the size of the particles, their solubility, penetration deposition and clearance mechanism in human respiratory tract. Fine particles may cause irritation of broncospasm, pulmonary oedema and allergic alveolitis, while certain moulds of larger particle size cause obstructive lung disease. As the presence of finer particle size increases, the percentage of particles deposited in upper part of respiratory tract decreases, thus particles are inhaled deeper. The soluble nature of particles of chemical origin may cause systematic intoxication in the body. Increased particle presence in ambient air increases the frequency of cough and phlegm. The susceptibility of infection in pulmonary system increases in case the inhaled particles are active particles constituting bacterial, fungal spores or viral strains. The acute effect of particulate air pollution results in changes in respiratory health status and depict several respiratory symptoms. The symptoms are often recorded into upper respiratory symptoms such as stuffy or running nose, sinusitis, sore throat, wet cough, head cold, hay fever and burning or red eyes. The lower respiratory symptoms include wheezing, dry cough, phlegm, shortness of breath, chest discomfort and pain. The cough is the most frequently reported symptom due to continued exposure to high particulate laden ambient air.

Asthma and allergic alveolitis are two main respiratory diseases related to chronic exposure to particles. Studies reveal a direct relationship in asthmatic attack with exposure to particles. Particles containing fungi, viral or bacterial pathogens loading in ambient air may play their role in transmission of infectious diseases. Increased particulate exposure increases the incidence of bronchitis. The bronchitis or pneumonia induced by air pollution in the presence of pre-existing heart problems might precipitate congestive heart failure and cardiovascular mortality.

IV. ***Health Effects of Carbon Monoxide (CO).*** Carbon monoxide is absorbed from the lung tissue in blood stream. Toxic effects of CO are mainly due to its high affinity for Hb which is 240 times greater than oxygen affinity. The COHb in blood of exposed population may be between 3.0 and 5.3 per cent whereas the safe limit is less than 2 per cent.

High dose exposure of CO may affect lung tissue and may lead to acute decrement in lung functions. CO level to about 5 per cent may cause cardiovascular effect in young healthy, non-smoking individuals leading to fatigue and reduced ability to work. The recurrent episode of exertial angina increase risk of precipitating heart attack, fatal arrhythmia or myocardial damage, increased risk of sudden death with coronary artery disease. Increased concentration of carbon monoxide also leads to stroke, head injury, artherosclerosis, hypertension, etc. High CO concentration has special effect on children and infants. There are strong evidences of reduction in birth weight, cardio megaley, delay in behavioural development and disruption of cognitive function and sometimes even infant death syndrome. The other systematic influence of CO poisoning include effects on lever, kidney, bone, immune capacity and spleen.

V. ***Health Effects of Ozone.*** Variations in ozone levels in urban environment are the main cause of concern, both with regard to health risk associated with concentration exceeding the standard and possible health effect associated with human exposure to somewhat lower ozone concentration over long period of many days. High elevation of ozone causes major problem of human health which includes eye, nose and throat irritation, chest discomfort, cough and headache. Ozone is a respiratory irritant, reacts rapidly with tissues and airways lining of lungs. The acute reversible decrement in lung functions and increased respiratory symptoms occur in individual exposed for 1 to 3 hours with ozone concentration ranging between 235 to 314 $\mu g/m^3$. Acute exposure to ozone may cause lung inflammation within a few hours. Long term ozone exposure has been associated with inflammation of lungs which may be involed in progression from chronic health effects. Ozone also increases susceptibility to pulmonary bacterial infections and it can exacerbate its severity of influenza infection. Acute exposure to low ozone

levels decreases activity pattern, may affect immune system leading to potential health risk.

VI. ***Health Effects of Benzene.*** Benzene is a hazardous air pollutant which accelerates carcinogenicity and human health risk from ambient air. Various studies have provided evidence regarding effect of benzene linked to genetic change, chromosomal aberration, etc. International Agency for Research on Cancer (IARC) has classified benzene as carcinogenic to humans which increases the frequency of cancer in human beings. Exposure to excessively high level of benzene may cause cancer in kidney, testes, brain, pancreas, stomach, lung, respiratory tract, bladder and uterus. Benzene acts as Leukaemogen in human beings, acting as etiologic agent of aplastic anaemia leading to acute myclogenous leukaemia. World Health Organisation (WHO) estimate a four in one million risk of leukaemia on exposure to benzene to a concentration of 1 mg/m^3. Benzene has also been recognised as causing DNA damage in mammalian cells. Prolonged exposure to even mild form of benzene may cause euphoria followed by giddiness, irregular heart beat, headache, dizziness, nausea and unconsciousness. Breathlessness, nervous irritability and unsteadiness in walking may persist for a long time. Acute benzene poisoning includes extensive petechial haemorrhage in the brain pleurae, pericardium, urinary tract, mucous membrane and skin. Pneumonitis and bronchitis can also be caused by direct action of benzene. The other effects of benzene are disorders of blood, harmful effect on bone marrow, anaemia and reduced ability of blood to clot, damage to immune system and reproductive and development toxicant.

It has been found that women are more susceptible than men to benzene. Benzene exposure may cause menstrual disorder and retard foetal development.

VII. ***Health Effects of Volatile Organic Compounds (VOC).*** The volatile compounds have potential carcinogenic effects on human beings and are termed as air toxins. These compounds react with oxides of nitrogen in the presence of sun light and give rise to photochemical smog. This smog is a dense haze which restricts visibility. Hazy fumes cause irritation to eyes and lungs and damage plant life.

VIII. ***Health Effects of Lead.*** Lead particles from the ambient air can be inhaled, can settle down as dust in neighbouring area, on vegetation and water bodies and may be partly ingested. Out of the total estimated release of lead from the vehicular emission, about 50-70% is released as emission into the environment and the remaining part gets deposited. *Lead is pervasive environmental poison which affects virtually every system in the body.* It can damage the kidneys, the nervous system, the reproductive system and cause high blood pressure.

Children are more prone to lead pollution because they absorb lead more readily than adults. It affects the development of brain of foetuses and young children. Children exposed to lead show lack of intelligence, behavioural problems and decreased ability to concentrate. Blood lead levels as low as 10 μg/decilitre are associated with harmful effects on the learning process of the children. Elevated blood lead level can be more harmful. At extremely high level (70 μg/decilitre or higher), seizure, coma and even death can occur.

Lead is specially harmful to pregnant women and infants. Lead can get accumulated and stored in bones for decades and can be released whenever there is demand for calcium such as during pregnancy and lactation. During lactation, lead crosses placenta and is detected in breast milk. This is the major source of lead to infants which causes neurological problems in the developing child.

Not to speak of women, infants and childrens, even adult males are not spared by lead pollution in the air. Chronic exposure with elevated blood lead levels are associated with hypertension, headache, confusion, irritability and insomnia. Further higher level cause drowsiness, loss of muscular coordination, kidney damage, fatigue, apathy and susceptibility to infection and anaemia. Higher blood lead level (80 μg/decilitre or more) also leads to gastro-intestinal problems and liver damage.

2. Effects of Air Pollutants on Materials

Air pollutants produce physical and chemical change in materials which results in their damage and destruction. The natural effects of corrosion and weathering are aggravated when the air is polluted. The most destructive air pollutants to materials are

TABLE 9.4. Air Pollutants and their Effects on Materials

Sl. No.	Air Pollutants	Effects
1.	Particulate Matter (PM)	— Physical erosion with abrasive action. — Particulate deposits cause streaky appearance. — Corrosion of metallic substances. — Deposition on electric contacts interfere with function, accelerate corrosion. — Soiling to textile, reduced wear life and abrasive effect.
2.	Sulphur dioxide (SO_2) and sulphur trioxide (SO_3)	— Flaking of surfaces due to formation of sulphuric acid from SO_x. — Acceleration of corrosion of steel and other metals. — Embrittlement of paper and leather. — Reduced strength of fibres in textiles.
3.	Oxides of nitrogen (NO_x)	— Corrosion effect on surface and metals. — Fabric discoloration and fading.

Source : Air Quality Status and Trends in India (2000), Central Pollution Control Board, p. 44.

smoke, grit, dust and oxides of sulphur. Sulphur dioxide is the most dangerous air pollutant. It changes to sulfurous and sulphuric acid with moisture and accelerates the rate of corrosion. Amount of moisture in the air determines the rate of corrosion—more the moisture, more the corrosion.

Different types of metals and metallic structures such as iron and steel, aluminium and aluminium alloys, copper and copper alloys are corroded when exposed to polluted air. Building materials are also corroded and disfigured with increasing pollution of air. Smoke, grit and soot deposits disfigure the buildings. During high winds, larger particulates can result in surface erosion. The oxides of sulphur react with limestone to form calcium sulphate. Slow loss of substances from surface occurs during rains which leads to blistering. Effects of various air pollutants on materials are shown in **Table 9.4**.

3. Effect of Air Pollution on Vegetation

In addition to its effects on health and materials, air pollution has damaging effect on vegetation also. The effects of air pollutants on vegetation depends upon their chemical nature, level of concentration and duration of exposure.

The principal air pollutants of prime concern to agriculture and vegetation are sulphur dioxide, SPM and photochemical oxidants. The air pollutants effects on vegetation are demonstrated by plants through following characteristics :

- Qualitative and quantitative changes in solar radiations input on leaf surface and alteration in energy exchange process.
- Decrease in chlorophyll and chloroplast injury.
- Increase in gaseous exchange process.
- Dust induced alteration in physico-chemical parameters.

Table 9.5 shows the impact of major air pollutants *viz.* sulphur dioxide, ozone and suspended particulate matter on vegetation.

Ambient Air Quality Standards. In order to arrest the deterioration in air quality and to provide for prevention and control of air pollution, the Government of India enacted the Air (Prevention and Control of Pollution) Act in 1981. The responsibility has been further emphasised under Environment (Protection) Act, 1986. It is necessary to assess the present and anticipated air pollution through continuous air quality survey/monitoring programmes. The Central Pollution Control Board had formulated and notified the National Ambient Air Quality Standards (NAAQS) for industrial, residential and sensitive areas. The notified ambient air quality standards are presented in **Table 9.6**.

TABLE 9.5. Effects of Air Pollutants on Vegetation

Sl. No.	Air Pollutants	Effects on Vegetation
1.	Sulphur dioxide	— Enters into leaf through stomata. — Excessive exposure causes injury on blade with ivory colour, brown to reddish brown spots, depending on plant and environmental conditions.
2.	Ozone	— High concentration causes dark brown to black lesions on upper surface of leaves.
3.	Suspended Particulate Matter	— Block the stomata through deposition on leaf surface. — Excessive dust deposition retards the growth of plant. — Automobile exhaust smoke damage lower surface of leaves, bronzing and silvering, upper surface shows fleck like marking.

Source : Air Quality Status and Trends in India (2000), Central Pollution Control Board, p. 47.

TABLE 9.6. National Ambient Air Quality Standards (NAAQS)

Pollutant	Averaging time	Indian air quality standards[1]			WHO[2] recommen-dations
		Sensitive areas	Residential, rural and other areas	Industrial areas	
Sulphur dioxide (μg/cum)	10 minutes	—	—	—	500
	1 hour	—	—	—	350
	24 hours (2)	30	80	120	100–150
	Annual (1)	15	60	80	40–60
Nitrogen oxides (μg/cum)	1 hour	—	—	—	400
	24 hours (2)	30	80	120	150
	Annual (1)	15	60	80	—
Ozone (μg/cum)	1 hour	—	—	—	150–200
	8 hours (2)	—	—	—	100–120
Suspended particulate matter (μg/cum)	24 hours (2)	100	200	500	150–230
	Annual (1)	70	140	360	60–90
Respirable particulate matter (μg/cum) (Particulate less than 10 microns)	24 hours (2)	75	100	150	70
	Annual (1)	50	60	120	—
Lead (μg/cum)	24 hours (2)	0.75	1.00	1.5	—
	Annual (1)	0.50	0.75	1.0	—
Carbon monoxide (mg/cum)	1 hour	2.0	4.0	10.0	30
	8 hours (2)	1.0	2.0	5.0	10

Note : μg/cum : Microgramme per cubic meter, mg/cum : milligramme per cubic meter WHO: World Health Organisation.

1. Annual arithmetic mean of minimum 104 measurements in a year taken twice a week 24 hourly, at uniform interval.
2. 24 hourly/8 hourly values should meet 98 per cent of the time in a year. However, 2 per cent of the time it may exceed, but not on two consecutive days.

Source : The Citizen's Fifth Report (2002), Centre for Science and Environment, p. 170.

As mentioned above, the Central Pollution Control Board (CPCB) is responsible for setting air quality standards. However, though World Health Organization (WHO) has applied guidelines for 1 hour, 8 hour and 24 hour averages, in India only annual mean and 24 hour average standards have been presented, except for carbon dioxide (CO) for which 8 hour and 1 hour standards have been notified.

Separate standards have been notified for industrial, residential and sensitive areas. This has drawn a lot of flak as this classification does not explain how the standards can satisfy the primary objective of protecting public health. It allows more lax limits for industrial areas. This issue had emerged at the World Bank-sponsored workshop on integrated approaches to vehicular pollution control in Delhi in April, 1998.

As a result of this classification, separate standards operate in Indian cities whereas WHO guidelines are common for all land-use areas. The national standards for annual sulphur dioxide emissions and SPM 10 levels in industrial areas is 1.6 times and 2.1 times higher than WHO norms. National annual suspended particulate matter standards for residential areas is 2.3 times higher than the 60 microgrammes per cubic metre (μg/cum) norm set by WHO (*See Table 9.5*). Significantly, Indian NO_X standards are stricter than WHO norms. While WHO allows 150 μg/cum over 24 hours, Indian residential standards are 80 μg/cum over 24 hours.

Air quality standards need to be made stricter if a lower level of pollutant affects health more than previously thought. However in India, the standards were revised only once in 1994 to create a new category called respirable suspended particulate matter (RSPM) to account for small particulate emissions.

Medical experts say that as standards are set for individual pollutants, they fail to show the combined effect. "All pollutants together can have an aggregate effect on health that is much greater than the individual effect. This needs to be kept in mind while setting air pollution standards."

National Air Monitoring Programme (NAMP)

Central Pollution Control Board initiated National Ambient Air Quality Monitoring (NAAQM) programme in the year 1984 with seven stations. Subsequently, the programme was renamed as National Air Monitoring Programme (NAMP). The number of monitoring stations under NAMP increased steeply from 28 in 1985 to 290 in 1992 and their number remained at the same level until 1999. Thereafter the number of monitoring stations increased and stood at 456 in 2010-11 covering 190 cities/towns in 26 states and 5 union territories as on 31st March, 2011.

SOME RECENT FINDINGS REGARDING AIR POLLUTION

The International Agency for Research on Cancer (ARC) announced, for the first time, that air pollution causes lung cancer. It also said that poisoned air's major component, particulate matter—smoke, dust and other dirty byproducts of road traffic, factories and construction—must now be classified a carcinogen, a cancer causing substance, alongside tobacco, asbestos and ultraviolet radiation.

- According to World Bank Report (2013), air pollution costs India about $ 30 billion or 3% of GDP.
- Of 400 locations monitored by the Central Pollution Control Board, 99% reported unsafe levels of PM 10 according to a 2013 analysis of national air quality data by Centre of Science and Environment. Ninety cities and towns reported critical air pollution levels and 23 are most critical which means they exceed safety limits by 300% or even more.
- In a World Bank report released in July, 2013 India ranked 126 out of 132 countries graded for environmental performance, behind China, Pakistan and Bangladesh. For effects of air pollution on its citizens, India ranked last *i.e.* 12 of 132.
- Every year, outdoor air pollution claims 109,000 lives of adults, and 7,513 lives of children below five years in India.
- Annually, over 37 lakh hospital admissions are reported due to outdoor air pollution in urban areas.

The number of critically polluted cities has increased from 49 in 2000 to 89 in 2013.

Objectives

The objectives of the NAMP are as follows :

- To determine status and trends of ambient air quality.
- To ascertain whether the prescribed ambient air quality standards are violated, and to assess health hazard and damage to materials.
- To continue ongoing process of producing periodic evaluation of air pollution situation in urban and industrial areas of the country.
- To identify non-attainment cities.
- To obtain the knowledge and understanding necessary for developing preventive and corrective measures.
- To understand the natural cleansing process undergoing in the environment through dilution, dispersion, wind based movement, dry deposition, precipitation and chemical transformation of pollutants generated.

According to Central Pollution Control Board Report 2012, India has ten most polluted cities where the average annual particulate matter is very high. Particulate matter is expressed in terms of $\mu g/m^3$ (micrograms per cubic metre of air). These cities are Delhi (261 $\mu g/m^3$). Amritsar (219 $\mu g/m^3$), Ludhiana (214 $\mu g/m^3$), Lucknow (204 $\mu g/m^3$), Nashik (113 $\mu g/m^3$), Kolkata (100 $\mu g/m^3$) Mumbai (97 $\mu g/m^3$), Hyderabad (79 $\mu g/m^3$), Bengaluru (60 $\mu g/m^3$) and Chennai (50 $\mu g/m^3$). Global Burden of Disease records deaths and illness from all causes every 10 years and in its report of 2013, it has been mentioned that outdoor air pollution caused 6.2 lakh deaths in 2010, which is a six fold jump from the one lakh deaths in 2000. This makes polluted out door air the fifth largest killer in India after high blood pressure, indoor air pollution, tobacco use and poor nutrition.

The Central Pollution Control Board 2012 Report also says that one in three people in India live in critically-polluted areas that have noxious levels of nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and lung-clogging particulate matter larger than 10 microns (PM10) in size. Of the 180 cities monitored by the board in 2012, only two—Malapuram and Pathanamthitta in Kerala—meet the criteria of low air pollution (50% below the standard of 60 $\mu g/m^3$).

Vehicular Pollution

Vehicular pollution has grown at an alarming rate due to growing urbanisation in India. The air pollution from vehicles in urban areas, particularly in big cities, has become a serious problem. The pollution from vehicles has begun to tell through symptoms like cough, headache, nausea, irritation of eyes, various bronchial and visibility problems.

The main pollutants emitted from the automobiles are hydrocarbons, lead/benzene, carbon monoxide, sulphur dioxide, nitrogen dioxide and particulate matter. The main cause of vehicular pollution is the rapidly growing number of vehicles. The other factors of vehicular pollution in the urban areas are 2-stroke engines, poor fuel quality, old vehicles, inadequate maintenance, congested traffic, poor road condition and old automotive technologies and traffic management system. In India, the number of vehicles increased from 0.3 million in 1951 to 58.3 million in 2001-02. About half the vehicles are concentrated in 39 metropolitan cities (cities with population of over one million). The two wheelers are the major contributors of vehicular air pollution followed by four-wheelers (*e.g.*, car, jeep, taxi etc.), trucks and buses in decreasing order of magnitude.

Delhi is a typical example of air pollution by vehicles. Delhi's vehicular population increased from an insignificant of 2.17 lakh in 1971 to 82 lakh in 2014. Over 1,400 vehicles are registered each day in Delhi. Delhi has more vehicles than Mumbai, Kolkata and Chennai put together. Unfortunately, number of vehicles in Delhi outpaces the road length.

Share of vehicular pollution in Delhi has increased from 23% in 1970-71 to 71% in 2013-14. In contrast share of industrial pollution decreased from 56% in 1970-71 to less than 20% in 2013-14.

Much of the vehicular air pollution can be avoided by maintaining proper speed of the vehicles. Vehicles standing on the road crossing or in traffic jams cause more pollution. The quantity of harmful emissions decreases with increasing speed (*See* **Table 9.7**).

TABLE 9.7. Emissions from Vehicles at Varied Speeds (gm/km)

Speed (km/hour)	Auto		Bus	
	Carbon monoxide	Hydrocarbons	Carbon monoxide	Hydrocarbons
10	33.02	4.47	22.6	5.7
25	21.20	2.60	14.6	2.3
50	9.80	1.30	8.2	0.0

Source : Centre for Science and Environment.

Delhi is a major point of intersection in north India, for both passenger and freight traffic. Delhi is connected to five national highways directly (NH 1—GT Karnal road, NH 2—Mathura road, NH 8—Gurgaon road, NH 10—Rohtak road, NH—24 Hapur road) and indirectly to two (NH 24 carries load of NH 58 and NH 91). Moreover, the city has 86 entry points out of which 17 are key points for commercial traffic. In order to divert the interstate traffic the 'Peripheral Expressway' has been proposed for the city. In fact two expressways are proposed to be constructed. The Eastern Expressway has two corridors—the Faridabad-NOIDA. Ghaziabad route (56 km) and the Ghaziabad-Kundli route (49 km). The western Expressway (88 km) will connect Faridabad with Kundli. A survey conducted at the Rana Pratap Inter State Bus Terminal at Kashmiri Gate in Delhi has revealed that 65 per cent buses from Uttar Pradesh, 50 per cent from Haryana and 25 per cent from Punjab emit more pollutants than the permitted limit. A World Bank study in Delhi showed that diesel vehicles were responsible for as much as 62.5 per cent of the total particulate load coming from all vehicles. Even after the implementation of the CNG programme, a recent World Bank study of 2004 confirms, based on actual measurements and characterisation of PM2.5 (a tiny fraction of the particulate), that diesel fuel's contribution could still rise as high as 23 per cent. Besides, air traffic also adds to the air pollution. More than 950 tonnes of pollutants are released by air traffic every day. With the increase in Air Traffic this pollution is bound to increase in future. Even smog (mixture of smoke and fog) is becoming a real threat to Delhi's air environment.

DELHI IS THE MOST POLLUTED CITY OF THE WORLD

According to a study released by the World Health Organisation (WHO) on May 7, 2014, Delhi, the capital city of India, has earned the dubious tag of being the world's most polluted city. The study described India's air pollution as the worst in the world. Delhi has surpassed Beijing with respect to air pollution. Beijing was treated as the world's most polluted city before the release of this study. Delhi is being followed by Beijing (China), Cairo (Egypt), Santiago (Chile) and Mexico City (Mexico). This study was based on data collected from 1,600 cities in 90 countries. Delhi's vehicle population has been estimated at 82 lakh in 2014 and the benefits of CNG introduced in 2000 have been lost. Thirteen out of dirtiest 20 cities were in India. After Delhi, Patna, Gwalior, and Raipur are in the top four spots.

In Mumbai about 52 per cent of the total pollution load is contributed by vehicles. Vehicles contribute about 54 per cent of SPM and 52 per cent of nitrogen dioxide in Mumbai. About 30 per cent of the total pollution load in Kolkata comes from vehicles. Among the metropolitan cities of India. Chennai seems to have clearer air. However, experts warn that SPM in many locations in Chennai is the cause of concern. According to latest studies, high SPM levels in some of the residential and other non-industrial localities is largely due to emissions by vehicles. Studies in Hyderabad show that between 1993-2013, the pollution level in the city had gone up by 270 tonnes per day largely because of increase in the number of vehicles. According to Andhra Pradesh State Pollution Control Board vehicles contribute more than 1600 tonnes of pollutants every day. About 68% of the pollutants are emitted by two-wheelers. The sad story of air pollution by vehicles is almost the same in most of the big cities of India.

Even in small towns such as Parwanoo in Himachal Pradesh, Agartala in Tripura, Dehra Dun in Uttarakhand, Alwar in Rajasthan and Puducherry, air is polluted mainly by vehicles and partly by industries and mining. Experts say that traditional non-motorized transport is fast giving way to polluting two and three wheelers. Jammu had only 24,000 vehicles just a decade ago. Today Jammu has 2 lakh vehicles out of which 80 per cent are two wheelers. In Guwahati and Jorhat there is unprecedented increase in air pollution due to rapid increase in the number of vehicles.

Industrial Pollution

There has been phenomenal growth of industries in India, particularly after independence. Industries emit all sorts of pollutants in the air and result in air pollution to great extent. The major industrial air pollutants are suspended particulates, carbon monoxide, sulphur dioxide, nitrogen oxides and many more.

In Delhi, besides big units there are 70,000 uncontrolled small scale industries, discharging into atmosphere gases, liquids and solid wastes producing health hazards. A recent study conducted by Central

Pollution Control Board has revealed that Najafgarh Road, Lawrence Road, Wazirpur, Kirti Nagar, DLF industrial area and Moti Nagar are the most polluted areas which suffer at the hands of polluting industries. In Mumbai, belt between Chembur and Trombay is highly industrialised and has 3 to 6 times more pollution than the remaining parts of the city. Tarapur Atomic Power Plant continues to spew out dangerous radiation doses. Kolkata's industrial units have led to precarious situation with regard air pollution. According to a report submitted by National Environmental Engineering Research Institute (NEERI), Nagpur, the total daily emission from all sources amounts 1,305 tonnes in Kolkata Metropolitan District wherein 900 tonnes of pollutants are produced in the industrial belt of Kolkata and the rest in Haora industrial belt. The major pollutants are suspended particulates (560 tonnes), carbon monoxide (450 tonnes), sulphur dioxide (125 tonnes), hydrocarbons (102 tonnes) and nitrogen oxides (70 tonnes). Surat is another example of air pollution. This industrial city has a very high average of suspended particulate matter (SPM) amounting to about 267 microgram per cubic metre of air per day. The discharges of sulphur dioxide, nitrogen oxide and hydrogen sulphide are 20.4, 24.6 and 0.5 microgram per cubic metre of the air respectively. Ahmedabad has a large number of textile mills as well as other industries which are contributing to air pollution.

The Bhopal Gas Tragedy

Air pollution is also caused by sudden gas leakage in industries. The Bhopal Gas Tragedy, which occurred on the night of December 2-3, 1984 from the Union Carbide Factory, is a living example of one of the deadliest disasters caused by human negligence. This is considered to be the biggest tragedy so far in the industrial history of the world. According to official sources, 2,500 human lives were lost due to leakage of deadly Methyl Iso-Cynate (MIC) gas but the non-governmental sources put the death toll at 5,000 persons. More than 3,000 persons fell seriously ill. About 200 women delivered dead babies and about 400 babies died within a few hours of their birth. Those who could survive, developed blue spots in their levers, suffered from coughs and asthma and most of them lost their eye sight. About 47 per cent of the pregnant women suffered from instantaneous abortion, whereas some pregnant women opted for voluntary abortion. According to official figures, 10,000 people have been rendered permanently disabled and another 30,000 partially handicapped. About 1.5 lakh persons have suffered minor disability. It is, therefore, righty said that *whereas industries, bring us economic prosperity, they cause ill health and death also*.

Thermal Power Plants

Thermal power plants comprise the second most dangerous source of air pollution, next only to vehicles. Most of the thermal power plants used large quantities of coal which produce huge amount of smoke, ash and other pollutants. The impact of thermal power plants on environment is of growing concern given the anticipated growth of this sector. The coal used in thermal power plants in India is rarely of good quality. The ash content of the inferior grade coal is 38 per cent and in future may rise to 42 per cent. As a result, emissions of SPM, SO_2 and fly ash are of very high order. It has been reported that more than half of the thermal power plants in the country are not complying with the standards and are spewing out as much as 40 million tonnes of flyash every year.

Supply of the beneficated coal—coal washed to lower ash content—has emerged as a serious policy issue in the last decade. Pollution control equipment can also function more efficiently if ash load is reduced by using washed coal.

Critically Polluted Areas

Industrial pollution has left several critically polluted areas in India. As many as 24 critically polluted areas have been identified. The critically polluted areas and the industries responsible for their pollution are detailed in **Table 9.8**.

The areal distribution of critically polluted areas is given in **Fig. 9.4**.

Reasons for High Air Pollution in India. Following are the main reasons for high air are pollution in India :

(i) Poor Quality of Fuel. Fuel used for industries and transport is by and large of poor quality.

Although various measures have been taken to improve the quality of fuel during the last few years, poor quality of coal and fuel oil is a matter of great concern.

(ii) Uncontrolled Growth of Vehicle Population. There had been uncontrolled growth of vehicle population in almost all the big and small cities of India. This has resulted in high level of air pollution.

(iii) Poor Vehicle Design. Poor vehicle design especially 2-stroke two wheelers results in high emission of air pollutants.

(iv) Haphazard Growth of Industries. The haphazard growth of industries, particularly after independence, has lead to large real air pollution in India.

(v) Wrong Siting of Industries. Wrong siting of industries especially close to residential areas results in people getting affected due to air pollution.

(vi) Old Process Technology. Old process technology is employed in many industries especially in small scale industries resulting in high emission of air pollutants.

TABLE 9.8. Critically Polluted Areas

Sl. No.	Problem Area	Type of Industry
1.	Singrauli	Power Plants, Mining, Aluminium Industry.
2.	Korba	Power Plants, Aluminium Industry, Mining.
3.	Vapi	Chemical Industries.
4.	Ankaleshwar	Chemical Industries.
5.	Greater Kochi	Oil Refineries, Chemical, Metallurgical Industries.
6.	Vishakhapatnam	Oil Refinery, Chemical, Steel Plants.
7.	Haora	Foundry, Rerolling Mills.
8.	Durgapur	Chemical Industries, Power Plants, Steel Plants.
9.	Manali (Tamil Nadu)	Oil Refineries, Chemical Industry, Fertilizer Industry.
10.	Chembur	Refineries, Power Plant, Fertilizer Industry.
11.	Mandi Gobindgarh	Secondary Steel Industry.
12.	Dhanbad	Mining, Coke Oven.
13.	Pali	Cotton Textile, Dyeing.
14.	Nagafgarh Drain Basin	Power Plants, Vehicles.
15.	Angul-Talcher	Mining, Aluminium Plants, Thermal Power Plants.
16.	Bhadravati	Iron & Steel, Paper Industry.
17.	Digboi	Oil Refinery.
18.	Jodhpur	Cotton Textile, Dye.
19.	Kala-Amb	Paper, Electroplating.
20.	Nagda-Ratlam	Viscose Rayon, Caustic, Dyes, Distillery.
21.	North Arcot	Tanneries.
22.	Parwanoo	Food Processing Unit, Electroplating.
23.	Patancheru-Bollaram	Organic Chemical, Paints, Petrochemical Industry.
24.	Tarapur	Chemical Industry.

Source : National Ambient Air Quality Status (June, 2004), Central Pollution Control Board, Delhi, pp. 2 and 3.

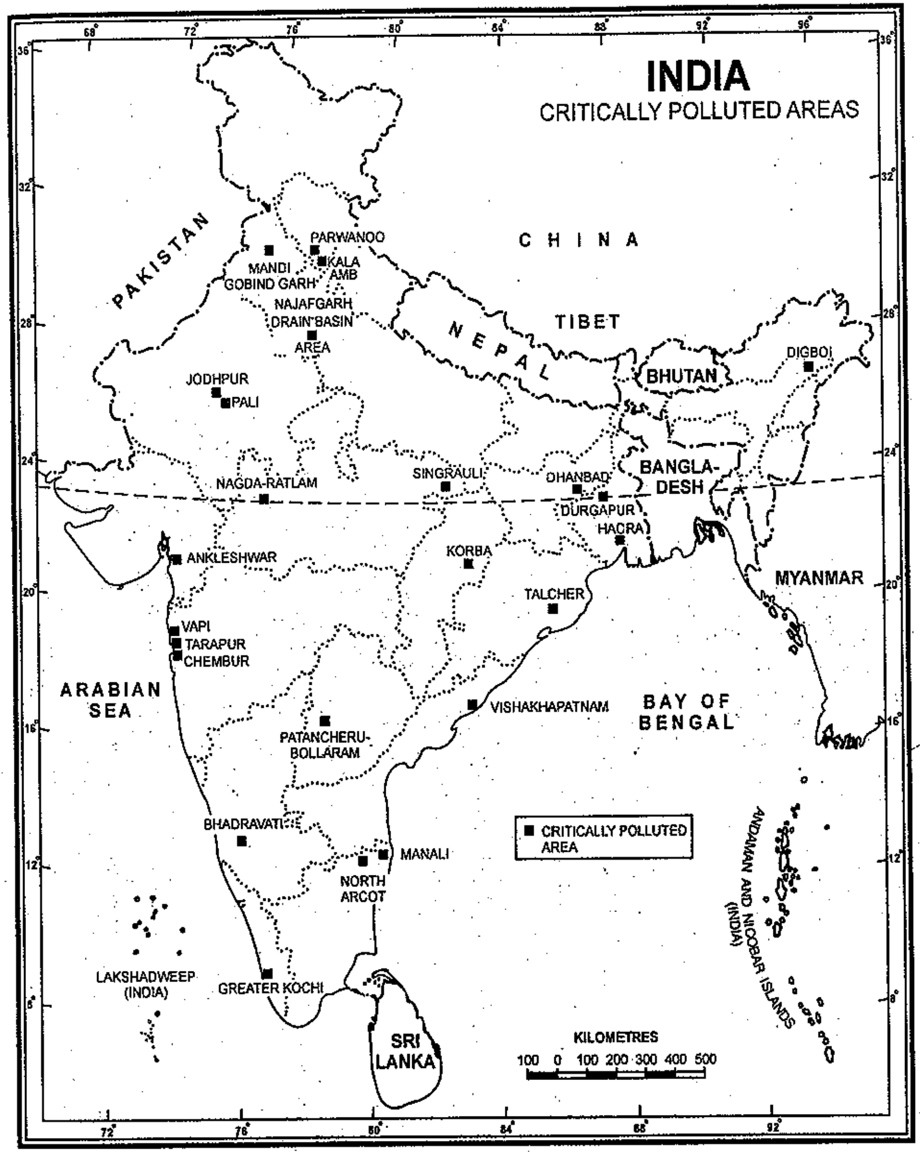

FIG. 9.4. India : Critically Polluted Areas

(vii) No Pollution Control Step in Early Stage of Industrialization. No pollution control steps were taken in early stages of industrialization which has resulted in high levels of air pollutants in many areas.

(viii) No Pollution Prevention and Control System in Small/Medium Scale Industry. Lack of pollution prevention and control system in small/medium scale industry results in high levels of air pollution.

(*ix*) ***Poor Compliance of Standards in Small/Medium Scale Industries.*** Poor compliance of standard in small/medium scale industries also results in high levels of air pollution.

Other Causes of Air Pollution

Large amount of garbage, lack of sanitary facilities and sewer wastage are also responsible for air pollution. Cigarette, *biri*, cigar, and *hooka* smoking have become a great pollutant of air both in urban as well as rural areas. The worst affected are the closed areas such as cinema houses, buses and railway compartments, etc. Smoking leads to some of the serious ailments like heart disease and cancer. The smoker not only spoils his own health but affects adversely the health of the silent smoker who is sitting by his side. A total ban on smoking will go a long way in reducing the pollution levels of air.

Large scale use of pesticides and insecticides, in the agricultural field during the last five decades, has resulted in air pollution in rural India. The life style of the Indian rural masses is closely related to air pollution. Most people in rural India burn wood, cowdung cakes, coal and kerosene oil to cook food. The kitchens are generally housed in unventilated rooms, where unscientific or conventional *chulhas* (ovens) are used. The fuels used in these kitchens emit large quantities of smoke, consisting of carbon monoxide, carbon dioxide, sulphur, etc. thereby polluting the air to a great extent. On an average, about 100 million tonnes of fire wood is burnt in India annually which produces about 3.14 million tonnes of particulate matter, 2.35 million tonnes of hydrocarbons, 1.96 million tonnes of sulphur dioxide, 0.16 million tonnes of carbon monoxide and 0.39 million tonnes of nitric oxides. The world's worst air pollution problem could be the wood smoke inhaled by poor Indian women, especially in rural areas, while cooking. A tonne of particulate from household wood stoves may actually lead to more than 500 times the human exposure than a tonne of particulate from coal fired power station. About 55 million tonnes of cowdung cakes are burnt in India emitting 7.2 lakh tonnes of particulate matter, 5.4 lakh tonnes of hydrocarbons, 4.5 lakh tonnes of sulphur dioxide, 90 thousand tonnes of nitric oxides and 38 thousand tonnes of carbon monoxide.

INITIATIVES FOR CONTROL OF AIR POLLUTION

Various measures have been taken to control air pollution from vehicles and industries. These measures are described as under :

Measures taken for Control of Air Pollution from Vehicles

1. Vehicular Emission Norms

The vehicular emission norms in India are detailed below :

Strict emission norms, particularly in metropolitan areas like Delhi, Mumbai, Kolkata, Chennai, etc., have been introduced and enforced from time to time so that air pollution level is controlled to the tolerable limits. Different phases of Euro and Bharat are worth mentioning in this context. However, rapidly increasing number of vehicles in our cities and towns has more or less multiplied the impact of vehicular emission norms with respect to air pollution.

Barely 20 Indian cities follow Euro IV emission standards for new vehicles, most follow Euro III. Euro IV is seven years behind. European standards and Euro III is behind by 12 years, as per report by Centre for Science and Environment (CSE), Delhi.

2. Fuel Quality Specifications

Diesel and Gasoline fuel quality with respect to environment related parameters had been notified under Environment (Protection) Act during April 1996. The specifications include low leaded gasoline, unleaded gasoline and low sulphur diesel.

(*i*) **Unleaded Gasoline.** With the progressive reduction of lead content in petrol (from 0.56 gm/l to 0.15 gm/l and then to 0.013 g/l in unleaded petrol) introduction of unleaded petrol for new passenger cars from April, 1995 and supply of only unleaded petrol for all vehicles from September, 1998, in NCT—Delhi a lethal pollutant from vehicular exhaust has been removed. The lead content in the atmosphere near traffic intersections of Delhi has reduced by more than 60% with the introduction of unleaded petrol.

(*ii*) **Benzene Reduction.** The fear of increased emission of benzene and reduced performance of engines by the use of unleaded petrol has also been falsified. The oil refineries were told to combine the benzene content in the unleaded petrol upto 5% (v/v) in 1996 and 3% (v/v) from the year 2000. In addition to phasing out of lead, it is considered necessary to reduce the benzene (to 1% or lower) and aromatics in petrol not only for Delhi but also for other parts of the country.

(*iii*) **Sulphur in Diesel.** Sulphur content in diesel supplied in Delhi was reduced to 0.5% in 1996 and it was further reduced to 0.25% from April 1996 onward. The diesel with 0.25% sulphur has been made available throughout the country by September, 1999. Considering the fact that several countries have introduced diesel with much lower sulphur content it is necessary to have low sulphur diesel for meeting the emission norms.

3. Quality Lubricants

Specifications of 2T oil for two stroke engines with respect to smoke emission has been notified under EPA during September 1998 for implementation from 1.4.1999 throughout the country. Pre-mix 2T oil dispenser has been installed at all petrol filling stations in big cities so that excessive oil is not being used by the vehicle owners. Sale of loose 2T oil has been banned from December 1998 in Delhi.

4. Alternate Fuels

A very important factor in reducing vehicular pollution is the introduction of alternative fuels such as CNG and LPG.

(*i*) Bio-fuels mainly Ethanol and Biodiesel (in B20 form) from Jatropa feedstock are the prospective options.

(*ii*) ***CNG (Compressed Natural Gas).*** CNG is a better and clean fuel providing limited emissions of various toxic gases. All Government vehicles were required to compulsorily fit CNG kit or catalytic converter by December 1996. New CNG taxies are being registered in Delhi as well as there is no restriction or registration of CNG vehicles in National Capital Territory (NCT) as they already comply EURO-II norms. CNG kits has been exempted from customs duty for promotion of installation of CNG kits in vehicles. Emission norms for CNG vehicles have been notified under Motor Vehicles Rules dated 24.4.2001. Besides Delhi and Mumbai the supply of CNG has been extended to the cities of Ankleshwar, Vadodara, and Surat in Gujarat and Kanpur, Bareilly, Agra and Lucknow in Uttar Pradesh. The total CNG vehicles in the country touched 3.54 lakhs in 2012.

(*iii*) ***LPG.*** The use of LPG as an alternate fuel in automobiles has been made applicable for which amendment has been made in Motor Vehicles Act to legally permit the use of LPG as automobile fuel Hon'ble Supreme Court permitted dual mode facility (CNG + Petrol) for the vehicles in its order dated 10th May 2000. Emission norms for LPG vehicles were modified on 24.4.2001. In Kolkata, three wheelers have been ordered to switch over to LPG mode from September, 2005.

(*iv*) ***Battery driven vehicles :*** Battery driven vehicles have been introduced in few corridors in Delhi and in some other big cities.

5. Phase out of Grossly Polluting Vehicles

(*i*) Registration of new auto rickshaws with conventional engine has been banned from May 1996 and registration of Defence Service and Govt. auctioned vehicles has been banned from April 1998 in Delhi.

(*ii*) Commercial vehicles more than 10 years old have been prohibited from plying in Delhi and other major cities of the country.

(*iii*) Registration on alternation of vehicles by replacing petrol engine with diesel has been banned from 1.4.1998 in Delhi.

6. Promotion of Comprehensive inspection and Certification

It has been possible to reduce 30-40% pollution loads generated by vehicles through proper periodical inspection and maintenance of vehicles. Such inspection and maintenance of vehicles is being carried on by State Pollution Control Boards, Pollution Control Committees and Transport Directorates in different parts of the country.

7. Traffic Management

(*i*) Restriction has been imposed on goods vehicles during day time in several big cities.

(*ii*) Time clocks have been installed in important red lights to enable the drivers to switch off their vehicles depending on the time left in the time clocks.

(*iii*) More fly-overs and subways have been constructed and T-Junctions have been closed for better traffic flow.

(*iv*) Almost all big cities are plagued with traffic jams on important roads. Standing vehicles cause much air pollution. Steps should be taken to avoid traffic jams as far as possible.

8. Public Transport System

(*i*) To discourage the use of individual motor vehicles by people, public transport system is augmented from time to time in various urban areas of the country. The number of buses has been increased in big cities like Delhi.

(*ii*) Private sector has been allowed to operate public transport buses to increase mobility.

(*iii*) Mass Rapid Transport System (MRTS) has been launched. Metro Rail Transport System is making rapid progress in a large number of cities and is likely to reduce pressure on transport system of these cities.

9. Technology

(*i*) Fitment of catalytic converter for new petrol passenger cars has been made compulsory.

(*ii*) Two wheeler scooters with four stroke engines have been introduced in the market from October 1998.

(*iii*) Registration of only rear engine auto rickshaws is being allowed from May 1996 onwards.

(*iv*) Only four stroke two wheelers are being registered.

10. Information Dissemination/Mass Awareness

(*i*) Messages/articles related to vehicular emissions are disseminated through newsletters, pamphlets, newspapers, magazines, Television, Radio, Internet and through Workshops, Summer Courses, Exhibitions, display, Pollution Control Camps etc.

(*ii*) Display of ambient air quality data through Electronic Display System as well as dissemination through newspapers, daily news and Internet.

(*iii*) Publishing reports related to vehicular pollution control and dissemination to various organisations.

(*iv*) Regular publication of air quality statistics regarding ambient air quality status in the country.

(*v*) Non-Government Organisations (NGOs) working in the area of Vehicular Pollution Control in different parts of the country are being encouraged for creating mass awareness.

Measures Taken for Controlling Air Pollution from Industries

The measures taken for controlling air pollution from industries are as follows :

1. Emission standards have been notified under the Environment (Protection) Act, 1986 to check pollution.
2. Industries have been directed to install necessary pollution control equipment in a time bound manner and legal action has been initiated against the defaulting units.
3. As many as 24 critically polluted areas have been identified. These areas are Singrauli, Korba, Vapi, Ankleshwar, Greater Kochi, Vishakhapatnam, Haora, Durgapur, Manali, Chembur, Mandi Gobindgarh, Dhanbad, Pali, Najafgarh Drain Basin, Angul-Talcher, Bhadravati, Digboi, Jodhpur, Kala Amb, Nagda-Ratlam North Arcot, Parwanoo, Patancheru, Bollaram and Tarapur, Action plans have been formulated for restoration of environmental quality in these areas.
4. Environmental guidelines have evolved for siting industries.
5. Environmental clearance has been made compulsory for 29 categories of development projects involving public hearing/NGO participation as an important component of Environmental Impact Assessment process.
6. The process of Environment Auditing has been initiated in highly polluting industries. The methodology has been standardised and finalised for respective group of industries. Submission of Environmental Statement has been made mandatory.
7. Under Indo-German Bilateral Programme, methodology for zoning, mapping and siting of industries has been developed in various states in collaboration with State Pollution Control Boards in order to identify the existing characteristics of the district, unsuitable zones for the industries, air quality mapping assessment of risk due to siting of air polluting industries and industrial suitability mapping. Based on zoning/siting programme, the site clearance procedure has been streamlined.
8. Minimal National Standards (MINAS) have been presented for highly polluting industries under The Air (Prevention and Control of Pollution) Act, 1981 and Environment (Protection) Act 1986.
9. Power plants (coal based) located beyond 1000 kms from the pit-head are required to use low ash content coal (not exceeding 34%) with effect from 1.6.2002. Power plants located in the sensitive areas are also required to use low ash coal irrespective of their distance from the pit head.

   It is estimated that about 40 million tonnes of fly ash is generated per annum from thermal power plants and contribute to particulate matter loading to environment. Fly ash possesses good pozzolinic properties due to presence of active and finely divided silica, alumina and calcium oxide, which provide it with cement like qualities in combination with lime rich material. Thus fly ash emitted by thermal power plants can be used for manufacturing bricks, blocks, aggregates and cement.
10. Use of cleaner technologies is a new dimension emerging rapidly for cleaner production and to increase production efficiency, and at the same time eliminate or atleast minimise emission and waste at their source rather than to treat them at the end of the production chain after they are generated.
11. Industrial wastes like slags, red mud, etc. are generated from iron and steel and during extraction of non-ferrous metals such as aluminium and copper. The slags are dumped in the vicinity of plant while red mud is disposed as slurry. This slurry becomes air borne after getting dried. In phosphoric fertilizer plants about 4.5 million tonnes of phospho-gypsum (with floride contents 0.7 to 1.5 %) are produced. This can be used for cement, gypsum board, partition panel, ceiling tiles, artificial marble and fibre boards. The thrust will have to be made for proper disposal and reutilisation of these waste materials.

WATER POLLUTION

Water is the most important element in the biosphere because it sustains all sorts of life on the planet earth. The purity and quality of water is of basic concern to mankind since it is directly related to human beings. Nature has given us plenty of water and even then we are feeling the shortage of water for drinking, washing, irrigation and industrial purposes because we have misused and polluted our water resources to a great extent. Water pollution may be defined as *alteration in the physical, chemical and biological characteristics of water, which may cause harmful effects on human and aquatic life*. Water pollution is now-a-days considered not only in terms of public health but also in terms of conservation, aesthetics and preservation of natural beauty and resources.

For the sake of simplicity, the water resources are divided into two categories *viz. surface water* and *ground water*. Surface water is found in the form of rivers, canals, lakes and ponds, etc. Some of the rain water percolates in the rocks under the surface and is available as underground water. This is used through hand pumps, wells, tube wells and springs.

In India, water pollution has been taking place on a large scale and for a long time. Both surface and ground water bodies are polluted to a great extent.

Surface Water Pollution

According to a report of NEERI, a staggering 70 per cent of the available water in India is polluted. From Dal Lake in the north to Periyar and Chalyar rivers in the south and from Damodar and Hugli in the east to Thane Creek in the west, the picture of water pollution is uniformly gloomy. Most of the rivers are carrying polluted water. We have been dumping all sorts of waste matter into our rivers—industrial waste, municipal sewage, residues of chemical fertilizers and what not. These wastes are both, solids as well as in dissolved form. Apart from polluting the river, they decrease the depth of the river and raise the level of river beds. Thus the river becomes a garbage can, without depth and flow. Most of the sewage of towns and cities is dumped into water courses without any treatment rendering the natural water course down stream unfit for drinking and even for bathing. About 14 river basins have been affected by untreated city sewage. Large scale pollution of rivers is turning them into septic drains posing serious threat to the health of millions of people.

Main Causes of Water Quality Degradation

There are several causes of water pollution in India. The main causes are briefly described as under:

1. Urbanisation

Rapid urbanisation in India during the recent decades has given rise to a number of environmental problems such as water supply, wastewater generation and its collection, treatment and disposal. Many towns and cities which come up on the banks of rivers have not given a proper thought to problem of wastewater, sewage, etc. In urban areas, water is tapped for domestic and industrial use from rivers, streams, lakes, ponds, wells, etc. Nearly 80% of the water supplied for domestic use passes out as wastewater. In most cases, this wastewater is let out untreated and causes large scale pollution of the surface water. A part of it percolates into the ground and contaminates the ground water. About 70% of the population of class I cities is provided with sewerage facility. The Ganga river basin contributes about one-third of the total wastewater of India.

As per the latest estimate, only 30 per cent is treated before letting out, the rest is disposed off untreated. The level of treatment available in cities with existing treatment plant varies from 2.5% to 89% of the sewage generated. Treated or partly treated or untreated wastewater is disposed into natural drains joining rivers or lakes or used on land for irrigation/fodder cultivation or to the sea or a combination of them by the municipalities.

Municipal water treatment facilities in India, at present, do not remove traces of heavy metals. Given the fact that heavily polluted rivers are the major sources of municipal water for most towns and cities along their courses, it is believed that every consumer has been, over the years, exposed to unknown quantities of pollutants in water they have consumed. To add to this, Indian towns and cities have grown in an unplanned manner due to rapid population growth.

Facilities for running water have been provided in many towns and even in some villages during the last couples of decades. This has resulted in the use of flush-latrines and much larger use of water in home for bathing, washing of clothes, utensils etc., generating large quantities of wastewater. Use of soaps and detergents and amounts of various food materials going to sink have also grown considerably with improved life standards. But sewerage has lagged far behind water supply. According to estimates made by the Central Pollution Control Board, only 22% of the wastewater from class I cities and 14% from class II cities is being collected through sewerage. A large number of cities/towns either do not have any sewerage system or the sewerage system is overloaded or defunct. All this results in large quantity of wastewater remaining uncollected.

Situation in big cities is worsened by migration of poor people from the surrounding rural areas. These people migrate to the cities in search of livelihood. According to an estimate by CPCB, only about 40-50% of the population of the major cities like Delhi, Mumbai, Kolkata, Chennai and Bengaluru are served by sewer systems. Even where there sewers exist, they often leak or overflow, releasing their contents to storm-water or other surface drains or percolate in to the soil to reach ground water. Very often uncollected and untreated sewerage water reaches the streams thereby polluting their water.

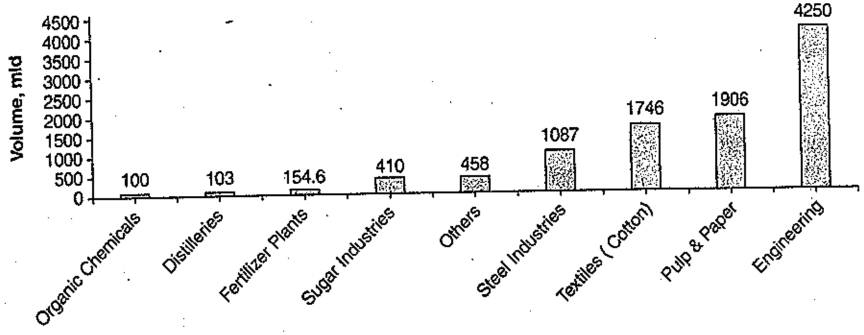

FIG. 9.5. Volume of wastewater generated from different industries in India

2. Industries

Most Indian rivers and other sources of fresh water are polluted by industrial wastes or effluents. All these industrial wastes are toxic to life forms that consume this water. The total wastewater generated from all major industrial sources is 83,048 Mld which includes 66,700 Mld of cooling water generated from thermal power plants. Out of remaining 16,348 Mld of wastewater, thermal power plants generate another 7,275 Mld as boiler blow down water and overflow from ash ponds. Engineering industries comprise the second largest generator of wastewater in terms of volume. Under this category the major polluting industries are electroplating units. Other significant contributors of wastewater are paper mills, steel plants, textile and sugar industries. The major contributors of pollution in terms of organic load are distilleries followed by paper mills. **Figure 9.5** shows the volume of wastewater from different industries in India.

Both large scale industries and small scale industries contribute their share of water pollution. While many large scale industries claim to have installed costly treatment and disposal equipments, these are often not in proper working order. Several examples can be cited, such as oil wastes present in the storm-water channel along Haldia Refinery and ammonia pollution in ground water around a urea factory of Kanpur and a natural spring close to the Zuari Agro Urea plant in Goa.

Small scale and cottage industries cause no less water pollution than the large scale industries. There are about 3 million small scale and cottage industrial units in India. These units neither have, nor can they afford, appropriate sanitation and/or pollutant disposal systems, and yet have not hasistated in adopting highly polluting production technologies such as chrome, tanning of leather, use of azo-dyes in fabrics, use of cadmium in ornaments and silver-ware, electroplating with cyanide baths, production of dye-intermediates and other refractory and toxic chemicals, etc. Their solid wastes and sludges get scattered around or dumped in unlined pits and effluents flow to streams through storm-drains or stagnate in depressions to percolate, leach or get washed-off during the next rainy season. This is the story of many industrial areas and urban centres in the country.

The pollution levels from domestic and industrial sources are quite different from each other. Comparison of pollution load generated from domestic and industrial resources is shown in **Fig. 9.6.**

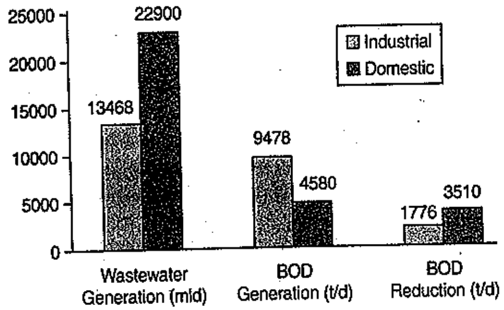

FIG. 9.6. Comparison of pollution load generation from domestic and industrial sources

3. Agricultural runoff and improper agricultural practices

Traces of fertilizers and pesticides are wasted into the nearest waterbodies at the onset of the monsoons or whenever there are heavy showers. As the point of entry of such agricultural inputs is diffused throughout the river basin, they are termed as *non-point* sources of pollution. Although irrigation has increased considerably in the country, precious little has been done to tackle the problem of the high salinity return water. This is the situation in Punjab and Haryana. In Haryana, the 40 km long drain No. 8 pours 250,000 kg/day of chlorides into the Yamuna to raise the chloride concentration in the river from 32 mg per litre just upstream of the drain confluence to 150 mg per litre just downstream of it. And most of these chlorides are from agricultural return flows. According to the findings of the CPCB, some of the seepage into the drain contain over 15,000 mg per litre of chlorides. Intensive and ever increasing usage of chemical fertilizers, pesticides, weedicides and other chemicals is adding a new dimension to such pollution. According to A.K. Dikshit, senior scientist with the Indian Agricultural Research Institute (IARI), New Delhi, farmers often indulge in excess usage of fertilizers and pesticides. When these are used more than the recommended doses, they pollute water, land and air.

Flood-plain cultivation is another significant contributor to water pollution. Fertilizers and pesticides used in these tracts of land are bound to be washed into rivers during the monsoons.

4. Withdrawal of Water

Indian rivers, particularly the Himalayan rivers, have plenty of water in their upper courses. They are, however, starved of water when they enter the plain area. Irrigation canals whisk away clean water soon after the rivers reach the plains, denying water to flow in the river downstream. What flows into the river is water trickling in from small insignificant streams and drains carrying untreated sewage and effluents. The river-turned drains flow downstream with little or no fresh water unless a large river augments the depleted flows.

As the quantity of fresh water in the river is negligibly small, pollution—either from urban and rural areas, industries or even natural forms of pollution—cannot get diluted and its ill effects are not reduced. The Yamuna has almost no water at Tajewala in Haryana where the Eastern Yamuna Canal and the Western Yamuna Canal abstract all the water for irrigation. Similarly, the Upper Ganga Canal and the Lower Ganga Canal have left the Ganga downstream almost dry. When the Yamuna and the Ganga flow past Delhi and Kanpur respectively, they are turned into stinking sewers. Therefore, it is essential that a minimum level of flow of water must be maintained in the river. This is known as ***minimum flow of rivers.*** According to a report of the Ministry of Water Resources on the study of minimum flows in the Ganga, impact on river water quality resulting from discharges of treated or untreated wastewater into the river will depend on the dilution offered by the quantum of flows in the river. Minimum flow in the recipient river will be required to maintain the desired water quality. Further, the study has expressed the view that it is not possible to fix the minimum flow of water in the entire course of the river because it depends on the pollution discharged at different points on the river. For example the existing minimum flow in the Ganga at Kanpur in May is hardly 50 cumecs (cubic metres per second) whereas the required minimum in the same month is 350 cumecs. The study further says that since the water is scarce it is not possible to add further fresh water for dilution. The solution lies in less amounts of pollution entering the river. In view of the increased demand of water for irrigation, the minimum flow is likely to fall further in future. In the words of K.C. Sivaramakrishnan, former director of the Ganga Action Plan (GAP), "maintenance of minimum flow is an important point. In simple terms a non-existent river cannot be cleaned. In case of the Ganga between Bijnore and Kanpur, the river is just a small stream. In case of the Yamuna, from Delhi till the point where the Chambal joins, the river is just a trickle. Other rivers like Sabarmati are almost devoid of water."

The Yamuna is dying a slow death in Delhi. In fact it is a dead river as it flows past Delhi. This river is relatively less polluted when it enters Delhi at Wazirabad barrage, but a mere 100 metres downstream the barrage, the river receives untreated sewage and industrial waste. The committee on minimum flows in the Yamuna indicates that if the minimum flows requirement in Delhi is met, that would suffice for the entire course of the river. According to report of the committee, discharge downstream of Tajewala and Okhla is less than 5 cumecs whereas minimum flow of 10 cumecs is required between Tajewala and confluence of the Yamuna with the Chambal. The committee states that this shortfall can be met either by creating storage facilities in the catchment area or from imports from another river basin. Increasing demand from the Yamuna water for irrigation and for meeting the urban requirements would leave very little freshwater in the river to maintain the minimum flow.

The maintenance of minimum flow, to sustain a river ecology through its course as well as its confluences, is a *recent awakening which requires serious thought.* This policy must be pursued vigorously so that river pollution is kept at certain permissible limit.

5. Religious and Social Practices

Religious faith and social practices also add to pollution of our river waters. Carcasses of cattle and other animals are disposed in the rivers. Dead bodies are cremated on the river banks. Partially burnt bodies are also flung into the river. All this is done as a matter of religious faith and in keeping with ancient rituals. These practices pollute the river water and adversely affect the water quality. Mass bathing in a river during religious festivals is another environmentally harmful practice. Studies have revealed that the biochemical oxygen demand (BOD) goes up drastically when thousands of people simultaneously take a 'holy dip'. Religious practices also demand that offerings from a ***puja*** be immersed in a river. It is now common to see people immersing offerings in plastic bags. Plastic bags are very dangerous and further add to the pollution load of the river. In 2013, Allahabad played host to the biggest and the most spectacular gathering of humanity in the world—the Maha Kumbh. A staggering 100 million congregated at the Sangam-up from 70 million in 2001 and the Ganga had to bear the brunt of this massive load of humanity.,

Effects of Water Pollution

Water pollution adversely affects the health and life of man, animals and plants alike. Polluted water is also harmful for agriculture as it adversely affects the crops and the soil fertility. Pollution of sea water damages the oceanic life.

1. Health Aspects of Water Quality. Consumption of polluted water is a major cause of ill health in India. Polluted water causes some of the deadly diseases like cholera, dysentery, diarrhoea, tuberculosis, jaundice, etc. About 80 per cent of stomach diseases in India are caused by polluted water. Water borne diseases are the single most important factor responsible for nearly 80 per cent of human mortality in India. Children are the worst affected, especially in rural areas and urban slums. Typical water borne diseases and their causative factors are summarised in the **Table 9.9**.

2. Effects of Organic Pollution on Water Quality. All organic materials can be broken down or decomposed by microbial and other biological activity (biodegradation). Organic and some of the inorganic compounds exhibit a biochemical oxygen demand (BOD) because oxygen is used in the degradation process. Oxygen is a basic requirement of almost all aquatic life. Aquatic life is adversely affected if sufficient oxygen is not available in the water. Typical sources of organic pollution are sewage from domestic and animal sources, industrial wastes from food processing, paper mills, tanneries, distilleries, sugar and other agro based industries.

3. Effects of Nutrients on Water Quality. Water supports aquatic life because of the presence of nutrients in it. Here the primary focus is on fertilizing chemicals such as nitrates and phosphates. Although these are important for plant growth, too much of nutrients encourage the over-abundance of plant life and can result in environmental damage called ***"entrophication'***. This can occur at both microscopic level in the form of algae or macroscopic level in the form of aquatic weeds. Nitrates and phosphates are contributed by sewage, agricultural run-off and run-off from un-sewered residential areas.

4. Effects of High Dissolved Solids (HDS) in Water Quality. Water is the best solvent and can dissolve a large variety of substances which come in its contact. The amount of dissolved solid is a very important consideration in determining its suitability for drinking, irrigation and industrial uses. In general, waters with a total dissolved solids of less than

500 mg/litre are most suitable for drinking purposes. Higher amount of dissolved solids may lead to impairment of physiological processes in human body. Dissolved solid is a very important criteria for irrigation. This is due to the fact dissolved solid accumulates on the ground resulting in salinization of soil. In this way it renders the agricultural land non-productive. Dissolved solids are harmful for industries also because they form scales, cause foaming in boilers, accelerate corrosion and interfere with the colour and taste of many finished products.

TABLE 9.9. Water Related Diseases and Causative Factors

Name of the disease	Causative organism
1. Water-borne diseases	
Bacterial	
• Typhoid	Salmonella typhi
• Cholera	Vibrio cholerae
• Paratyphoid	Salmonella paratyphi
• Gastroenteritis	Enterotoxigenic Escherichia coli
• Bacterial dysentery	Variety of *Escherichia coli*
Viral	
• Infectious hepatitis	Hepatitis-A virus
• Poliomycetis	Polio-virus
• Diarrhoeal diseases	Rota-virus, Norwalk agent, other virus
• Other symptoms of enteric diseases	Echono-virus, Coxsackie-virus
Protozoan	
• Amoebic dysentery	Entamoeba hystolitica
2. Water-washed diseases	
• Scabies	Various skin fungus species
• Trachoma	Trachoma infecting eyes
• Bacillary dysentery	*E. coli*
3. Water-based diseases	
• Schistosomiasis	Schistosoma sp.
• Guinea worm	Guinea worm
4. Infection through water related insect vectors	
• Sleeping sickness	Trapanosoma through tsetse fly
• Malaria	Plasmodium through Anaphelis
5. Infections primarily due to defective sanitation	
• Hookworm	Hook worm, Ascaris

Source : Water Quality in India, Status and Trends (1990-2001), Central Pollution Control Board (March 2003), pp. 31-32.

5. Effects of Toxic Pollutants on Water Quality. Toxic pollutants mainly consist of heavy metals, pesticides and other individual xenobiotic pollutants. The ability of a water body to support aquatic life, as well as its suitability for other uses depends on many trace elements. Some metals *e.g.*, Mn, Zn and Cu present in trace quantities are important for life as they help and regulate many physiological functions of the body. Some metals, however, cause severe toxicological effects on human health and the aquatic ecosystem.

6. Effects of Thermal Discharges on Water Quality. The discharge of cooling water from industrial and commercial operations generally heats up the aquatic environment. Organisms may become physiologically stressed or may even be killed when exposed to heated water. If water heating is supplemented by the summer heat, the impact on aquatic environment can be disastrous. Thermal pollution also causes a decrease in the driving force or oxygenation which may directly kill aquatic life through asphyxiation. If toxic pollutants are present in the aquatic environment. thermal pollution may increase their toxicity to the aquatic life. Bioavailability of many pollutants may also increase due to thermal pollution, which may ultimately adversely affect the aquatic life.

Water Quality Monitoring

Water quality monitoring is defined by the International Organisation for Standardization (ISO) as : "the programmed process of sampling, measurement and subsequent recording or signalling or both, of various water characteristics, often with the aim of assessing conformity to specific objectives." Water quality monitoring is essential to ensure that the water quality is being maintained or restored at desired level. With the introduction of

Water (Prevention and Control of Pollution) Act, 1974 and its subsequent amendment in 1981, the prime responsibility has been to maintain or restore the wholesomeness of water. It was therefore imperative to establish a water quality monitoring network to update on the existing water quality *vis-a-vis* the derived quality depending on the designated best use. The first water quality (WQ) stations were chosen on the river Yamuna. Central Pollution Control Board (CPCB) initiated water quality monitoring in 1976-77 with 18 stations on the Yamuna river. The number of stations gradually increased based on available resources and water quality problems. CPCB has been identified as the Government of India's agency to serve as a focal point for carrying water quality monitoring under the Global Environment Monitoring System (GEMS) programme of World Health Organisation (WHO) in India.

The number of monitoring network rose to 2,500 stations in 2011-12 in 28 states and 6 union territories. The monitoring network covers 445 rivers, 154 lakes, 12 tanks, 78 ponds, 41 creeks/seawater, 25 canals, 45 drains, 10 water treatment plants and 807 wells.

Water Quality Status

The water quality monitoring results indicate that organic and bacterial pollution are the critical parameters in Indian aquatic resources. This is mainly due to discharge of domestic wastewater, mostly in untreated form, from the fast growing urban centres of the country. By and large the municipal corporations do not have the requisite resources and are not able to treat the increasing load of municipal sewage flowing into the water bodies. Besides the receiving water bodies do not have adequate water for dilution. Therefore, the oxygen demand and bacterial pollution in Indian water bodies is increasing with each possing day. This is the main cause of increasing trend of water borne diseases.

Most of the surface water in India is found in rivers and there are several river basins in India. It will, therefore, be relevant to study the problem of water pollution on the basis of river basins. The pollution status of major river courses is shown in **Fig. 9.7** and is discussed as under :

1. The Ganga Basin

This is the largest river basin of India. It covers over one-fourth of the country's total geographical area and is the home for about half of her population. The Ganga basin accounts for nearly 50 per cent of Class I and Class II towns of the country and the mode of discharge of the municipal waste is mainly into the river system.

TABLE 9.10. Sewage generation and Treatment capacity in Ganga (2012)

Sewage Generated (MLD)	2,723.30
Treatment Capacity (MLD)	1,208.80
Gap	1,514.50
% gap : treated vs. untreated	55

Source : State of India's Environment 2014, Centre for Science and Environment, p. 23.

The polluted stretches include large stretches of the Ganga itself, the Yamuna (Delhi to Etawah), the Chambal (downstream of Nagda to downstream of Kota), the whole of the Kali river, the Hindon (Saharanpur to Confluence with the Yamuna), Kshipra (around Ujjain and downstream), Damodar (downstream of Dhanbad to Haldia), Gomati (Lucknow to confluence with Ganga), Betwa (along Mandideep and Vidisha), Son etc.

Pollution of water in some of the major rivers of the Ganga basin is described as under :

GANGA. The Ganga is the most sacred and at the same time one of the most polluted rivers of India. Keeping in view the rapidly falling water quality level of the Ganga and its tributaries, a large number of water quality monitoring stations have been set up in this river basin. The entire basin is dotted with 101 water quality monitoring stations out of a total of 507 in the whole country. Out of these 101 stations, 27 are on the main Ganga river while the remaining 74 are on its tributaries. These stations are constantly monitoring the water quality in the Ganga and its tributaries. Out of its total length of 2,525 km from its source in Gangotri to its mouth in the Bay of Bengal, as much as 600 km or about one-fourth of total length is reported to be badly polluted. The main cause of water pollution in the Ganga is rapid growth of urban and industrial centres all along the length of its banks.

The story of polluting the holy Ganga starts from Rishikesh and continues upto Kolkata. Following cities/towns are primarily responsible for pollution of the holy Ganga :

Haridwar. The industrial wastes from Bharat Heavy Electricals Limited (BHEL) and Indian Drug and Pharmaceuticals Ltd. (IDPL) cause large scale pollution of the river. About 15 large and small drains

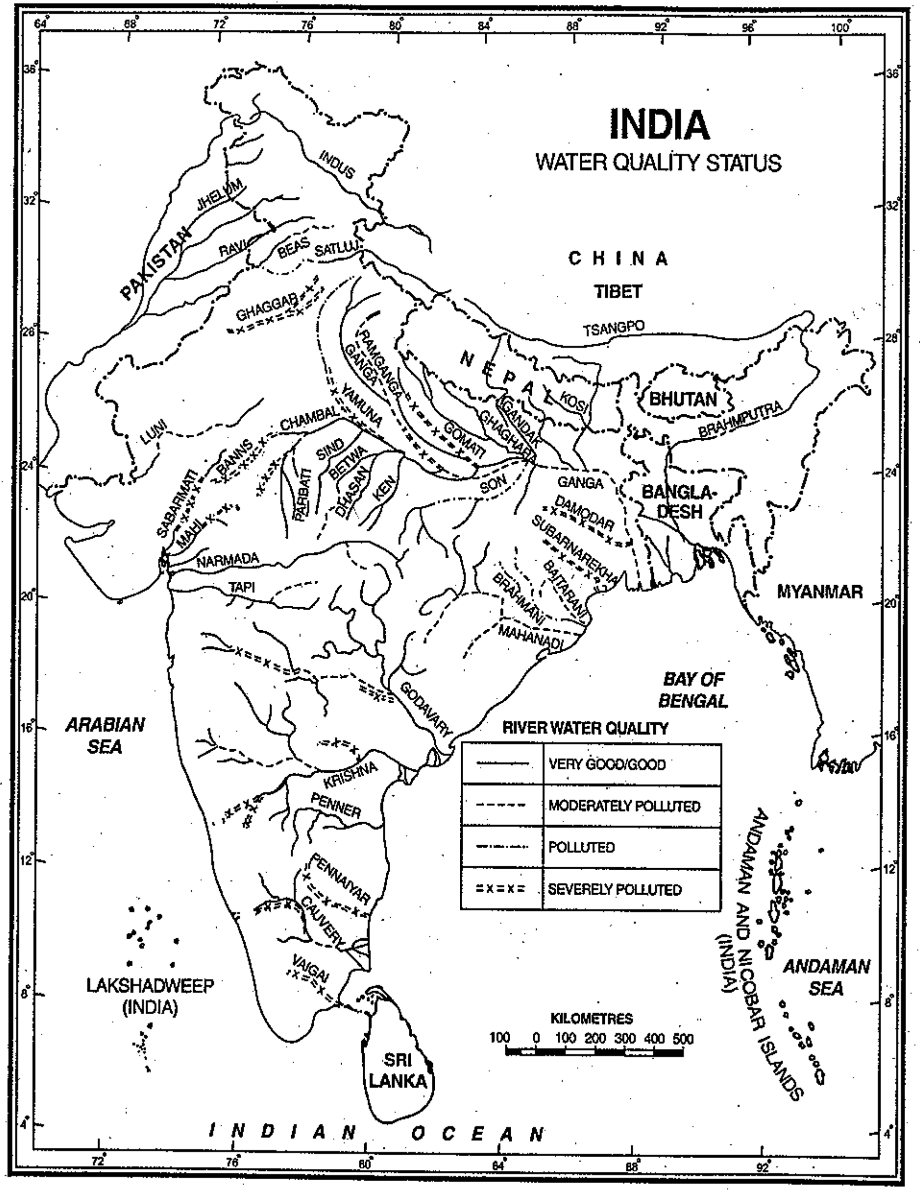

FIG. 9.7. India : Water Quality Status

TABLE 9.11. Difference between sewage generation estimates

State	Sewage generation (MLD)	BOD load tonnes/day	Gap untreated waste
Uttarakhand	61.30	42	95%
Uttar Pradesh	937.40	761	86%
Bihar	407.20	97	71%
West Bengal	1317.30	97	69%
Ganga Mainstream	2723.30	999	80%

Source : State of India's Environment 2014, Centre for India and Environment, p. 23.

According to a report published in the international journal '*Nature*' in 2013, the Ganga was ranked as the second-most polluted river in the world after Citarum river of Indonesia. The pollution level of the Ganga was about 3,000 times of the safe limit prescribed by the World Health Organisation (WHO) for human use. Only 45% of sewage that flows into the Ganga is treated. People living in the vicinity of the river are vulnerable to cancer.

discharge urban wastes into the river at Haridwar. Haridwar is one of the holiest places of the Hindu religion. Thousands of people from all over the country come to this place to perform various religious rituals. Community bathing, discharges of milk pots, discharges of flowers and leaves, etc, cause pollution of the Ganga water at Haridwar. According to the latest findings, the Ganga water at Haridwar is unfit for drinking, bathing and even for irrigation.

Kanpur is a big industrial city where the story of the Ganga becomes pathetic. The World Health Organisation (WHO) has declared Kanpur as one of the 10 most polluted cities of the world. The city has also come to be known as ***'industrial graveyard'*** and the ***'capital of tuberculosis'*** in the recent past. The city generates over 360 Mld of sewage. Besides there are 300 odd tanneries that keep dumping toxic wastes. Industrial wastes from cotton and woollen textile mills, jute mills, synthetic rubber mills, paper and pulp mills, distilleries, sugar mills and factories manufacturing synthetic chemicals like D.D.T., pesticides, etc. are also discharged into the river. Ironically people living in 100 towns along the river banks use the river water for various purposes including drinking. Intestinal and skin ailments are rampant.

Allahabad represents the sacred confluence of the Ganga and the Yamuna. The city has 13 drains discharging 110 Mld of sewage, partly into the Ganga and partly into the Yamuna. Besides urban effluents from the city itself, industrial wastes from Naini Industrial complex and Chemical fertilizer plant at Phulpur are also released into the river. Venerated as a pilgrim centre by the Hindus, Allahabad is also the venue of the 12 yearly *Kumbh* Fair, which is said to attract the largest crowd in the world. This causes large scale pollution of the Ganga water at Allahabad.

Varanasi. According to studies conducted by Uttar Pradesh Pollution Control Board (UPPCB), the Ganga becomes very polluted in Varanasi where dissolved oxygen (DO) is less than the permissible limit of 5 mg/l and B.O.D. is as high as 8.8 mg/l which is much higher than the permissible limit of 3 mg/l. There are about 71 large and small sewer drains which discharge huge quantities of effluents from the city into the Ganga. Even more significant reason of pollution of the Ganga is the dumping of cadavers into the river. Police sources admit that the Ganga is a major dumping site for victims killed in gang wars and shootouts in the crime-prone eastern Uttar Pradesh districts. The problem peculiar to Varanasi arises from the Hindu belief that the dead cremated here attain *moksha* (salvation). This results in hundreds of bodies being cremated at the *ghats* every day. Every year about 40,000 bodies are burnt in the two burning *ghats* of the city—Manikarnika and Harishchandra. This amounts to nearly 15,000 tonnes of ash per month, which is dumped into the river. Partially burnt wood, unburned portions of dead bodies and unburned or partially burnt skeletons are also thrown into the river which highly pollute the water near several *ghats*. Wood required to burn dead bodies at Varanasi results in deforestation of over one hundred hectares of forest land each year. Burning of dead bodies raises the water temperature between 30 to 50°C which reduces the dissolved oxygen by 30 to 50 per cent. Besides, about 7,000 dead animals are also thrown into the Ganga near Varanasi every year.

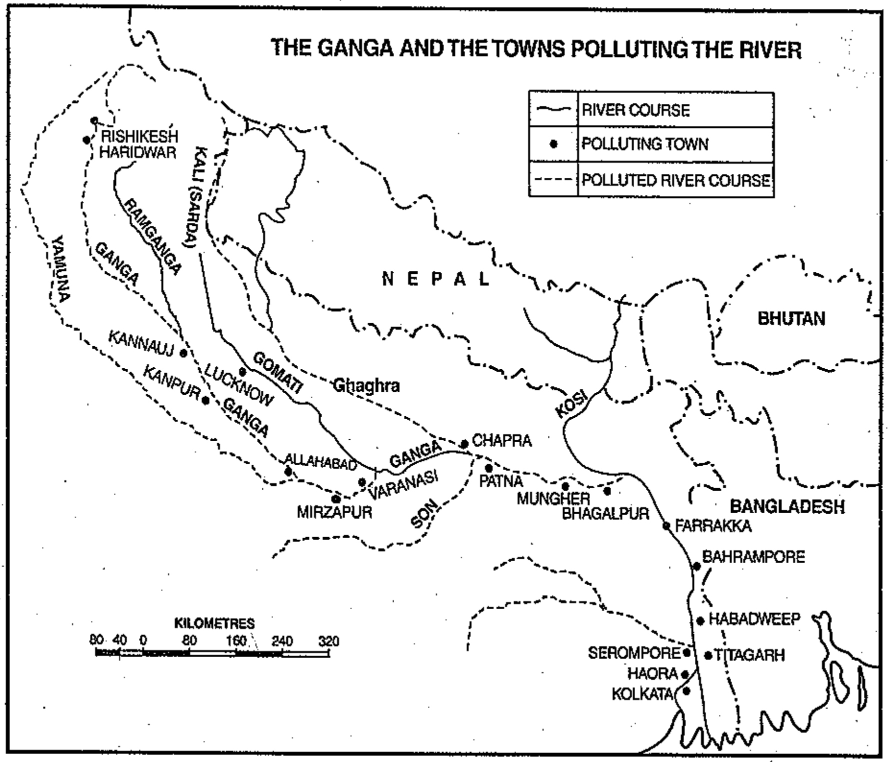

FIG. 9.8. The Ganga and the towns polluting the river

Like Haridwar and Allahabad, Varanasi is a very important place of the Hindu religion. As such it attracts lakhs of pilgrims every year. The river has to bear the brunt of this onslaught with pilgrims defecating, bathing and washing their clothes on the river banks. The pollution problem of the Ganga at Varanasi is further complicated by effluents from the diesel locomotive works located in the city. It is estimated that Varanasi is responsible for about one-fourth of Uttar Pradesh's contribution of pollutants to the Ganga.

Patna has become a major polluting city of the Ganga during the last few years. About 100 Mld of wastewater is discharged into the Ganga through nine major outfalls in the cities. Patna has extended mostly along the Ganga which means more garbage is dumped into the river. Large amount of toxic effluents are discharged by Bata factory and McDowel Distillery. One redeeming factor is the high discharge of fresh water even during dry months because the Ganga is augmented by the Ghaghra and the Son upstream of Patna, and the Gandak joins it downstream. Oil refinery at *Barauni* throws large quantities of chemical wastes in the river.

The Ganga is known as ***Padma*** after Farrakha barrage, flowing into Bangladesh and part of the river flowing into West Bengal is called the ***Hugli***. The fairly large volume and high flow of water between Allahabad and Farrakka renders this stretch less vulnerable to pollution, as compared to downstream of Farrakka. The annual flow of the river at Behrampore is in West Bengal is much less than the annual flow and Patna in Bihar. This is because some water is to be released into the Padma in Bangladesh as per agreement between the two countries. Huge amounts of residential wastewater and toxic effluents from industries are discharged in a long stretch of about 100 km along the Hughli river. **Figure 9.8** shows the major cities which are primarily responsible for pollution of the holy Ganga.

Some of the tributaries of the Ganga like the *Kali*, the *Gomati, the Sone, the Damodar*, etc. are badly polluted. The water of the *Gomati* river is polluted by sugar mills at Sitapur and distilleries of Lucknow. The effluents discharged by the distilleries contains a toxic substance called ***aldehyde***, which caused death to a large number of fish in 1986. Shahdol near the bank of the *Sone* river has one of the largest paper manufacturing mill in India. This mill takes about 73,000 kilolitres of fresh water from the river and throws back about 25,000 kilo litres of black, foul smelling and foaming water into the river per day. The river water is polluted for a stretch of about 70 km downstream of the mill.

THE DAMODAR deserves a special mention with respect to water pollution. Traditionally notorious as the sorrow of Bengal, the river is now the sorrow of both Bengal and Jharkhand. It is one of the most polluted rivers of the country. The high level of pollution of this river has rendered its water unfit for drinking, bathing and even for agriculture. Indiscriminate and uncontrolled discharge of industrial effluents has led to this sad state of affairs. The presence of high concentration of oil and grease (mostly mineral oils), toxic substances, etc., have made the Damodar water harmful and useless. These substances are of industrial origin and have rendered the river a ***'biological desert'*** showing hardly any existence and propagation of aquatic life in the vulnerable stretch of about 300 km between Girdih and Durgapur. Nevertheless, the river is the main source of drinking water for immunerable rural, urban and industrial people along its banks. Raw materials are available in plenty and the requisite infrastructure has been developed. Thus, the region has seen unprecedented industrial growth (**Fig. 9.9**). This has resulted in gross pollution of the river, rampant deforestation, soil erosion and siltation of the river course. Most of the catchment area of the river falls in the mining belt. Overburden from open cast mines are often dumped near the mined areas and are carried off with surface runoff. At places, this has even blocked the river. At present, many stretches of the Damodar and its tributaries (Konar and Barakar), resemble large drains carrying black, highly turbid water. The total suspended soils (TSS) count at most places is 40

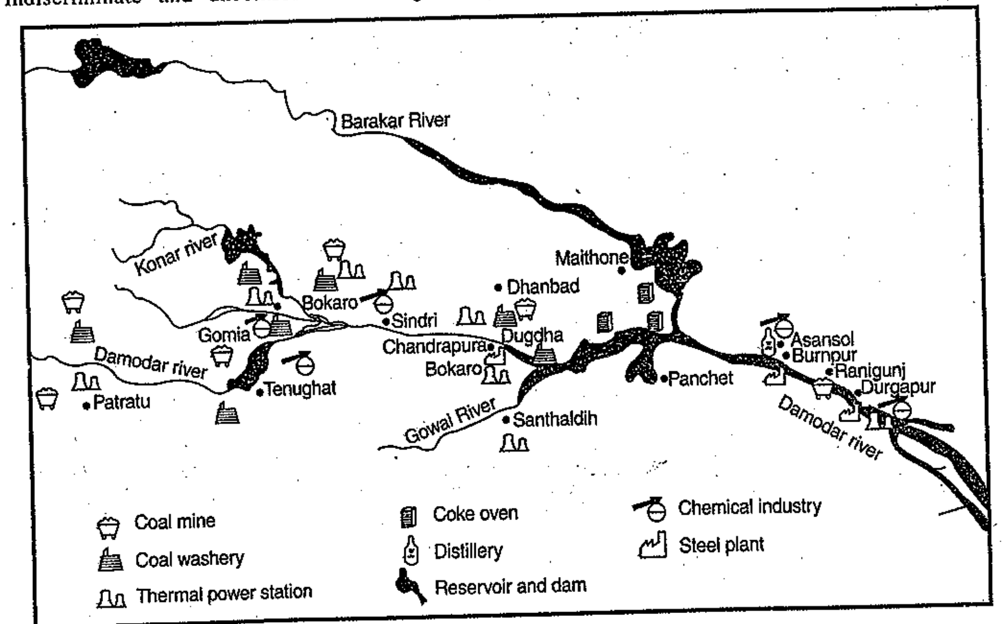

FIG. 9.9. Industries responsible for water pollution in the Damodar River

to 50 times higher than the permissible limit. For most parts the river carries a film of oil and grease from industrial effluents. The Damodar basin has about one-third of India's coal reserves and is the most outstanding producer of coal in the country. Consequently over half of the industries of the region comprise coal mining, coal washeries—and coke oven plants. Since coal is easily available, several thermal power plants, steel plants and ancillary industries have come up in the basin.

As many as 50 medium and 100 small scale industries are concentrated in the middle-stretch of the river. A total of about 6,000 Mld of mostly untreated industrial wastewater is discharged into the river. This excludes the wastewater from mine based activities and sewage from towns and cities on the course of the river. Conservative estimates put the daily outfall of pollutants and effluents at 60 tonnes of BOD (Biochemical Oxygen Demand) load, 2 tonnes of non-metallic toxins and 1.2 tonnes of toxic metallic substances. Industrial effluents generally carry high suspended solids in terms of fine coal particles and flyash. According to recent studies, the lowest observed concentration of oil and grease is no less than 2 milligrammes per litre which is 200 times higher than the accepted limit for use as source for public water supply. An estimated 3,100 tonnes of nitrogen, 500 tonnes of phosphorus (from fertilizers) and 30 kg of persistent pesticides reach the river annually, through surface runoff from agriculture. Coal washeries account for bulk of pollution in terms of TSS, oil and grease.

THE YAMUNA. The Yamuna, the most important and sacred tributary of the Ganga, is also

THE YAMUNA AND THE POLLUTING TOWNS ALONG ITS STRETCH

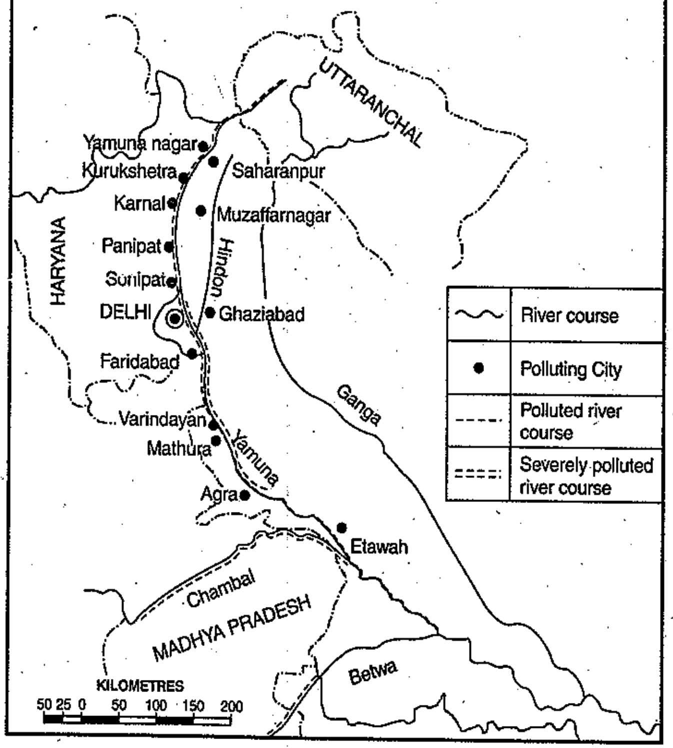

FIG. 9.10. The Yamuna and the polluting towns along its stretch

one of the most polluted river of India. Sewage and runoff from industries, towns and vast agricultural tract in Haryana and Uttar Pradesh have been emptied into the Yamuna for the last several years. Still it is the main source of drinking water for millions of inhabitants of Delhi, Faridabad, Mathura, Agra and so many other towns located on its banks. The water quality of the river begins to deteriorate as soon as it enters the plain area after coming down from the mountain area. At every step, fresh water is drawn from the river and large loads of polluted water are poured into it. This results in successive degradation of the river water. The Hindon, Chambal, Sindh, Betwa and Ken join the river at various places in its 1376 km long journey through the plains. From pollution point of view, the Yamuna's course has been divided into five segments—Himalayan (172 km), Upper (224 km), Delhi (22 km), Eutrophicated (490 km) and Diliated (468 km). Of these, the Upper segment, the Delhi segment and Eutrophicated segment are badly polluted stretches.

Upper Segment. The deterioration of the water quality starts right at the beginning of the upper segment at Tajewala barrage. At the Tajewala barrage, 172 km from its source, the West Yamuna Canal and the East Yamuna Canal take away almost the entire water of the river. Thus the flow of water downstream Tajewala is reduced drastically leaving the river with little diluting capacity. Besides, the Yamuna itself and the West Yamuna Canal flow through the industrial belts of Yamuna Nagar, Kurukshetra, Karnal, Panipat and Sonepat before entering Delhi. These towns discharge domestic wastewater and industrial effluents into the river. Discharge of effluents from domestic, industrial and agricultural sources are reflected in the water quality of the Yamuna river in the West Yamuna Canal.

Delhi Segment. Delhi is the largest polluter of the Yamuna river. The Yamuna is comparatively less polluted before entering into Delhi. But as soon as it enters Delhi, the river is polluted at a much faster rate. In Delhi, the Yamuna seems to be *dying a slow death*. Everyday about 3,600 million litres of domestic and 300 million litres of industrial waste water is discharged into the Yamuna through 17 open drains (**Table 9.12**). While Delhi has a capacity to treat 2330 Mld, only 1478 Mld is actually treated. The toxic effluents discharged into the *Yamuna* carry 132

TABLE 9.12. Estimated Pollution Load Generation along the Yamuna

Name of town	Wastewater flow (mld)	BOD load (tonne/day)
Yamunanagar**	28	4.15
Karnal*	23	3.45
Panipat*	25	3.75
Sonepat*	19	8.10
Gurgaon	20	3.03
Faridabad	102	15.15
Delhi	3600@	300@
Saharanpur	45	6.75
Muzzafarnagar	35	5.25
Ghaziabad	180	27.00
Noida	75	11.25
Vrindavan	5	0.75
Mathura	31	4.65
Agra	90	13.50
Etawah	15	2.25

Note : *Waste from these towns enters the Yamuna.
**Waste from these towns enters the Western Yamuna Canal.
BOD : biochemical oxygen demand.
mld : million liter per day.
@ : Figures for 2004.

Source : Citizen's Fifth Report (October, 2002), Centre for Science and Environment, p. 71.

tonnes each of B.O.D. (Biological Oxygen Demand) and suspended solids and 250 tonnes of dissolved solids. Before the Yamuna enters Delhi, 100 millilitres of its water contain only 7,500 disease causing bacteria but after getting polluted by Delhi the same amount of water contains 24 million disease causing bacteria. The Yamuna is rightly described as the ***'Open sewer of Delhi'***. Interestingly, the length and the basin area of the Yamuna in Delhi is only 2 per cent of the total length of the river, but the pollution loads contributed by this city are 71 per cent of the total waste water and 55 per cent of total BOD discharged into the river every day. Industrial waste from 20 large, 25 medium and about 93,000 small scale industries located in Delhi also flows through these drains. Through the large and medium industries form only about 0.05 per cent of the total industries located in Delhi, they contributed about 50 per cent of the total industrial waste. These are mostly engineering, textiles, chemicals, electronics and electrical goods factories. Common service industries, including service stations and garages catering to automobiles, discharge oils and other effluents. Manufacturing industries like electroplating units, dyeing, metal-pickling and anodizing units—discharge acids and similar effluents into the open drains. Efforts to re-locate non-conforming industries from the residential areas to alternate site at Bawana have not been able to make much difference. The problem of the Yamuna water in Delhi is becoming more complicated with the passage of time because Delhi administration lacks sufficient sewage treatment facilities.

Entrophicated Segment continues for a distance of about 490 km from the Okhla barrage in Delhi to the confluence of the Yamuna with the Chambal in Etawah district of Uttar Pradesh. Beyond this point, is the diluted segment for a distance of 468 km upto its confluence with the Ganga at Allahabad. This is **diluted segment** because Sindh. Betwa and Ken flow into the Yamuna and dilute the pollutants in the river water.

2. The Indus Basin

The Indus basin consists of the main Indus river and its five major tributaries *viz*. the Jhelum, the Chenab, the Ravi, the Beas and the Satluj. The basin is the home of about six million urban people living in Class I and Class II cities and towns. These cities and towns generate about 800 million litres of wastewater and 1700 tonnes of solid waste every day.

Three polluted river stretches have been identified in this river system. These are the Satluj from down stream of Ludhiana to Harike, the Beas from upstream of Manali to Mandi and from down stream of Mandi to Himachal Pradesh state border.

3. The Brahmaputra Basin

The Brahmaputra river basin covers large parts of Assam, Arunachal Pradesh, Nagaland, Meghalaya and West Bengal. The basin and catchment area receives heavy rainfall and the Brahmaputra has the highest discharge of all the rivers of India. There are a number of class I and Class II cities in this basin which generate about 233 Mld of wastewater and 414 tonnes of solid waste every day. Guwahati produces the largest amount of wastewater and solid waste of all the towns located in this basin. Although the water quality of the river and its tributaries is not affected much due to enormous dilution available in the river, still there is need for water management.

One of the 22 problem areas identified by CPCB for priority action is Digboi which is located in this basin. It has caused water pollution in the Digboi Nadi which is a sub-tributary of the river Brahmaputra. Oil refinery located at Digboi is primarily responsible for deterioration of the water quality of the Digboi Nadi. To restore water quality of the Digboi Nadi, modernization of the refinery along with the installation of catalytic reforms unit in the existing plant have been recommended as part of the action plan. Processing of oil bearing sludge containing 50-60% hydrocarbons has also been suggested.

Fertilizer units at Kamrup and Namrup as well as thermal power stations and oil refineries in Kokrajhar, Kamrup, Dibrugarh, Guwahati, Numaligarh and Bongaigaon also add to the problem of water pollution in this basin.

4. The Mahi and the Sabarmati Basins

The Mahi basin extends in the states of Gujarat, Madhya Pradesh and Rajasthan. The Sabarmati basin extends in the states of Gujarat and Rajasthan. Both the river basins have a number of class I and class II cities. The cities of the Mahi basin generate about 160 Mld wastewater and 514 tonnes of solid wastes per day. The respective figures for the Sabarmati basin are about 677 Mld wastewater and 1877 tonnes of solid waste. The water quality monitoring results indicate that organic pollution is the major problem in these river basins. Vadodara and Ahmedabad are the two main polluting cities.

5. The Narmada Basin

The Narmada is the largest west flowing river of the peninsular India. The major urban centres in this basin are Jabalpur, Hoshangabad, Dewas and Khandwa in Madhya Pradesh and Bharuch in Gujarat. Class I and Class II cities generate 68.6 Mld of wastewater and about 430 tonnes of solid waste every

day. Dhar, Jabalpur, and Bharuch are the main industrial districts. These districts are marked by clusters of pharmaceuticals, pesticides, dyes and distilleries, leather and fertilizer units. In Jabalpur, Khandwa and Hoshangabad, the main industrial activity consists of paper mills.

6. The Tapi Basin

The urban areas of the Tapi basin generate about 293 Mld wastewater and nearly 1650 tonnes of solid wastes per day. The most populous city in the Tapi basin is Surat followed by Amravati and Dhule. Industrialisation has taken place in the East Nimar (Khandwa) district of Madhya Pradesh and Jalgaon district of Maharashtra. Distillery units contribute the largest share of pollution in Maharashtra whereas textiles occupy the predominant place in Gujarat followed by food and beverages and chemical industries. The Tapi river from Nepanagar to Burhanpur has been identified as a polluted stretch under the National River Action Plan (NRAP).

7. The Mahanadi Basin

The Mahanadi, along with its tributaries like Seonath, the Kharoon, the Hasdeo, the Mand, the Ib and the Tel forms an important river basin in the north east of the Deccan plateau. Mahanadi river basin is comparatively less polluted. However, certain stretches like. downstream portion of river Ib at Brajrajnagar, downstream of Sambalpur and Cuttack have higher degree of pollution. The Ib river is seriously polluted by discharges from the paper mill at Brajrajnagar. A large number of towns on the banks of the main Mahanadi river and its tributaries discharge domestic and industrial wastewater. Korba has been identified as a critically polluted area in this basin. Industrial as well as domestic wastewater is being discharged into the Hasdeo river. Besides iron and steel industry at Bhilai, cement industries at Durg and Raipur, distillery at Raipur, textile industry at Rajnandgaon are the main pollutants.

The Odisha portion of the Mahanadi basin is marked by paper, textiles and thermal power plants at Choudwar, fertilizer and breweries at Paradeep, sugar industry at Nayagarh, Badamba, cement industry at Bargarh, paper industry at Brajrajnagar, coal mining areas of Rampur and Ib valley and an aluminium smelter at Hirakud.

8. The Godavari Basin

The Godavari is the largest river basin of the peninsular India and extends over ten per cent of the total geographical area of the country. It may be mentioned here that inspite of its massive catchment area, the discharge of water is not very impressive due to moderate annual average rainfall in the basin. On account of high concentration of population and industries, towns and cities in this basin discharge large quantities of domestic and industrial waste into the river. It is observed that Class I cities and Class II towns of the basin generate about 761 Mld of wastewater and 2773 tonnes of solid waste every day. Out of the total wastewater only 85.4 Mld is treated.

Amongst the five states which share the Godavari river basin, Odisha is the least industrialised followed by Madhya Pradesh, Chhattisgarh and Karnataka, with Maharashtra having high concentration of industrial pockets. The highest concentration of industries is found in Aurangabad and Nashik in Maharashtra and East and West Godavari districts of Andhra Pradesh. In Maharashtra, sugar and distillery units are in large number. This is followed by pharmaceuticals, leather, pulp and paper and pesticide units. In Andhra Pradesh, sugar and distillery units are in large number followed by pulp and paper and fertilizer industries. All these industries consume a lot of fresh water and generate large quantities of wastewater.

The river Godavari from downstream of Nashik to Nanded in Maharashtra and upstream of Bhadrachalam at Mancheral and Ramgundam in Andhra Pradesh have been identified as the polluted stretches to be taken up under the National River Action Plan (NRAP). The major sources of pollution in the polluted stretches are from domestic and industrial wastewater generated from cities between Nashik and Nanded cities in Maharashtra and Mancheral, Ramgundam and Bhadrachalam cities in Andhra Pradesh.

9. The Krishna Basin

Though the Krishna is the third largest river of India, yet it has poor water wealth because of low rainfall in the basin. Lying in the Deccan plateau, this basin covers large areas in the states of Maharashtra, Karnataka and Andhra Pradesh. The river has two large tributaries—the Bhima and the Tungabhadra and four smaller tributaries—the Ghataprabha, the Malprabha, the Musi and the Muneru.

The urban areas of this basin generate about 1,404 million litres of wastewater (out of which only 204 Mld is treated) and 4,488 tonnes of solid waste every day.

With an annual consumption of about 7,941 tonnes of pesticides, agricultural runoff adds 120 mg/l nitrogen, 26 mg/l phosphorus and 31 mg/l potassium to the river basin. The total domestic pollution load in the Krishna basin is 1,433,084 kg per day—50.6% rural and 49.4% urban. Of the total BOD load generated, Andhra Pradesh accounts for 40.6%, Karnataka 32.7% and Maharashtra 26.7 per cent. Urban BOD load is 707.8 tonnes per day of which domestic is 77.6 per cent and industrial 22.4 per cent.

Several industrial units have come up along the river and the load of industrial waste is quite high in this river. The largest industrial pollution load in Maharashtra part of the basin comes from Pimpri Chinchwada New Corporation part of Pune urban agglomeration. In Karnataka, the Harihar Polyfibres Ltd. at Harihar in Dharwar district abstracts nearly 35,000 cum per day of water from the Tungabhadra and discharges about 33,000 cum per day of wastewater into the river. Bhadra river is badly polluted by Mysore Paper Mills and Visveswaraya Iron and Steel Limited.

10. The Cauvery Basin

With almost 95 per cent abstraction of water, the Cauvery is one of its most exploited rivers of India. The Cauvery has watered agricultural lands of Tamil Nadu, Karnataka and Kerala. Sharing of the Cauvery waters has been the bone of contention between the two contending states, *viz.*, Tamil Nadu and Karnataka. High rate of application of chemical fertilizers and insecticides in agricultural field results in discharge of large quantities of chemicals in the river water, thereby polluting the river to a great extent. Coffee production in the districts of Coorg, Hassan and Chickmagalur contributes heavily to the BOD level of the river water which ranges from 2,000-4,000 mg/l. Coffee industry contributes 4,730 tonnes of BOD load in each season.

The urban areas in this basin generate about 750 million litres of wastewater and 3,500 tonnes of solid waste every day. Important cities are in Karnataka (Bengaluru, Hassan, Mandya and Mysore) and Tamil Nadu (Salem, Erode, Coonoor, Tiruppur, Valparai, Dindigul, Tiruchchirapalli, Kumbakonam, Thanjavur and Coimbatore). The industrial activity is very high in this basin, particularly in the Bengaluru area in Karnataka and Methur as well as Coimbatore in Tamil Nadu, followed by districts of Mysore and Mandya in Karnataka and Periyar and Salem in Tamil Nadu. A total of 61 industries in Karnataka and 1,139 in Tamil Nadu contribute heavily to the pollution load, especially during the lean flow period of the year. In Tamil Nadu, some water-intensive industries such as textiles, sugar mills, paper mills, chemical units, engineering units, tanneries, etc., have come up which contribute to the pollution load of the river.

Noyyal is one of the most polluted tributaries of the Cauvery river. It is polluted by 800 odd dyeing and bleaching units located at Tiruppur. This 173 km long river carries untreated sewage and industrial effluents from the towns of Coimbatore and Tiruppur for most part of the year.

GROUNDWATER QUALITY

The term 'groundwater' is defined as the water that occurs below the surface of the earth. The source of groundwater is precipitation and infiltration of surface water from runoff and streams. In a country of monsoon climate like India, where rainfall is seasonal, erratic, undependable and variable and where the surface water is always in short supply, groundwater plays a vital role in everyday life of the masses. Most of the drought prone areas largely depend on groundwater.

Sources and Types of Groundwater Contaminants

Groundwater contamination leads to several problems like taste, colour, hardness and foaming. The problem of groundwater contamination becomes serious when pathogenic organisms, flammable or explosive substances or toxic chemicals are present. Once polluted, groundwater may remain unusable or even in hazardous condition for decades or even centuries. It is often difficult to identify the nature and sources of groundwater pollutants and water quality problems. Normally speaking, the quality of

groundwater is affected by waste disposal and land use. The water-soluble substances which are dumped, spilled, spread or stored on the land surface eventually may infiltrate into the ground water. The disposal of fluids through wells and sinkholes directly into acquifers also results in contamination of the groundwater. Infiltration of contaminated water also causes groundwater contamination.

SOIL OR LAND POLLUTION

Soil is a very important environmental attribute because it supports all sorts of plant life found on land. Soil becomes polluted due to the *misdeeds of man* or at times the *mischiefs of nature*. The main factors of soil pollution are the high state of soil erosion, excessive use of chemical fertilizers, biocides (pesticides, insecticides and herbicides), polluted liquids and solids from urban and industrial areas, forest fires, water-logging and related capillary processes, leaching, drought, etc. Some of the micro-organisms and unwanted plants enter the soil and result in soil pollution. Some of the air-borne pollutants from the industries are deposited on the land surface and pollute the soil. Solid particles from mining areas pollute the neighbouring land to a great extent redering it unsuitable for agriculture. Many areas near mica and manganese mines in Jharkhand have fallen prey to this type of pollution. Soils near copper smelting units are so polluted that no plant growth is possible there. Main sources of land pollution are briefly described as under :

1. Chemical Fertilizers and Biocides. The accelerated use of chemical fertilizers and biocides in agriculture is the major cause of soil pollution. They are used to increase the yields and to save the crops from insects, pests and unwanted plant growth. It should be particularly noted that biocides first kill germs and unwanted plants and then degrade the quality of soil. Among the pesticides, the most widely used are the chlorinated hydrocarbons, *e.g.* D.D.T., B.H.C., endrin, aldrin, dieldrin and lindane and organophosphorus compounds such as parathion and malathion. When these are used in excess, their remnants are absorbed by soil particles and contaminate crops grown in such soils. They are further transferred into carnivores through herbivores and finally enter the human bodies in course of food chains. They are responsible for several incurable diseases and even cause death. Biocides are, thus, called as ***creeping deaths.***

The use of biocides gained momentum in India with the commencement of Green Revolution in 1966-67. The introduction of high yielding varieties (HYV) of seeds gave birth to heavy dozes of chemical fertilizers and biocides. The overall per hectare consumption of fertilizers rose from a mere 0.55 kg in 1950-51 to 67 kg in 1992-93 and to 144.33 kg in 2011-12.

For reducing the impact of chemical fertilizers, it is suggested that use of organic manures, composts, and agricultural wastes should be encouraged. Composition of NPK in different farmyard manures and composts is given in **Table 9.13**. Organic farming refers to farming which does not use any form of chemical fertilizers or other agro chemicals and is dependent entirely on organic sources of crop nutrition and crop husbandry. Organic farming can also be defined as system in which the maintenance of soil fertility and the control of pests and diseases are achieved through the enhancement of biological process and ecological interaction. The major component of organic farming is the maintenance of

TABLE 9.13. Composition of NPK in different Farmyard Manure and Compost (in percentage)

Waste	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Total Nutrient
Rural compost	0.75	0.5	0.5	1.75
Urban compost	1.00	1.00	1.00	3.00
Neem cake	5.20	1.00	1.40	7.60
Farmyard Manure	0.60	0.20	0.60	1.40
Poultry droppings	3.00	2.60	1.40	7.00

Source : Environmental Atlas, (June 2001), Central Pollution Control Board, p. 97.

soil fertility through maximizing nutrient recycling and minimizing losses. Organic farming also helps in improving the physical properties, microbial production and humus content of soil while increasing its water holding capacity.

Organic farming involves the use of farmyard manure (FYM) which has been used as a resource for plant nutrient since ancient times. It also includes the application of vermicomposts, green manuring and biofertilizers. FYM consists of animal dung, waste, crop residue, poultry manure/litter, etc. The urban or rural wastes composted are also sources of plant nutrients.

Green manuring involves cultivation of fast-growing leguminous crops and ploughing them back into the soil as fertilizers. Biofertilizers help leguminous crops fix atmospheric nitrogen into the soil.

2. Municipal Solid Waste. Municipal solid waste (MSW) is a heterogeneous mixture of various constituents. According to Scavenging and Cleaning Act, MSW includes :

- dust, ashes, refuse and rubbish.
- trade refuse.
- carcasses of dead animals and other matter.
- sweeping, sand stones, leaves and other dead vegetation.
- wastes from shops and market areas including paper, straw and cardboard packing, decaying fruits and vegetables and other described items; and
- other solid wastes generated from establishments such as hospitals, schools, offices and small cottage industries.

Depending upon putrescibility municipal solid waste (MSW) can be classified into two categories *viz.* 'garbage' and 'rubbish. The term ***garbage*** is defined as the fraction of waste associated with preparation and consumption of food (*e.g.* meat and vegetable scraps), often called putrescibles. All other wastes not classified as 'garbage' are designated as ***'rubbish'***.

Municipal Solid Waste Generation Status in Class-I Cities

The quantity of municipal solid waste generated by a city depends upon a number of factors of which size of population, standard of living, food habits, scale of commercial and industrial activities, etc. are of primary importance. As such the per capita generation of solid waste differs greatly from one city to another. It varies from 200 to 500 gm/person/day with an average of 376 gm/person/day. With the passage of time the level of urbanisation and standard of living of the urban people is likely to improve which will result in increased generation of total solid waste as well as per capita solid waste.

Disposal of such large quantities of garbage is a difficult job. The dumping grounds of such garbage are invariably polluted. It is estimated that about 25 human diseases are associated with solid wastes. Rats and flies flourish on garbage heaps. Rats are carriers of insects and other bio-organisms and are responsible for spreading deadly diseases like *plague, cholera,* etc. The flies which carry pathogenic organisms cause diseases such as dysentery, diarrhoea, etc. Studies reveal that an approximate of 70,000 flies can be produced on one cubic foot of garbage.

Management of Municipal Solid Waste (MSW)

In India, recently solid waste management systems are assuming larger dimensions in keeping with the Municipal Solid Wastes (Management & Handling) Rules, 2000. Many of the municipalities are taking appropriate actions to improve various component systems like collection of solid waste from generation areas, its transportation to processing and disposal site(s), utilising the recycling potential of Municipal Solid Waste (MSW) and ultimately disposing of by landfilling.

In view of this, under the sponsorship of Central Pollution Control Board (CPCB), NEERI has carried out extensive studies to assess the pathways of pollution for various environmental media. Further, a site selection criteria has been developed in the form of guidelines to suit Indian conditions in keeping with the findings of the other studies.

The urban solid waste management is an essential municipal service for protection of environment and health of citizens. All the citizens, industries, hospitals and NGOs should co-operate with the Municipal authorities to ensure safe management of urban solid waste. Segregation of

inorganic recyclable materials like plastic, glass, metal, paper at the source should be promoted and every effort should be made to provide collection of these in separate containers or bags in each house. Solid waste should be collected from each house on a daily basis and transported to the disposal site. Direct transfer of garbage from primary collection carts to covered transportation vehicles should be encouraged.

Refuse from vegetable and fruit markets should be collected and transported to the composting facilities. Large restaurants/hotels should be encouraged to develop their own onsite treatment facilities.

Sanitary landfills would be the main option for disposal of urban solid waste. The concerned authorities must make adequate provision of land allocation for scientific landfill sites.

Composting along with land disposal on non-compostables are the most preferred options for MSW and could take care of up to 20-30 per cent of municipal solid waste/organic fraction. The urban solid wastes of Indian cities have low calorific value and high moisture content with high percentage of non-combustible materials and hence it is unsuitable for thermal technologies. However, application of technologies such as incineration, palletisation and pyrolysis-gasification should be evaluated through research and development and pilot scale studies.

According to latest figures (2013) Delhi is generating about 9,500 metric tonnes of garbage everyday and is fast running out of landfill sites. It appears that garbage will soon become the single most important issue for Delhi which requires immediate solution. It is felt that unless a new technology is adopted, there will be no space left for garbage in the next few years.

Hazardous Waste Generation. The term 'hazardous waste' is generally used for wastes, which are highly toxic and hazardous in nature. According to "Hazardous Waste (Management and Handling) Rules" notified in 1989, 'hazardous substance' means any substance or preparation of which, by reason of its chemical or physio-chemical properties, or handling, is likely to cause harm to human beings, other living creatures, plants, micro-organisms, property or environment." As per Hazardous Waste (Management and Handling) Amendment Rules, 2000, 'hazardous waste' is defined as "Waste substances, which are generated in the process, and consists of wholly or partially of the waste substances referred to in the schedule."

Prevention and Control of Soil Pollution

Maximum soil pollution is done by use of biocides (pesticides, insecticides and herbicides) and chemical fertilizers. Farmers should be properly educated to make judicious use of these chemicals. Immediate restriction should be imposed on the use of DDT. At the same time, efforts should be made to develop less harmful and more useful chemicals for use in agriculture.

Urban and industrial effluents can be used for irrigation after proper treatment. Compostable organic substances such as vegetables, plant leaves, animal and human wastes should be properly composted, so that there is proper disposal of the solid waste and it can also produce organic manure. According to an estimate, a town with one lakh population may produce 20,000 tonnes of garbage and 8,000 tonnes of night soil which can be converted into 18,000 tonnes of compost (organic manure). Today, plastics are proving to be a big environmental hazard because they are practically indestructable. It takes hundreds of years for plastics to disintegrate, adding to solid waste buildup, especially in urban and industrial areas. There is an urgent need to restrict the use of plastics and to find out ways and means of recycling them.

NOISE POLLUTION

Noise is unwanted sound and covers all sounds which can result in hearing impairment or are harmful to health, or otherwise dangerous. According to **K.E. Maxwell**, "Noise is any sound that is not wanted. It is one of the more common forms of atmospheric pollution." *Noise pollution may be defined as the state of discomfort and restlessness caused to humans by unwanted high intensity sound.* More and more noise is created as the modern civilization moves ahead. It has now become a major environmental pollutant especially in urban areas. In 1972, the UN Environment Conference at Stockholm, noise pollution has been accepted as a problem, which needs proper control.

Measurement of Sound/Noise and Its Intensity

The most popular measure of noise level is the *decibel* measured by an instrument known as ***decibel meter***. A sound between 0 and 1 decibel is about the weakest that the average human can hear. For testing purposes, 0 decibel is considered to be the threshold of hearing. A whisper is about 20 decibels and an average speaking voice is about 60 decibels. The loudest sound that a person can stand without discomfort is about 80 decibels. Automobile horns may reach 90 decibels and a jet airplane may have an intensity of about 140 decibels. The levels of common noise is given in **Table 9.14** and has also been depicted in **Fig. 9.11.**

Actually, loudness alone is not the sole cause of noise problem, although this is the most apparent characteristic of noise that creates environmental problems. Pitch of the noise also influences the degree of annoyance—the higher the pitch, the greater the annoyance. Similarly, duration of the noise also determines how annoying or irritating noise will be. The degree of noise in an enclosed space or indoors is different from the level of outdoor noise.

TABLE 9.14. Intensity of Various Sounds

Sound Source	Intensity (in decibels)	Response Criteria
	0–10	Just audible
Broadcasting studio	20	—
Soft whisper	30	very quiet
Library, bedroom slow radio	30–50	quiet
Light auto traffic, air conditioning unit	50–70	intrusive
Freeway traffic, freight tram	70–80	annoying
Motor cycle, heavy traffic	80–100	very annoying, hearing damage
Rail noise	110-130	intolerable
Lighting thunder	120	intolerable
Carrier deck jet operation	140–150	painfully loud

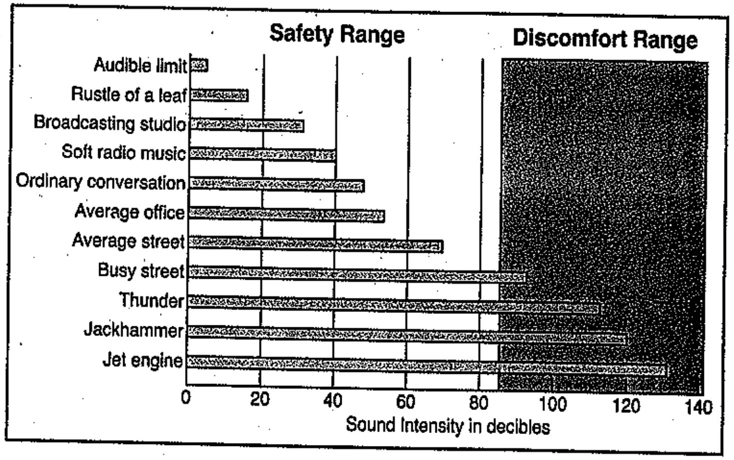

FIG. 9.11. Levels of Common Noise (After T. Berland)

NOISE POLLUTION IN INDIA

Noise pollution in India has increased considerably with the increase in urbanization and industrialization. In most of the Indian cities, early morning tranquillity is shattered by automobiles, factory machines and loudspeakers from religious places. Television and radio sets played at very high pitch, marriages and other processions, festivals, cultural programmes and a host of other sources of noise add to the problem of noise pollution. Most of the big cities of India have noise pollution much higher than the permissible limit of 60-70 dB. Delhi (89 dB), Kolkata (87 dB), Mumbai (85 dB), Chennai (82 dB), Kochi (80 dB), Madurai (75 dB) and Nagpur (75 dB) are some of the examples of cities suffering from noise pollution.

Effects of Noise Pollution

Continuous and prolonged exposure to noise pollution leads to many disorders and ailments. The most immediate and acute is the impairment of hearing. It also results in mental tension, blood pressure, heart diseases and stomach trouble. Noise pollution also causes annoyance, irritation and fatigue which result in low efficiency and high rate of errors. High and sudden noise may lead to abortion in early stages of pregnancy. According to Kudesia, "It is possible that due to disco dance and rock 'n' roll music we are raising a nation of teenagers who will be hard of hearing before they reach the age of 35 years. Those who listen songs from radio on loud pitch fall in the same line". A study to measure the Noise Induced Hearing Loss (NIHL) among the factory workers in the textile, automobile, fertilizers and chemical industries in Chennai, Coimbatore, Madurai, Kochi and Thiruvananthapuram revealed that about 25% of the factory workers and 10% people such as traffic constables and pavement vendors suffer from NIHL. About 60% of the students in the age group of 5-10 years living in industrial areas, railway colonies and other areas of high noise cannot concentrate on their studies.

Prevention and Control of Noise Pollution

It has been observed that noise pollution, like other forms of pollution, has become a serious problem. Since noise pollution is created by man, it can be controlled by adopting certain measures. Some of the measures are as follows :

(*i*) Noise producing industries should be located away from residential areas.

(*ii*) Inside industries proper arrangements to minimise noise be done by constructing sound proof walls and also to provide such instruments to workers which can protect their ears from noise.

(*iii*) Much of the industrial noise can be reduced by replacement of old noise producing machines with quieter alternatives, proper maintenance, greasing and oiling of the machines.

(*iv*) The automobile horn should be designed in such a way that the noise it produces may not be harmful.

(*v*) Use of horn should be minimum and pressure horn should be banned as has been done in many countries.

(*vi*) Noise pollution by road transport can be reduced by quieter engines, enforcing speed limits and laying the transport routes away from the residential areas such as by-passes. Tree plantation along the road side reduces the noise by 10 to 15 dB.

(*vii*) The noise created by railways can be checked by construction of ballastless rail tracks.

(*viii*) Special arrangements be done to check noise near air bases. Control of aircraft noise requires several changes, which should be done.

(*ix*) Intensity of noise can be reduced to a great extent by proper acoustic designing of cinema, dance and community halls, as well as religious places and other buildings of high noise intensity.

(*x*) The noise created by musical instruments, and other indoor equipments can be checked by individuals in their own interest.

(*xi*) Effect of noise on the ear can be reduced by 40 to 50 dB by putting ear-plugs or earmuffs.

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CHAPTER 10

Population : General Characteristics

SIZE OF INDIAN POPULATION

With a total population of 1,210.2 million according to 2011 census figures, India is the second most populous country of the world, next only to China, a country with a population of 1,341.0 million in 2010. India covers only 2.4 per cent of the land area of the world, but is the home of about 17.5 per cent of the world's population as compared to 19.4 per cent of the world's population living in China. Thus a little more than one out of every six persons in the world is from India. With about 308.7 million population, the USA is the third largest country of the world with respect to population size. However, there is yawning gap of more than 901 million between the population of India and the USA which is about three times the total population of that country. Further it is worth noting that gap between population of India and China is only 130.8 million (*i.e.* 1.9%) while between population of India and the USA is 901.5 million (*i.e.* 13%). Our population is almost equal to the combined population of the USA, Indonesia, Brazil, Pakistan, Bangladesh and Japan put together, the population of these six countries totals 1214.3

TABLE 10.1. Population of ten most populated countries of the world

Sl. No.	Country	Reference date	Population (in millions)	Percentage of total world population
1.	China	01-11-2010	1341.0	19.4
2.	India	01-03-2011	1210.2	17.5
3.	U.S.A.	01.04.2010	308.7	4.5
4.	Indonesia	31.05.2010	237.6	3.4
5.	Brazil	01.08.2010	190.7	2.8
6.	Pakistan	01.07.2010	184.8	2.7
7.	Bangladesh	01.07.2010	164.4	2.4
8.	Nigeria	01.07.2010	158.3	2.3
9.	Russian Fed.	01.07.2010	140.4	2.0
10.	Japan	01.10.2010	128.1	1.9
	Other Countries	01.07.2010	2844.7	41.2
	World	01.07.2010	6908.7	100

Source : Data computed from Census of India 2011, Provisional Population Totals, Paper 1 of 2011 Series 1, p. 39.

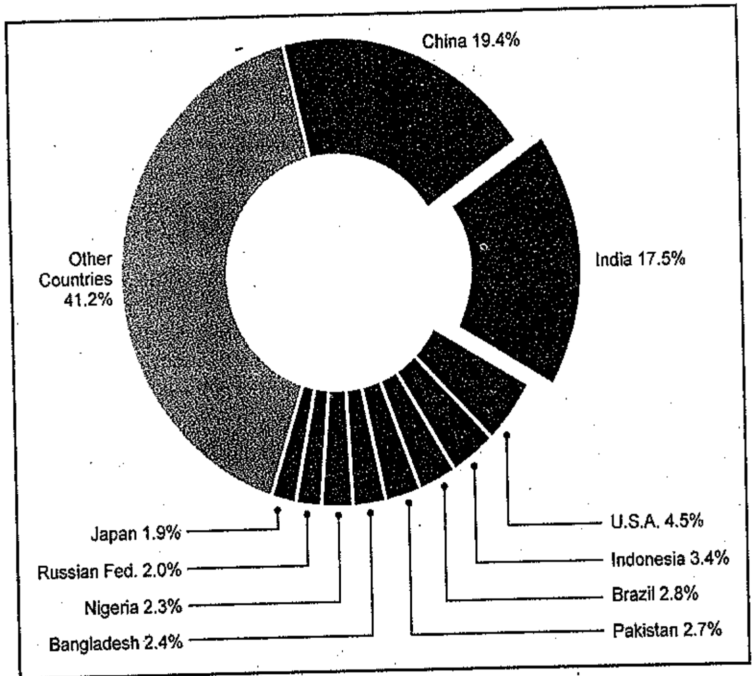

FIG. 10.1. India in world population

million. If we look at the area of the major countries of the world, Russian Federation is more than five times, Canada is over three times, the USA is 2.8 times, Brazil is 2.6 times and Australia is 2.3 times as large as India. But their combined population is only 63 per cent of the total population of India. India's population is a little over twice the population of Latin America and 1.2 times the population of whole of Africa.

Table 10.1 gives an idea of India's dominant position among ten most populous countries of the world.

CENSUS OF POPULATION

Data regarding population are collected through censuses all over the world. A census count offers a spectrum of population at a particular point in time covering a wide range of demographic, social and economic attributes of population. The year 1872 marked the beginning of census taking in India. Although it marked an auspicious beginning, it was neither a synchronous project nor did it cover the entire country. The first complete and synchronous census covering the entire country and providing vital demographic data was conducted in 1881. Since then the census in India has been conducted regularly after every ten years. The 2011 census represents the fifteenth census of India as reckoned from 1872 and seventh after Independence. With a view to widen the scope and improve the quality of census data, modifications in its schedule and questionnaire have been introduced from time to time.

India's population is so large that population of some states is larger or almost equal to the total population of several large countries of the world (*see box on next page*).

Growth of Population : Basic Concepts

1. Growth Rate. Growth of population is the change in the number of people living in a particular area between two given points of time. The net change between two points of time is expressed in percentage and is described as the growth rate of population.

Comparison of population of some Indian states with that of some large countries of the world. Population in millions (2011)	
Indian States	Countries
1. Uttar Pradesh : 199.6	Brazil : 190.7
2. Maharashtra : 112.4	Japan : 128.1
3. Bihar : 103.8	Philippines : 98.0
4. West Bengal : 91.3	Germany : 82.3
5. Madhya Pradesh : 72.6	Egypt : 73.0
6. Gujarat : 60.4	Italy : 59.3, UK : 61.0
7. Odisha : 41.9	Argentina : 41.0
8. Kerala : 33.4	Iraq : 33.0; Afghanistan : 32.9
9. Chhattisgarh : 25.5	Ghana 25.4, Australia : 21.9
10. NCT of Delhi : 16.7	Angola : 16.3

The combined population of Uttar Pradesh and Maharashtra is about 312 million which is substantially greater than the population of U.S.A., third largest country of the world with respect to population.

2. Natural Growth. The difference between the natural birth-rate and death-rate is called the *natural growth* of population.

3. Migratory Growth. This growth of population is caused by migration of people.

4. Positive Growth. When the population increases between two given points of time, it is called ***positive growth***. It takes place when the birth rate is higher than the death-rate or people migrate from other countries.

5. Negative Growth. The growth of population is called ***negative*** if the population decreases between two given points of time. It takes place if the birth-rate is lower than the death-rate or people migrate to other places.

There has always been positive growth rate of population in India ever since first census of India was conducted. However, 1921 is an exception when the growth was negative.

Several attempts have been made to estimate the population of India before first census was conducted in 1872. According to an estimate, India's population was just 100 million in 1600 A.D. It rose to 120 million in 1800, 130 million in 1841, and 255 million in 1871. This can be termed as a negligible growth compared to the present trends.

Population Growth Since 1901

Trends in population growth since 1901 have been given in Table 10.2. A close look at this table shows that there have been significant demographic divides as far as trends in population growth are concerned. These significant turning points are the census years 1921, 1951 and 1981. Thus the demographic history of India can be charted and classified into the following four distinct phases.

1. Period of Stagnant Population (1901-1921)
2. Period of Steady Growth (1921-1951)
3. Period of Rapid High Growth (1951-1981)
4. Period of High Growth with Definite Signs of Slowing Down (1981-2011)

1. Period of Stagnant Population (1901-1921)

During most of the 19th century India witnessed sporadic, irregular and slow growth of population which drifted into twentieth century until 1921. Thus the population growth during this period can be termed more or less stagnant when compared to the growth rates observed during the consequent periods. The high birth rate was counterbalanced by high death rate. The progressive growth rate in 1921 over 1901 was only 5.42 per cent. In fact, the census year 1921 registered a negative growth rate of –0.31 per cent which happened only once throughout the demographic history of India. It is because of this decline in place of rise in population that the year 1921 is called the ***'demographic divide'*** in the demographic history of India. The high mortality during this period was the product of large scale abnormal deaths due to epidemics of influenza, plague, small pox, cholera, etc. Influenza alone claimed 12 million lives in 1918. Food shortages caused by severe droughts in 1911, 1913, 1915, 1918 and 1920 claimed their own toll. In addition, thousands of Indian soldiers lost their lives during the World War I (1914-18). Lakhs of people emigrated to a number of countries in Africa.

From the view point of population studies, India has been divided into six zones. They are : (*i*) **northern zone** (Haryana, Himachal Pradesh, Jammu and Kashmir, Punjab, Rajasthan, Chandigarh and Delhi), (*ii*) **eastern zone** (Bihar, Jharkhand, Sikkim,

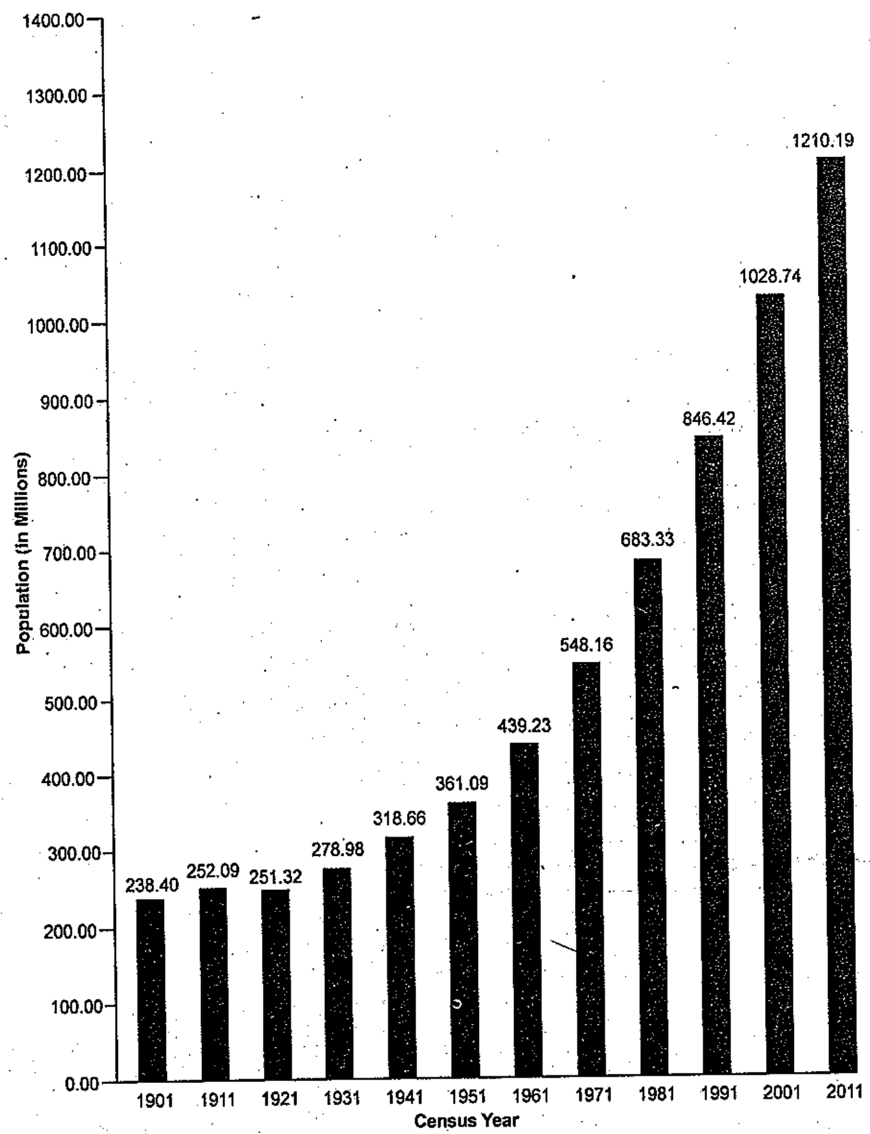

FIG. 10.2. India : Decadal Growth of Population 1901-2011.

West Bengal, Odisha and Andaman and Nicobar Islands), (*iii*) **north-east zone** (Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland and Tripura), (*iv*) **central zone** (Chhattisgarh, Madhya Pradesh, Uttar Pradesh, Uttarakhand), (*v*) **western zone** (Gujarat, Maharashtra, D & N Haveli, Daman and Diu) and, (*vi*) **southern zone** (Andhra Pradesh, Telangana, Karnataka, Kerala, Tamil Nadu, Lakshadweep, Telangana, Puducherry and Goa.)

During the period 1901-1921, the northern zone suffered a net loss of 1.4 per cent of its population due to various famines and epidemics. In contrast the north-eastern zone registered a very high growth rate mainly due to large scale inmigration/immigration and to some extent lesser sufferings from famines and epidemics. Assam, Manipur, Tripura and Nagaland experienced very high population growth. Assam attracted large number of immigrants in its tea gardens. The southern zone experienced normal growth rate of 11.1 per cent because it did not suffer from famines and epidemics. However, Kerala was an exception which registered a sharp growth of 22 per cent.

2. Period of Steady Growth (1921-51)

During 1921-51, the population of India increased from 251 million to 361 million (Table 10.2). This duration of 30 years has thus registered a growth of 47.3 per cent. Therefore, this period is called the period of steady growth rate. The mortality rate started showing downward trend as a result of improvement in general health and sanitation conditions after 1921. These developments helped in controlling epidemics like plague, cholera and malaria. The crude death rate which stood at a high of 47 per thousand in 1921 declined to 27 per thousand in 1951 (*see* **table 10.3**). On the contrary, the crude birth rate continued to stay at an abnormally high level and decline only to 40 per thousand in 1951 as against 48 per thousand in 1921. Decline in death rate was also achieved partly through the improvement in

TABLE 10.2. Decadal Growth Rates in India, 1901-2011

Census Year	Total Population	Growth Rate* Absolute Number	Growth Rate* % of Growth
1901	238396327	.....	.....
1911	252093390	(+) 13697063	(+) 5.75
1921	251321213	(–) 772117	(–) 0.31
1931	278977238	(+) 27656025	(+) 11.00
1941	318660580	(+) 39683342	(+) 14.22
1951	361088090	(+) 42427510	(+) 13.31
1961	439234771	(+) 78146681	(+) 21.64
1971	548159652	(+) 108924881	(+) 24.80
1981	683329097	(+) 135169445	(+) 24.66
1991	846421039	(+) 163091942	(+) 23.87
2001	1028737436	(+) 182316397	(+) 21.54
2011	1210193422	(+) 181455986	(+) 17.64

*Decadal growth rate : $g = \frac{P_2 - P_1}{P_2} \times 100$

Where P_1 = Population of the base year

P_2 = Population of the present year

Source : Census of India, 2011, Provisional Population Totals Paper 1, p. 41.

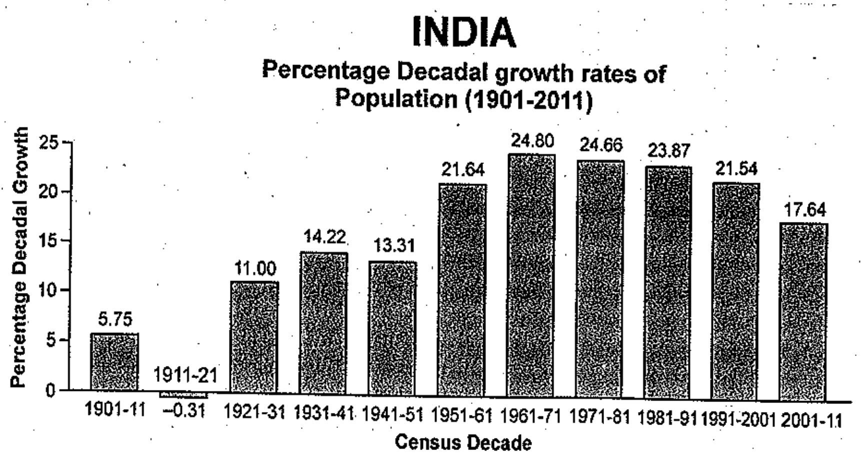

FIG. 10.3. India's Percentage Decadal Growth Rates of Population 1901-2011

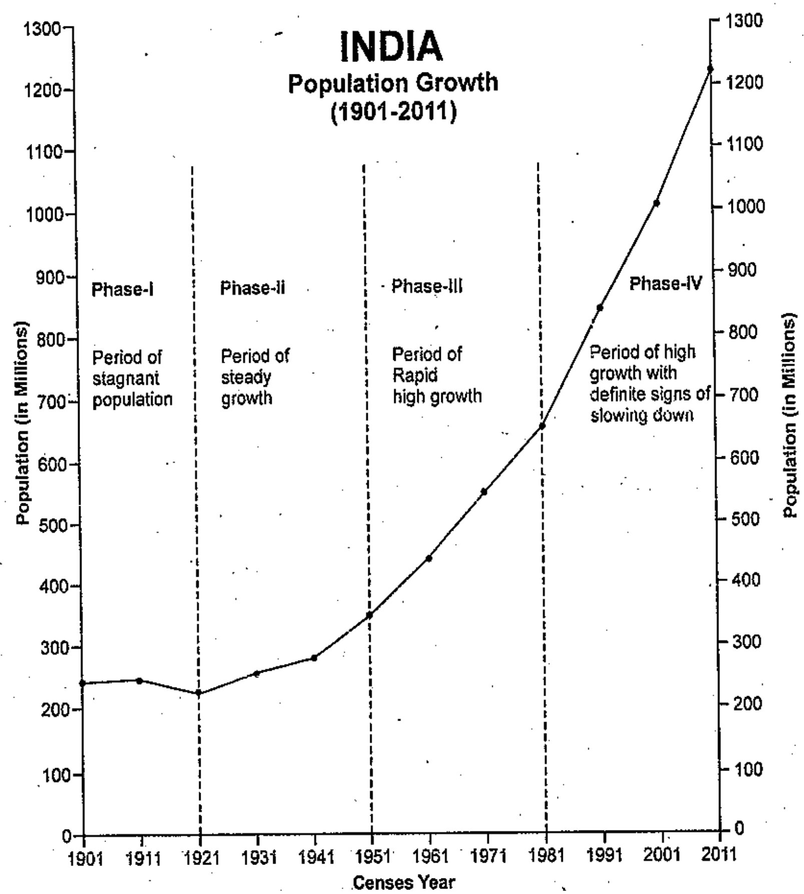

FIG. 10.4. India : Population Growth : 1901-2011

the distribution system as a result of improved transportation so that timely supplies of food could be made available to drought and famine stricken areas. The combined effect of these factors was that the population started increasing steadily. Since crude death rate declined considerably and crude birth rate remained very high, the population growth during this period is called ***mortality induced*** growth. During this period, the northern, eastern and southern zones registered growth rates close to the national average. The central zone registered comparatively low growth rate of 35.6 mostly due to higher rate of mortality and substantial out migration. The western zone experienced high growth rate of 56 per cent partly due to national growth and mainly due to immigration caused by industrial growth in Mumbai, Ahmedabad, Vadodara and Surat.

3. Period of Rapid High Growth (1951-81)

After 1951, there was a steep fall in the mortality rate but the fertility remained stubbornly high. Therefore, this period experienced very high rate of population growth and is often referred to as the ***period of population explosion***. As a matter of fact, the birth rate increased from 40 per thousand in 1951 to 42 per thousand in 1961 and stayed at 36 per thousand in 1981. In contrast, death rate fell rapidly from 27 per thousand in 1951 to 12 per thousand in 1981. Consequently the natural rate of growth, which fell slightly from 14.0 per thousand in 1941 to 13 per

TABLE 10.3. India—Changing Birth Rates, Death Rates and Natural Increase, 1911-2009

Year	Crude Birth rate per thousand	Crude Death rate per thousand	Natural rate of increase per thousand
1911	49	43	6
1921	48	47	1
1931	46	36	10
1941	45	31	14
1951	40	27	13
1961	42	23	19
1971	39	15	24
1981	36	12	24
1991	31	11	20
2001	25	8	17
2009	22.5	7.3	15.2

*Census of India, Sample Registration System (SRS) Bulletin.

thousand in 1951 rose steeply to 4 per thousand in 1971 and remained at the same level in 1981 also. The total population of the country increased from 361.09 million in 1951 to 683.3 million in 1981 recording an increase of 89.36 per cent in a short span of thirty years. This unprecedented growth rate was due to the accelerated developmental activities and further improvement in health facilities. The living conditions of the people improved enormously. Death rates declined much faster than the birth rates (**Table 10.3**). This situation resulted in high natural increase. Thus, it was ***fertility induced growth.*** During this period, the northern zone experienced the high growth rate of 111 per cent whereas the southern zone, which had higher than the national average during 1901-21 and 1921-51 had the lowest growth rate during 1981-81.

4. Period of High Growth Rate with Definite Signs of Slowing Down (1981-2011)

The last phase of 20th century and the early phase of 21st century *i.e.*, the period between census years 1981 and 2011 is known as the period of high growth with definite signs of slowing down. Although the rate of growth was still very high, it started declining after 1981. The highest ever growth rate of 2.48 per cent was recorded in 1971 which remained at a high of 2.46 in 1981 also. It declined to 2.38 per cent in 1991, 2.15 per cent in 2001 and further to 1.76 in 2011. Thus the growth rate registered the sharpest declines of 2.46 per cent per annum during the decade 2001-2011. During the period 1981-2011, the northern zone and the southern zone had the highest and lowest growth rates respectively. This declining trend marks the beginning of the new era in the country's demographic history. During this period, birth rate declined rapidly, from 36 per thousand in 1981 to 22.5 per thousand in 2009 (**Table 10.3**). Declining trend of death rate continued but at a slower rate. The difference between birth and death rates narrowed to 15.2 per thousand. This declining trend is a positive indicator of the official efforts of birth control and people's own inclination to opt for smaller families. Although population growth rate in India continues to decline since the 1971 census year yet India's population growth rate is much higher as compared to that of China, U.S.A., Japan, Brazil, Indonesia, Bangladesh, etc. (**Fig. 10.5**). Russian Federation and some other European countries have recorded negative growth. During 2001 and 2011, India's population increased by 181.45 million which is slightly less than the total population of Brazil and much more than that of Bangladesh, Nigeria, Russian Federation or Japan. These countries are amongst the ten most populated countries of the world. In fact we, each year we are adding to our population which is almost equal to the population of Australia.

According to the United Nations population report released on June 13, 2013, India would pip China as the most populated country in the world by 2028 when India's population will be about 1448 million as compared to China's 1443 millions. The report based on new fertility data says that India's population would increase to 1620 million till 2050 and then decline to around 1540 million by the end of the 21st century. China would enter the downturn era in population from 2025 onwards and lose its top spot to India in 2028.

Growing longivity will be another major factor responsible for population growth as the life expectancy would increase from 64.9 years in 2013 to 80.6 years in 2100 and would just be one per cent point below the global average. Now it is 2.2 per cent

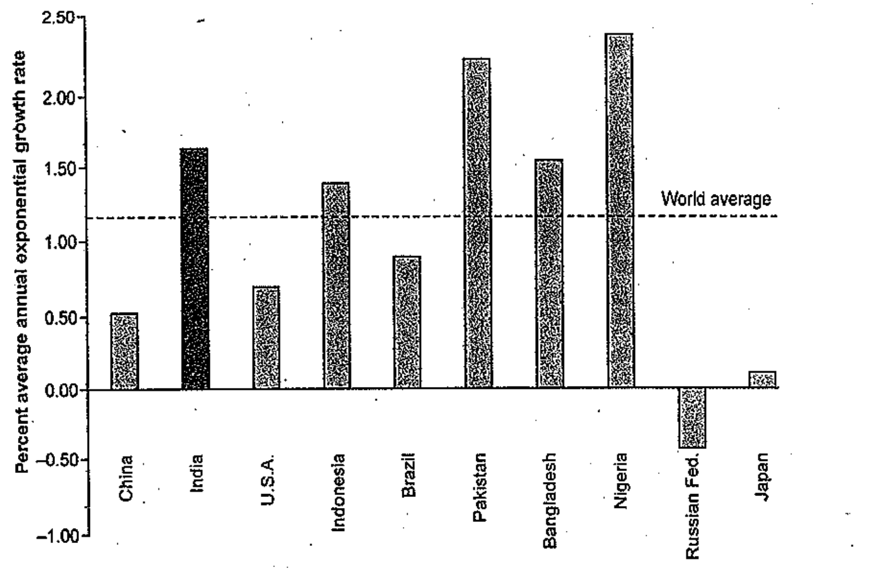

FIG. 10.5. Population Growth Rate of Ten most populated countries of the world (2000-2010)

points below the world average of 67.1 years. However, the fertility rate per woman will fall below 2 in 2050 to 1.84 in 2100. It would result in proportion of the children below the age of 14 years to fall by ten percentage points between 2013 and 2050. Even this fall will not help India much in

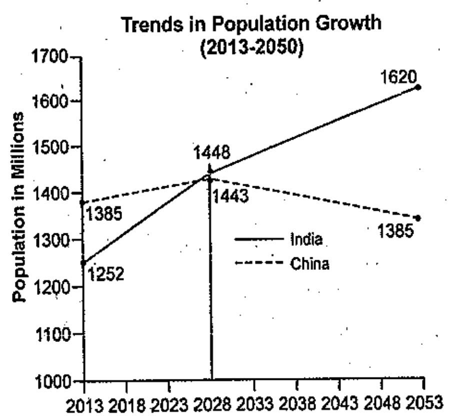

FIG. 10.6. Trends in population growth in India and China from 2013 to 2050 according to UN Department of Economics and Social Affairs.

controlling the population growth because the base population would be too large for any desired results.

The report also says that India will have one of the worst sex ratios in the world. India's sex ratio could be behind only the Middle East. Presently, India has 107 men for every 100 women, a ratio worse than Pakistan, Bangladesh and Sri Lanka. The world population will increase from 7162 million in 2013 to 8193 million in 2028 and 9580 million in 2050.

Demographic Transition. Demographic transition is the process of change in population of a society. It consists of the following four stages :

(*a*) ***Stage 1.*** High death and birth rates, low growth rate.

(*b*) ***Stage 2.*** Rapid decline in death rate, continued high birth rate, very high growth rate.

(*c*) ***Stage 3.*** Rapid decline in birth rate, continued decline in death rate, growth rate begins to decline.

(*d*) ***Stage 4.*** Low death and birth rates, low growth rate.

The story of population growth in India is fairly in tune with the classical theory of demographic transition. During most of the nineteenth century India witnessed a fluctuating but ultimately more or less a stagnant growth of population, which drifted into the twentieth century until 1921. Thereafter, country passed through successively all the phases of demographic transition and is now widely believed to have entered the final phase which is normally characterised by rapidly declining fertility. It is yet to be seen as to how long will this phase extend and when India will achieve a stable population. However UN Department of Economics and Social Affairs has estimated that India's population will continue to increase till 2050 when it will reach a staggering figure of 1620 millions after which it will start decreasing and by the end of 21st century it will stand at 1540 million.

Spatio-Temporal Variations in Population Growth

The average population growth rate of 17.64 per cent during 2001-11 does not give true picture as there are differences in the growth rate with reference to space and time. These are called spatio-temporal variations in population growth. There can be different reasons for differential growth-rate in different parts of India. A study of **Table 10.4** and **Fig. 10.7** gives an idea of regional variations in population growth.

Exactly half of the 20 most populous states, each with a population of ten million or more, have added lesser persons in the decade 2001-2011 compared to the decade 1991-2001. Had these ten states added the same number of persons during 2001-2011 as they did in the previous decade, India would have added another 9.7 million more persons during this decade. The phenomenon of low growth has spread beyond the boundaries of the southern states during 2001-2011, where in addition to Andhra Pradesh, Tamil Nadu and Karnataka in the south, Himachal Pradesh and Punjab in the north, West Bengal and Odisha in the east and Maharashtra in the west have registered growth rate between 11 and 16 per cent in 2001-2011.

Among the smaller states and union territories, Dadar and Nagar Haveli and Daman and Diu registered the highest growth rate of 55.5 and 53.54 per cent respectively. In contrast, Lakshdweep, Andaman Nicobar Islands and Goa have registered low growth rate remaining in single digit only. A glaring down trend in the growth has been observed in Nagaland, where there had been a steep fall in growth rate from 64.53 per cent in 1991-2001 to negative growth rate of –0.47 per cent. The second minimum growth of 4.86 per cent has been recorded by Kerala. This state has reached high level of demographic transition and can be easily compared with the advanced countries of Europe and America. Some of the more populous states have registered very high growth rate of over 20 per cent. Among them Bihar (25.07%), Jammu & Kashmir (23.71%), Chhattisgarh (22.59%) and Jharkhand (22.34) are worth noting. Some other states with small population but higher growth rate are Meghalaya (27.82%) and Arunachal Pradesh (25.92%).

Fifteen states and union territories registered a decline of over five percentage points in decadal growth rate from the previous census decade. These states and union territories are Jammu & Kashmir, Punjab, Haryana, Rajasthan, Uttar Pradesh, Sikkim, Nagaland, Manipur, Mizoram, Maharashtra, Goa, Delhi, Chandigarh, Lakshadweep and Andaman and Nicobar Islands and account for more than 39% of India's population. Delhi has registered the sharpest drop of 26 percentage points during 2001-2011, followed by Haryana (8.53), Rajasthan (6.97) and Maharashtra (6.74). Seventeen stages and union territories have shown 1 to 5 per cent points fall in their growth rates during 2001-11 as compared to 1991-2011. These states and union territories account for more than 52% of total population of India. Thus more than nine out every ten Indians live in states and union territories that have registered declining trend in population growth.

TABLE 10.4. Population, percentage decadal growth and average annual exponential growth rates 1991-2001 and 2001-2011

State/UT Code	India/State/Union Territory	Total Population		Percentage Decadal growth	
		2001	2011	1991-2001	2001-2011
1	2	3	4	5	6
	INDIA	1,02,87,37,436	1,21,01,93,422	21.54	17.64
1	Jammu & Kashmir	1,01,43,700	1,25,48,926	29.43	23.71
2	Himachal Pradesh	60,77,900	68,56,509	17.54	12.81
3	Punjab	2,43,58,999	2,77,04,236	20.1	13.73
4	Chandigarh	9,00,635	10,54,686	40.28	17.1
5	Uttarakhand	84,89,349	1,01,16,752	20.41	19.17
6	Haryana	2,11,44,564	2,53,53,081	28.43	19.9
7	NCT of Delhi	1,38,50,507	1,67,53,235	47.02	20.96
8	Rajasthan	5,65,07,188	6,86,21,012	28.41	21.44
9	Uttar Pradesh	16,61,97,921	19,95,81,477	25.85	20.09
10	Bihar	8,29,98,509	10,38,04,637	28.62	25.07
11	Sikkim	5,40,851	6,07,688	33.06	12.36
12	Arunachal Pradesh	10,97,968	13,82,611	27	25.92
13	Nagaland	19,90,036	19,80,602	64.53	–0.47
14	Manipur	22,93,896	27,21,756	24.86	18.65
15	Mizoram	8,88,573	10,91,014	28.82	22.78
16	Tripura	31,99,203	36,71,032	16.03	14.75
17	Meghalaya	23,18,822	29,64,007	30.65	27.82
18	Assam	2,66,55,528	3,11,69,272	18.92	16.93
19	West Bengal	8,01,76,197	9,13,47,736	17.77	13.93
20	Jharkhand	2,69,45,829	3,29,66,238	23.36	22.34
21	Odisha	3,68,04,660	4,19,47,358	16.25	13.97
22	Chhattisgarh	2,08,33,803	2,55,40,196	18.27	22.59
23	Madhya Pradesh	6,03,48,023	7,25,97,565	24.26	20.3
24	Gujarat	5,06,71,017	6,03,83,628	22.66	19.17
25	Daman & Diu	1,58,204	2,42,911	55.73	53.54
26	Dadra & Nagar Haveli	2,20,490	3,42,853	59.22	55.50
27	Maharashtra	9,68,78,627	11,23,72,972	22.73	15.99
28	Andhra Pradesh	7,62,10,007	8,46,65,533	14.59	11.10
29	Karnataka	5,28,50,562	6,11,30,704	17.51	15.67
30	Goa	13,47,668	14,57,723	15.21	8.17
31	Lakshadweep	60,650	64,429	17.3	6.23
32	Kerala	3,18,41,374	3,33,87,677	9.43	4.86
33	Tamil Nadu	6,24,05,679	7,21,38,958	11.72	15.6
34	Puducherry	9,74,345	12,44,464	20.62	27.72
35	Andaman & Nicobar Islands	3,56,152	3,79,944	26.9	6.68

Source: Census of India, 2011; Provisional Population Totals, paper 1. p. 54.

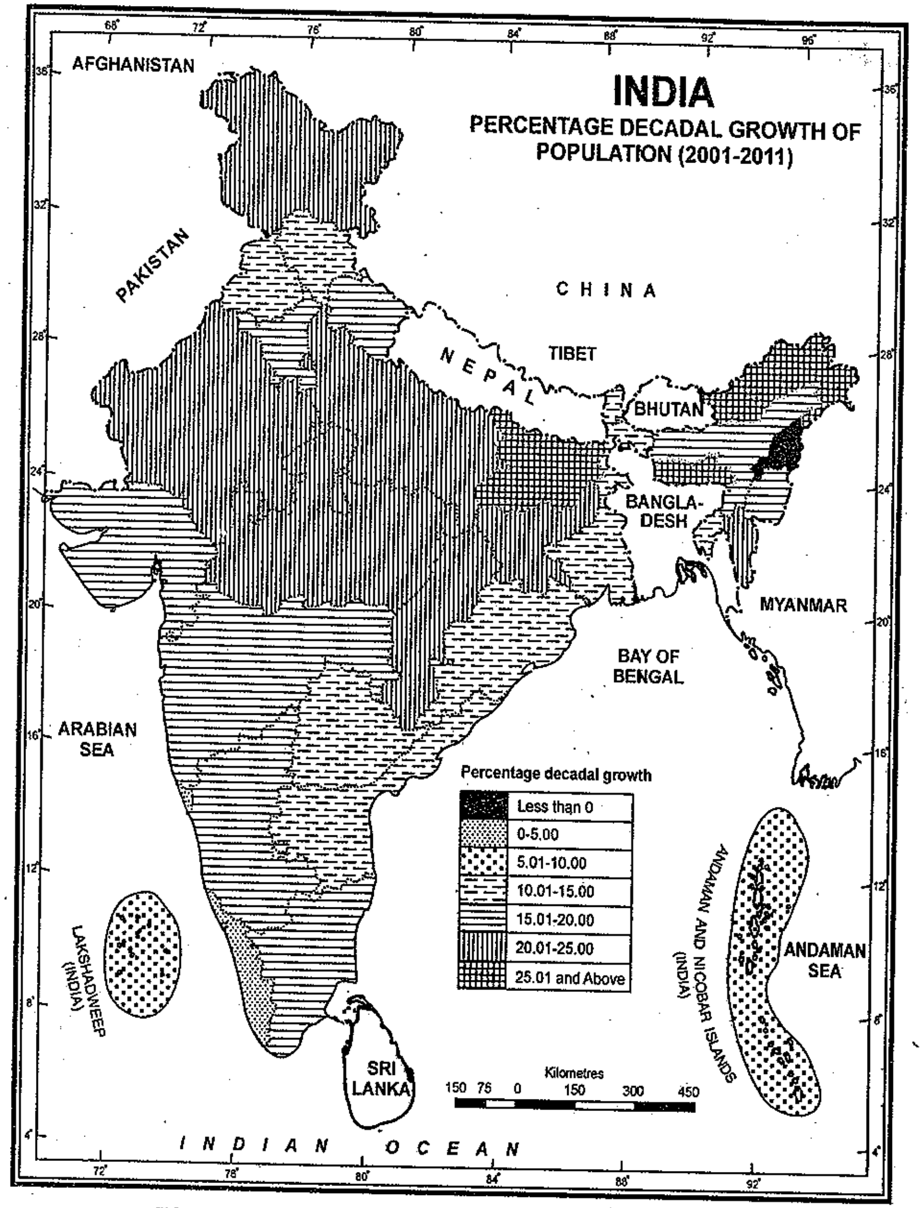

FIG. 10.7. India : Percentage decadal; growth of population (2001-2011)

Table 10.6 gives the distribution of states and union territories by ranges of percentage decadal growth as well as the percentage of population of these states and union territories which highlights the major shift in the distribution of states and union territories by ranges of growth rates between 1991-2011 and 2001-11. The number of states and union territories with percentage decadal growth below the

TABLE 10.5. States and union Territories arranged in descending order of growth rate or population : 1991 -2001 to 2001-2011

Rank	India/State/ Union Territory#	1991 -2001	India/State/ Union Territory#	2001 -2011
1	Nagaland	64.53	Dadra & Nagar Haveli#	55.50
2	Dadra & Nagar Haveli#	59.22	Daman & Diu#	53.54
3	Daman & Diu#	55.73	Meghalaya	27.82
4	NCT of Delhi#	47.02	Puducherry#	27.72
5	Chandigarh#	40.28	Arunachal Pradesh	25.92
6	Sikkim	33.06	Bihar	25.07
7	Meghalaya	30.65	Jammu & Kashmir	23.71
8	Jammu & Kashmir	29.43	Mizoram	22.78
9	Mizoram	28.82	Chhattisgarh	22.59
10	Bihar	28.62	Jharkhand	22.34
11	Haryana	28.43	Rajasthan	21.44
12	Rajasthan	28.41	NCT of Delhi#	20.96
13	Arunachal Pradesh	27.00	Madhya Pradesh	20.30
14	Andaman & Nicobar Islands#	26.90	Uttar Pradesh	20.09
15	Uttar Pradesh	25.85	Haryana	19.90
16	Manipur	24.86	Uttarakhand	19.17
17	Madhya Pradesh	24.26	Gujarat	19.17
18	Jharkhand	23.36	Manipur	18.65
19	Maharashtra	22.73	**INDIA**	**17.64**
20	Gujarat	22.66	Chandigarh#	17.10
	INDIA	**21.54**	Assam	16.93
21	Puducherry#	20.62	Maharashtra	15.99
22	Uttarakhand	20.41	Karnataka	15.67
23	Punjab	20.10	Tamil Nadu	15.60
24	Assam	18.92	Tripura	14.75
25	Chhattisgarh	18.27	Odisha	13.97
26	West Bengal	17.77	West Bengal	13.93
27	Himachal Pradesh	17.54	Punjab	13.73
28	Karnataka	17.51	Himachal Pradesh	12.81
29	Lakshadweep#	17.30	Sikkim	12.36
30	Odisha	16.25	Andhra Pradesh	11.10
31	Tripura	16.03	Goa	8.17
32	Goa	15.21	Andaman & Nicobar Islands#	6.68
33	Andhra Pradesh	14.59	Lakshadweep#	6.23
34	Tamil Nadu	11.72	Kerala	4.86
35	Kerala	9.43	Nagaland	-0.47

Union Territory

Source : Census of India, Provisional Population Totals, Paper 1 of 2011 Series 1, p. 167.

TABLE 10.6. Number of states and union territories by range of percentage decadal growth rates 1991-2001 and 2001-2011

Percentage decadal growth	Number of states/ union territories 1991-2001	Percentage of population to total population 2001	Number of states/ union territories 2001-2011	Percentage of population to total population 2011
12 and below	2	9.16	6	10.08
12-15	1	7.41	6	14.22
15-18	7	17.55	5	22.96
18-21	5	7.9	7	32.02
21-24	3	16.96	5	11.63
24-27	4	22.28	2	8.69
27-30	6	16.8	2	0.35
30 and above	7	1.94	2	0.05

Source : Census of India 2011, Provisional Population Totals, Paper I of 2011, Series 1, p. 56

national average of 17.64% has increased substantially from 10 in 1991-2001 to 17 in 2001-11 and the number of states and union territories with percentage decadal growth above the national average growth has reduced significantly from 25 to 18. The sum of total population of states and union territories which registered less than the national average has shown an impressive increase from about 34 per cent in 2001 to 47 per cent in 2011. As many as 12 states and union territories with a combined population of slightly more than 24 per cent of India have grown by less than 15 per cent during 2001-11. The number of such states and union territories was only 3 during 1991-2001.

Population Growth in EAG and non-EAG States

The demographic centre of gravity shifted from the Indus Valley into the Gangatic plain after the immigration by the Aryans about 3500 years ago. The patterns of growth rates in India remained more or less similar to those prevailing throughout the historic

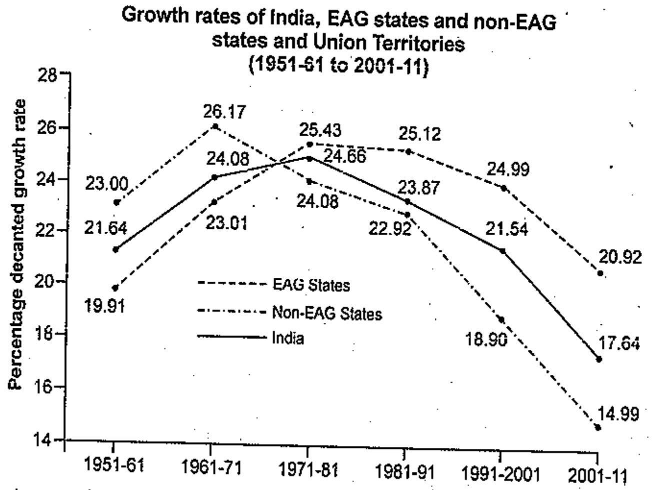

FIG. 10.8. Growth rates of India, EAG states and non-EAG states and union territories 1951-61 to 2001-2011

times. For a close analysis, the Indian states and union territories are divided into two broad groups namely Empowered Action Group (EAG) and non Empowered Action Group (non-EAG). EAG includes Rajasthan, Uttar Pradesh, Uttarakhand, Bihar, Jharkhand, Madhya Pradesh, Chhattisgarh and Odisha. The remaining states and union territories are included in non-EAG. **Fig. 10.8** shows the growth trajectory of India, the EAG group and the non-EAG group of states from 1951-1961 to 2011-2011. The EAG states hosted between 43 and 46 per cent of India's population.

During the period of two decades between 1951 and 1971, population of both EAG and non-EAG states and union territories increased which led to overall increase in population of India. During this period, the population of non-EGA states grew at a faster rate as compared to that of EAG states. From 1971 onwards, the growth rate in non-EAG states and union territories declined continuously due to decline in fertility rate. The growth rate in EAG states almost stagnated around 25 per cent. During 1991-2001, the growth rate for EAG states remained same as that in the previous decade, whereas there was continuous reduction in the growth rate of non-EAG states and union territories. This was primarily responsible for bringing about a significant fall of about 2.3 per cent in the growth rate of the country as a whole. During 2001-2011, for the first time in the demographic history of the country, the growth momentum for EAG states has given the signal of slowing down, falling by about 4 per cent points. Thus, together with similar reduction in non-EAG states and union territories has brought down the rate of growth for the country by 3.9 per cent. In fact, census 2011 marks a milestone in the demographic history of the country, as it is perhaps for the first time, there is significant fall in the growth rate of population in the EAG states after decades of stagnation.

District Level Patterns. Regional variations in population growth come in sharp focus when studied at the district level. Spatio-temporal variations in population growth are much larger at the district level as compared to the state level. It is important to note that the number of districts was 466 in 1991 which increased to 593 in 2001 and 640 in 2011 because several states came out with the creation of new districts for various political, social economic and administrative reasons. **Table 10.7** presents a frequency distribution of districts according to their 1991-2001 and 2001-2011 decadal growth rates. Decadal growth rates for 1991-2001 have been presented according to data for 640 districts and, therefore, may not tally with earlier analysis.

This table shows that 102 districts had very high growth rate of over 30 per cent in 1991-2001 and this number was reduced to 47 in 2001-11. Similarly the number of districts with growth rate 25.01-30.00 was reduced from 127 in 1991-2001 to 72 in 2001-11 and the number of districts with 20.01-25.00 growth rate was reduced from 132 in 1991-2001 to 108 in 2011-11. Wokha district of Nagaland had a population of 161,098 in 2001 and registered a very high growth rate of 95.16 per cent. Kiphire district of Nagaland registered the highest growth rate of 95.64 per cent in 1991-2001 (**Table 10.8**). Most districts in the north-eastern states registered growth rates during 1991-2001 which were much higher than the national average, and this was largely due to in-migration.

In contrast, the number of districts in lower growth range increased considerably. For example, the number of districts with 0-10 per cent growth rate increased from 58 in 1991-2001 to 89 in 2001-11. Similarly, the number of districts with negative growth rate has increased from 3 in 1991-2001 to 19 in 2001-11 (*see* **Table 10.7**). Majority of these

TABLE 10.7. Distribution of districts according to decadal population growth rate, 1991-01 and 2011-11

Decadal growth rate (per cent)	Number of districts 1991-2001	2001-11
Above 30.00	102	47
25.01-30.00	127	72
20.01-25.00	132	108
16.01-20.00	134	155
10.01-15.00	84	150
0.01-10.00	58	89
0 and Below	3	19
Total	640	640

Source : Census of India 2011, Series 1, India, *Provisional Population Totals*, Paper 1 of 2011; Districtwise data on *censusindia.gov.in* website.

districts are in Kerala and Tamil Nadu. These two states registered decadal growth rate of 9.43 per cent and 11.72 per cent respectively in 1991-2001. This achievement was made possible by decline in natural growth rate and outmigration from these districts.

It is worth noting that twelve districts including Mumbai, Kolkata and New Delhi (basically urban districts with no scope for growth) had growth rates below five per cent. Further, 'central' Delhi district and Mamit district in Mizoram had negative growth rates for different reasons.

It is important to note that in 1991-2001, six out of ten districts recording highest growth rate in India were in Nagaland. This situation has completely been reversed as there was not even a single district in the whole of Nagaland with high growth rate in 2001-11.

As a matter of fact, three of the districts which recorded high growth rate during 1991-2001 (Kiphire, Longleng and Mon) registered negative growth rate during 2001-11. Longleng district of Nagaland recorded largest negative growth rate of –58.39% during 2001-11. In addition to the above mentioned three districts of Nagaland, Lahul and Spiti (Himachal Pradesh), Mumbai (Maharashtra), Zunheboto and Mokokchung (Nagaland), Central Delhi, New Delhi, Nicobars (Andaman and Nicobar Islands) also recorded negative growth rate of more than –5.0 per cent during 2001-11 (Table 10.8). Although factors leading to negative growth rate in most districts of Nagaland requires close examination, negative growth rate in Central Delhi and New Delhi is largely due to outmigration.

TABLE 10.8. Ten districts with highest decadal growth rates, 1991-01 and 2001-11 and ten districts with lowest decadal growth rates, 1991-01 and 2001-11

State/UT	District	1991-01	State/UT	District	2001-11
Ten districts with highest decadal growth rates					
Nagaland	Kiphire	95.64	Arunachal	Kurung Kumey	111.01
Nagaland	Wokha	95.16	Puducherry	Yanam	77.15
Nagaland	Dimapur	86.13	Haryana	Gurgaon	73.93
Daman & Diu	Daman	83.55	Daman & Diu	Daman	67.43
Nagaland	Longleng	79.58	Dadra & N Haveli	Dadra & Nagar Haveli	55.50
Nagaland	Mon	70.12	Uttar Pradesh	Gautam Buddha Nagar	51.52
Nagaland	Tuensang	69.20	Arunachal	Upper Subansiri	50.34
Arunachal	Papumpare	67.56	Arunachal	Lower Subansiri	48.65
Manipur	Chandel	66.62	Andhra Pradesh	Rangareddy	48.15
Delhi	North East	62.92	Karnataka	Bengaluru	46.68
Ten districts with lowest decadal growth rates					
Tamil Nadu	Kanniyakumari	4.73	Maharashtra	Ratnagiri	-4.96
Maharashtra	Sindhudurg	4.41	Himachal Pradesh	Lahul & Spiti	-5.10
Tamil Nadu	Theni	4.25	Maharashtra	Mumbai	-5.75
West Bengal	Kolkata	3.93	Nagaland	Zunheboto	-8.79
Uttarakhand	Garhwal	3.91	Delhi	Central	-10.48
Kerala	Pathanamthitta	+3.84	A & N Islands	Nicobars	-12.39
Uttarakhand	Almora	3.67	Nagaland	Mokokchung	-16.77
Assam	Chirang	-0.08	Delhi	New Delhi	-25.35
Delhi	Central	-1.55	Nagaland	Kiphire	-30.54
Mizoram	Mamit	-2.77	Nagaland	Longleng	-58.39

Source : Census of India 2011.

TABLE 10.9. India : Child Population in the age group 0–6 (2011)

India/State/Union Territory	Person	Male	Female	Decadal Change 2001-11	Percentage proportion of child population to total population
INDIA	**15,87,89,287**	**8,29,52,135**	**7,58,37,152**	**-50,48,108**	13.12
Uttar Pradesh	2,97,28,235	1,56,53,175	1,40,75,060	-18,96,393	14.90
Bihar	185,82,229	96,15,286	89,66,949	17,76,166	17.90
Maharashtra	1,28,48,375	68,22,262	60,26,113	-8,22,751	11.43
Madhya Pradesh	1,05,48,295	55,16,957	50,31,338	-2,33,919	14.50
Rajasthan	1,05,04,916	55,80,212	49,24,704	-1,46,086	15.31
West Bengal	1,01,12,599	51,87,264	49,25,335	-13,01,623	11.07
Andhra Pradesh	86,42,686	44,48,330	41,94,356	-15,29,171	10.21
Gujarat	74,94,176	39,74,286	35,19,890	-38,228	12.41
Tamil Nadu	68,94,821	35,42,351	33,52,470	-3,40,339	9.56
Karnataka	68,55,801	35,27,844	33,27,957	-3,26,299	11.21
Jharkhand	52,37,582	26,95,921	25,41,661	2,80,755	15.89
Odisha	50,35,650	26,03,208	24,32,442	-3,23,160	12.00
Assam	45,11,307	23,05,088	22,06,219	13,232	14.47
Chhattisgarh	35,84,028	18,24,987	17,59,041	29,112	14.03
Kerala	33,22,247	16,95,935	16,26,312	-4,70,899	9.95
Haryana	32,97,724	18,02,047	14,95,677	-37,813	13.01
Punjab	29,41,570	15,93,262	13,48,308	-2,30,259	10.62
Jammu & Kashmir	20,08,642	10,80,662	9,27,980	5,22,839	16.01
NCT of Delhi[#]	19,70,510	10,55,735	9,14,775	-46,339	11.76
Uttarakhand	13,28,844	7,04,769	6,24,075	-31,188	13.14
Himachal Pradesh	7,63,864	4,00,681	3,63,183	-29,273	11.14
Meghalaya	5,55,822	2,82,189	2,73,633	87,843	18.75
Tripura	4,44,055	2 27,354	2,16,701	7,609	12.1
Manipur	3,53,237	1,82,684	1,70,553	26,871	12.98
Nagaland	2,85,981	1,47,111	1,38,870	-3,697	14.44
Arunachal Pradesh	2,02,759	1,03,430	99,329	-3,112	14.66
Mizoram	1,65,536	83,965	81,571	21,802	15.17
Goa	1,39,495	72,669	66,826	-6,473	9.57
Puducherry[#]	1,27,610	64,932	62,678	10,451	10.25
Chandigarh[#]	1,17,953	63,187	54,766	2,340	11.18
Sikkim	61,077	31,418	29,659	-17,118	10.05
Dadra & Nagar Haveli[#]	49,196	25,575	23,621	8,997	14.90
Andaman & Nicobar Islands[#]	39,497	20,094	19,403	-5,284	10.40
Daman & Diu[#]	25,880	13,556	12,324	5,302	10.65
Lakshadweep[#]	7,088	3,715	3,373	-2,003	11.00

Source : Census of India 2011, Provisional Population Totals, Paper 1 of 2011, Series 1, pp. 64-65.

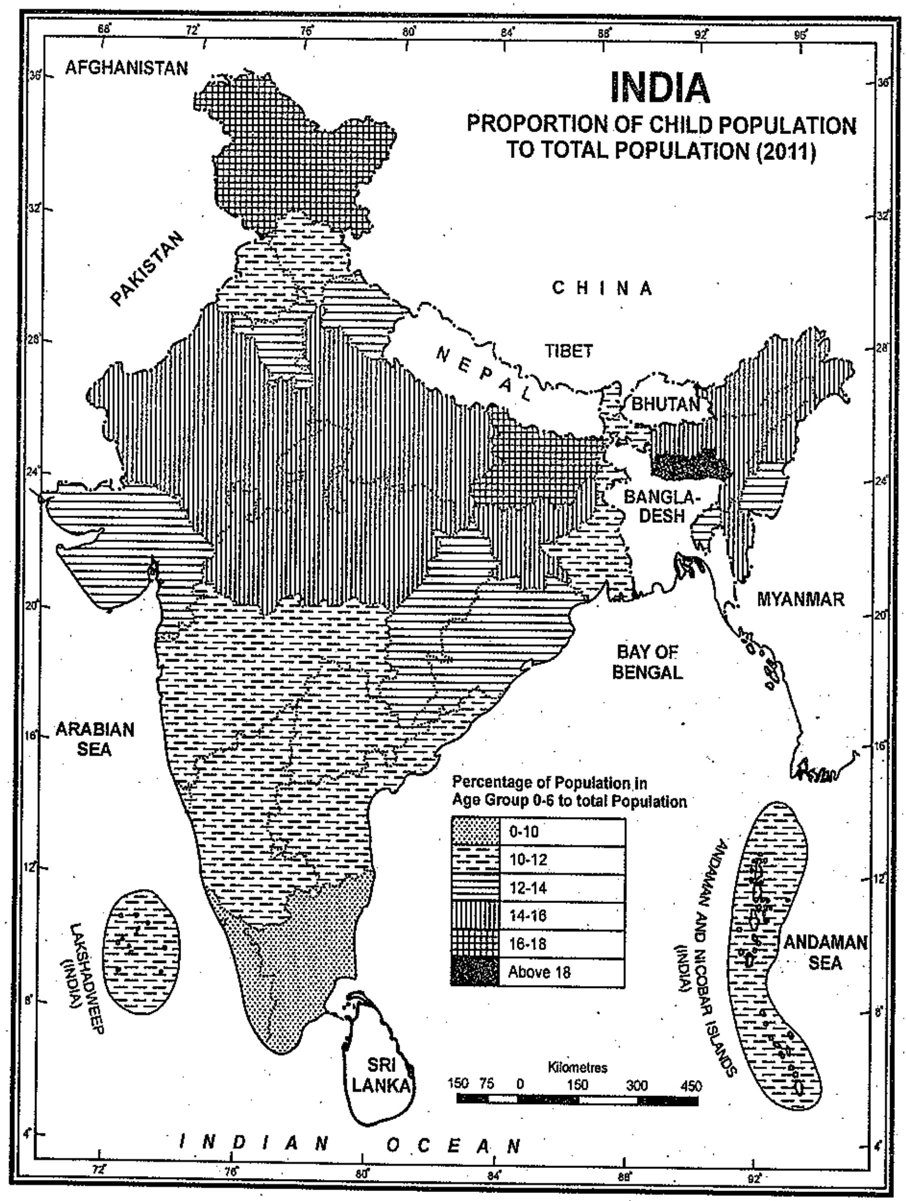

FIG. 10.9. India : Proportion of child population to total population (2011)

It has been found that districts with high growth rates are distributed in almost all parts of the country. However, there is a patch of five districts in Arunachal Pradesh, four in Jammu and Kashmir, three each in Uttar Pradesh and Chhattisgarh that have recorded high growth rates of above 30 per cent. Among ten districts with very high growth rates, Kurung Kumey in Arunachal Pradesh (111.01%),

Yanam in Puducherry (77.15%), Gurgaon in Haryana (73.93%), Daman (67.43%), Dadra and Nagar Haveli (55.50%), Gautam Buddha Nagar in Uttar Pradesh (51.52%) and Upper Subansiri in Arunachal Pradesh (50.34%) are seven districts which have reported more than 50 per cent growth during the decade 2001-2011 (**Table 10.8**).

Growth of Child Population

Child population in the age group 0-6 years has special significance in our demographic scene because this segment of population determines the future course of trends in population growth when it reaches the reproductive age. According to 2011 census figures, the total number of children in the age-group 0-6 years in 158.8 million which is about 5 million less than the number recorded in 2001. Reduction in child population in the age group of 0-6 years is an indication of a fall in fertility rate which is a positive sign. However, the total number of children in India is a little more than the total population of Nigeria—the eighth largest country of the world with respect to population. It is important to note that out of the absolute increase of 181 million in India's population during the decade 2001-2011, 88 per cent has been contributed by the Child Population. Five states namely Uttar Pradesh (29.7 million), Bihar (18.6 million), Maharashtra (12.8 million), Madhya Pradesh (10.5 million) and Rajasthan (10.5 million) have the largest number of children constituting 52% of India's child population. On the other hand, Lakshadweep, Daman & Diu, Andaman and Nicobar Islands, Dadra and Nagar Haveli and Sikkim have least number of children. A comparison of figures of census 2011 with those of census 2001 reveals that the maximum decline in absolute numbers of children has been in Uttar Pradesh. This is followed by Andhra Pradesh, West Bengal, Maharashtra, and Kerala. On the other extreme are the states of Bihar, Jammu and Kashmir, Jharkhand, Meghalaya and Chhattisgarh, where maximum increase in child population has been recorded between 2001 and 2011. As per gender composition of child population, it has been found that decline in females (29,91,976) has been much more as compared to decline in males (20,56,132) during the decade 2001-2011. **Table 10.9** shows that 20 states and union territories have over one million children in the age groups 0-6 years. On the other hand there are five states and union territories that are yet to cross one lakh mark.

DISTRIBUTION AND DENSITY OF POPULATION

One of the most important aspects of India's population is its uneven distribution. On one hand the population of India is highly concentrated in some pockets such as highly urbanized and industrialised areas and areas of high agricultural productivity, while on the other hand there are virtually demographic deserts in high mountains, arid lands, thickly forested areas and some remote corners of the country. Such a situation needs some explanation and the explanation is found, to a great extent, by the study of some geographical factors which affect the distribution and density of population in a given area. Besides some social, demographic, political and historical factors play their own role in influencing the distribution and density of population. It may further be emphasised that these factors act in totality and not individually. While some scholars attach more importance to natural factors, Clarke and Zelinsky are of the view that cultural factors are more prominent in determining the concentration of population in an area. According to Clarke, economic conditions, technological development, social organisation, government policy, etc. play a vital role in the distribution of population. Major factors influencing the distribution and density of population are described as under :

1. Terrain. Terrain of land is a potent factor which influences the concentration and growth of population. Normally speaking, plain areas encourage higher density of population as compared to mountain regions. The steep slopes in mountain areas restrict the availability of land for agriculture, development of transport, industries and other economic activities which may tend to discourage concentration of population and its proper growth. It is because of these adverse circumstances that the Himalayan region, though occupies about 13 per cent of India's land area, supports only 1-2 per cent of the country's population. In contrast to this, the Great Plain of North India is a land of extremely gentle slope and offers great opportunities for the growth of agriculture, transport and industries. This results in higher concentration of population. Although the

Great Plain of North India covers less than one fourth of the country's land area, it is the home to more than half of India's population.

2. Climate. Climate is as important as terrain in influencing population. Of all the climatic factors, twin elements of rainfall and temperature play the most important role in determining the population of an area. Man cannot go beyond the limits set by climate. Extremes of climate discourage the concentration of population. Such climates include the too cold climate of Himalayas, and the too hot and dry climate of the Thar Desert. A moderate climate, on the other hand, is favourable for population.

Of the twin factors of rainfall and temperature, rainfall is more effective in determining the distribution of population. It is generally said that *the population map of India follows its rainfall map.* Rainfall supplies sufficient water for agriculture which is the main occupation of Indian masses. As we move from the Ganga-Brahmaputra Delta in the east towards the Thar Desert in the west, the amount of rainfall and consequently the density of population decreases. However, there are a few exceptions to this general observation. The Assam valley in the north-east and the Circars coast on the Bay of Bengal have moderate density of population although these areas receive heavy rainfall. Similarly, southern face of the Himalayas is scarcely populated though this area receives sufficiently high rainfall. Some of the adverse factors such as steep slope, frequent floods, infertile soils and dense forests counterbalance the positive effect of rainfall. Increased use of irrigation facilities in north-west India comprising Punjab, Haryana and western Uttar Pradesh has resulted in higher concentration of population than normally expected considering the amount of rainfall received by this region.

Since India is a tropical country, temperature is fairly high and does not play as important a role as is done by rainfall except in extreme cases. On high altitudes, in the Himalayan region, climate is too cold beyond 2,000 m and population is sparse there. There is practically no population in areas over 3,000 m above sea level.

3. Soil. Soil is an important factor in determining the density of population in an overwhelmingly agricultural country like India. Fertile soil supports higher population density while infertile soil leads to low density. In the northern plain of India, the soil is regularly enriched by annual floods of the great rivers like the Indus, the Ganga and the Brahmaputra and their tributaries. Therefore, this is an area of high population density. The coastal plains also have fertile soils and are areas of high population density. The Black soil of the Deccan Plateau also supports high population density. On the other hand, desert soils, mountain soils, laterite soils are infertile soils and are not capable of supporting high population densities. However, new technology in the agricultural field may change the future population scenario to some extent.

4. Water Bodies. Availability of water plays a significant role in determining the population of a given area. Water is the basic necessity for several purposes including irrigation, industries, transport and domestic use. Rivers are the greatest source of fresh potable water. Therefore, most of the population is concentrated in the river valleys.

5. Mineral Resources. Minerals act as great source of attraction for people from different areas, which results in higher density of population. The higher population densities in the Chhota Nagpur Plateau of Jharkhand and in the adjoining areas of Odisha are largely due to the availability of minerals.

6. Industries. Industrial growth offers massive employment opportunities and acts as a great magnet to attract people, particularly from the neighbouring areas. This results in higher population density. Industrial areas are almost invariably associated with areas of high population densities. One hectare of industrial land is capable of supporting several thousand persons, while the most fertile area devoted to agriculture may not support more than a few hundred persons per hectare. One of the major causes of high population density in West Bengal, Bihar, Jharkhand, Odisha, Maharashtra and Gujarat is the phenomenal growth of industries in these states.

7. Transport. Growth of population is directly proportional to the development of transport facilities. The northern plain of India has a dense network of transport routes and is a densely populated region. The peninsular plateau has moderate network of transport routes and is moderately populated area.

The Himalayan region badly lacks transport facilities and is sparsely populated.

8. Urbanization. Urbanization and population concentration go hand-in-hand and are closely related to each other. All the urban centres are marked by high density of population. The minimum density, that an area should have to be designated as urban, is 400 persons per sq km. The highly urbanized districts of Kolkata, Chennai, Greater Mumbai, Hyderabad, Delhi and Chandigarh have population densities of over 6,000 persons per sq km. Delhi has the highest population density of 11,297 persons per sq km as per 2011 census figures.

DISTRIBUTION OF POPULATION

The total population of India according to the 2011 census is 1210.2 millions. A casual look at Table 10.10 will reveal that the distribution of India's population is very uneven. The contrasts in population distribution are quite clear at the level of the states, and are further sharpened at the level of districts. These contrasts are due to varying size of the states and wide variations in their resource base. Uttar Pradesh has the largest population of 199.5 millions. This is followed by Maharashtra (112.3 millions), Bihar (103.8 millions). West Bengal (91.3 millions) and Andhra Pradesh including Telangana (84.6 millions). These five states account for about half of the country's population. More than one-fourth of our people live in two-states of U.P. and Maharashtra alone. This, however, does not imply that states with large areas have large population also. For example. Rajasthan is the largest state of India accounting for over 10.4 per cent area of the country. But this state supports only 5.67 per cent population of India. Similarly, Madhya Pradesh, the second largest state in terms of area, has 6.0 per cent of population on 9.38 per cent of area of the country. Contrary to this, Uttar Pradesh supports 16.49 per cent of population on only 7.33 percent of area of the country. In fact, U.P. has more people than the two largest states of Rajasthan and Madhya Pradesh. The three southern states of Kerala, Karnataka and Tamil Nadu together have less population than Uttar Pradesh. Bihar has 9.29 per cent of population on 9.86 per cent of area. In all, in eleven states and six union territories population size is much larger in comparison to the areas. This means that these states have higher pressure of population than the national average. On the other hand, Jammu and Kashmir covers 6.76 per cent area but supports only 1 per cent population of India. Arunachal Pradesh has 0.11 per cent of population on 2.55 per cent of area. Sikkim, a Himalayan mini-state has only 6 lakh population which is only 0.05 per cent of the total population of India. In fact, Sikkim has the smallest population among all the states of India. Delhi with 16.75 million has the largest population among all the union territories. It is a matter of fact that more people live in Delhi than in the state of Jammu and Kashmir or in all the Union Territories put together.

Causes of Uneven Distribution of Population

The uneven distribution of population described above is the result of several factors of which physical, socio-economic and historical factors are more important.

***(i)* Physical Factors.** Among the physical factors, relief, climate and availability of water are the chief factors which determine the population of an area. It is because of these factors that the North Indian Plains, deltas and coastal plains have higher proportion of population than the interior districts of southern and central Indian states, the Himalayas, some of the north eastern and the western states. However, development of irrigation facilities by Indira Gandhi Canal in Rajasthan, rich deposits of mineral and energy resources in Chotanagpur plateau of Jharkhand have resulted in moderate to high proportion of population in these areas which were previously very thinly populated (**Fig. 10.10**).

***(ii)* Socio-economic and Historical Factors.** Evolution of settled agriculture and agricultural development; pattern of human settlement; development of transport network, industrialisation and urbanisation are some of the important socio-economic and historical factors which influence the distribution of population. Generally speaking river plains and coastal areas have larger concentration of population due to early history of human settlement and development of transport network. Urban areas like Delhi, Mumbai, Kolkata, Bengaluru, Pune, Ahmedabad, Chennai and Jaipur have high

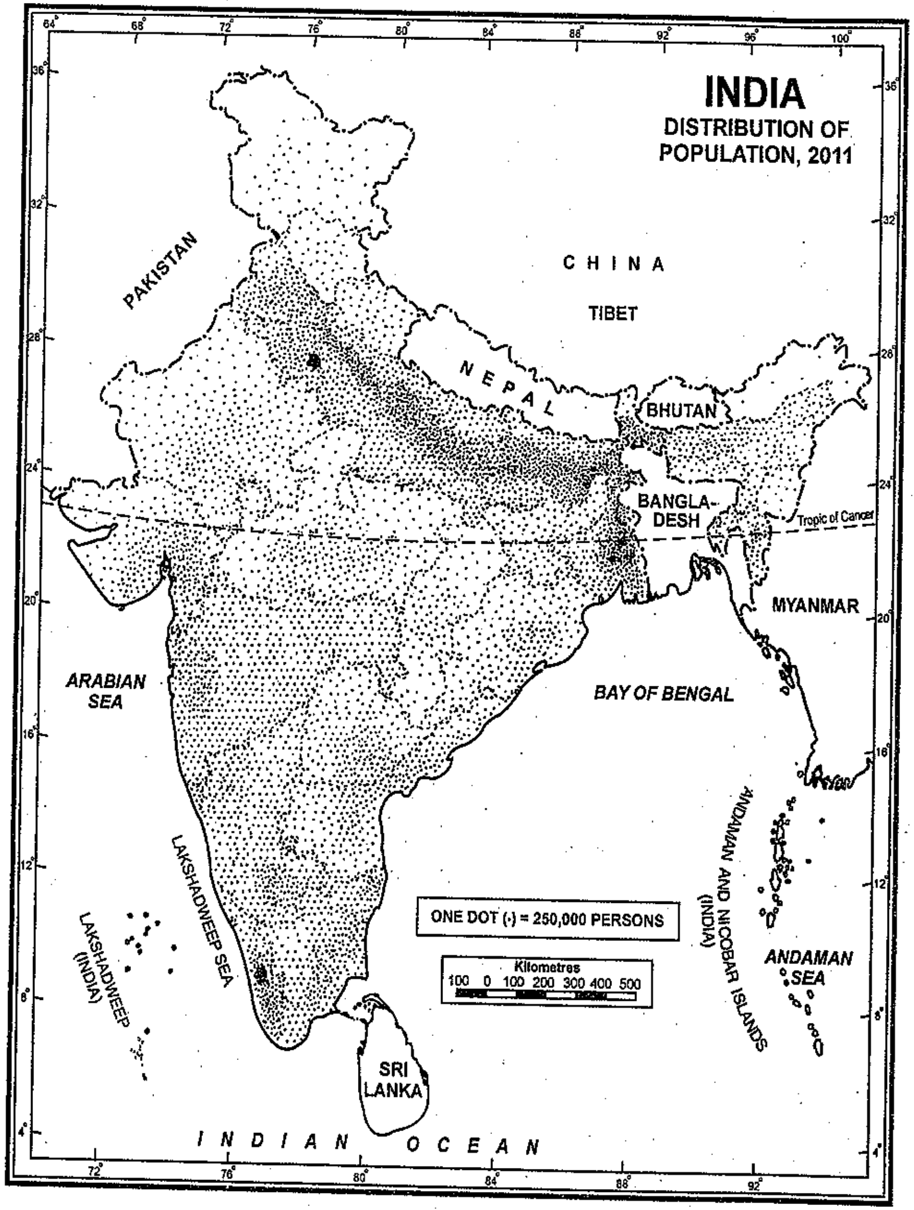

FIG. 10.10. India : Distribution of population, 2011

TABLE 10.10. Ranking of States and Union Territories by Population : 2001 and 2011

Rank in 2011	India/State/Union Territory	Population 2011	Percent to total population of India 2011	Percent to total population of India 2001	Rank in 2001
	India	**1,21,01,93,422**	**100.00**	100.00	
1	Uttar Pradesh	19,95,81,477	16.49	16.16	1
2	Maharashtra	11,23,72,972	9.29	9.42	2
3	Bihar	10,38,04,637	8.58	8.07	3
4	West Bengal	9,13,47,736	7.55	7.79	4
5	Andhra Pradesh (including Telangana)	8,46,65,533	7.00	7.41	5
6	Madhya Pradesh	7,25,97,565	6.00	5.87	7
7	Tamil Nadu	7,21,38,958	5.96	6.07	6
8	Rajasthan	6,86,21,012	5.67	5.49	8
9	Karnataka	6,11,30,704	5.05	5.14	9
10	Gujarat	6,03,83,628	4.99	4.93	10
11	Odisha	4,19,47,358	3.47	3.58	11
12	Kerala	3,33,87,677	2.76	3.10	12
13	Jharkhand	3,29,66,238	2.72	2.62	13
14	Assam	3,11,69,272	2.58	2.59	14
15	Punjab	2,77,04,236	2.29	2.37	15
16	Chhattisgarh	2,55,40,196	2.11	2.03	17
17	Haryana	2,53,53,081	2.09	2.06	16
18	NCT of Delhi#	1,67,53,235	1.38	1.35	18
19	Jammu & Kashmir	1,25,48,926	1.04	0.99	19
20	Uttarakhand	1,01,16,752	0.84	0.83	20
21	Himachal Pradesh	68,56,509	0.57	0.59	21
22	Tripura	36,71,032	0.30	0.31	22
23	Meghalaya	29,64,007	0.24	0.23	23
24	Manipur	27,21,756	0.22	0.22	24
25	Nagaland	19,80,602	0.16	0.19	25
26	Goa	14,57,723	0.12	0.13	26
27	Arunachal Pradesh	13,82,611	0.11	0.11	27
28	Puducherry#	12,44,464	0.10	0.09	28
29	Mizoram	10,91,014	0.09	0.09	30
30	Chandigarh#	10,54,686	0.09	0.09	29
31	Sikkim	6,07,688	0.05	0.05	31
32	Andaman & Nicobar Islands#	3,79,944	0.03	0.03	32
33	Dadra & Nagar Haveli#	3,42,853	0.03	0.02	33
34	Daman & Diu#	2,42,911	0.02	0.02	34
35	Lakshadweep#	64,429	0.01	0.01	35

Union Territory

Source : Census of India, 2011 : Provision Population Totals, Paper 1, p. 47.

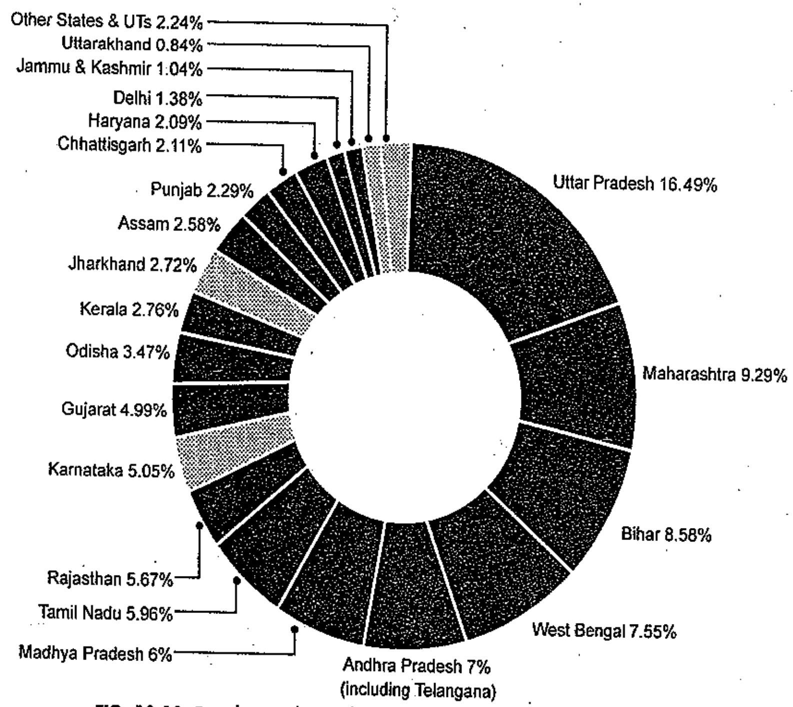

FIG. 10.11. Population Share of States and Union Territories, India: 2011.

concentration of population due to high level of industrialisation and urbanisation. People in large numbers migrate from rural to urban areas.

DENSITY OF POPULATION

Density of population is a better measure of understanding the variation in the distribution of population. It is expressed as number of persons per unit area. In other words, it is the ratio of total population to the total area of the country or a part thereof. For example the total population of India according to 2011 census is 1210.1 million living on a total area of 3.17 million square kilometres (excluding the area of Jammu and Kashmir illegally occupied by Pakistan and China). Therefore, the density of population of India in 2011 is :

$$\frac{\text{Totgal population}}{\text{Total area}} = \frac{1210.1}{3.17}$$
$$= 382 \text{ persons per sq. km)}$$

India's population density of 382 persons per sq. km is much higher than China's 141 persons per sq. km. Among the most populous ten countries of the world, India stands second in density; the first being Bangladesh (1141 persons per sq km). Thus heavy pressure of population on land is one of the serious problems of the country. The main cause of worry is that the population density in India has been consistently increasing since 1921 (Table 10.11). There has been almost five fold increase in the density of population between 1921 and 2011. The density of population increased rapidly between 1951 and 2011.

TABLE 10.11. Density of Population, India : 1901-2011

Census Year	Density (per sq km)	Absolute Increase	%age Increase
1	2	3	4
1901	77		
1911	82	5	6.5
1921	81	–1	–1.2
1931	90	9	11.1
1941	103	13	14.4
1951	117	14	13.6
1961	142	25	21.4
1971	177	35	24.6
1981	216	39	22
1991	267	51	23.6
2001	325	58	21.7
2011	382	57	17.5

Source : Census of India 2011, Provisional Population Totals, Paper 1 of 2011 Series 1, p. 138.

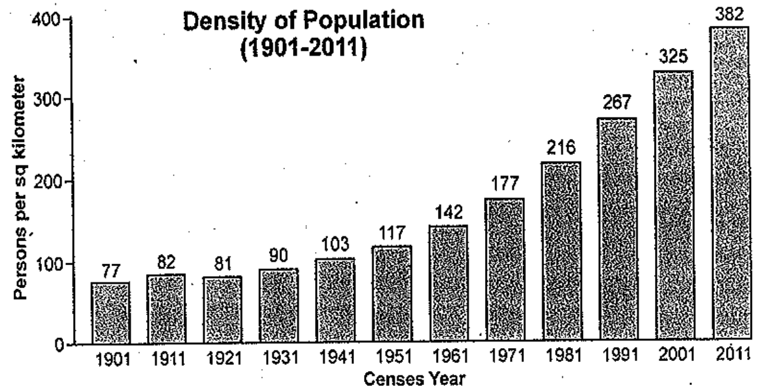

FIG. 10.12. India : Density of population (1901-2011)

It is clear from **table 10.11** and **Figure 10.12** that density of population in India is very high and is increasing at a very fast rate. During the decade 2001-11 alone, India's population density increased by 57 persons per sq km which means each sq km of land has to feed 57 new mouths. This is a matter of great concern as it puts immense pressure on our natural resources. This increase is nearly double the existing density of the USA (30 persons/sq km), seven times the existing density of Russia (8 persons/sq km) and a more than one-third the existing density of China (141 persons/sq km). Hence among the large sized countries of the world, India is not only the most densely populated but is also adding to its density at an alarming rate.

State Level Patterns

Table 10.12 shows that there are large scale variations in the population density from one state/union territory to another. These variations are depicted in **Figure 10.13**.

Table 10.12 shows that the national average of 382 persons per sq km does not give a clear idea of nature of unevenness of population density as it varies from a minimum of 17 persons per sq km in Arunachal Pradesh to a maximum of 1102 persons per sq km in Bihar. Among the union territories, Delhi is the most thickly populated with 11,297 persons per sq km, while Andaman and Nicobar Islands have the lowest density of only 46 persons per sq km.

For the sake of convenience, the spatial distribution of population density is classified into following categories :

1. Areas of Extremely Low Density. Areas having 100 persons per sq km and less than that are included in this class. They include Arunachal Pradesh (17), Mizoram (52), Andaman and Nicobar Islands (46) and Sikkim (86). Arunachal Pradesh and Mizoram are located in a remote and inaccessible part of north-east India. Sikkim is also a mountainous area with low density of population. Andaman and Nicobar Islands are situated far away from the Indian mainland. Hot and humid climate of these islands is injurious to health and very little economic development has taken place here.

2. Areas of Low Density. Areas having population density of 101 to 250 persons per sq km are included in this class. These states are Nagaland (119), Manipur (122), Himachal Pradesh (123), Jammu and Kashmir (124), Meghalaya (132), Chhattisgarh (189), Uttarakhand (189), Rajasthan 201) and Madhya Pradesh (236). Meghalaya, Manipur, and Nagaland are hilly, forested and dissected areas of north-east India. These areas suffer

TABLE 10.12. Ranking of States and Union Territories by density : 2011 and 2001

Rank in 2011	State/Union Territory	Density (per sq km) 2011	Density (per sq km) 2001	Rank in 2001
1	2	3	4	5
	India	382	325	
1	NCT of Delhi	11,297	9,340	1
2	Chandigarh	9,252	7,900	2
3	Puducherry	2,598	2,034	3
4	Daman & Diu	2,169	1,413	5
5	Lakshadweep	2,013	1,895	4
6	Bihar	1,102	881	7
7	West Bengal	1,029	903	6
8	Kerala	859	819	8
9	Uttar Pradesh	828	690	9
10	Dadra & N. Haveli	698	449	13
11	Haryana	573	478	12
12	Tamil Nadu	555	480	11
13	Punjab	550	484	10
14	Jharkhand	414	338	16
15	Assam	397	340	15
16	Goa	394	364	14
17	Maharashtra	365	315	17
18	Tripura	350	305	18
19	Karnataka	319	276	20
20	Andhra Pradesh (+ Telangana)	308	277	19
21	Gujarat	308	258	21
22	Odisha	269	236	22
23	Madhya Pradesh	236	196	23
24	Rajasthan	201	165	24
25	Uttarakhand	189	159	25
26	Chhattisgarh	189	154	26
27	Meghalaya	132	103	29
28	Jammu & Kashmir	124	100	31
29	Himachal Pradesh	123	109	28
30	Manipur	122	103	30
31	Nagaland	119	120	27
32	Sikkim	86	76	32
33	Mizoram	52	42	34
34	Andaman & Nicobar Islands	46	43	33
35	Arunachal Pradesh	17	13	35

Source: Census of India, 2011; Provisional Population Totals, Paper 1, p. 140.

from almost the same problems as those of Arunachal Pradesh and Mizoram, although to a lesser extent. Himachal Pradesh and Uttarakhand are parts of the north-western Himalayan region and have very little level land to support high population density. Jammu and Kashmir has vast areas devoid of population. Only some parts of Jammu region and Kashmir valley are thickly populated. Large stretches of Leh (Ladakh) and Kargil have population density less than ten persons per sq km. On the whole Kargil has population density of 10 persons/sq km while Leh (Ladakh) has only 3 persons per sq km. These are dry and cold areas and badly lack the basic amenities of life. Rajasthan is the largest state of India. There are obviously large variations in the density of population in different parts of the state depending upon the local conditions. Most of Rajasthan is a sandy desert lacking in water resources and does not support high population density. Western part of the state is having even less than 50 persons per sq km whereas eastern and north-eastern parts of this state have sufficient resources and have comparatively high density of population. Madhya Pradesh is a part of the Deccan Plateau and is having rugged topography of hard rocks. Like Madhya Pradesh, Chhattisgarh has rugged topography, is thickly forested and is largely inhabited by the tribal people. As such, the population density in this state also is low.

3. Areas of Moderate Density. This class includes those areas which are having 251 to 500 persons per sq km. The average for whole of India (382 persons per sq km) also falls in this class. Odisha (269), Gujarat (308), Andhra Pradesh including Telangana (308), Karnataka (319), Tripura (350), Maharashtra (365), Goa (394), Assam (397), and Jharkhand (414) are included in this category. These areas are wide apart from one another and there are different reasons for moderate density of population in different areas. For example, Assam has tea estates whereas Andhra Pradesh, Telangana, Odisha, Karnataka and Jharkhand have agricultural and mineral resources. Maharashtra is highly urbanised and industrialised state. The neighbouring state of Gujarat also has urban and industrial growth, although at a scale smaller than that of Maharashtra. Among the north-eastern states, Tripura has sufficient level land which supports moderate population density.

4. Areas of High Density. These are areas having population density of 501 to 1000 per sq km. States and union territories included in this category are Punjab (550), Tamil Nadu (555), Haryana (573), Dadra & Nagar Haveli (698), Uttar Pradesh (828) and Kerala (859). Punjab and Haryana have highly developed agriculture based on heavy inputs in the form of high yielding varieties of seeds, chemical

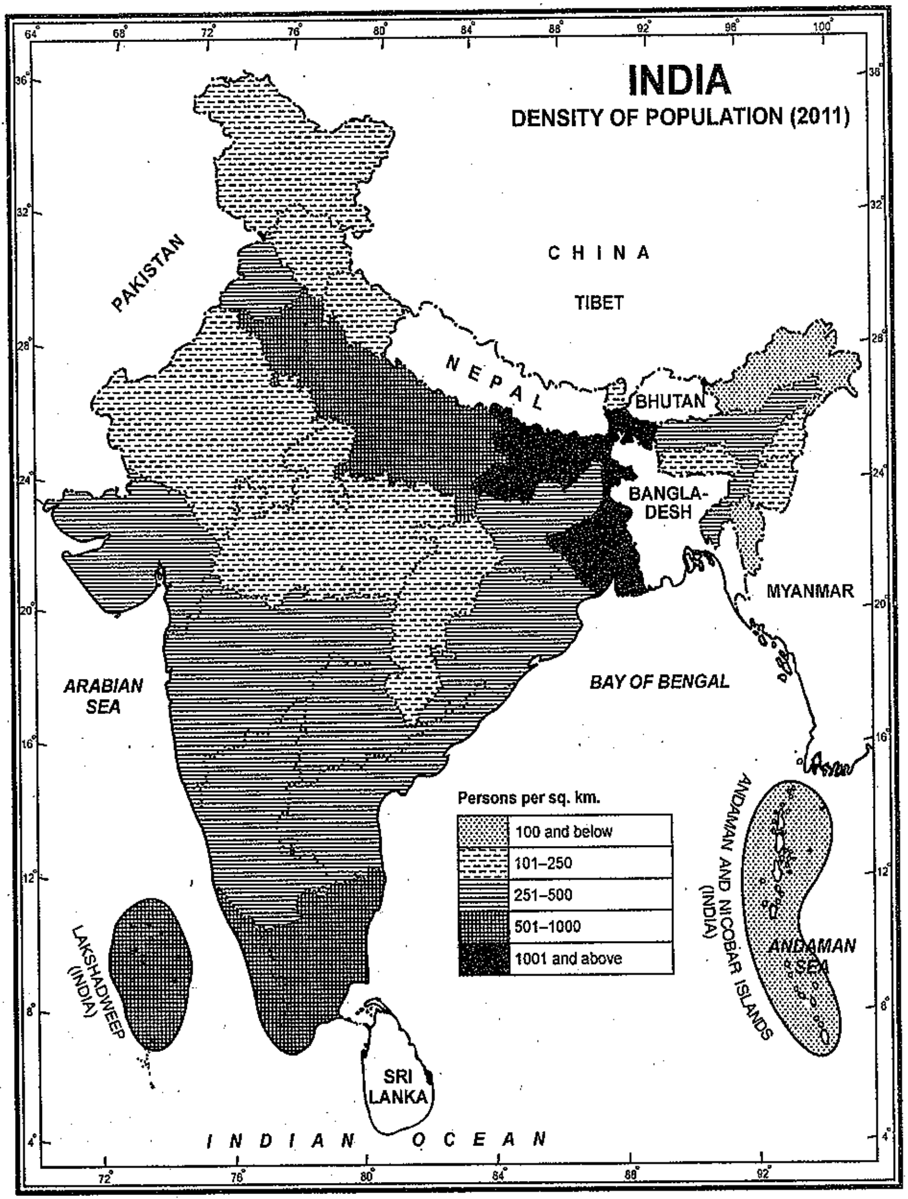

FIG. 10.13. India: Density of Population 2011.

fertilizers and canal and tube-well irrigation. Similarly, Tamil Nadu's population is based on agriculture and industries. The coastal plain of Kerala is also very fertile. However, Kerala has started showing decline in the growth rate of population. Uttar Pradesh is located in the fertile Ganga Plain and supports high population density.

5. Areas of Very High Density. Areas having more than 1000 persons per sq km are termed as areas of very high population density. West Bengal (1029), Bihar (1102), Lakshadweep (2013), Daman & Diu (2169) Puducherry (2548), Chandigarh (9252) and Delhi (11,297) have very high density of population due to different factors operating in different areas. Like Uttar Pradesh, Bihar is located in the fertile plain of Ganga and supports very high population density. It seems that measures to control for population growth have not given the desired results and Bihar has now surpassed West Bengal as the state with highest density of population among the major states. West Bengal is located in the Ganga delta which is one of the most fertile areas of the world, producing 3-4 crops of rice in a year. In addition, India's biggest industrial cluster is located in the Hugli basin. These factors combine together to make West Bengal the second most densely populated state of India. Among the union territories, Delhi has experienced one of the fastest population growths as a result of which its population density has increased considerably. This growth is primarily due to large scale migration of people from the surrounding areas. People migrate to Delhi in large numbers in search of livelihood, and better amenities of life.

District Level Patterns

States are often too large in area to give a realistic picture of population density. Some states with low density of population have very high density districts. The *vice versa* is also true. The range in district level densities is very wide. The highest density of 37,346 persons per sq km is in Northeast Delhi district and lowest is only one person per sq km in Dibang valley of Arunachal Pradesh. **Table 10.13** gives the distribution of density for all the 640 districts in India for 2001 and 2011. This table shows that the number of districts with higher population densities has increased while those with lower densities has decreased. **Table 10.14** gives details of ten districts with highest density and another ten districts with lowest densities.

TABLE 10.13. Distribution of districts according to population density 2001 and 2011

Population density	Number of districts	
	2001	2011
2000 and Above	22	28
1000-1999	38	71
500-999	149	145
250-499	178	186
100-249	183	150
Below 100	70	60
Total	640	640

Source : Census of India 2011, Series 1, India, *Provisional Population Totals*, Paper 1 of 2011. Districtwise density data for 2011 obtained from census website <censusindia.gov.in>.

The belt comprising districts with densities above the national density of 382 persons per sq km starts from the plains of Punjab, runs through the Ganga-Yamuna plains, the middle and lower reaches and delta of the Ganga system, winds through the eastern coast to Kanniyakumari traversing the deltas of Mahanadi, the Godavari, the Krishna, the Kaveri and other rivers and finally turns north along the western coastal districts, especially in Kerala. In contrast, districts in north- east, especially those in Arunachal Pradesh, Manipur, and Mizoram; and a few from Himachal Pradesh, Jammu and Kashmir, Uttarakhand; and arid districts of Rajasthan have recorded very low densities.

Population Problems

As mentioned earlier, India is the second most populous country of the world, next only to China. Obviously India is facing serious problems regarding population and there are spatial and temporal variations in these problems. Perhaps the most serious problems being faced by India today are in connection with her people. Some of the major population problems are briefly described as under :

1. Rapid Growth of Population. In spite of several steps taken by the government, population of India is growing at a rapid pace. India's population was just 36.1 crores at the time of first census (1951) after Independence which rose to over 121 crores in 2011. Thus our population has increased more than three fold in a short span of half a century. During the last century, the world population grew by three times while India's population grew by four times. Although the growth rate of our population has come down from 24.8 per cent in 1961-71 to 17.64 per cent in 2001-11, it is still vary high as compared to world average growth rate of 12.3 per cent and is much higher than 5.3 per cent of the most populous country of the world—China. During 2001-11 India's population increased by 181.4 millions against China's 79.7 millions. At this rate our population is likely to exceed the population of China in 2028. The population growth was so high during 1951-81 that it is often referred to as ***'population explosion'***.

2. Uneven distribution of Population. One of the most striking features of India's population is its uneven distribution. On one hand, there are almost empty lands like Arunachal Pradesh where population density is only 17 persons per sq km and large tracts of the Himalayas have less than five persons per sq km. On the other hand Bihar's one sq km has to

TABLE 10.14. Ten districts with highest density per sq. km. in 2001 and 2011 respectively and ten districts with lowest density per sq. km. in 2001 and 2011 respectively

State	District	Density	State	District	Density
Ten districts with highest density, 2011			Ten districts with highest density, 2001		
Delhi	North East	37,346	Delhi	North East	29,468
Tamil Nadu	Chennai	26,903	Delhi	Central	25,855
Delhi	East	26,683	Tamil Nadu	Chennai	24,963
West Bengal	Kolkata	24,252	West Bengal	Kolkata	24,718
Delhi	Central	23,147	Delhi	East	22,868
Maharashtra	Mumbai (Suburban)	20,925	Maharashtra	Mumbai	21,261
Maharashtra	Mumbai	20,038	Maharashtra	Mumbai (Suburban)	19,373
Delhi	West	19,625	Telangana	Hyderabad	17,649
Telangana	Hyderabad	18,480	Delhi	West	16,503
Delhi	North	14,973	Delhi	North	13,246
Ten districts with lowest density, 2011			Ten districts with lowest density, 2001		
Himachal Pradesh	Kinnaur	13	Arunachal Pradesh	West Kameng	10
Arunachal Pradesh	Upper Subansiri	12	Sikkim	North	10
Arunachal Pradesh	West Kameng	12	Jammu & Kashmir	Kargil	9
Sikkim	North	11	Arunachal Pradesh	Upper Subansiri	8
Jammu & Kashmir	Kargil	10	Arunachal Pradesh	Kurung Kumey	7
Arunachal Pradesh	Upper Siang	5	Arunachal Pradesh	Upper Siang	5
Arunachal Pradesh	Anjaw	3	Arunachal Pradesh	Anjaw	3
Jammu & Kashmir	Leh	3	Jammu & Kasahmir	Leh	3
Himachal Pradesh	Lahul & Spiti	2	Himachal Pradesh	Lahul & Spiti	2
Arunachal Pradesh	Dibang Valley	1	Arunachal Pradesh	Dibang Valley	1

Source : Census of India 2011.

support as many as 1102 persons per sq km on an economy which is heavily dependent on agriculture. Urbanized union territories like Chandigarh and Delhi have unmanageable densities of 9,252 and 11,297 persons per sq km.

Rapid growth and uneven distribution of population have put enormous pressure on our scarce natural resources to varying degrees in different parts of the country. Main problems arising out of such a situation are unemployment, poverty, hunger, malnutrition, environmental degradation and lower standard of living. These problems will be discussed in the following paragraphs.

3. Unemployment. In view of rapidly growing population and limited resources, the employment seekers far outnumber and outpack the growth of employment opportunities. Indian economy is heavily dependent on agriculture which the largest employment provider in the country. At present 68.84 per cent of India's population is living in rural areas which solely depends on agriculture for its livelihood. More than 58% of the population of the country earns its livelihood from agriculture. But in spite of heavy inputs in agriculture in the form of high yielding variety of seeds, chemical fertilizers and machines, agricultural progress has failed to keep pace with the growing demand for employment due to fast increasing population. Moreover, agriculture is a seasonal activity in which labour is required only during the sowing and harvesting seasons and the agricultural labourers are without employment for about six months in a year. The secondary and tertiary sectors have also not grown in proportion to demand for employment. As such, the employment opportunities for unskilled, semi-skilled, and skilled people are very limited. Even the educated and professional technocrats are finding it difficult to get a suitable jobs and they have a tendency to migrate to developed countries resulting in a serious crisis of **brain drain.** According to official figures there are more than forty million unemployed youths in India and their number is fast growing. This situation of unemployed youth is very dangerous because the younger people are more liable to be involved in anti-social activities like theft, cheating, drugs, murder, rape, etc.

4. Hunger and Malnutrition. Situation of hunger and malnutrition arises when the population growth outpaces the growth of foodgrains and food items become so costly to be out of reach of the common man. The Global Hunger Index (GHI) released in 2012 showed that India's ranking was a miserable 65 out of 79 countries and this is termed as alarming situation. Table 10.15 shows that many of India's neighbours have done better in tackling issues of hunger and malnutrition.

TABLE 10.15. Global Hunger Index (GHI) of India as compared to Pakistan and China

Country	1990	1996	2001	2012
India	30.3	22.6	24.2	22.9
Pakistan	25.5	21.8	21.7	19.7
China	11.8	8.9	6.6	5.1

Note : Higher the Global Hunger Index, more serious is the problem of hunger.

***Source* :** International Food Policy Research Institute (2012).

Although India's rating has improved from 30.3 in 1990 to 24.2 in 2001 and 22.9 in 2012, it is still very high as compared to other countries. It is estimated that nearly 870 million people across the globe go hungry each day and a fourth of them—more than 200 million—live in India. With a rank of 66 out of 88 nations on the global hunger index, we were only slightly better than Bangladesh (68) and worse off than Pakistan (57), China (2) and even certain African countries. The report analysed three indices—under nourishment in the population, under five mortality and underweight children under-five. India's record with respect to all three indices is dismal. It has been reported that 19% is the proportion of under-nourished population (2006-08), 6.3% is the under-five mortality rate (2010) and 43.5% is the prevalence of underweight in children under 5 years (2005-10). In 2011 around 50% of global under-5 deaths occurred in just five countries and India held the top position. India reported 16.55 lakh deaths in contrast to Nigeria (7.56 lakh), Democratic Republic of Congo (4.65 lakhs) Pakistan (3.52 lakhs) and China (2.49 lakhs).

Among the Indian states, Madhya Pradesh is the worst sufferer so far as hunger is concerned (**Fig. 10.14**). Many other states of India are as bad as some of the poorest countries of the world (**Table 10.16**).

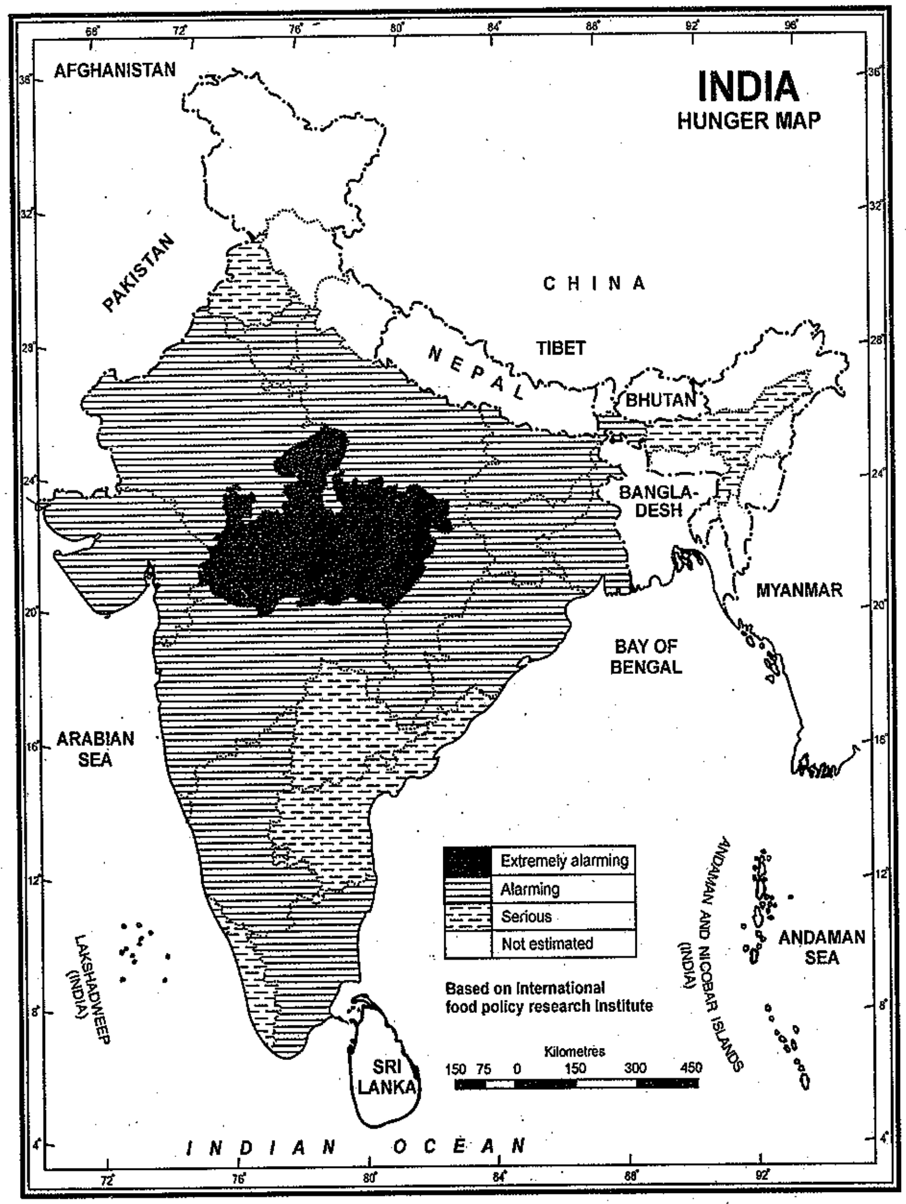

FIG. 10.14 : India : Hunger Map

5. Poverty. Poverty is another serious population problem, but million dollar question is "who is a poor Indian". Different criteria have been followed by different committees and the number of families living below poverty line have varied widely from each other. For example in 2010 Wadhwa Committee

TABLE 10.16. Hunger levels in seven major states of India along with their nearest world equivalents

1.	Madhya Pradesh 30.85 = Ethiopia
2.	Bihar 27.30 = Yemen
3.	Gujarat 24.70 = Bangladesh
4.	Maharashtra 22.80 = Djibouti
5.	Assam 19.83 = Mali
6.	Kerala 17.63 = Senegal
7.	Punjab 13.63 = Philippines

Note : (*i*) Higher score reflects higher hunger levels.
(*ii*) For states versus world, closest approximation is used.

Source : India State Hunger Index 2008 and Global Hunger Index 2008.

Some glaring facts about hunger in India (as per International Food Policy Research Institute)

- 20 per cent is the prevalence of caloric under-nourishment in India.
- 25 is the number of Sub-saharan countries better off than India in terms of food security. We are worse off than even Pakistan.
- 4 African nations—Nigeria, Cameroon, Kenya and Sudan—have far lower per capita income than India but manage hunger better.
- 410 million is the number of people who are poor and food insecure in just 8 Indian states—more than many sub-Sarahan countries (according to an Oxford University report).
- There is not even a single state in India with low or even moderate levels of hunger.
- **Punjab** the food bowl of India, India's best performing state, falls in serious category (Fig. 10.14) and ranks behind Vietnam and Saudi Arabia.
- Madhya Pradesh, India's worst state, besides Gujarat, Chhattisgarh and Haryana are worse off than Sudan.
- Bihar and Jharkhand rank lower than Zimbabwe and Haiti.

put BPL (Below Poverty Line) families at 20 crores, while State Government estimated 10.5 crore. Tendulkar Committee at 9.25 crores and World Bank at 7.5 crore BPL families in India. However, general parameters for determining poverty status are agreed upon by majority of investigators (see box below).

STUDY PARAMETERS

Who were automatically counted as poor :

- Households without shelter
- Destitute or beggars
- Manual scavengers
- Primitive tribal groups
- Legally released bonded labour

Depreciation indicators

- Households with one room having kucha walls and roof.
- No adult member between 16 and 59 years of age.
- Female-headed household with no adult male between 16 and 59 years of age.
- No able-bodied adult member and no literate member above 25 years of age.
- Scheduled caste, scheduled tribe and landless households.

The Planning Commission estimates poverty using data collected by National Sample Survey Office (NSSO) every five years and defines poverty line on the bases of monthly per capita consumption expenditure (MPCE). The expert group headed by Prof. Suresh D. Tendulkar submitted its report in December 2009. This report computed the poverty line at all India level as MPCE of ₹ 447 for rural and ₹ 579 for urban areas in 2004-05. This survey was again conducted in 2009-10 and accordingly the poverty lines were decided at all India level as an MPCE of ₹ 673 for rural and ₹ 860 for urban areas in 2009-10. Based on these cut off, the percentage of people living below poverty line in the country has declined from 37.2 per cent in 2004-05 to 29.8 per cent in 2009-10. Even in absolute terms, the number of poor people has fallen by 52.4 million during this period. Of this 48.1 million are rural poor and 4.3 million are urban poor. Thus poverty has declined on an average by 1.5 percentage points per year between 2004-05 and 2009-10. The annual average rate of decline during the period 2004-05 to 2009-10 is thrice the rate of decline during the period 1993-94 to 2004-05. However **table 10.17** shows that even with changes in NSSO surveys and criteria for fixing the level of families below poverty line as many as 269.3 million or 21.9 per cent of India's population is living below poverty line which is unable to have enough food to eat and enjoy even the basic necessities of life. This section of population lives under conditions of serious deprivation.

TABLE 10.17. Number and Percentage of Poor

	Rural	Urban	Total
Poverty ratio (per cent)			
2004-05	41.8	25.7	37.2
2011-12	25.7	13.7	21.9
Number of poor (million)			
2004-05	326.3	80.8	407.1
2011-12	216.5	52.8	269.3
Annual averge decline 2004-05 to 2011-12 (percentage points per annum)	2.32	1.69	2.18

Source : Economic Survey 2013-14, p. 233.

The BJP led government at the centre, in July 2014, declared that those spending ₹ 32 in rural areas and ₹ 47 in urban areas should not be considered poor. This means that 29.5% of the Indian population lives below poverty according to a report by Rangarajan Committee. According to the Millennium Development Goals (MDG) report released in July 2014, about 32.9 per cent of the world's poorest surviving on less than ₹ 80 ($1.25) a day live in India. As against this 12.8% of the world's poorest live in China. That country leads the way in global poverty reduction, with extreme poverty dropping from 60% in 1990 to 16% in 2005 and 12.8% in 2014. Some other countries with a sizeable percentage of poor people are Nigeria (8.9%), Bangladesh (5.3%, and Congo Democratic Republic (4.6%). The remaining 35.5% of the poor people live in the rest of the world.

6. Low Agricultural Productivity. In most parts of India, agriculture is tradition bound and is of subsistence type in which the entire agriculture produce is consumed by the family members of the farmer. A large percentage of farmers are poor and cannot afford costly inputs like agricultural machines, high yielding seeds, and chemical fertilizers etc. Moreover land tenancy, small and fragmented fields also create hindrances in agricultural growth. For the last so many years the annual rate of agricultural growth has been very slow and is not able to meet the growing demand of teeming millions. Further agricultural sector has failed to provide suitable employment opportunities to growing number of rural youth.

7. Slow Growth of Industries. Although industrial sector has grown faster than agricultural sector, yet this sector is unable to provide sufficient employment to our young population, particularly to those who migrate from rural to urban areas. The basic problem is that the labour which migrates from rural to urban areas largely consists of unskilled workers for whom there is little scope in the industrial sector. Financial constraints and lack of proper infrastructure are also great hindrances in industrial growth. A high percentage of Indian population consists of poor people and there is lack of proper market for industrial products.

8. Frequent Strikes and Bandhs. The fast growing population has resulted in underemployment, unemployment, hunger, malnutrition, poverty, deprivation and lack of basic necessities of life and has led to overall frustration, particularly among the youngsters and they become indisciplined. Consequently, there are frequent strikes in different spheres of life and industrial sector is the worst sufferer. This reduces the overall productivity of the people.

9. Religion, Tradition and Orthodoxy. Indian population is primarily religious minded society and followers of almost all religious can be found in this country. Some of the religions do not believe in family planning practice. This leads to unchecked growth of population which has its own implications. Further, Indian society is tradition-bound and this is more true of rural society. Orthodoxy and ignorance are their major social aspects of Indian population. All these traits are major obstacles in the way to adopt new technology and innovative ideas. Hence masses are still in a backward state and lead miserable life. In order to overcome these obstacles, large scale literacy and education campaign is necessary.

10. Terrorism and insurgency. India's socio-economic system has undergone drastic changes during the last few decades and economic disparities have increased tremendously. In the existing socio-economic scenario, a few people have become very rich while a large proportion of population is living a life of misery and deprivation. The youthful section of society becomes frustration in the absence of opportunities to earn a livelihood and the youngsters resort to anti-social activities like thefts, robberies, kidnapping, extortion, murder, etc. Some of them go to the extent of resorting to terrorism and insurgency. There are many terrorist groups operating in different parts of the country and the frequency as well intensity of terrorist attacks is increasing with the passage of time. A lot of insurgency is taking place in the peripheral states, particularly in the north-eastern states.

11. Environmental Degradation. Growing pressure of population on natural resources is leading to depletion of these resources and at the same time it has several problems regarding environment and ecology. Large scale destruction of forests for forest products and for making land available for other uses has resulted in drastic ecological imbalance. Shifting agriculture, known as Jhum culture, in the north-eastern stages is the main cause of forest destruction there, because the duration of completing the Jhum cycle has been reduced due to increase in demand for agricultural crops caused by growth in population. Over irrigation in Punjab, Haryana and western parts of Uttar Pradesh has caused large scale depletion of ground water and increase in salinity and alkalinity in soil over vast areas. Air and water in (both surface and ground) have been polluted over large tracts in different parts of the country. Noise pollution has become a serious problem in large cities of India. Environmental pollution leads to ill health and cause several diseases which put undue pressure on health services.

12. Pressure on infrastructure and low standard of living. Rapidly growing population puts undue pressure an infrastructure,. Educational institutes, hospitals, transport system always remain over crowded and there is acute shortage of housing amenities. Supply of drinking water and electricity is almost invariably erratic and condition of roads and streets is pathetic. Overall deprivation leads to social tensions, and the number of people involved in anti-social activities is increasing with each passing day. Thus the overall standard of living of the masses is very low and people are deprived of even the basic amenities.

Measures to Solve Population Problems

1. Rapid growth of population in India is the main problem concerning population of the country and all other problems are the off-shoots of this basic problem. If population growth is checked, all other problems will be automatically solved. Following few steps are suggested to solve this problem.

(*i*) People should be persuaded to adopt family planning methods and opt for small families.

(*ii*) Incentives should be given to those couples who opt for small families.

(*iii*) There should be a complete ban on child marriage and minimum age for marriage (18 years for girls and 21 years for boys) should be strictly followed and violators should be given severe punishment. System of child marriage is more prevalent in the rural areas and rural masses should be educated about the ill effects of child marriage.

(*iv*) There is close correlation between infant mortality and birth rate. Unfortunately both are high in India which adversely affect the family planning programmes. There is urgent need to bring these rates down considerably.

(*v*) Illiteracy and high birth rate go hand in hand together and high birth rate leads to high growth rate of population. Although literacy rate has increased considerably during the last few decades still more than 35 per cent of India's population is illiterate. This section of society generally fails to understand in significance of population control and the population increases unchecked. It is often said that "*education is the best contraceptive.*" Thus spread of education can be a great instrument in controlling the population growth.

(*vi*) As mentioned earlier, a large section of our population is suffering from hunger and malnutrition. This makes us a nation of unhealthy people who are unable to make much contribution to economic growth. Proper arrangements should be made to feed these teeming millions so that the nation moves faster on the path of economic growth. It is hoped that the food security bill passed by the Parliament in 2013 will go a long way to eradicate hunger and malnutrition from our country.

(*vii*) A section of our population, particularly in the rural areas, sufferer from the sense of social insecurity and a very high percentage of Indian parents cpt for larger number of children who could look after them in their old age. Such a thinking has to be washed away by providing some measure of social security to this section of society.

The other methods to solve our population problems are briefly discussed below.

2. Special attentions should be paid to agriculture for solving the food problem. Incentives should be given for larger used of agricultural inputs like high yielding varieties of seeds, fertilizers and farm mechanisation. From 1960s onwards, Green Revolution has been helping India to solve her food problem. But in the post Green Revolution era, growth of population outpaced the growth of food grains and India is again finding it difficult to provide proper food to her masses. We are looking forward to see the positive results of the Second Green Revolution.

3. Unproductive lands such as waste land, barren lands should be improved by providing proper inputs and should be brought under plough.

4. Different types of natural resources such as minerals, soils, water, natural vegetation, etc. should be judiciously used and wisely conserved so that they are easily available in sufficient quantities for the present and the future generations.

5. Incentives should be given to industrialization and urbanization so that employment and housing facilities could be provided to large number of people.

6. Migration of the people from densely populated areas to sparsely populated areas should be encouraged so that regional imbalances in population distribution are removed or at least reduced. This will help in reducing pressure of population in crowded areas and using the resources of sparsely populated areas.

Population Policies

Rapidly growing population of India has forced our planners to frame a solid population policy to keep the rate of population growth at a reasonable level and the importance of such a policy was raised immediately after independence.

When the population policy was designed in the *First Five Year Plan (1951-56)* the population of India had already crossed 361 million mark. It was realised that this base of population was very large and it was difficult to check the trend of rapidly growing population within a limited time period. According to provision of the First Five Year Plan, the programme for family limitation and population control was design to :

(*i*) present an accurate picture of the factors. responsible for rapid increase in population.

(*ii*) discover suitable techniques of family planning and devise suitable methods by which knowledge of these techniques could be widely disseminated, and

(*iii*) give advice on family planning as an integrated part of the service of government hospitals and public agencies.

However, the financial allocation for family planning programme was only ₹ 0.65 million which was so meager that it could not yield any tangible results.

A voluntary sterilization programme was introduced in the *Second Five Year Plan* (1956-57 to 1960-61) for which provision of ₹ 50 million was made. This account was mainly used to set-up 1650 family planning centres in different parts of the country.

In the *Third Five Year Plan* (1961-62 to 1965-66), logistics were provided for family planning, which motivated about one million people to accept sterilization.

In the *Fourth Five Year Plan* (1969-74), the main emphasis was on family planning programme in which a time bound programme of reducing the birth rate from 3.9 per cent to 2.3 per cent by 1979 was fixed. The outlay for family planning programme in this plan was raised to ₹ 2,860 million. This amount was spent to cover nearly 9 million couples under sterilization and about 6 million couples under other family planning methods. It is estimated that about 7 million births were averted during this period.

Strict population control policy followed by the central government led by Mrs. Indira Gandhi particularly during emergency period was vigorously opposed by the mass and this led to an unprecedented defeat of the government in 1977 elections. Consequently a more pragmatic population policy was adopted in the Seventh (1985-1990) and Eighth Plan (1992-97) periods in which more emphasis was laid on persuation, publicity as well family and individual well-being.

Unfortunately the above mentioned population policies could not give the desired results and India's population kept on growing at a fast rate and almost took the shape of a *population explosion*. Compelled by the prevailing circumstances, the government came out with a solid population policy in 2000, a brief summary of which is given below :

National Population Policy, 2000. It is a very comprehensive policy which spells out 14 demographic goals and 12 strategic themes. The immediate objectives of this policy was to meet all the unmet needs for contraception and health care for women and children. The medium-term objective was to bring the Total Fertility Rate (TFR) to replacement level (TFR of 2.1) by 2010, and the long-term object is to achieve population stabilisation by 2045. However, the subsequent events reveal that the goals set under the policy were rather over-ambitious. For example, National Population Policy (NPP) wanted Infant Mortality Rate (IMR) to be reduced to below 30 per thousand live births. But figures released by Office of Registrar General India in 2008 show that IMR stood at a high of 53 per thousand live births which was nowhere near the desired figures of 30 per thousand. The situation in regard to other goals is also depressing.

Most scholars agree with the concluding paragraph of NPP, 2000 which is reproduced below.

"The vast numbers of the people of India can be its greatest asset if they are provided with the means to lead healthy and economically productive lives. Population stabilisation is a multi-sectoral endeavour requiring constant and effective dialogue among a diversity of stakeholders, and coordination at all levels of the government and society. Spread of literacy and education, increasing availability of affordable reproductive and child health services, convergence of service delivery at village levels, participation of women in the paid workforce, together with a steady, equitable improvement in family incomes, will facilitate early achievement of the socio-demographic goals. Success will be achieved if the Action Plan contained in the NPP 2000 is pursued as a national movement."

EXCERPTS

National Socio-Demographic Goals for 2010

1. Address the unmet needs for basic reproductive and child health services, supplies and infrastructure.
2. Make school education upto age 14 free and compulsory, and reduce dropouts at primary and secondary school levels to below 20 per cent for both boys and girls.
3. Reduce infant mortality rate to below 30 per 1000 live births.
4. Reduce maternal mortality rate to below 100 per 100,000 live births.
5. Achieve universal immunisation of children against all vaccine preventable diseases.
6. Promote delayed marriage for girls, not earlier than age 18 and preferably after 20 years of age.
7. Achieve 80 per cent institutional deliveries and 100 per cent deliveries by trained persons.
8. Achieve universal access to information/ counselling, and services for fertility regulation and contraception with a wide basket of choices.

9. Achieve 100 per cent registration of births, deaths, marriage and pregnancy.
10. Contain the spread of Acquired Immuno Deficiency Syndrome (AIDS), and promote greater integration between the management of reproductive tract infections (RTI) and sexually transmitted infections (STI) and the National AIDS Control Organisation.
11. Prevent and control communicable diseases.
12. Integrate Indian Systems of Medicine (ISM) in the provision of reproductive and child health services, and reaching out to households.
13. Promote vigorously the small family norm to achieve replacement levels of TFR.
14. Bring out convergence in implementation of related social sector programmes so that family welfare becomes a people centred programme.

Strategic Themes

Following 12 strategic themes must be followed to achieve that national socio-demographic goals for 2010.

I. Decentralised Planning and Programme Implementation. The 73rd and 74th Constitutional Amendment Act, 1992 made health, family welfare, and education a responsibility of village panchayats in the context of NPP 2000. As may as 33 per cent of elected panchayat seats were reserved for women to promote a gender sensitive, multi-sectoral agenda for population stabilisation that will "think, plan and act locally and support nationally". Panchayat demonstrating exemplary performance will be nationally recognised and honoured.

II. Convergence of Service Delivery at Village Levels. Efforts at population stabilisation will be effective only if we direct an integrated package of essential services at the village and household levels. A flexible approach has to be promoted by extending basic reproductive and child health care through mobile clinics and counselling services particularly to remote, inaccessible or sparsely populated regions in the country like hilly and forested areas, desert regions and tribal areas.

III. Empowering Women for Improved Health and Nutrition. The complex socio-cultural determinants of women's health and nutrition have cumulative effects over a life time. Discrimination against girl child leads to her malnutrition and impaired physical development. This situation is compounded by early childbearing and consequent risk of serious pregnancy related complications. Women's risk of premature death and disability is the highest during their reproductive years. Shockingly maternal mortality ratio (MMR) in India is among the highest in the world. Programmes for Safe Motherhood, Universal Immunisation, Child Survival and Oral Rehydration have been combined into Integrated Reproductive and Child Health Programme.

IV. Child Health and Survival. India suffers from high rate of mortality and morbidity among infants and children below 5 years of age. For solving this problem, a National Technical Committee consisting of consultants in obstetrics, pediatrics, family health, medical research and statistics from academic, public health professionals, clinical practitioners etc. has to be set-up. The baby friendly hospital initiative (BFHI) should be extended to all hospitals, upto to sub-centre levels. Breast-feeding should be encouraged.

V. Meeting the Unmet Needs for Family Welfare Services. There are unmet needs in both rural and urban areas for contraceptives, supplies and equipment for integrated service delivery, mobility of health providers and patients, and comprehensive information. It is necessary to meet these requirements and strengthen health infrastructure at the village, sub-centre and primary health centre levels.

VI. Under-Served Population Groups. Following groups of population are under-served which need due attention of the government and the concerned organisations :

(*a*) **Urban slums** with little or no access to potable water, sanitation facilities and health care services.

(*b*) **Tribal Communities, Hill Area Populations and Displaced and Migrant Populations** in remote and low density areas.

(*c*) **Adolescents** representing about a fifth of India's population need protection from unwanted pregnancies and sexually transmitted diseases, particularly in rural areas.

(*d*) **Increased Participation of Men in Planned Parenthood.** In the past, population programmes have tended to exclude menfolk but now active participation of men is recognised in all efforts in planning families. Nearly 97 per cent of sterilisations are tubectomics and this gender imbalance needs to be corrected.

VII. Diverse Health Care Providers. Considering the large unmet goals, it is imperative to increase the numbers and diversify of the categories of healthcare providers.

VIII. Collaboration with and commitments from Non-Government Organisations and Private Sector. Government alone cannot reach each and every household and partnership of non-government voluntary organisation and private corporate sector with government must be encouraged.

IX. Mainstreaming Indian Systems of Madicine and Homeopathy. Indian system of medicine has sustained life in the country for centuries with minimal side effects and this branch of medicine will expand the pool of effective health care providers at low cost.

X. Contraceptive Technology and Research on Reproductive and Child Health. The government has to take steps to advance, encourage, and support medical, social science, demographic and behavioural science, research on maternal, child and reproductive health care issues. This will improve medical techniques relevant to country's needs.

XI. Providing for the Older Population. Keeping in view the increasing life expectancy it is estimated that in proportion of population above 60 years and above will increase considerably. Considering the weakening traditional support system, the elderly are becoming increasingly vulnerable, needing protection and care. Promotion of old age health care and support will also serve to reduce incentive for large families. National Policy for Older Persons was adopted by the Ministry of Social Justice and Empowerment in January, 1999.

XII. Information, Education and Communication. Information, education and communication (IEC) of family welfare messages must be clear, focussed and disseminated everywhere, including the remote corners of the country and in local dialects.

National Commission on Population

The Government of India constituted the National Commission on Population on May 11, 2000 with the Prime Minister as the Chairman and the Deputy Chairman of Planning Commission as its vice chairman. The Commission has the mandate to :

- review, monitor and give direction for the implementation of the National Population Policy with the view of achieving the goals it has set;
- promote synergy between health, educational, environmental and developmental programmes so as to hasten population stabilisation;
- promote inter-sectoral coordination in planning and implementation of the programmes through different agencies at the Centre and in the states; and
- develop a vigorous people's programme to support this national effort.

A Strategic Support Group consisting of secretaries of concerned sectoral ministries has been constituted as a standing advisory group to the Commission. Nine working groups were constituted to look into specific aspects of implementation of the programmes aimed at achieving the targets set in the National Population Policy.

Health Indicators

Health is one of the most important constituent of human development. Life free from illness and having reasonably long span is termed as healthy life.

Following are important health indicators :

1. Life expectancy at birth. This is an important health indictor which indicate the number of years a person (male and female) would live after birth. Due to improvement in health and sanitation services, life expectancy at birth in India has improved considerably during the last over four decades (**Table 10.18**).

TABLE 10.18. Life expectancy at birth by sex, India

Year	Males	Females	Difference Female–Male
1970-75	50.5	49.0	–1.5
1981-85	55.4	55.7	+0.3
1991-95	59.7	60.9	+1.2
2001-06	63.8	66.1	+2.3
2006-11	65.8	68.1	+2.3
2011-16	67.3	69.6	+2.3
2016-21	68.8	71.1	+2.3
2021-26	69.8	72.3	+2.5

Source : (*i*) Premi Mahendra K. and Das Dependra Nath (2012) Population of India 2011, p. 47.
(*ii*) Bose Ashish (2010), India's Quest for Population Stabilisatior, p. 89.

Table 10.18 shows that the difference between female-male life expectancy has been in favour of males in 1970-75 whereafter it become in favour of females. It is also worth noting that the gap between female and male life expectancy has gradually increased between 1981-85 and 2001-06. This gap is likely to remain constant upto 2016-21 after which is will increase further.

2. Crude Birth Rate (CBR). Crude birth rate is expressed in terms of number of births in a year per thousand of mid year population. It is worth noting that only live births during the year are to be taken into account. It is calculated as under :

$$CBR = \frac{Bt}{P} \times 1000$$

where Bt = live births during the year

and P = estimated mid-year population

This is the simplest and most widely used measure of human fertility. CBR in India has fallen from 49.2 per thousand in 1901-10 to 23 per thousand in 2001-07 (**Table 10.19**). This is an indication of some success in controlling the birth rate.

3. Total Fertility Rate (TFR). Total Fertility Rate is expressed as the number of children born to a women during her entire reproductive age. TFR in India decreased from 6 in 1960 to less than 3 in 2003. Thus India has crossed two-third of the way towards its goal of replacement level fertility of 2.1. Some states like Kerala, Tamil Nadu, Andhra Pradesh and Karnataka have already achieved this goal.

TABLE 10.19. India : Child Birth Rate and Crude Death Rate

Year	Crude Birth Rate (per thousand)	Crude Death Rate (per thousand)
1901-10	49.2	42.6
1911-20	48.1	48.6
1921-30	46.4	36.3
1931-40	45.2	31.2
1941-50	39.9	27.4
1951-60	41.7	18.0
1961-70	41.2	19.2
1971-80	37.2	15.0
1981-90	29.6	10.8
1991-2000	26.0	8.6
2001-2007	23.0	7.0

Source : (*i*) Registrar General India.
(*ii*) India : A Reference Annual, 2008.

4. Crude Death Rate (CDR). It is the simplest measure of mortality indicating the number of deaths in a particular year per thousand of population. It is expressed as under :

$$CDR = \frac{D}{P} \times 100$$

where D = Number of deaths in a year
P = Estimated mid-year population

Table 10.19 shows that CDR in India declined from 42.6 per thousand in 1901-10 to a mere 7.0 per thousand in 2001-07. This is an indication of improvement in our health services and increased availability of health facilities.

5. Infant Mortality Rate (IMR). Infant Mortality Rate refers to the death rate among infants and is calculated for connoting mortality among children of less than one year of age. It is expressed as under :

$$IMR = \frac{D_o}{B_l} \times 1000$$

where D_o = number of deaths of children under one year of age

and B_l = number of live births.

Thus IMR is the ratio of number of deaths among children under one year of age to the number of live births.

In India, infant mortality rte was 61 per thousand in 2001-06 which decrease to 54 per thousand in 2006-11. It is likely to fall to 49 per thousand in 2011-16, 44 per thousand in 2016-21 and further to 40 per thousand in 2021-25. This is an indication of our concern about the newly born infants because this section of population will decided the future course of population trends in India.

6. Under Five Mortality Rate. This is another health indictor which is concerned with children below the age of 5 years. Drive to care for children especially in the rural areas, has paid rich dividends. It is heartening to note that under five mortality rate decreased considerably in the Post-Independent era, from 326 per thousand in 1951 to 55 per thousand in 2011.

7. Maternal Mortality Rate (MMR) is the indicator of health of women during pregnancy and delivery. MMR declined from 20.2 per cent at the time Independence to at low of less than 4 per cent in 2011. This decline is the result of medical facilities available to prospective mothers. Levels of MMR vary greatly across regions due to variation in access to emergency obstetric care (EOC), parental care, anaemia rates among women, education level of women and other factors.

HUMAN DEVELOPMENT

Growth and Development. Although both growth and development refer to changes over a period of time, yet these terms differ from each other. **Growth** is *quantitative* and value natural which may have a positive or a negative sign. This means that the change may be either positive (increase) or negative (decrease). Development on the other hand is *qualitative* change which is always value positive. This means that development cannot take place unless there is an increment or addition to the existing conditions. Development occurs when positive growth takes place. Yet, positive growth does not always lead to development. Development occurs when there is a positive change in quality. For example, if the population of a city grows from five lakhs to ten lakhs over a period of time, we say the city has grown. But if the basic facilities of life such as housing, water, power, transport, severage etc. remain the same or do not grow in proportion to population growth, then the growth has not been accompanied by development.

Before 1990s, a country's development was gauged as a measure of its economic progress. This implied that countries with better economic conditions were more developed while poor countries were less developed. This however, did not reflect the true nature of development because in many cases the benefit of economic growth did not reach the common man who deserved it the most. Quality of life of the people, the opportunities they have and the freedom they enjoy are important aspects of development.

The above mentioned ideas were clearly spelt out for the first time in the late 1980s and early 1990s by two great economists of Asia. One was **Dr. Mahbub-ul-Haq** of Pakistan and the other was **Nobel Laureate Dr. Amartya Sen** of India. **Dr. Mahbub-ul-Haq** created the Human Development Index (HDI) in 1990. According to him, *development is all about enlarging people's choices in order to lead long, healthy lives with dignity*. Dr. Haq believed that people are central to all development. The choices of the people are not fixed but keep on changing. The chief objective of development is to create conditions in which people can live meaningful lives.

A meaningful life is not just a long one. It must be a life with some purpose. This means that people must be healthy, be able to develop their talents, participate in society and be free to achieve their goals.

Dr. Amartya Sen expressed the opinion that an increase in freedom (or decrease in unfreedom) is the main objective of development. Increasing freedom is one of the most effective ways of bringing about development. He laid much emphasis on the role of social and political institutions and processes of increasing freedom.

Following three are the most important aspects of human development:

(*i*) Leading long and healthy life.

(*ii*) Attaining ability to gain knowledge.

(*iii*) Having enough means to be able to live a decent life.

In view of the above mentioned aspects, it is essential to have access to resources, health and education. But very often, people fail to attain capability and freedom to make even basic choices. This may be due to various reasons of which lack of knowledge, poverty, social discrimination etc. are important. Such a situation prevents people from leading healthy lives, being able to get educated and to lead a decent life. Therefore, in order to enlarge the choices of the people, it is essential to build their capabilities in the areas of health, education and access to resources. The choices become limited in the absence of these capabilities.

Generally speaking "Development is freedom". Development and freedom are often associated with modernisation, leisure, comfort and affluence. In the present day world computerisation, industrialisation, efficient transport and communication network, large education system, advanced and modern medical facilities, safety and security of individuals, etc. are considered as the symbols of development. Level of development is measured with respect to the availability and access to these modern things. But this is only one sided view of development which is often called the *'western or euro-centric'* view of development. For a postcolonial country like India, colonisation, marginalisation, social discrimination and regional disparity etc. show the other face of development.

In India, development is a mixture of opportunities as well as neglect and deprivation. A few people in urban areas are enjoying all the facilities of modern life while on the other hand vast humanity living in rural areas and urban slums do not have even the basic amenities of life. People belonging to scheduled castes, scheduled tribes, landless agricultural labourers, poor farmers, slum dwellers etc. are the worst sufferers. The condition of female population is more pathetic.

Lack of development leads to deteriorating human conditions and results in environmental pollution. Air, soil, water and noise pollution are posing a great threat to the very existence of our society. Consequently, the poor are being subjected to three inter-related processes of declining capabilities; *i.e.* (1) social capabilities — due to displacement and weakening social ties (social capital), (2) environmental capabilities—due to pollution and, (3) personal capabilities—due to increasing incidence of diseases and accidents. This, in turn, has adverse effects on their quality of life and human development.

Why Human Development ?

According to **Paul Streeten**, human development is necessary due to following reasons :

1. The main purpose of human development is to improve the human conditions and to enlarge people's choices.
2. It is a major tool of achieving higher level of productivity. A well-nourished, healthy, educated, skilled, alert labour force is the most productive asset. Therefore, investments on these sectors are justified on grounds of productivity too.
3. It helps in reducing the rate of growth of population.
4. Human development is friendly to the physical environment also. Deforestation, desertification and soil erosion decline when poverty declines.
5. Improved living conditions and reduced poverty contribute to a healthy civil society, enhanced democracy and greater social stability.
6. Human development also helps in reducing civil disturbances in the society and in increasing political stability.

The Four Pillars of Human Development

Just as any building is supported by pillars, the idea of human development is supported by the concepts of equity, sustainability, productivity and empowerment.

1. Equity. Equity means making equal access to opportunities available to everybody. The opportunities available to people must be equal irrespective of their gender, race, income and in the Indian case, caste. Yet this is very often not the case and happens in almost every society. Normally, the poor and persons belonging to socially and economically backward groups fail to have access to equity.

2. Sustainability. Sustainability refers to continuity in the availability of opportunities. This means that each generation must have the same opportunities. Therefore, we must use our environmental, financial and human resources in such a way that our future generations are not deprived of these opportunities.

3. Productivity. Productivity means human labour productivity or productivity in terms of human work. It must be enriched by building capabilities in people. In fact, people of a country are its real wealth. As such sincere effort should be made to increase their knowledge and provide better facilities of health and education so that they can attain better work efficiency.

4. Empowerment. It refers to have power to make choices. Such power comes from increasing freedom and capability. Good governance and people-oriented policies are required to empower people. The empowerment of socially and economically disadvantaged groups is of special importance.

Indicators of Human Development

Although it is not possible to have a flawless quantitative measure of human development, the United Nations Development Programme (UNDP) has developed a composite index, now known as the Human Development Index (HDI). It includes (*i*) longevity of life, (*ii*) knowledge base, and (*iii*) a decent material standard of living. To keep the index simple, only a limited number of variables are included. Initially, life expectancy was chosen as an index of longevity, adult literacy as an index of knowledge and per capita Gross National Product adjusted for **Purchasing Power Parity (PPP)** as an index of decent life. These variables are expressed in different units. Therefore, a methodology was evolved to construct a composite index rather than several indices.

In India, three sets of indicators have been selected for preparing the Human Development Report. Among them, a core set of composite indices presents the state of human development for the society as a whole. Besides, Gender Equality Index has been estimated to reflect the relative attainments of women, and the Human Poverty Index to evaluate the state of deprivation in the society.

Several other variables have gradually been added to the above sets of indicators. Among them, *health indicators* related to longevity are birth rate, death rate with special reference to infant mortality, nutrition, and life expectancy at birth. *Social indicators* include literacy particularly female literacy, enrollment of school-going children, drop out ratio, and pupil-teacher ratio. *Economic indicators* are related to wages, income, and employment. Per Capita Gross Domestic Product, incidences of poverty and employment opportunity are also favoured indicators in this group. They are converted into a composite index to present the holistic picture of the Human Development.

WHAT IS HUMAN DEVELOPMENT?

"Human development is a process of enlarging the range of people's choices, increasing their opportunities for education, health care, income and empowerment and covering the full range of human choices from a sound physical environment to economic, social and political freedom."

Thus, enlarging the range of people's choices is the most significant aspect of human development. People's choices may involve a host of other issues, but, living a long and healthy life, to be educated and have access to resources needed for a decent standard of living including political freedom, guaranteed human rights and personal self-respect, etc. are considered some of the non-negotiable aspects of the human development.

Approaches to human development

Four important approaches to human development are :

1. The income approach;
2. The welfare approach;
3. Minimum needs approach;
4. Capabilities approach.

Measuring Human Development

Human Development is measured in terms of Human Development Index (HDI). It measures average achievements in basic human development in one simple composite index and produces a ranking of countries on the basis of their performance in key areas of health, education and access to resources. These rankings are based on a score between 0 & 1 that a country earn from its record in key areas of health, education and access to resources.

TABLE 10.20. Approaches to Human Development

1. Income Approach	This is one of the oldest approaches to human development. Human development is seen as being linked to income. The idea is that the level of income reflects the level of freedom an individual enjoys. Higher the level of income, the higher is the level of human development.
2. Welfare Approach	This approach looks at human beings as beneficiaries or targets of all development activities. The approach argues for higher government expenditure on education, health, social secondary and amenities. People are not participants in development but only passive recipients. The government is responsible for increasing levels of human development by maximising expenditure on welfare.
3. Basic Needs Approach	This approach was initially proposed by the International Labour Organisation (ILO). Six basic needs i.e., health, education, food, water supply, sanitation and housing were identified. The question of human choices is ignored and the emphasis is on the provision of basic needs of defined sections.
4. Capability Approach	This approach is associated with Prof. Amartya Sen. Building human capabilities in the areas of health, education and access to resources is the key to increasing human development.

1. Health. The indicator chosen to assess health is *life expectancy at birth*. It means that people have a better choice to lead longer and healthier life. Higher the life expectancy at birth, higher is the human development index.

2. Education. Education here involves adult literacy rate and gross enrolment ratio. It means that a country should have larger number of adults who are able to read and write and larger number of children enrolled in schools to be placed higher in human development index.

3. Access to resources. Access to resources is measured in terms of purchasing power (in U.S. dollars).

The Human Development Report was first published in 1990 by the United Nations Development Programme (UNDP). Since then it is published every year. This report gives an interesting rank wise list of the member countries according to the level of human development. The Human Development index and the Human Poverty index are two important indices to measure human development used by the UNDP.

International Comparisons

Human Development is not necessarily related to size or per capita income of a country. It has been found that smaller and economically poorer countries are often ranked higher in terms of human development than the bigger and richer countries. For example Norway and Iceland are much smaller and poorer countries in terms of GDP than the U.S.A. But these two small countries rank much higher than the U.S.A. with respect to HDI value. Similarly Sri Lanka, Trinidad and Tobago have smaller economies than that of India but have higher rank than India in terms of human development index (HDI). In India, Kerala has higher rank than Panjab and Gujarat despite having lower per capita income than these states.

Member countries have been divided into three broad groups on the basics of the human development scores earned by them. Countries with a score of above 0.8 are termed as having high index value. Countries with score of between 0.5 and 0.799 are placed in medium level of development. Countries having development index below 0.5 are said to have low level of human development. (*see* **Table 10.21**)

TABLE 10.21. Human Development Categories, Criteria and Countries

Level of Human Development	Score in Development Index	Number of Countries
High	above 0.8	57
Medium	between 0.5 up to 0.799	88
Low	below 0.5	32

Source : Human Development Report, 2011.

Computing the HDI

To construct the Index, fixed minimum and maximum values have been established for each of the indicators :

- Life expectancy at birth : 25 years and 85 years;
- General literacy rate : 0 per cent and 100 per cent;
- Real GDP per capita (PPP$) ; PPP$ 100 and PPP$ 40,000.
- Purchasing power party.

Individual Indices are computed first on the basis of a given formula. HDI is a simple average of these three indices and is derived by dividing the sum of these three indices by 3.

With normalisation of the values of the variables that make up the HDI, its value ranges from 0 to 1. The HDI value for a country or a region shows the distance that it has to travel to reach the maximum possible value of 1 and also allows intercountry comparisons.

The closer a score is to one, the greater is the level of human development. Therefore, a score of 0.983 would be considered very high while 0.268 would mean a very low level of human development.

TABLE 10.22. Human Development, International Comparison

HDI Rank	Country	1980	1990	2000	2005	2009	2010	2011	Average annual HDI Growth Rate (per cent)		
									1980–2011	1990–2011	2000–2011
1	Norway	0.796	0.844	0.913	0.938	0.941	0.941	0.943	0.55	0.53	0.29
2	Australia	0.850	0.873	0.906	0.918	0.926	0.927	0.929	0.29	0.30	0.23
39	Poland	—	—	0.770	0.791	0.807	0.811	0.813	—	—	0.50
61	Malaysia	0.559	0.631	0.705	0.738	0.752	0.758	0.761	1.00	0.90	0.69
66	Russian Fed.	—	—	0.691	0.725	0.747	0.751	0.755	—	—	0.81
84	Brazil	0.549	0.600	0.665	0.692	0.708	0.715	0.718	0.87	0.86	0.69
92	Turkey	0.463	0.558	0.634	0.671	0.690	0.696	0.699	1.34	1.08	0.90
101	China	0.404	0.490	0.588	0.633	0.674	0.682	0.687	1.73	1.62	1.43
97	Sri Lanka	0.539	0.583	0.633	0.662	0.680	0.686	0.691	0.80	0.81	0.80
103	Thailand	0.486	0.566	0.626	0.656	0.673	0.680	0.682	1.10	0.89	0.78
112	Philippines	0.550	0.571	0.602	0.622	0.636	0.641	0.644	0.51	0.58	0.62
113	Egypt	0.406	0.497	0.585	0.611	0.638	0.644	0.644	1.50	1.24	0.88
124	Indonesia	0.423	0.481	0.543	0.572	0.607	0.613	0.617	1.23	1.19	1.17
123	South Africa	0.564	0.615	0.616	0.599	0.610	0.615	0.619	0.30	0.03	0.05
128	Vietnam	—	0.435	0.528	0.561	0.584	0.590	0.593	—	1.50	1.06
134	**India**	**0.344**	**0.410**	**0.461**	**0.504**	**0.535**	**0.542**	**0.547**	**1.51**	**1.38**	**1.56**
145	Pakistan	0.359	0.399	0.436	0.48	0.499	0.503	0.504	1.10	1.12	1.33
143	Kenya	0.420	0.456	0.443	0.467	0.499	0.505	0.509	0.62	0.52	1.27
146	Bangladesh	0.303	0.352	0.422	0.462	0.491	0.496	0.500	1.63	1.69	1.55
	World	**0.558**	**0.594**	**0.634**	**0.66**	**0.676**	**0.679**	**0.682**	**0.65**	**0.66**	**0.66**

Source : HDR 2011.

HDI of India

As compared to the pre-independence days, India has done well in development in general. As per Human Development Reports (HDRs) published annually by the UNDP, India has consistently improved on human development front and is grouped among the countries with '*medium human development*'. According to Human Development Report 2011 published by the United Nations Development Programme (UNDP) [which estimates the Human Development Index (HDI) in terms of three basic capabilities to live a long and healthy life, to be educated and knowledgeable and to enjoy a descent economic standard of living] the HDI of India was 0.547 in 2011 with an overall global ranking of 134 (out of 187 countries) compared to 119 (out of 169 countries HDR 2010).

However, a comparable analysis of the trends during 1980-2011 (**Table 10.22**) shows that although lower in HDI ranking, India has performed better than

TABLE 10.23. India's Global Position in Human Development 2011

Country	HDI 2011	HDI rank 2011	Gross national income (GNI) per capita (constant 2005 PPP $) 2011	Life expectancy at birth (years) 2011	Mean years of schooling (years) 2011[a]	Expected years of schooling (years) 2011[a]
Norway	0.943	1	47,557	81.1	12.6	17.3
Australia	0.929	2	34,431	81.9	12.0	18
Poland	0.813	39	17,451	76.1	10.0	15.3
Malaysia	0.761	61	13,685	74.2	9.5	12.6
Russian Fed.	0.755	66	14,561	68.8	9.8	14.1
Brazil	0.718	84	10,162	73.5	7.2	13.8
Turkey	0.699	92	12,246	74.0	6.5	11.8
China	0.687	101	7,476	73.5	7.5	116
Sri Lanka	0.691	97	4,943	74.9	8.2	12.7
Thailand	0.682	103	7,694	74.1	6.6	12.3
Philippines	0.644	112	3,478	68.7	8.9	11.9
Egypt	0.644	113	5,269	73.2	6.4	11.0
Indonesia	0.617	124	3,716	69.4	5.8	13.2
South Africa	0.619	123	9,469	52.8	8.5	13.1
Vietnam	0.593	128	2,805	75.2	5.5	10.4
India	**0.547**	**134**	**3,468**	**65.4**	4.4	**10.3**
Pakistan	0.504	145	2,550	65.4	4.9	6.9
Kenya	0.509	143	1,492	57.1	7.0	11.0
Bangladesh	0.5	146	1,529	68.9	4.8	8.1
World	**0.682**		**10,082**	**69.8**	7.4	**11.3**

Source : HDR 2011.

Note : a—Data refer to 2011 or the most recent year available; PPP is purchasing power parity.

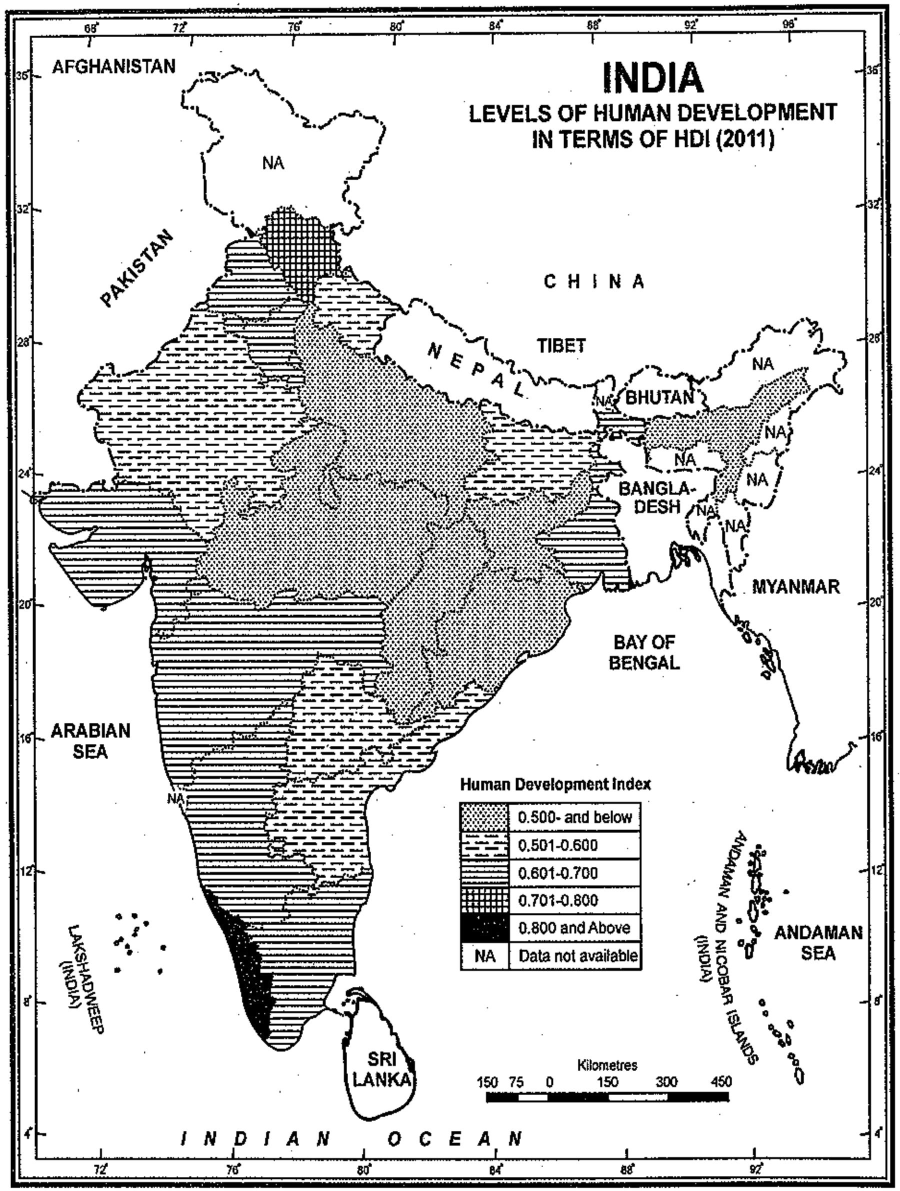

FIG. 10.15. India : Levels of Human Development in terms of HDI (2011)

most (including high and very high human development) countries in terms of average annual HDI growth rate. India is behind only China and Bangladesh in this regard. If average annual HDI growth of 2000-11 is viewed, India (1.56 per cent) is even ahead of China (1.43 per cent) (**Table 10.22**). While China performed very well in terms of growth of HDI in the 1980s, there was a deceleration in the

1990s and 2000s. On the other hand India, which seems to have faltered in the 1990s, has picked up again with its growth rates during 2000-11 surpassing even those of the 1980s.

However, there should be no room for complacency as India is still in the medium human development category with countries like China, Sri Lanka, Thailand, Philippines, Egypt, Indonesia, South Africa, and even Vietnam having better overall HDI ranking within the same category. The existing gap in health and education indicators as compared to developed countries and also many of the developing countries indicates the need for much faster and wider spread of basic health and education. Life expectancy at birth in India was 65.4 years in 2011 as against 81.1 years in Norway, 81.9 years in Australia, 74,9 years in Sri Lanka, 73.5 years in China, and the global average of 69.8 years. However, it has increased by one percentage points from 64.4 in 2010 to 65.4 in 2011. The other countries referred to were almost stagnant during this period. Similarly, the performance of India in terms of mean years of schooling is not only much below that of countries like Sri Lanka, China, and Egypt which have higher per capita incomes but also below that of Pakistan, Bangladesh, and Vietnam which have lower per capita incomes. It is also much lower than the global average (**Table 10.23**). The National Human Development Report (NHDR) 2011 of the Institute of Applied Manpower Research and Planning Commission states that India's HDI between 1999-2000 and 2007-08 has increased by 21 per cent, with an improvement of over 28 per cent in education being the main driver. The increase in HDI in the poorest states of India has been much sharper than the national average and hence the convergence in HDI across states.

In terms of the gender inequality index (GII), India with a value of 0.617 ranks 129 out of a total of 187 countries as per HDR 2011. The GII captures the loss in achievement due to gender disparities in the areas of reproductive health, empowerment, and labour force participation with values *ranging from 0* (perfect equality) to 1 (total inequality). The GII value of 0.617 indicates a higher degree of gender discrimination in India compared to countries like China (0.209), Pakistan (0.573), Bangladesh (0.550), Bhutan (0.495), and Sri Lanka (0.419). It is even higher than the global average 0.492.

TABLE 10.24. State level patterns of Human Development Index (HDI) in 2011

Name of State	Human Development Index (HDI)	HDI Ranking
1. Andhra Pradesh	0.580	15
2. Assam	0.407	16
3. Bihar	0.563	21
4. Chhattisgarh	0.417	23
5. Gujarat	0.633	11
6. Haryana	0.627	9
7. Himachal Pradesh	0.717	3
8. Jharkhand	0.500	19
9. Karnataka	0.627	12
10. Kerala	0.817	1
11. Madhya Pradesh	0.430	20
12. Maharashtra	0.650	7
13. Odisha	0.450	22
14. Punjab	0.667	5
15. Rajasthan	0.587	17
16. Tamil Nadu	0.637	8
17. Uttar Pradesh	0.473	18
18. Uttarakhand	0.530	14
19. West Bengal	0.650	13

Source : India HDR 2011 Quoted in Economic Survey 2011-12, p. 310.

Table 10.24 shows that Kerala is the most prospectus state of India with respect to human development index. This state can easily match with some of the advanced countries of the world so far as human development is concerned. Surprisingly Himachal Pradesh also has high human development which is higher than the so called advanced states of Punjab, Haryana and Gujarat. This shows that human development does not always correspond with economic growth and so many other factors are also considered while computing human development index. States with lower human development index are Assam, Chhattisgarh, Jharkhand, Madhya Pradesh, Odisha and Uttar Pradesh. Again this is surprising that the mineral rich state of Jharkhand is having low HDI while states with meager minerals have sufficiently high HDI.