Climate Change and Its Impact on India

Climate change is one of the main environmental challenges facing the world today. India is facing several problems. Climate change is associated with various adverse impacts on agriculture, water resources, forest and biodiversity, health, coastal management and increase in temperature. Decline in agricultural productivity is the main impact of climate change on India. A majority of population depends on agriculture directly or indirectly. Climate change would represent additional stress on the ecological and socioeconomic systems that are already facing tremendous pressure due to rapid industrialization, urbanization and economic development. This paper analyzes the impact of climate change and its various aspects in the Indian context.

Keywords: Climate change, Greenhouse gas, Kyoto protocol, Forest

Introduction

Accumulation of trace gases such as carbon dioxide (CO_2) and methane (CH_4) in the atmosphere, caused mainly due to anthropogenic activities such as burning of fossil fuels, is believed to be altering the earth's climate system. The Intergovernmental Panel on Climate Change (IPCC) in its fourth assessment report observed that "warming of climate system is now unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global seal level" (Soloman *et al.*, 2007). India has a reason to be concerned about climate change, as a vast population depends on climate-sensitive sectors like agriculture, forestry and fishery for their livelihood. The adverse impact of climate change in the form of decline in rainfall and rise in temperature has resulted in increased severity of livelihood issues in the country. Climate change would represent additional stress on the ecological and socioeconomic systems that are already under tremendous pressure due to rapid industrialization, urbanization and economic development.

Climate change is one of the most important global environmental challenges facing humanity with implications for food production, natural ecosystems, freshwater supply, health, etc. According to the latest scientific assessment, the earth's climate system has demonstrably changed on both global and regional scales since the pre-industrial era. Further, evidence shows that most of the warming (of 0.1 °C per decade), observed over the last 50 years, is attributable to human activities (IPCC, 2001a and 2001b).

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The Intergovernmental Panel on Climate Change projects that the global mean temperature may increase between 1.4 and 5.8 °C by 2100. This unprecedented increase is expected to have severe impact on the global hydrological system, ecosystem, sea level, crop production and related processes. The impact would be particularly severe in the tropical areas, which mainly consist of developing countries, including India (Jayant *et al.,* 2006).

In 1992, the UN Conference on Environment and Development (UNCED) at Rio de Janeiro led to FCCC (Framework Convention on Climate Change), which laid the framework for the eventual stabilization of greenhouse gases in the atmosphere, recognizing the common but differentiated responsibilities and respective capabilities, and social and economic conditions. The Convention came into force in 1994. Subsequently, the 1997 Kyoto Protocol, which came into force in 2005, reasserted the importance of stabilizing greenhouse gas concentrations in the atmosphere adhering to sustainable development principles. The Protocol laid out guidelines and rules regarding the extent to which a participating industrialized country should reduce its emissions of six greenhouse gases, viz., carbon dioxide, methane, nitrous oxide, chlorofluorocarbon, hydrofluorocarbons and perfluorocarbons.

The urban population of India stood at 286 million or 27.80% of the total population of 1.02 billion, according to the Census of India 2001. This population is projected to rise to 368 million by the year 2012. The urban population lives in 5,161 cities and towns of India, and faces severe water and sanitation stress. According to a World Bank report, India's water economy makes the point that India is fast running out of water and by 2020 it will be under severe stress, and forecasts that by 2050 demand outstrips supply. In a fast growing economic scenario, the demand for water is bound to go up. The continuous and unabated emission of millions of tons of carbon dioxide into the atmosphere, even if originating mainly from a few countries or regions, can lead to global and permanent climatic changes with potentially disastrous consequences such as rise of sea waters and submergence of numerous islands and coastal areas, and a rise in ambient temperatures leading to significant impact on cropping patterns and agricultural productivity (*The Hindu* Survey of Environment, 2009).

India is a large developing country with nearly 700 million rural population directly depending on climate-sensitive sectors and natural resources such as water, biodiversity, mangroves, coastal zones, and grasslands for their subsistence and livelihood. Further, the adaptive capacity of dry land farmers, forest-dwellers and nomadic shepherds is very low. Despite being symbolically important, Kyoto Protocol is now widely considered as a 'failure' because it neither has initiated emission reduction globally nor it has promised required further cuts in greenhouse gas emissions. Scientists have long warned that even 100% adherence to Kyoto Protocol will do little to limit the change in climate, yet almost 15 long years are spent globally in creating this policy failure. Almost exclusive focus on mitigation in Kyoto Protocol acts against the interest of the developing countries. Unsustainable consumption patterns of the rich industrialized nations are responsible for the threat of climate; only 25% of the global population lives in these countries, but they emit more than 70% of the total global CO_2 emissions and consume 75 to 80% of many of the other resources of the world (Parikh *et al.,* 1991).

India should be concerned about the climate change because it might have adverse impact on the country. Not all possible consequences of climate change are yet fully understood, but the main 'categories' of impacts are those on agriculture, rise in sea level leading to submersion of coastal areas and increased frequency of extreme events which pose serious threats to India. The paper discusses elaborately the impact of climate change on India, especially in agriculture, water, health, forest, sea level and risk events.

Greenhouse Gas Emission from India

Climate change arising due to the increasing concentration of greenhouse gases in the atmosphere since the pre-industrial times has emerged as a serious global environmental issue and poses threats and challenges to mankind. Climate change is increasingly recognized as one of the potential critical factors in sustainable development trajectories and there is an emerging international literature that considers methodological issues and empirical results of studies that explore interlinkages, trade-offs and synergies between the different policy areas involved. Estimations of anthropogenic greenhouse gas emission inventories in India began in a limited scale in 1991 which were enlarged and revised, and the first definitive report for the base year 1990 was published in 1992 (Mitra, 1992). A comprehensive inventory of the Indian emissions from all energy, industrial processes, agricultural activities, land use, land use change and forestry, and waste management practices has been prepared by UNFCCC (NATCOM 2004). Table 1 summarizes the greenhouse gas inventory estimates reported under the aegis of India's Initial National Communications.

The Compounded Annual Growth Rates (CAGR) of CO_2 equivalent emissions from India between 1990 and 2000 show an overall increase by 4.2% per annum (Table 2). On a sectoral basis, the maximum growth in emissions is from the industrial process sector (21.3% per annum), followed by the emissions from the waste sector (7.3% per annum). The energy sector emissions have only grown by 4.4% per annum with almost no increase in emissions registered from the agriculture sector. Significant increase in emissions from the industrial process sector can be attributed to the growth in cement and steel production in India over the decade. Similarly, increase in emissions from the waste sector can be attributed to increase in quantity of waste generated due to the large influx of population from villages to cities (Gaikwad *et al.,* 2004) in 2000.

Agriculture and Food Security

Highly climate-sensitive Indian agriculture, 65% of which is in rainfed areas, contributes nearly 25% of GDP, employs 65% of the total workforce and accounts for 13.3% of total exports together with allied activities (GOI, 2002). Several studies predict that despite substantial increase in national foodgrain production, the productivity of some important crops such as rice and wheat could decline considerably with climate change (Achanta, 1993).

Table 1: Summary of Greenhouse Gas Emission in Gg (Thousand Tons from India in 1994 by Sources and Sinks)

Greenhouse Gas Source and Sink Categories	CO_2 (Emissions)	CO_2 (Removals)	CH_4 (Emissions)	N_2O (Emissions)	CO_2 Equivalent (Emissions)
All energy	679,470	–	2,896	11.4	743,820
Industrial process	99,878	–	2	9	102,710
Agriculture	–	–	14,175	151	379,723
Land use, land use change and forestry	37,675	23,533	6.5	0.04	14,292
Wastes	–	–	1,003	7	23,233
Total national emission (giga gram per year)	817,023	23,533	18,083	178	1,228,540

Source: Subodh Sharma (2006)

Table 2: Trends of GHG Emission in India

Greenhouse Gas Sources and Sink (Gg)	1990 (CO_2 eq. mt)	1994 (CO_2 eq. mt)	2000 (CO_2 eq. mt)	CAGR in 1999-2000
All energy	622,587	743,820	959,527	4.4
Industrial process	24,510	102,710	168,378	21.3
Agriculture	325,188	344,485	328,080	0.1
Land use, land use change and forestry	1,467	14,291	–	–
Waste management	14,133	23,233	26,637	7.3
Total emission (Gg)	987,885	1,228,539	1,484,622	4.2
Population	853	914	1,000	–
Per capita emission (tons/capita)	1.2	1.3	1.5	–

Source: Subodh Sharma (2006); ALGAS (1998); NATCOM (2004)

The rate of CO_2 release into the atmosphere has increased by 30 times in the last 3-4 decades. It is estimated that a 0.5 °C rise in winter temperature could reduce the wheat yield by 0.45 ton per hectare. A recent World Bank report studied two drought-prone regions in Andhra Pradesh and Maharashtra and one flood-prone region in Orissa on climate change impacts. It found that climate change could have the following serious impacts:

- In Andhra Pradesh, dry land farmers may see their incomes plunge by 20%.
- In Maharashtra, sugarcane yields may fall dramatically by 25-30%.

- In Orissa, flooding will rise dramatically leading to a drop in rice yields by as much as 12% in some districts.

With melting glaciers, flood risks would increase in the near future. In the long-term, there can be no replacement for the water provided by glaciers that could result in water shortages on an unparalleled scale. Floods and drought are thus projected to multiply as a consequence of climate change. This will lead to a huge crop loss and leave large patches of arable land unfit for cultivation. To sum up, it will threaten food security. Due to a 2 to 3.5 °C rise in temperature accompanied by a 7% to 25% change in precipitation, farmers may be losing a net revenue between 9% and 25% which may adversely affect the GDP by 1.8% to 3.4% (Kavi Kumar and Parikh, 1998). There will be serious consequences for food security in the south and India stands to lose a massive 125 mt equivalent to some 18% of its rainfed cereal production (Fisher *et al.,* 2001).

In India, the estimated total requirement for foodgrains would be more than 250 mt by 2010. The gross arable area is expected to increase from 191 to 215 mha by 2010, which would require an increase of cropping intensity to approximately 150% (Sinha *et al.*, 1998). Because land is a fixed resource for agriculture, the need for more food in India can be met only through higher yield per unit of land, water, energy and time, such as through precision farming. Kavi Kumar and Parikh (2001) showed that even with farm-level adaptations, the impacts of climate change on Indian agriculture would remain significant. They estimated that with a temperature change of +2 °C and an accompanying precipitation change of +7%, farm level total net-revenue would fall by 9%, whereas with a temperature increase of +3.5 °C and precipitation change of +15% the fall in farm level total net-revenue would be nearly 25%. Mall *et al.* (2006) provide an excellent review of climate change impact studies on Indian agriculture mainly from physical impacts perspective. The available evidence shows significant drop in yields of important cereal crops like rice and wheat under climate change conditions. However, biophysical impacts on some of the important crops like sugarcane, cotton and sunflower have not been studied adequately.

Kavi Kumar (2009) has analyzed a cross-sectional data in climate sensitivity of Indian agriculture. The field level analysis showed that while most farmers are familiar with the term climate change, their understanding is often overlapping with other phenomena. Significantly higher impacts were reported during the period mid-1980s to late 1990s. The findings of the study corroborate the growing evidence of weakening agricultural productivity over the similar period in India. The impacts estimated using India-specific climate projections show that impacts declined during the period 1971-1985 and again increased further possibly due to improved resilience of Indian agriculture during this period and also due to the regional variation in the climate projection. Table 3 reports the all-India level impacts estimated during each time period.

Water Resources

India's rich water resources are unevenly distributed and result in spatial and temporal shortages. The demand for water has increased tremendously over the years due to an

Table 3: Climate Change Impacts Over Time						
	1956-1970		1971-1985		1986-1999	
Scenario	**Impacts**	**% of 1990 Net Revenue**	**Impacts**	**% of 1990 Net Revenue**	**Impacts**	**% of 1990 Net Revenue**
+2 °C/7%	–53.7	–6.1	–76.8	–8.7	–188.7	–21.3
+3.5 °C/14%	–297.4	–33.6	–303.4	–34.3	–754.9	–85.3
India-Specific CC Scenario	–219.6	–24.8	–153.6	–17.4	–544.4	–61.5

Note: Impacts are in billion rupees, 1999-2000 prices; Net revenue in India in 1990 was ₹885 bn (1990-2000 prices). The first two scenarios use hypothetical increases in temperature and precipitation in degree centigrade and percentage, respectively.

Source: Kavi Kumar (2009)

increasing population, expanding agriculture, and rapid industrialization which are responsible for considerable imbalance in the quantity and quality of water resources. According to the Ministry of Water Resources, the amount of water available per person in India decreased steadily from 3,450 cm in 1951 to 1,250 cm in 1999, and is expected to decline further to 760 cm per person in 2050.

Lower rainfall and more evaporation would have the dire consequence of less runoff, substantially changing the availability of freshwater in the watersheds, decline of soil moisture and increasing aridity level of hydrological zones. By the year 2050, the average annual runoff in the river Brahmaputra will decline by 14%. If the current warming rates are maintained, Himalayan glaciers could decay at extremely rapid rates, shrinking from the present 5,00,000 km^2 to 1,00,000 km^2 by the 2030s. This is also a cause for concern when considering Himalayan hydropower as a partial solution to India's energy needs, as climate change will sharply reduce the effectiveness of the planned mammoth investments.

The general impacts of climate change on water resources have been brought out by the Third Assessment Report of the IPCC (Houghton, 2000). It indicates an intensification of the global hydrological cycle affecting both ground and surface water supply. Changes in the total amount of precipitation, its frequency and intensity have also been predicted. Such changes, when on the surplus side, may affect the magnitude and timing of runoff but shall create drought-like situations when these are on the deficit side. Thus, climate change impacts are going to be most severe in the developing world, because of their poor capacity to adapt to climate variability. India also comes under this category. Gosain *et al.* (2006) have used the HadRm2 daily weather data to determine the spatial-temporal water availability in the river system. The initial analysis has revealed that under the greenhouse gas scenario, severity of droughts and intensity of floods in various parts of the country may get deteriorated. However, there is a general overall reduction in the quantity of the available runoff under the greenhouse gas scenario. Luni with the west-flowing rivers Kutch and Saurastra which occupies about one-fourth of the area of Gujarat and 60% of the area of Rajasthan shall face acute water scare conditions. River basins of Mahi, Pennar, Sabarmati and Tapi shall also face water shortage conditions. River basins belonging to Cauvery, Ganga, Narmada and Krishna shall experience seasonal or regular water-stressed conditions. River basins belonging to Godavari, Brahmani and Mahanadi shall not have water shortages but are predicted to face severe flood conditions (MoEF, 2004a and 2004b).

Automatic delineation of the river basins is done by using the Digital Elevation Model (DEM) which represents a topographic surface in terms of a set of elevation values derived at a finite number of points. Table 4 presents the threshold values used on the DEM of the respective river basins during the process of automatic delineation. It also provides the number of sub-basins the river basin got sub-divided into as a result of this threshold. The total area of the river basin as obtained from the automatic delineation has also been provided.

Table 4: Some of the Basic Details of the Basins Analyzed

Basin	Threshold Value Used (Ha)	No. of Sub-Basins	Total Area (Ha)
Brahmani	99,700	19	4,999,399
Cauvery	350,000	11	6,467,199
Ganga	2,000,000	29	87,180,000
Godavari	600,000	27	30,003,299
Krishna	600,000	21	24,647,200
Luni	750,000	9	12,793,400
Mahanadi	400,000	21	14,027,300
Mahi	100,000	13	3,579,000
Narmada	350,000	15	9,765,000
Pennar	200,000	11	5,524,600
Subarmati	48,900	8	1,668,026
Tapi	200,000	13	6,853,799

Source: Gosain (2006)

Forest

Global assessment has shown that future climate change is likely to have a significant impact on forest ecosystems. Climate is probably the most important determinant of vegetation patterns globally and has a significant influence on the distribution, structure and ecology of forest (Krischbaum *et al.*, 1996). India is a mega-biodiversity country where forests account for about 20% (64 million ha) of the geographical area (State Forest Report, 2001). With nearly 200,000 villages classified as forest villages, there is obviously large

Table 5: Annual Rainfall and Temperature Changes in Different Types of Forests of India Under B2 GHG Scenario for the Year 2085						
Forest Type	**Number of Grids**	**% Area**	**Mean Annual Rainfall (mm)**	**Change in Rainfall (mm)**	**Mean Temperature (°C)**	**Change in Temperature (°C)**
Blue pine (kali)	311	0.88	763.0	223.5	10.5	3.0
Chir pine	791	2.25	1,373.4	437.4	17.1	2.8
Mixed conifer	1,071	3.04	930.1	375.9	9.3	3.0
Hardwoods conifers mix	296	0.84	1,560.7	585.6	13.1	2.8
Upland hardwoods	881	2.50	1,523.8	476.9	16.4	2.7
Teak	3,364	9.56	1,314.6	353.0	26.1	2.9
Sal	4,251	12.08	1,435.2	348.3	24.6	2.7
Bamboo forest	567	1.61	2,268.3	564.9	23.8	2.7
Mangrove	201	0.57	1,734.3	280.8	26.6	2.5
Miscellaneous forest	22,339	63.48	1,679.8	374.5	23.0	2.7
Western Ghat evergreen forest	163	0.46	3,111.3	368.7	25.4	2.4
Source: FSI (2001)						

dependence of communities on forest resources (Ravindranath *et al.,* 2006). Table 5 explains data from FSI which can be used to map the location of various types of forests across India. The major forest types in India (those occupying 0.5% or more of the forested area) are presented in Table 5. Forests in India are extremely diverse and heterogeneous in nature, and it is difficult to classify them into a small number of categories. As a result, the pan-Indian 'Miscellaneous forest' category (with no dominant species) shows the highest (63%) proportion. The miscellaneous forest area occurs under all the forest types. The other two most dominant forests are *Shorea robusta* or sal (12%) in the eastern part of Central India and *Tecton grandis* or teak (9.5%), spread across Central India and the Western Ghats in southern India.

Changes in climate in the forest areas are assessed using the B2 scenario[1] projections and FSI categories of forests. The temperature and rainfall means are obtained by considering all the grids of each forest type, occurring in different parts of India. In general, under B2 scenario projections, the mean rainfall (and mean temperature) in areas under forest cover is somewhat higher than that in the non-forested areas. The increase expected in rainfall under the changed climate is also relatively larger for the forested areas with about 376 mm,

[1] Climate change is likely to significantly impact forest ecosystems. This assessment is based on climate projections of regional climate model of the Hadley Centre (HadRM3) using A2 (740 ppm CO_2) and B2 (575 ppm CO_2) scenario of special report on emissions scenario and BIOME4 vegetation response model.

compared to the overall average of about 235 mm. The mean change in temperature, however, is not different from that in the non-forested regions. As expected, the changes in climate are not uniform in different forest types—ranging from a large increase of more than 550 mm/year for hardwood and bamboo forests to a modest 220 mm for the colder fir/blue pine forests (Table 5).

Impact of Climate Change on Forest Types

A comparison of the extent of area that is likely to occur in each of the forest type under the present climate regime and that under the two future climate scenarios reveals the magnitude of changes that are expected to take place in each of the forest types. The BIOME4[2] model was run for a total of 10,864 grid points (10 min x 10 min) located in the Indian region, using the CRU[3] 10-min climatology. Due to gaps in data related to soil parameter values, the model could assign vegetation types to only 10,429 of these grid points. As mentioned earlier, a comparison with the FSI database (available at a much finer resolution of 2.5 min x 2.5 min) allowed us to use the information from 35,190 FSI grids. There was a reasonable match between the forests types predicted by BIOME4 and the forest types assigned by FSI. Thus, tropical evergreen forests were seen in the southern Western Ghats and in the northeastern region, while the temperate forests were seen to occur in regions corresponding to fir/spruce/deodar forests (Ravindranath *et al.* 2006).

Thus, climate change could cause irreversible damage to unique forest ecosystems and biodiversity, rendering several species extinct locally and globally (IPCC, 2001a and 2001b). Forest ecosystems require the longest response time to adapt, say through migration and regrowth (Leemans and Eickhout, 2004). Further, a long gestation period is involved in developing and implementing adaptation strategies in the forest sector. A review of studies by IPCC and Gitay *et al.* (2002) have shown that forest biodiversity or the species assemblage is projected to undergo changes due to the projected climate change. Biodiversity is likely to be impacted under the projected climate scenarios due to the changes or shifts in forest or vegetation types (in 57 to 60% of forested grids), forest dieback during the transient phase, and different species responding differently to climate changes even when there is no change will be an additional pressure and will exacerbate the declines in biodiversity resulting from socioeconomic pressures.

[2] As an equilibrium vegetation model, BIOME4 is an ideal tool for assessing vegetation distribution at a particular time in the past. However, plant assemblages heavily influenced by short-term dynamic processes (e.g., fire, recurrent extreme weather events) may be incorrectly simulated in the model. In this application, we have run BIOME4 using a 2.5° by 3.75° grid corresponding to the same resolution as the HadAM3 GCM. Absolute values for monthly mean surface temperature, precipitation, and cloud cover derived from the ten-year climatological means from the HadAM3 Pliocene control run were used to provide the climatic information necessary for the BIOME4 model.

[3] CRU (Climate Research Unit)—the global climate data set for a 10 min x 10 min grid available from the Climate Research Unit of the University of East Anglia. Ravindranath *et al.* (2006) have used the present climate based on the data centered during the period 1960-90. Monthly values of rainfall and mean monthly values of temperature, and cloud cover were available as a time series. Additionally, they were used to obtain the monthly averages needed by the BIOME4 model.

Sea-Level Rise

Coastal ecosystem will be affected by sea-level rise and temperature increases. Heavily populated mega delta regions, in particular, will be at the greatest risk due to increased flooding. The changes in the Godavari, Indus, Mahanadi and Krishna coastal deltas will potentially displace millions of people. Projected sea level rise could damage aquaculture industries, and exacerbate already declining fish productivity. There will also be higher risks of increased frequency and intensity of coastal surges and cycles (GoI, 2005).

If a one-meter sea level rise were to take place today, it would displace 7 million persons in India (ADB, 1995). In future, many more may be displaced. Around 35% of the land in Bangladesh would be submerged by a one-meter rise. The estimates of costs to build walls along the zones vulnerable to sea-level rise for the US is $107 bn as per the 1989 prices (Yohe, 1990). That may be a small share of the GDP of the developed countries, but such measures, even scaling for their coastlines, for say Bangladesh, could require a very large share of its GDP. Who shall pay Bangladesh or India for such a wall? Given that these countries are unlikely to be able to pay for protective measures, millions of people will be displaced in Bangladesh and many of them could spill over to India (Parikh and Parikh 2002). Sea level changes can be of two types: (i) changes in the mean sea level; and (ii) changes in the extreme sea level. An analysis of the past sea level measurement, recorded by tide gauges located at various ports in different parts of the world, indicated a mean sea level rise of 1 to 2 mm/year during the last century. These changes are generally attributed to global warming. Various consequences of global warming such as melting of sea ice, volume expansion due to temperature increase in the ocean, etc., can contribute to global sea-level rise (Church *et al.,* 2001).

Recent studies on the occurrences of cyclones in the Bay of Bengal have not shown any trends during the last century (Bhaskar Rao *et al.,* 2001). In coastal regions, wind stress plays an important role than the inverse barometric effects. In India, most of the earlier studies on storm surges were based on numerical modeling on particular events based on the track of the cyclone and pressure drop in the cyclone as input. The wind fields computed using the cyclone parameters, are used to drive the storm surge model (Unnikrishnan *et al.*, 2006). The estimates of sea-level rise along the coast of India were made by analyzing the past tide gauge data. Among the stations considered for the analysis, Mumbai, Visakhapatnam and Kochi showed a sea-level rise of slightly less than 1 mm/year; however, the analysis for Chennai showed a rate of decrease. These estimates need to be corrected by subtracting the measurements on vertical land movements, which are not available at present, in order to get the net sea-level rise (Unnikrishnan *et al.*, 2006).

Health

The health status of millions of people is projected to be affected through, for example, increases in malnutrition, increased deaths, diseases and injury due to extreme weather events, increased burden of diarrhoeal diseases, increased frequency of cardiorespiratory diseases due to higher concentrations of ground-level ozone in urban areas related to climate change, and the altered spatial distribution of some infectious diseases (IPCC, 2007). In its Third Assessment Report, the United Nations IPCC concluded that "climate change is projected to increase threats to human health". Climate change can affect human health directly (e.g., impacts of thermal stress, death/injury in floods and storms) and indirectly through changes in the ranges of disease vectors (e.g., mosquitoes), waterborne pathogens, water quality, air quality, and food availability and quality. Global climate change is, therefore, a newer challenge to ongoing efforts to protect human health (IPCC, 2001a and 2001b).

In India, almost half of the children under age five and more than one-third of the adults are undernourished. In Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, and Orissa, more than two out of five women are undernourished. Anemia is another major nutritional health problem in India, especially among women and children. Among children between the ages of 6 and 59 months, a majority (70%) are anemic. More than half of the women (55%) and one-fourth of the men are anemic in India. Anemia can result in maternal mortality, weakness, diminished physical and mental capacity, increased morbidity from infectious diseases, perinatal mortality, premature delivery, low birth weight, and (in children) impaired cognitive performance, motor development, and scholastic achievement (IIPS, 2007). Changes in climate are likely to change frequency, lengthen the transmission seasons, and alter the geographic range of important vector-borne diseases, malaria and dengue being the most important. There is historical evidence of associations between climatic conditions and vector-borne diseases. Malaria is of great public health concern and seems likely to be the vector-borne disease most sensitive to long-term climate change. Malaria varies seasonally in highly endemic areas. The link between malaria and extreme climatic events has long been studied in India. Early last century, the river-irrigated Punjab region experienced periodic malaria epidemics. Excessive monsoon rainfall and high humidity were identified early on as a major influence, enhancing mosquito breeding and survival. Recent analyses have shown that the malaria epidemic risk increases around fivefold in the year after an El Nino event (Bouma and van der Kaay, 1996). Increasing global temperature affect levels and seasonal patterns of both man-made and natural airborne particles, such as plant pollen, which can trigger asthma. About 6% of children suffer from respiratory tract infection and 2% of adults suffer from asthma (IPCC, 2001a and 2001b). Asthma deaths are expected to increase by almost 20% in the next 10 years if urgent actions to curb climate change and prepare for its consequences are not taken (WHO, 2008).

Increased Temperatures and Extreme Events

Climate change impacts will lead to an increased frequency of hot days, heat waves, droughts (declining water tables, crop failures, etc.) and natural disasters resulting from cyclones. Kothawale (2005) studied the temperature extremes in India by using the data of 40 stations well distributed over India for the period 1970-2002, and noted that heat wave conditions are relatively more frequent in May than in June, while very few heat waves occurred in the months of March and April. He also noted that the number of hot days is maximum over central part of India and minimum along the west coast of India during the pre-monsoon season. In the warming atmosphere, more summer rainfall is expected. Recent data have shown reduced snowfall over the Himalayas and also over the high mountain ranges of the Alps in a warming climate (Cyranoski, 2005). The monsoon cloudiness mostly seen in south India is also reduced by increased concentration of small dust particles in the lower troposphere and thus the summer monsoon rainfall also reduces (Ramanathan *et al.*, 2002). Analysis of meteorological measurement in India already indicates large difference in trends in the minimum temperature and cloud amounts between north and south India. Several severe examples of the consequences of climate change are available around the globe. Nine of the hottest years recorded in more than a century have occurred since 1988. Worldwide, July 1988 was the hottest month ever. In 1998, India experienced its worst hot spell in 50 years, which took a toll of over 3,000 lives. The tropical cyclone of Orissa in 1999 took a toll of about 10,000 lives. Himalayas and glaciers are retreating at the rate of 18 m per year in Gangotri.

Under future scenarios of increased greenhouse gas concentrations, a marked increase in rainfall and temperature is projected in the 21st century. India's climate could become warmer by 2.33 to 4.78 °C under the condition of doubling of CO_2 concentration (Longern 1998). An increase in the annual temperature of 0.7 to 1.0 °C by 2040 is predicted with respect to the 1980s (Lal *et al.,* 1995). There is an overall decline in the number of rainy days over a major part of the country. This decline is more in the western and central parts (by more than 15 days) while near the foothills of Himalayas and in north-east India, the number of rainy days may increase by 5 to 10 days.

The impact of climate variability and change, climate policy responses, and associated socioeconomic development will affect the opportunities for and success of climate policies. In particular, the socioeconomic and technological characteristics of different development paths will strongly affect missions, the rate and magnitude of climate change, climate change impacts, the capability to adapt and the capacity to mitigate.

Conclusion

Climate change is expected to affect the human well being in many different ways such as capital, ecosystem, disease and migration. Irrespective of the importance of the issue, it is not clear how to compute the value with the current state of the art of economics. A meaningful development involves at least transformation from agricultural to a non-agricultural economy reducing the dependence on agriculture. Since most of the labor force—about 70%—directly and indirectly depends on the sector for livelihood and employment, it is when this sector is more productive and ensures food self-sufficiency that it will release the necessary labor and capital for the manufacturing and service sectors. In the context of the current debate about climate change, it is necessary to show, far from being inactive in India, that considerable actions in terms of policies, programs and projects are being taken. Technology transfer can speed up the modernization process and additional funds can accelerate government in energy conservation. However, policies for poverty alleviation must be given priority.

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