GEOGRAPHY
Value Added Material
Key Features:
Syllabus & PYQ-Based
Structuring:
Targeted syllabus
coverage with PYQ
insights.
Integrated Approach:
Integrated Approach:
Seamless integration
of key concepts.
Static + Current
Static + Current
Affairs:
Combining core
concepts with current
updates.
Visual Learning Tools:
Visual Learning Tools:
Exam-focused maps
and diagrams for
quick recall.
Mains 2025

AHMEDABAD | BENGALURU | BHOPAL | CHANDIGARH | DELHI | GUWAHATI | HYDERABAD | JAIPUR | JODHPUR | LUCKNOW | PRAYAGRAJ | PUNE | RANCHI

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Preface

A Message to the Dedicated Mains 2025 Aspirant

Dear Aspirant,

Congratulations on conquering the first and most challenging stage of the Civil Services Examination. The journey from Prelims to Mains is a true test of not just knowledge, but of strategy, endurance, and the ability to connect diverse themes.

We understand that this crucial period is often marked by a sense of urgency and confusion, especially for a multi-disciplinary subject like Geography. With a vast syllabus that links the physical world to human activity, you might find yourself asking: How do I structure my preparation? How do I integrate static concepts with dynamic current events to gain a competitive edge?

It is with a deep understanding of these challenges that we have crafted this Geography Value Added Material (VAM) for Mains 2025. This document is not just another compilation of notes; it is a strategic tool designed to be your trusted companion in navigating the complexities of the GS Paper 1 Geography section.

Syllabus of Geography for GS Paper-1

- Salient features of World's Physical Geography
- Distribution of Key Natural Resources across the world (including South Asia and the Indian sub-continent); factors responsible for the location of primary, secondary, and tertiary sector industries in various parts of the world (including India)
- Important Geophysical Phenomena such as earthquakes, Tsunami, Volcanic activity, cyclone etc., geographical features and their location-changes in critical geographical features (including water-bodies and ice-caps) and in flora and fauna and the effects of such changes.

The Philosophy: Precision and Relevance through Thematic Analysis

The foundation of this VAM lies in a thoughtful and objective analysis of the UPSC Mains Geography questions from recent years. This rigorous analysis of PYQs has been done in the beginning of each chapter and is the guiding light in designing the document.

How Will This Document Empower Your Mains Preparation?

Our primary goal is to equip you with the content and confidence to write high-scoring, analytical answers. This VAM is structured to achieve several key objectives:

- Structured and Thematic Syllabus Coverage: We have broken down the macro syllabus into logical, thematic units to serve as a clear roadmap for your preparation.
  - The section on Salient features of World's Physical Geography is covered under four distinct sub-sections: Geomorphology, Climatology, Oceanography, and a dedicated

chapter on the Physiography of India.

■

Distribution of Key Natural Resources across the world (including South Asia and the Indian sub-continent); factors responsible for the location of primary, secondary, and

tertiary sector industries in various parts of the world (including India) are addressed in two separate chapters on the Distribution of Key Natural Resources and Industries.

•

Integrated Approach in the document: We recognize that geography is an integrated science.

■

Instead of treating important geophysical phenomena as standalone topics, we have woven them into their relevant chapters. You will find earthquakes, tsunamis, volcanoes Landslides, and Avalanches discussed within Geomorphology, while cyclones and heatwaves are covered in Climatology, providing you with a holistic and interlinked understanding.

■

Changes in the critical geographical features like cryosphere melting, melting of Himalayan glaciers, increasing land degradation, Elnino and variations in monsoons, wetlands and urban flooding have been covered in the document.

•

One-Stop Solution: This single document addresses the entire syllabus, ensuring that you get all the required topics in one consolidated book, saving you precious time and effort.

Our Commitment to Your Success

This document is a culmination of dedicated effort aimed at simplifying your preparation and maximizing your output. We believe that with a clear strategy and the right resources, you can transform your hard work into success. Trust the process, utilize this material to its fullest potential, and walk into the examination hall with the confidence that you have prepared smartly.

1. GEOMORPHOLOGY

Previous year questions (PYQs)

•

Bring out the causes for the more frequent occurrence of landslide in the Himalayas than in the Western Ghats. (2013)

•

What do you understand by the theory of 'continental drift? Discuss the prominent evidences in its support. (2013)

•

Explain the formation of thousands of islands in the Indonesian and Philippines archipelagos. (2014)

- Why are the world's fold mountain systems located along the margins of continents? Bring out the association between the global distribution of fold mountains and earthquakes and volcanoes. (2014)
- Discuss the geophysical characteristics of Circum-Pacific Zone. (2020)
- Briefly mention the alignment of major mountain ranges of the world and explain their impact on local weather conditions, with examples. (2021)
- Describe the characteristics and type of primary rocks. (2022)
- How are the fjords formed? Why do they constitute some of the most picturesque areas of the world? (2023)

PYQs Analysis

UPSC’s questions on Geomorphology over the years have been conceptual in nature with a practical orientation. These questions are not just about recalling theories but connecting them with spatial occurrences. Thematic variation is a key pattern.

For Example:

- Tectonic Theories & Landforms: The Continental Drift Theory (2013), Circum-Pacific Zone (2020), and Fold Mountains & their seismic-volcanic association (2014) highlight the focus on plate tectonics, mountain building, and geohazards.
- Disaster-Prone Landscapes: Recurrent interest in Landslides (2013), Earthquakes, Volcanoes, and Tsunamis shows that UPSC likes asking about regions vulnerable due to geomorphic or structural causes (e.g., Himalayas vs Western Ghats).
- Landforms & Their Formation: Questions like fjords (2023), island arcs in Indonesia & Philippines (2014), or weather impacts of mountain alignment (2021) show interest in physical processes shaping landscapes.

1.1. Origin and Evolution of Earth

Our Earth is part of a larger solar system puzzle. To understand its origin, we need to look at how the entire solar system formed. Scientists have suggested various theories about this process, and they all contribute to the overall story of the Big Bang theory.

Theory

Processes

Challenges

Nebular
Hypothesis

- A massive, hot cloud (nebula) cools and contracts, causing it to spin faster. This increased spin creates a bulge in the middle, eventually shedding rings of material due to centrifugal force.
- These rings then clump together due to gravity, forming planets, while the remaining central mass condenses into our Sun.
- Fails
to
explain

vast
difference
in
angular
momentum between Sun
and planets
•
Not enough mass in shed
rings for planet formation

Student Notes:
Planetesimal
Hypothesis
•
A passing star disrupts the Sun, pulling a cigar-shaped tidal bulge of material from its surface. This ejected material condenses into planets as it remains in orbit.
•
Material originating from the Sun's interior would be extremely hot, likely escaping into space rather than condensing to form planets
Tidal
Hypothesis
•
A close encounter with another star causes the Sun to bulge significantly. A large filament of material is pulled from the Sun, which then breaks apart and condenses into planets.
•
Doesn't account for the potential disruptive forces within the Sun during such a close encounter
Protoplanet
Hypothesis
•
A rapidly rotating nebula flattens into a disc. Within this disc, large rotating masses of gas, called protoplanets, emerge.
•
These protoplanets then gravitationally attract surrounding material, growing larger and eventually forming planets.
•
It does not fully explain

how protoplanets, the early building blocks of planets, formed in detail.

1.1.1. The Big Bang Theory

The Big Bang Theory states that, 13.8 billion years ago, all of space was contained in a single point of very high-density and high temperature state. From this single point the universe has been expanding in all directions ever since.

Evidences for the Big Bang Theory

The Big Bang theory is widely supported by multiple lines of evidence, including:

- Redshift: When light shifts to the red end of the spectrum, it means that the light waves are getting longer. This happens when an object in space, like a galaxy, is moving away from us. Observing redshift in distant galaxies supports the idea of an expanding universe.
- Cosmic Microwave Background (CMB): The theory suggests the universe is filled with weak microwave radiation. This radiation is believed to be a leftover from the early, hot universe. Its properties match predictions made by the Big Bang theory.
- Abundance of Light Elements: The observed abundance of lighter elements like hydrogen and helium in the universe aligns with the Big Bang's nucleosynthesis (the process of creating chemical elements in stars through nuclear fusion reactions) predictions for the early universe.

These three pieces of evidence provide strong support for the Big Bang theory as the prevailing cosmological model for the universe's origin and evolution.

Student Notes:

1.1.2. Missions to Understand the Origin and Evolution of Earth

Space exploration helps us understand the universe's origins and structure. It drives technological advancements, leading to improvements in material science and communications. Additionally,

it aids in identifying threats to Earth and exploring future possibilities for space habitation and resource use.
Recent important Space exploration are mentioned below:
Mission
Objective
What
Explored
By
Whom
Findings
Hubble
Space
Telescope
Revolutionized our
understanding of the
universe, observing
distant galaxies and
providing deep views
into our own solar
system.
Deep
space,
planets,
stars,
nebulae
NASA,
ESA
•
Insights into early universe
conditions for star and solar
system formation.
•
Observations of star and
planetary nebulae, potential
birthplaces of new solar
systems.
James
Webb
Space
Telescope
Successor to Hubble,
designed to peer
further back in time
and observe faint
objects in the
infrared spectrum.
Early
universe,
formation
of galaxies
and stars,
exoplanets
NASA,
ESA,
CSA
•
Observations of the early

universe, potentially
capturing light from the first
stars and galaxies.
•
Study of exoplanet
atmospheres, searching for
potential conditions
favorable for life.
Aditya-L1
Dedicated to
studying the Sun,
focusing on the
corona and solar
wind.
Sun's
corona,
solar wind
ISRO
•
Understanding the Sun's
influence on early Earth's
environment, including
solar wind interactions with
Earth's atmosphere.
•
Studying the Sun's activity,
which can impact Earth's
climate and habitability.
OSIRIS-
REx
To collect a sample
from asteroid Bennu
and return it to Earth
for study. To study
the asteroid's
composition and
map its surface.
Asteroid
Bennu
NASA
•
Confirmed the presence of
water-bearing minerals on
Bennu's surface.
•
Collected a significant
sample from the asteroid,
providing material for
detailed analysis back on
Earth
Chandray
aan-3
To achieve a soft
landing on the lunar
south pole and
deploy a rover for in-
situ analysis.

The Moon,
specifically
attempting
a soft
landing
near its
South Pole.
ISRO

- Successfully demonstrated soft landing near the lunar south pole.
- The Pragyan rover conducted experiments, confirming the presence of various elements, including sulfur, aluminum etc.

Student Notes:

1.2. Internal Structure of the Earth

The Earth is composed of several distinct layers, each with its own characteristics and composition. Understanding these layers helps us comprehend various geological processes, natural phenomena, and the Earth's overall structure.

Understanding these layers and their interactions is essential for studying geological phenomena like plate tectonics, volcanic eruptions, and mountain formation.

1.2.1. Sources of Information about Earth’s Interior

Most of our knowledge about the interior of the Earth is largely based on estimates and inferences. Yet, a part of the information is obtained through direct observations and analysis of materials.

Student Notes:

By weaving together these diverse threads of evidence, geographers continue to refine our understanding of Earth's hidden realm. Since seismic activities are quite common on Earth and are widely used to determine its interior, they are discussed in detail below.

1.2.2. Seismic Waves

Seismic waves are caused by sudden movements within the Earth's crust, such as earthquakes or volcanic eruptions.

Types of seismic waves and Concept of shadow zone

Direct sources

Indirect sources

- Volcanic Eruption- Volcanic eruption forms another source of obtaining direct information.
  - As and when the molten material (magma) is thrown onto the surface of the earth, during volcanic eruption it becomes

available for laboratory analysis.

- Deep Ocean Drilling Project
  - o Scientists world over are working on two major projects such as “Deep Ocean Drilling Project” and “Integrated Ocean Drilling Project”.
  - o The deepest drill at Kola (Russia), in the Arctic Ocean, has so far reached a depth of 12 km.
  - o This and many deep drilling projects have provided a large volume of information through the analysis of materials collected at different depths.
- Meteorites- Meteors and Earth are born from the same nebular cloud. Thus, they are likely to have a similar internal structure.
- Gravitation- Gravity changes depending on how mass is spread out in the Earth. This unevenness is called a gravity anomaly, and it helps us understand how mass is distributed in the Earth's crust.
- Magnetic Field- Earth's magnetic field is created by the geodynamo effect, which involves the movement of molten iron in the outer core.
  - ■ Studying these magnetic fields and shifts in it, helps scientists understand the Earth's core.
- Seismic Activity- Seismic waves (earthquake waves) The velocity of seismic waves changes as they travel through different layers of the earth.
  - ■ By analyzing these changes, scientists can infer the composition and layering of the Earth's interior.

Student Notes:
There are two main types of body waves: P-waves and S-waves that travel through the Earth's interior after an earthquake.
Characteristic
P Waves (Primary Waves)
S Waves (Secondary Waves)
Type of Wave
Longitudinal
(Compressional):
Particle displacement is parallel to
wave direction.
Transverse
(Shear):
Particle
displacement is perpendicular to
wave direction.
Propagation
Speed
Faster: First to be detected by
seismographs after an earthquake.
Slower: Second to be detected by
seismographs after an earthquake.
Movement
Particles move back and forth in
the same direction as the wave
travels.
Particles move up and down or side-
to-side
perpendicular
to
wave
direction.
Medium of
Travel
Solids, liquids, and gases: Can
move through all layers of the
Earth, including the core. Provides
information about different layers
of earth.
Solids
only:
Cannot
propagate
through liquids or gases, limiting
travel path. Cannot provide direct
information about the liquid outer
core.
Penetration
Can travel through Earth's core:
Able to move through both the
solid inner core and the liquid
outer core,
Cannot travel through Earth's liquid
outer core: Limited to the solid parts
of the Earth,
How do the P and S waves help in understanding the earth’s interior?
Non-linear travel path confirms that the Earth’s composition is not homogeneous rather

heterogeneous.

- Curved path tells us that on average, there is an increase in density as one moves deeper into the earth.
- By observing how the speed of seismic waves changes, scientists have identified three main layers (crust, mantle, core) inside the Earth with different densities.
- Bouncing back of the waves after hitting the abrupt boundary between two layers help to determine the depth of the discontinuities and thickness of various layers.
- Absence of S-waves inside the core confirms the presence of liquid core at the depth of 2900 km.

Having explored the intricate composition and structure of Earth's interior, we now shift our focus to the dynamic forces that sculpt our planet's surface. These forces, collectively known as geomorphic processes, are responsible for the ever-evolving landscape we inhabit.

Geomagnetism

Geomagnetism is the study of Earth's magnetic field, generated by the movement of molten iron in the outer core.

Current Issues with Earth's Magnetism

- Magnetic Pole Shift: The magnetic north pole is moving from Canada towards Russia, which affects navigation systems and can impact satellite operations.
- Field Weakening: Some regions are experiencing a weakening of Earth's magnetic field, potentially linked to changes in the flow of molten iron in the core.

Student Notes:

Impacts of Changing Magnetism

- Navigation Disruptions: Changes in the magnetic field can lead to inaccuracies in compass-based navigation and affect GPS systems.
- Satellite Operations: A weaker or shifting magnetic field can increase

radiation exposure for satellites, potentially causing malfunctions or damage.

- Power Grids: Variations in the magnetic field can induce electrical currents in power grids, leading to potential power outages or damage to electrical infrastructure.
- Health Effects: Increased exposure to solar radiation due to a weakened magnetic field might have health implications, although this is still under study.

Protection from Solar Flares

Earth’s magnetic field provides crucial protection against solar radiation. The Sun emits charged particles and radiation that can be harmful to technology and living organisms.

Earth's magnetic field acts as a shield by deflecting most of these charged particles away from the surface.

- Additionally, the magnetic field creates protective Van Allen belts around the planet, which trap some of these particles, further reducing their impact.
- When particles interact with the magnetic field near the poles, they can create auroras, releasing energy away from the surface.

Auroras

These are radiant, multi-coloured bands of glowing plasma that appear in the upper atmosphere

near
the
Earth's
magnetic poles.
What
triggers
the
Formation of Aurora?
The natural light shows are the result of solar storms and activity on the Sun's surface, such as solar flares or coronal mass ejections (ejected gas bubbles).

Student Notes:

- Charged Particles from Space: These events release vast clouds of electrically charged particles that travel millions of miles through space. Some of these particles eventually reach Earth, while others continue traveling further into space.
- Deflection by Earth's Magnetic Field: Most of the charged particles are deflected by Earth's magnetic field, preventing them from reaching the surface. However, some particles become trapped in the magnetosphere and are funneled toward Earth's poles along the magnetic field lines.
- Collision with Atmospheric Gases: As the charged particles are directed toward the poles, they collide with gases in Earth's atmosphere, such as oxygen and nitrogen.
- Excitation: These collisions transfer energy to the atmospheric gases, a process known as excitation. This is similar to heating a gas until it emits light, creating the spectacular natural phenomenon we observe as auroras.

1.3. Forces Acting on Earth

The configuration of the earth is the result of various processes operating within as well as outside the earth. Multiple forces affect the earth's crust.
These forces causing physical stresses and chemical actions on earth materials and bringing about changes in the configuration of the surface of the earth are known as geomorphic processes.

1.3.1. Endogenic Forces

Endogenic forces, also known as internal forces. These forces originate deep within the Earth. They are responsible for shaping the earth's surface over long periods of time.

- These lead to vertical and horizontal movements and result in subsidence, land upliftment, volcanism, faulting, folding, earthquakes, etc.
- They are land building forces that play a crucial role in the formation of the earth's crust.
- Primordial heat, radioactivity, tidal and rotational friction from the earth result in the creation of these forces.

Endogenic forces are of two types:
a) Diastrophic forces are slow movements. It involves epeirogenic and orogenic movements.
Epeirogenic movements are the vertical forces that are responsible for continent building. These vertical movements can lead to submergence as well as emergence of earth's crust.
Orogenic movements are the horizontal forces that are responsible for mountain building. They can be categorized into two

major pressures, such as the pressure of tension and the pressure of compression.

Student Notes:

b) Sudden Movements- These are Catastrophic forces which result in fast movements like earthquakes and volcanism.

Distribution of oceans and continents

Before examining how endogenic forces contributed to the formation of continents and oceans, it's crucial to review the various theories that explain their distribution and formation.

Understanding these theories is essential for a comprehensive grasp of how continents and oceans came to be.

1.3.1.1. Continental Drift Theory

Alfred Wegener proposed that Earth's crust has two layers: Sial (continental) and Sima (oceanic).

- He suggested that all continents were once joined in a supercontinent called Pangaea, surrounded by the Panthalassa Ocean.
- Pangaea split into Laurasia and Gondwanaland, which eventually became today's continents.
- Wegener attributed continental drift to

■

Polar
Fleeing
Force
(Earth's
rotation) and
■
Tidal Force (gravitational pull from the sun and moon).
Evidence for Continental Drift Theory
Criticism
Jigsaw Fit of Continents: Continents' shorelines, like Africa and America, fit together.
Same-Age Rocks: Ancient rocks on Brazil and Western Africa are identical.
Glacial Deposits: Tillite (a form of glacial deposit) from the Gondwana system in India are the same across six different landmasses.
Placer Deposits: Gold deposits in Ghana are linked to gold-bearing veins in Brazil.
Fossil Distribution: Mesosaurus fossils in Brazil and South Africa suggest these lands were once connected.
Carboniferous Glaciation: Evidence of glaciation in Brazil, Falkland, South Africa, and India shows that these areas, now in tropical regions, were once near the poles around 300 million years ago.
Insufficient Forces: Proposed forces (lunar/solar gravity, Earth's rotation) are too weak to move continents.
Incomplete Explanation: Did not account for continental positions before the Carboniferous period.
Unjustified Drift Direction: Lacked explanation for the specific direction of continental drift.
Inaccurate Model: Model of continents on a fluid layer (Sial on Sima) is outdated; modern understanding involves the lithosphere floating on the asthenosphere.

Student Notes:

1.3.1.2. Convectional Current Theory

Proposed by Arthur Holmes in the 1930s, the theory suggests that convection currents in the Earth's mantle drive continental movement. These currents arise from thermal differences caused by the presence of radioactive elements within the mantle.

Criticisms:

- Heat Source Reliability: Critics argue that the amount of heat required to generate convection currents from radioactive materials in the mantle may be insufficient.
- Formation of Convective Currents: Without adequate heat, the formation of convection currents is questionable.

Despite its criticisms, the Convectional Current Theory paved the way for the development of the Sea Floor Spreading Theory.

1.3.1.3. Sea Floor Spreading Theory

Harry Hess proposed the theory of seafloor spreading, which explains how the ocean floor changes. Magma rising at mid-ocean ridges forms new seafloor and pushes tectonic plates apart. At subduction zones, oceanic crust sinks beneath other plates and is destroyed. This process, along with plate tectonics, has transformed our understanding of Earth's changing surface.

Evidence for Seafloor Spreading Theory

Age of Oceanic Crust

- Radiometric Dating: Rocks at mid-ocean ridges are the youngest, while rocks near continental margins are the oldest.
- Sediment Thickness: Sediment layers are thinner near ridges and thicker farther away, showing older crust.

Heat Flow Measurements

- High Heat Flow at Ridges: Higher temperatures at mid-ocean ridges indicate new crust formation from rising magma.
- Decreasing Heat Flow with Distance: Heat flow decreases as you move away from ridges, showing cooling of older crust.

Student Notes:

Magnetic Stripes on the Ocean Floor

- Magnetic Reversals and Symmetrical Pattern: Ocean floor rocks record Earth's magnetic field direction when they cool.

Magnetic stripes on both sides of ridges show alternating polarity, indicating new crust formation and spreading.

Seismic Activity

- Earthquake Distribution: Earthquakes occur along mid-ocean ridges and transform faults, showing active crustal movement.
- Transform Faults: Transform faults offset mid-ocean ridges and are characterized by shallow-focus earthquakes. These faults show the relative movement of crustal plates.

1.3.1.4. Plate Tectonics Theory

The Plate Tectonic Theory explains how Earth's lithosphere moves and changes.

- It combines ideas from continental drift and seafloor spreading to show how large plates on Earth's surface shift.
- This theory helps explain the formation of mountains, and the distribution of earthquakes and volcanoes.

Plate Tectonics- Evolution from Continental Drift & Seafloor Spreading

- From Continental Drift: This theory proposed that Earth's continents were once united as a supercontinent named Pangaea. This idea that continents have moved significantly over geological time was crucial, establishing that continents are not static but capable of shifting and drifting.
- From Seafloor Spreading: This concept introduced the mechanism of new oceanic crust forming at mid-ocean ridges, as magma rises and solidifies, pushing older crust away. This provided the essential understanding of how tectonic plates move and how new crust is continuously generated.

Plate Tectonic Theory Overview

- Tectonic Plates: These are large, irregularly-shaped slabs of solid rock.
  - Plates are classified as either oceanic or continental. For example, the Pacific Plate is mostly oceanic, while the Eurasian Plate is mainly continental.

Student Notes:
■
Earth's lithosphere is broken into major and minor plates.
•
Plate Movement: Plates move slowly across Earth's surface at several centimeters per year. This movement is known as plate tectonics. This movement is driven by the convective currents in the mantle beneath the Earth's crust.
•
Mechanism of Plate Movement: The lithosphere is divided into many plates, surrounded by features like mountain ridges, trenches, and faults. Continents move with the plates they are part of.
Major and Minor Plates
Plate Boundaries
Plate boundaries are the edges where two plates meet. Most geologic activities, like earthquakes, volcanoes, and mountain building, take place at plate boundaries.
1. Divergent Plate boundaries
Divergent plate boundaries, also known as constructive boundaries, occur where two tectonic plates move away from each other.
•
As the plates separate, magma from the mantle rises to fill the gap, creating a new crust as it cools and solidifies.
•
This process is most commonly observed at mid-ocean ridges but can also occur within continental plates.
Key features of divergent plate movement include:
•
Mid-Ocean Ridges: These underwater mountain ranges are formed by the upwelling of magma at divergent boundaries in the ocean. An example is the Mid-Atlantic Ridge.
•
Seafloor Spreading: The continuous addition of new material at mid-ocean ridges leads to the expansion of the ocean floor.
•
Formation of Rift Valleys: When divergence occurs within a continental plate, it creates rift valleys.

Student Notes:
East African Rift valley-
The process of rift valley formation involves several stages:
1. Initial Uplift: Mantle plumes or other heat sources cause the lithosphere to bulge upwards, creating a dome-like structure.
2. Rifting: As the lithosphere continues to stretch and thin, it begins to crack and break apart.
3. Volcanism and Sedimentation: Magma can rise through the fractures,

leading to volcanic activity. Over time, sediments accumulate in the rift valley, often creating fertile land and basins that can become lakes or even seas.

2. Convergent plate boundaries

Convergent plate boundaries, or destructive boundaries, occur where two tectonic plates collide. They involve oceanic-oceanic, oceanic-continental, or continental-continental plates and are key to understanding mountain formation, volcanic activity, and earthquakes.

A. Oceanic-Oceanic Convergence

When two oceanic plates converge, one of the plates subducts beneath the lighter plate.

- As the subducted plate descends into the mantle, it releases fluids and volatile elements that cause the overlying mantle to melt.
- This molten rock, or magma, rises to the surface and erupts, forming a chain of volcanic islands and oceanic trench.

Student Notes:

- Examples of volcanic island arcs include the Mariana Islands, the Aleutian Islands, the Japanese Islands and Philippines Archipelago.
  - The convergence of the Pacific Plate and the Philippine Sea Plate leads to the formation of the Japanese Archipelago.
  - Characteristics: This process results in volcanic activity, creating a series of islands and frequent earthquakes.

B. Oceanic-Continental Convergence

In oceanic-continental convergence, the denser oceanic plate subducts beneath the lighter continental plate.

- As the oceanic plate descends, it carries sediments scraped off the seafloor. These sediments get squeezed, heated, and eventually pushed upwards along the continental margin.
- The descending

oceanic crust also
releases fluids that trigger the partial melting of the overlying mantle.

- This molten rock, or magma, rises towards the surface, often leading to the formation of a chain of volcanoes and creation of fold mountain ranges along the continental margin. This explains why most fold mountains are found along the continent margins.
- Example: Andes Mountains
  - Formation: The Andes Mountains in South America are formed by the subduction of the Nazca Plate beneath the South American Plate. The chain of volcanos are also found along the Andes.

Distribution of fold Mountains around the world

Student Notes:

C. Continental-Continental Convergence

In continental-continental convergence, neither plate subducts due to their buoyancy. Instead, the collision causes the crust to buckle and fold, leading to the formation of extensive mountain ranges.

Formation of the Himalayas

- Collision of Plates: The Himalayas were formed by the collision of the Indian Plate with the Eurasian Plate.
- Subduction and Accretion: As the Indian Plate moved northward, the ocean floor of the Tethys Ocean was forced under the Eurasian Plate. Sediments from the Indian margin were scraped off and added to the Eurasian continent.
- Continent-Continent Convergence: The collision between two continental plates (India and Eurasia) caused the marine sediments to fold and crumple. Unlike oceanic-continental or oceanic-oceanic convergence, there was no clear subduction because both plates were similar in density.
- Double Layering Effect: This convergence resulted in a 'double layering effect,' increasing the crust's thickness in the region.

The intense collision led to the Himalayas and the Tibetan Plateau reaching great heights. The collision is still ongoing, causing the Himalayas to continue rising. The mountains formed in three successive phases, creating the three layers seen today.

Student Notes:

3. Transform Fault Boundaries

A transform fault, also known as a strike-slip boundary, is where two tectonic plates slide past each other horizontally. At these boundaries, landforms are deformed but not created or destroyed. The fracture zone where this sliding occurs is called a transform fault.

- Example: North Anatolian Fault & San Andreas Fault (Silicon Valley lies dangerously close to the fault line) along the western coast of the USA] is the best example for a transcurrent edge on continents.

Limitations of plate tectonic theory:

- The theory of plate tectonics explains the movement of plates, largely attributing it to mantle convection. However, this explanation does not fully account for phenomena like volcanic hotspots caused due to mantle plumes—rising hot rocks.

Mantle Plumes

Mantle plumes are large columns of hot, molten rock that rise from deep within the Earth's mantle.

- Heat Source: They are heated by the decay of radioactive elements and residual heat from Earth's formation.
- Function: As they rise, they can melt the rock above them, forming magma that can reach the surface and create volcanoes.

Role in Plate Tectonics

- Hotspots: Mantle plumes create volcanic activity in areas not near plate boundaries. For example, the Hawaiian Islands are formed as the Pacific Plate moves over a stationary mantle plume.
- Rifting and Plate Breakup: Plumes can weaken the Earth's lithosphere, contributing to rifting and the breakup of

tectonic plates. The
East African Rift illustrates this process.

Student Notes:

Formation of Deccan traps can be explained through hotspots:

Formation of the Deccan Traps

Around 60 million years ago, a massive volcanic eruption from the Réunion hotspot led to the creation of the Deccan Traps.

- Process: This hotspot caused the eruption and the opening of a rift that once separated India from the Seychelles plateau.
- Current Location: As India drifted north, it moved away from the hotspot, which is now beneath Reunion Island.

Result: The lava flows from this eruption spread over a large area of western India, forming the Deccan Traps.

- The theory simplifies the nature of plate boundaries by treating plates as rigid blocks, but in reality, these zones experience complex deformation.
- Some volcanic activity occurs away from plate boundaries, indicating that the theory needs refinement to fully explain such occurrences.

Quick Revision: Characteristics, tectonic processes, features, and examples of plate boundaries

Plate Boundary	Plate Movement	Crust Types	Sea Floor Created or Destroyed	Sea Floor Feature(s)	Geographic Examples
Divergent Plate Boundary	Apart	Oceanic–oceanic,	Created	Mid-ocean ridge; volcanoes; young lava flows	Mid-Atlantic Ridge, East Pacific Rise;
		Continental–continental	As a		

continent
splits apart,
new
seafloor is
created.
Rift valley;
volcanoes;
young
lava flows
East African Rift
Valleys, Red
Sea, Gulf of
California
Convergent
Plate
Boundary
Together
Oceanic–
continental,
Old seafloor
is destroyed.
Trench;
volcanic arc
on land
Peru–Chile
Trench, Andes
Mountains;
Oceanic–
oceanic,
Old seafloor
is destroyed.
Trench;
volcanic arc
on land
Mariana
Trench,
Aleutian
Islands;
Continental–
continental
Mountain
building
Tall
mountains
Himalaya
Mountains,
Alps
Transform
Plate
Boundary
Past
each
other
Oceanic
Sea floor
conserved
(neither

created nor
destroyed)
Fault
Mendocino
Fault, Eltanin
Fault (between
mid-ocean
ridges)

Student Notes:
Continental
Sea floor
conserved
(neither
created nor
destroyed)
Fault
San Andreas
Fault, Alpine
Fault (New
Zealand)

Some of the key effects of plate tectonics are earthquakes and volcanic activity, which are discussed under the head of key geophysical phenomenon.

1.3.2. Exogenic Forces

Exogenic forces, also known as external forces, are those that originate from outside the Earth and act on its surface. They derive their energy from two sources:

- Solar Energy: It drives the water cycle, which includes evaporation, condensation, precipitation, and runoff. This energy also powers wind and ocean currents.
- Gravity: Gravity causes water to flow from higher to lower elevations, leading to processes like erosion, transportation, and deposition of sediments. It also influences mass wasting events like landslides and rockfalls.

These forces are the basic reason that leads to weathering, mass movements, and erosion is development of stresses in the body of the earth materials.

Concept of Denudation

Denudational processes refer to the combined actions that result in the wearing down or stripping away of the Earth's surface layers. These processes are critical in shaping landscapes and are a subset of the broader category of exogenic or external geomorphic processes.

Weathering: This is the process of breaking down rocks and minerals at the Earth's surface. It can be physical, chemical, or biological.

- Physical weathering involves processes like freezing and thawing, causing rocks to crack and crumble.
- Chemical weathering involves the interaction of water, air, and acids with rocks, dissolving minerals and changing their composition.
- Biological weathering involves the action of plants, animals, and microorganisms breaking down rocks.

Erosion: Once rocks are weathered, exogenic forces like wind, water, ice, and gravity can transport the loosened material. This process is called erosion.

Student Notes:

- Wind erosion blows away loose particles, creating features like mushroom rocks.
- Water erosion, by rivers, glaciers, and waves, carries away sediment, carving valleys, canyons, and coastlines.

Mass Wasting: This refers to the downhill movement of rocks, debris, and soil under the influence of gravity. Landslides, mudflows, and rockfalls are all examples of mass wasting.

Deposition: As eroded materials are transported, they eventually get deposited in new locations.

- Wind can deposit sand to form beaches and dunes.
- Rivers deposit sediment along their floodplains and deltas.
- Glaciers leave behind piles of debris called moraines.

1.3.2.1. Landforms and Their Evolution

A landform is a natural feature on the Earth's surface with a distinct shape and structure. Landforms are created and modified by forces such as tectonic activity, weathering, erosion, and deposition.

1.3.2.1.1. Landforms of Glaciation

Glacier is a huge mass of moving ice that moves due to gravity. Erosion by glaciers is mainly due to plucking and abrasion.

1. Erosional landforms

Features/characteristics

- Cirques are deep, long and wide troughs or basins with very steep concave walls at their heads as well as sides.
- A lake of water can be seen quite often within the cirques after the glacier disappears. Such lakes are called cirque or tarn lakes.
- Horns are high, sharp pointed and steep sided peaks formed when three or more radiating glaciers cut headward until their cirques meet.
- Artes (serrated ridges) are formed when the divides between cirque side walls get narrow because of

progressive erosion.
Significance of Weathering
Ecological Significance: It forms soil that supports vegetation, influencing biomes and biodiversity.
Economic Significance: It concentrates valuable ores like iron and copper, essential for the economy.
Mineral Release: It releases vital minerals for plant and animal life.
Erosion Facilitation: It weakens rocks, aiding erosion and landscape formation.

Student Notes:
Fjords/fiords are very deep glacial troughs filled with sea water and make up shorelines (in high latitudes).

- Fjords, also spelled fiords, are long, narrow inlets of the sea with steep sides or cliffs created by glaciers.
- These dramatic landforms are found on the coasts of Antarctica, the Arctic etc.

2. Depositional landforms
Features/ Characteristics

- Moraines are accumulations of dirt and rocks that have fallen onto the glacier surface or have been pushed along by the glacier as it moves.
- Eskers are ridges made of sands and gravels, deposited by glacial melt water flowing through tunnels within and underneath glaciers, or through melt water channels on top of glaciers.
- Drumlins are elongated, teardrop-shaped hills of rock, sand, and gravel that formed under moving glacier ice. They can be up to 2 kilometres (1.25 miles) long. They form “baskets of egg” topography
- Outwash Plains are plains at the foot of glacial mountains covered with

glacio-fluvial deposits in the form of
broad flat alluvial fans which may
join to form outwash plains of gravel,
silt, sand and clay.

Glaciated landforms are indicators of paleo-climate (climate of the past). For example, the glaciated boulders found in Talcher in Orissa show that the region might have been under the influence of some kind of glaciers in the past.

1.3.2.1.2. Fluvial Landforms

Fluvial landforms are shaped by rivers and streams, especially in humid regions:

- Early Stages: Rivers cut downward into the land, creating deep valleys and steep slopes.
- Middle Stages: Rivers erode the valley sides more than the beds, widening the valleys. Divides between drainage basins are worn down.
- Late Stages: The landscape becomes almost flat, forming a peneplain with a few hills or monadnocks as remnants.

1. Erosional fluvial landforms

Features/Characteristics	Representation
Waterfall: A waterfall is when a river falls over a vertical slope. It is found in the youth stage of a river where there are areas of hard and soft rocks.	
Canyon and Gorge: A gorge is a deep valley with very steep to straight sides and a canyon is characterised by steep step like side slopes and may be as deep as a gorge.	
River Valleys: It is a long lowland between ranges of mountains, hills, or other uplands, often having a river or stream running along the bottom.	
Potholes: These are holes scoured into bedrock by swirling water/sediments. Abrasion by sediment which enters a depression; bedrock scoured by swirling sediment.	

River terraces are surfaces marking old valley floor or floodplain levels.

- They may be bedrock without any alluvial cover or with alluvial cover.
- They result due to vertical erosion by the stream into its own depositional floodplain.

•
The river terraces may occur at the same elevation on either side of the rivers in which case they are called paired terraces
2. Depositional landforms
Features /characteristics
Representation
Alluvial fans are formed when streams flowing from higher levels break into foot slope plains and the sediments get dumped and spread as a broad low to high cone shaped deposit.
•
Many channels and distributaries form.
•
In humid areas normally low cones with gentle slopes are formed and in arid and semi-arid areas high cones with steep slopes are formed.
Natural Levees and Point Bars: Natural levees are found along the banks of large rivers.
•
They are low, linear and parallel ridges of coarse deposits along the banks of rivers.
•
Point bars are found on the concave side of meanders of large rivers and are sediments deposited in a linear fashion by flowing waters along the bank.
•
They are almost uniform in profile and in width and contain mixed sizes of sediments.
Meanders are loop-like channel patterns developing over floodplains.
•
Meander is not a landform but is only a type of channel pattern.
•
This is formed because:
o
Water moves laterally over gentle gradients.
o
Water exerts pressure laterally on the unconsolidated nature of alluvial deposits making up the banks.
o
Coriolis force acting on the fluid water deflects it.
•
As meanders grow into deep loops, the same may get cut-off due to erosion at the inflection points and are left as ox-bow lakes.

Student Notes:
Deltas are like alluvial fans but develop at a different location.
•
The depositional feature of a river or stream having a triangular shape at the mouth of a river emptying either in a lake or a sea is called delta
•
The coarsest materials settle out first and the finer fractions like silts and clays are carried out into the sea.
1.3.2.1.3. Coastal Landforms
Coastal landforms are shaped by natural forces like waves, tides, currents, and wind.
•
Waves erode and deposit sediments, forming beaches and cliffs.
•
Tides and currents move sediments, creating tidal flats, estuaries, spits, and barrier islands.
•
Wind shapes coastal dunes by transporting sand. Sediment from rivers and cliffs contributes to these formations.
Sea-level changes alter the coastline, making coastal landscapes dynamic and ever-changing.
1. Coastal erosion landforms
Eventually coastal hills and cliffs disappear because of wave erosion giving rise to narrow coastal plains, and with an onrush of deposits from over the land behind may get covered up by alluvium or may get covered up by shingle or sand to form a wide beach.
2. Coastal depositional landforms
Features/characteristics
Representation
Beaches: Beaches are made up from
eroded
material
that
has
been
transported from elsewhere and then deposited by the sea.
Spits: A spit is an extended stretch of sand or shingle jutting out into the sea from the land. Spits occur when there is a change in the shape of the landscape or there is a river mouth.
Bars: Sometimes a spit can grow across a bay, and joins two headlands together. This landform is known as a bar.

Student Notes:
Lagoons: Bars can trap shallow lakes behind the bar, these are known as lagoons. Lagoons do not last forever and may be filled up with sediment.

Types of Coasts
a) Coastlines of submergence: Submergent coastlines form either when sea level rises or the land level fall.
b) Coastlines of Emergence: The coast has been raised (due to fall in sea level or a rising of the crust) and the ocean waves now erode a lower level.5.2.2.4. Landforms Associated With Groundwater
Groundwater through the chemical process of dissolution develops varieties of landforms in rocks like limestones or dolomites rich in calcium carbonate. The topography produced is called Karst topography.
Favourable Conditions for development of Karst Topography:

- Widely distributed limestone rocks in both areal and vertical dimensions.
- Massive, thickly bedded limestone rocks.
- Non-porous rocks to avoid water passage and consequent collapse.
- Folded and fractured rocks.
- Enough presence of water to dissolve carbonate rocks.

Student Notes:
1. Erosional landforms

- Swallow holes are small to medium sized round to sub-rounded shallow depressions on the surface of limestones through solution.
- Sinkholes are funnel shaped openings ranging from a few sq. m to a hectare and with depth from a less than half a metre to thirty metres.
- Dolines are the collapse sinks.
- Uvalas (valley sinks) are formed when sinkholes and dolines join because of slumping of materials along their margins or due to roof collapse of caves.
- Caves: Long and narrow to wide voids.
  - They are mainly formed in areas where there are alternating beds of rocks (shales, sandstones, quartzites) with limestones or dolomites in between.
  - Caves normally have an opening through which cave streams are discharged.

o
Caves having openings at both the ends are called tunnels.
2. Depositional Landforms
•
Stalactites hang as icicles of different diameters. Normally they are broad at their bases and taper towards the free ends.
•
Stalagmites rise from the floor of the caves. In fact, stalagmites form due to dripping water from the surface or through the thin pipe of the stalactite, immediately below it.
•
The stalagmite and stalactites eventually fuse to give rise to columns and pillars of different diameters.

The Meghalayan Era

Mawmluh Cave in Meghalaya, which features impressive stalactites, is significant because scientists studied a stalactite there and made important discoveries. They found evidence of a major global climate event that occurred around 4,200 years ago, leading to severe droughts worldwide.

This finding helped define the Meghalayan Era, the most recent phase of the Holocene Epoch on the geological timescale, named after Meghalaya because of this crucial discovery.

Student Notes:
1.3.2.1.4. Wind/Aeolian Landforms
These landforms are found in hot desert regions. These landforms have conditions such as very less vegetation cover, insufficient rainfall, high rate of evaporation etc.
1. Erosional landforms
2. Depositional landforms

Sand Dunes

These are hills or mounds made of loose sand grains, piled up by the wind as it carries sand and drops it when it slows down. They are not only found in deserts but also in places with a lot of sand and strong winds.

Two fundamental types of dunes have been identified based on their shapes:
Transverse Dunes
Longitudinal Dunes
These, also called barchans, form at a right angle

to the direction of the wind.

•

These dunes are shaped by gentle winds and
are usually found along coastlines or at the
edges of deserts.
These, also called seifs, are long, narrow s
the same direction as the wind.

•

They usually form in the central parts o
strong winds either blow steadily in
direction with the seasons.

Student Notes:

1.4. Key geophysical phenomenon

1.4.1. Earthquakes

An earthquake is the shaking or trembling of the Earth’s surface caused by sudden release of energy within the Earth’s crust or upper mantle.

Seismographs or seismometers are the instruments used to detect, measure, and record the seismic waves produced by earthquakes. These devices are vital in monitoring and understanding seismic activity and the Earth’s movements.

Causes of earthquakes

Earthquakes are caused due to release of energy. The release of energy occurs along a fault.
Rocks
along a fault tend to move in opposite directions. The release of energy, along a fault line, may be due to several factors. They may be categorised as:

1. Tectonic earthquake - The movements along fault lines are attributed to different tectonic boundaries, leading to distinct seismic activities.

•

At convergent boundaries, reverse faults can cause powerful earthquakes, such as the 2004 Indian Ocean earthquake and tsunami.

•

Normal faults at divergent boundaries induce less severe earthquakes, like the 2010 Iceland earthquake along the Mid-Atlantic Ridge.

•

Transform boundaries, like the San Andreas Fault, experience significant earthquakes from strike-slip faults, exemplified by the 1906 San Francisco earthquake.

2. Volcanic Activity- Volcanic earthquakes result from the movement of magma within a volcano or related tectonic processes. These earthquakes, generally less severe, can act as early indicators of eruptions, as seen with the 1980 eruption of Mount St. Helens.

Student Notes:

3. Reservoir
Induced
Seismicity-
The
formation of large artificial lakes from
dam
construction
can
alter
stress

conditions in the Earth's crust, leading to earthquakes. Water percolation can lubricate faults, making them more susceptible to movement.

- Examples include the Koyna Dam reservoir in Maharashtra, which has been linked to increased seismic activity in 1967, and the 2008 Sichuan earthquake in China, which is believed to be associated with the Zipingpu Dam.

Consequences Of Earthquakes

- Damage to Life and Property: Earthquakes shake the ground, causing destruction to buildings and infrastructure. Example: The 2015 Nepal earthquake (magnitude 7.8) led to extensive damage due to poor construction and design.
- Landslides and Avalanches: Earthquakes can trigger landslides and avalanches, particularly in mountainous areas. Example: The 2011 Sikkim earthquake caused landslides impacting hydel projects.
- Floods: Earthquakes can damage dams and block rivers, leading to floods. Example: The 1950 Assam earthquake created debris that blocked the Dihang River, causing upstream floods.
- Tsunamis: Earthquakes can displace the ocean floor, generating tsunamis. Example: The 2004 Indian Ocean tsunami resulted from an earthquake off Sumatra.
- Nuclear Accidents: Earthquakes can damage nuclear plants, leading to accidents. Example: The 2011 Tohoku earthquake caused a tsunami that led to a meltdown at Fukushima Daiichi.

Recent Major Earthquakes

Global Distribution of Earthquakes

Earthquakes are not randomly distributed across the globe but are concentrated in specific zones that coincide with tectonic plate boundaries. These zones, often referred to as earthquake belts,

The Wadati–Benioff zone

It is a subduction zone where earthquakes are frequent and often very powerful.

It extends to depths of about 700 kilometers.

It can occur at convergent boundaries between oceanic and oceanic plates (O-O), continental and oceanic plates (C-O), or continental and continental plates (C-C), such as in the Himalayan region.

Student Notes:

experience a higher frequency and intensity of seismic activity due to the interactions between Earth's tectonic plates.

The Circum-Pacific Belt (Pacific Ocean)

The Mid-Continental Belt (Alpine-Himalayan or Mediterranean Belt)

The Mid-Atlantic Belt

(Mid-Atlantic Ridge)
Earthquake Activity: The most seismically active region with frequent and powerful earthquakes.
Contributing Factors:

- Subduction Zones: The Pacific Oceanic plate is pushed under American plates, causing pressure and seismic activity.
- Active Volcanoes: Volcanic activity along the "Ring of Fire" also causes earthquakes.

Example: The 1960 Chilean earthquake (magnitude 9.5), the largest ever recorded.
Earthquake Activity: Significant seismic activity, but less frequent and smaller than in the Circum-Pacific belt.
Contributing Factors:

- Collision of Continental Plates: African and Indian plates are colliding with the Eurasian plate, causing pressure and earthquakes.
- Weak Folded Mountain Zones: Sensitive crust areas are more prone to earthquakes.

Example: The 2001 Gujarat earthquake (magnitude 7.7) in India, due to the collision of the

Indian and Eurasian Plates.
Earthquake Activity: Generally shallow-focus, low-magnitude earthquakes compared to the other two belts.
Contributing Factors:

- Sea-Floor Spreading: As tectonic plates move apart, moderate earthquakes occur.
- Fissure Volcanoes: Volcanic activity from plate separation causes seismic events.

Example: The 2016 Azores Earthquake (magnitude 6.2) along the Mid-Atlantic Ridge.

Earthquake Vulnerability Across the Himalayas

The entire Himalayan Belt is highly vulnerable to earthquakes due to a combination of geological and man-made factors.

1. Primary Cause: Unified Tectonic Collision

- The entire Himalayan range is seismically active because the Indian Plate is continuously pushing under the Eurasian Plate. This creates immense stress along the entire ~2,400 km mountain belt.

Student Notes:

2. Common Vulnerabilities: Unsafe Terrain & Construction

- The entire region has young, unstable mountains. Developmental activities like road cutting and dam construction increase landslide and seismic risks everywhere.

3. Pan-Himalayan Challenge: Weak Preparedness & Awareness

- Building codes and disaster management

plans exist but are poorly enforced across the
entire Himalayan region.

- A general lack of a "safety culture" and insufficient community-level preparedness is a common problem from Kashmir to Arunachal Pradesh, making the entire population highly vulnerable.

1.4.2. Volcanoes

Volcanism refers to the processes and phenomena associated with the movement of molten rock (magma) from the interior of the Earth to its surface intense heat and pressure beneath the Earth's crust. This includes the formation of volcanoes, the eruption of magma, and the related activities like the release of gases and ash.

Causes of volcanism

1. Plate Tectonics

- Divergent Boundaries: Plates move apart, allowing magma to form new crust.
  - Example: Mid-Atlantic Ridge.
- Convergent Boundaries: Oceanic plates subduct under continental plates, creating volcanoes.
  - Example: Andes Mountains.
- Transform Boundaries: Plates slide past each other, occasionally causing volcanic activity.
  - Example: San Andreas Fault.

2. Hotspots

Hotspots are areas where mantle plumes create volcanoes away from plate boundaries.
Example: Hawaiian Islands, with Mauna Loa and Kilauea.

Hotspot volcanism

Hot spots are areas of volcanic activity that occur away from plate boundaries due to mantle plumes - columns of hot rock that rise from deep within the Earth's mantle. These plumes form when heat builds up at the core-mantle boundary, causing material to become buoyant and rise through the mantle.

Global Distribution of Hot Spots

There are approximately 40-50 recognized hot spots on Earth today. Some notable examples include:

Student Notes:

- Hawaii-Emperor seamount chain (Pacific Ocean) - The most well-studied hot spot
- Iceland (Mid-Atlantic) - Unusual as it sits on both a hot spot and a mid-ocean ridge
- Yellowstone (North America) hotspot - A continental hot spot with a massive caldera
- Reunion (Indian Ocean) hotspot- Responsible for the Deccan Traps flood basalts when

India passed over it
•
Afar (East Africa) - Associated with the East African Rift System
How Hot Spot Volcanism Differs from Plate Boundary Volcanism-
Feature
Hot Spot Volcanism
Plate Boundary Volcanism
Location
Within plates, away from boundaries At convergent or divergent plate bounda
Magma Source Deep mantle plumes
Shallow melting due to pressure chan
water addition
Magma Type
Primarily basaltic, alkaline
Variable:
basaltic
at
spreading
ce
andesitic/rhyolitic at subduction zones
Eruption Style Generally effusive, shield-building
Varies: effusive at spreading centers; exp
at subduction zones
Time Pattern
Progressive chain formation as plates
move over fixed hot spot
Continuous activity along the boundary
Types of Volcanos
Following is the Classification of volcanoes based on shape and size-
Calderas and their formation
A caldera is a large, cauldron-like depression in the Earth's surface that is formed by the collapse of a volcano. It is significantly larger than a volcanic crater, which is the smaller, circular depression typically found at the summit of a volcano.
The formation of a caldera is a dramatic geological process that occurs in several distinct stages:
•
A massive magma chamber accumulates and swells beneath a volcano, causing the ground surface to bulge upwards.

Student Notes:
•
A powerful, explosive eruption takes place through ring-shaped fractures, violently emptying the magma chamber.
•
With its underlying support gone, the roof of the magma chamber and the overlying volcano collapse inward, forming the vast depression.
•
The caldera often fills with water to become a lake or can host smaller, secondary volcanic eruptions on its floor.
Effects of Volcanoes
Volcanic activity is an amazing display of Earth's heat from within, and it plays an important role

in shaping the land and affecting the air given below:

Distribution of Volcanoes

Seismic activities, such as earthquakes, are primarily located in zones where tectonic plates interact. Similarly, the global distribution of volcanoes and fold mountains is influenced by these plate interactions.

Student Notes:

Endogenic forces shape the Earth from the inside, while exogenic forces work on the Earth's surface, shaping it from the outside. Now, let's explore the exogenic forces that influence the Earth's surface.

Key Geophysical Phenomena of the Circum-Pacific Zone

The zone of circumpacific is dominated by subduction, where dense oceanic plates slide beneath continental plates. This process is the primary driver of all the region's intense geological activity.

- Coastal Mountain Ranges: The compressive forces from plate collision buckle and uplift the edges of the continents, forming extensive fold mountain ranges parallel to the coast.
- Extreme Volcanic Activity: As the subducting plates melt, magma is generated, fueling a nearly continuous chain of volcanoes. This zone contains about 75% of the world's active and dormant volcanoes.
- High Seismicity (Earthquakes): The immense friction and stress released at these colliding plate boundaries cause about 90% of the world's earthquakes, including its most powerful and destructive ones.

Student Notes:

- Deep Oceanic Trenches: The downward plunge of the oceanic plates creates the deepest parts of the ocean floor, known as trenches. The Mariana Trench, the deepest point on Earth, is a classic example.

The Connection between Fold Mountains, Earthquakes, and Volcanoes

The world's major fold mountain ranges, active volcanoes, and zones of frequent earthquakes are all found in the same geographical belts, most notably around the "Pacific Ring of Fire" and the Alpine-Himalayan belt. This association is not a coincidence. Following are the reasons for association:

- Fold Mountains: When two plates collide, the immense pressure buckles and folds the Earth's crust, pushing it upwards to form massive mountain ranges (e.g., the Himalayas, the Andes).
- Earthquakes: The immense friction and stress built up as these massive plates grind against each other is suddenly released, causing the ground to shake violently.
- Volcanoes: As one plate (usually an oceanic plate) is forced beneath another (a process called subduction), it melts into magma. This magma then rises to the surface and erupts, forming volcanoes.

Thus, the intense pressure that folds the mountains also causes the earthquakes, and the melting of the subducting plate that drives this process also creates the volcanoes.

1.4.3. Tsunamis

A tsunami is a series of extremely long waves caused by a large and sudden displacement of the ocean, usually an earthquake below or near the seafloor. In deep oceans, these waves are barely noticeable, but they grow to dangerous heights in shallow coastal waters.

Causes of Tsunamis

- Submarine Earthquakes: The most common cause (over 80%). They occur at subduction zones and must be of high magnitude and shallow focus to vertically displace the seafloor.
  - Example: The 2004 Indian Ocean tsunami, which affected 14 countries, was triggered by a Magnitude 9.1 earthquake off Sumatra.
- Volcanic Eruptions: The explosive collapse of a coastal or island volcano or large pyroclastic flows entering the sea can create powerful waves.
  - Example: The 1883 Krakatoa tsunami was generated by the catastrophic explosion of the volcano, creating waves up to 120 ft high.
- Underwater Landslides: Large-scale landslides on the seafloor, often triggered by smaller earthquakes, can displace a massive volume of water.
  - Example: The 1998 Papua New Guinea tsunami was worsened by a major submarine landslide that was triggered by a Magnitude 7.0 earthquake.

Student Notes:

Characteristics of Tsunamis

- Extremely Long Wavelength: Wavelengths can be over 100-200 km, which is why they are often imperceptible in the deep ocean.
- High Speed in Deep Water: Can travel at speeds of over 800 km/h, comparable to a jet aircraft. The speed is dependent on ocean depth.
- "Shoaling" Effect: As the wave enters shallower coastal water, its speed decreases, and its energy is compressed, causing a dramatic increase in wave height.
- Drawback Phenomenon: Rapid recession of coastal water, exposing the sea floor just before the first wave hits.
- Wave Train: Tsunamis arrive as a series of waves over a period of hours. The interval between crests can range from 10 minutes to over an hour.

Mitigation Measures

Early Warning Systems (EWS)

Structural Measures

Non-Structural Measures

Detection: Networks of seismic stations (to detect earthquakes) and DART buoys (to confirm wave

generation).
Dissemination: Issuing timely warnings through SMS, sirens, radio, and television.
Construction of sea walls, breakwaters, and floodgates.
Building tsunami-resilient structures and critical infrastructure on elevated ground.
Coastal Zone Management: Strict regulation of development in high-risk coastal areas (e.g., Coastal Regulation Zone norms in India).
Natural Barriers: Protection and regeneration of mangroves and coral reefs, which act as effective bio-shields.

1.4.4. Landslides

A landslide is defined as the movement of rock, debris, or earth down a sloped section of land. It is a form of mass wasting, denoting any down-slope movement of soil and rock under the direct influence of gravity.

Causes of Landslides with Examples

The stability of a slope is compromised when forces acting down-slope (primarily gravity) exceed the shear strength of the earth materials. Causes are a combination of preparatory factors (which make a slope vulnerable) and triggering factors (which initiate the movement).

Student Notes:

Natural Causes

- Geological Weakness: Inherently weak materials, weathered rock, and adverse geological structures (e.g., fractured or sheared rock) make slopes unstable.
- Seismic Activity: Intense ground shaking during earthquakes

destabilizes slopes, leading to widespread, simultaneous landslides.

- Intense Rainfall & Cloudbursts: Prolonged or exceptionally high-intensity rainfall saturates soil, increasing its weight and pore water pressure, which reduces the frictional strength of slope materials.
- Erosion: Toe-cutting by rivers or coastal erosion by waves can steepen slopes, removing the base support and leading to failure.

Anthropogenic (Man-Made) Causes

- Unscientific Construction: Improperly planned construction of roads, buildings, and dams often involves cutting into slopes or loading them, disturbing their natural stability.
- Deforestation: Removal of vegetation cover for agriculture or construction reduces the binding action of roots, exposing soil to erosion and increasing water infiltration, thereby destabilizing slopes.
- Vibrations from Blasting: Mining and quarrying activities that use explosives create artificial vibrations that can fracture rock and weaken slopes.
- Shifting Agriculture (Jhum Cultivation): The practice of clearing and burning forests on hill slopes for cultivation degrades the soil structure, making it highly susceptible to erosion and landslides during rains.

Comparison: Landslides of the Himalayas vs. Western Ghats

Differentiating Factor
Himalayas
Western Ghats
Core Geology
Geologically young, tectonically active mountains of soft, unconsolidated rock. The entire rock mass is unstable.
Geologically old, stable mountains of hard, crystalline rock. Failure occurs in the thick, weathered soil

cover (laterite) on top.
Primary Trigger
Earthquakes
(due
to
high
seismicity) and intense, short-
duration rainfall (cloudbursts).
Prolonged,
high-intensity
monsoonal rainfall that saturates
the topsoil.
Landslide Type
& Scale
Prone to large-scale, deep-seated
rockslides involving huge volumes
of rock and coarse debris.
Characterized by shallower debris
flows
and
mudflows,
where
saturated soil flows down the
slope.
Human
Influence
Stress is driven by large-scale
infrastructure
projects
(major
highways, tunnels, hydropower
dams).
Stress is mainly from land-use
changes
(deforestation
for
plantations,
mining,
and
quarrying).

Student Notes:

Land Subsidence in the Himalayas: A Ticking Time Bomb

Land subsidence is the gradual settling or sudden sinking of the Earth's surface due to the removal or displacement of subsurface materials.

The Sinking Town of Joshimath

The crisis in Joshimath, a bustling town in Uttarakhand’s Chamoli district, serves as a stark warning for the entire Himalayan region.

Primary causes

- Location on Paleo-Landslide Debris: The town is not built on solid bedrock. It sits atop a thick deposit of loose sand and stone from an ancient landslide. This material has low shear strength and poor load-bearing capacity, making it inherently unstable.
-

Unplanned Urbanization: Joshimath transformed from a small settlement into a major hub for pilgrimage (to Badrinath and Hemkund Sahib) and tourism (to Auli). This led to a massive, unregulated construction boom without proper geological assessments.

- Construction of Tapovan-Vishnugad hydropower project: construction of tunnel in 2009 punctured major underground aquifer. This event caused a massive drainage of subsurface water, which disturbed the area's natural stability.

Avalanches in the Himalayas

The Himalayas represent one of the most ecologically fragile and tectonically active zones in the world - increasingly prone to avalanches

SASE (Snow and Avalanche Study Establishment) reports a 10–15% increase in avalanche incidents in the past decade in regions like Lahaul–Spiti, Pithoragarh, Chamoli, and Kargil.

Why the Himalayas are Avalanche-Prone?

- Steep Terrain and Geology: The Himalayas are young fold mountains, still rising due to the Indian-Eurasian plate collision.
    - Steep, unstable slopes make the region inherently vulnerable to mass-wasting processes, especially snow avalanches.
- Heavy Snow Accumulation: The region receives heavy snowfall during winter, particularly due to Western Disturbances.
    - Thick layers of snow often accumulate without proper bonding, creating unstable snowpacks that can collapse.
- Climate Change and Warming Trends: The Himalayas are warming at nearly twice the global average, especially at elevations above 3,000 m.
    - A 2023 ICIMOD report confirms the rise of wet-snow avalanches in the Western Himalayas, where spring temperatures have increased by ~0.5°C per decade since 1980.
- ‘Glacier Retreat and Permafrost Thaw: Melting glaciers and thawing permafrost weaken slope stability.
    - As frozen soils warm, they lose their structural integrity, allowing ice and snow to slip more easily.

Student Notes:

Recent Incidents: Chamoli Avalanche (2021), BRO Camp Avalanche (2025)Near Mana Pass in Uttarakhand and 2023 Avalanche in Sikkim.

1.5. Rocks and rock cycle

Rocks are classified into three main types based on how they are formed: Igneous, Sedimentary, and Metamorphic.

Feature	Igneous Rocks	Sedimentary Rocks	Metamorphic Rocks
Formation	Forms when magma or lava cools and solidifies. (e.g., Granite)	Forms from the build-up of small pieces (sediments) of other rocks, plants, or animal remains, then compacted and cemented. (e.g., Sandstone)	Formed when existing igneous or sedimentary rocks are subjected to intense heat and pressure. (e.g., Marble)
Economic Importance	Source of valuable metals like iron, nickel, and copper.	Primary source of fossil fuels like coal, petroleum, and natural gas. Provide materials for cement and construction.	Provide valuable and beautiful building materials like marble and slate.

Student Notes:

1.5.1 Rock Cycle

The Rock Cycle is a fundamental concept that describes the continuous process of rocks transforming from one type to another.

1. Formation from Magma: The cycle begins when molten magma from beneath the Earth's crust cools and solidifies to form igneous rocks.
2. Creation of Sediment: All rock types on

the surface are broken down by weathering and erosion into small particles (sediment). These particles are then compacted and cemented together to create sedimentary rocks.

3. Transformation by Heat and Pressure: When any existing rock is subjected to intense heat and pressure deep within the Earth, it changes without melting into a metamorphic rock.

4. Recycling back to Magma: Any rock can be forced deep into the mantle, where it melts back into magma. This magma can then cool to form new igneous rocks, ensuring the process is a continuous cycle.

1.6. Soils

Soil is a dynamic medium in which many chemical, physical and biological activities go on constantly. Soil formation, also known as pedogenesis, starts with weathering. The weathered material, or the layer of broken-down rock, is the main starting point for soil to form.

1.6.1. Soil forming factors

Factor	Role / Description	Impact on Soil
Parent Material	The original rock from which soil develops.	Determines the soil's texture, mineral composition, and chemical properties. For example, volcanic rock leads to black soil.
Topography	The shape of the land, such as being steep or flat.	Steep slopes have thin soils due to erosion, while flat areas develop thick, dark soils rich in organic matter.
Climate	The most important active factor, working through moisture and temperature.	Temperature sets the speed of chemical reactions, while moisture (rain) breaks down minerals and transports them.
Biological Activity	The influence of plants, animals, microbes, and other living organisms.	Adds humus (organic matter) to the soil, which improves fertility, structure, and moisture retention.
Time	The duration over which soil-	

forming processes have acted.
Determines the soil's maturity. Mature soils have well-developed layers (profiles), while young soils are often uniform.

Student Notes:

Soil Horizons

Soil is made up of different layers, called horizons, each with its own characteristics.

- O Horizon: Top layer with organic matter like humus (decomposed plants/leaves).
- A Horizon (Topsoil): Rich in minerals and organic content—supports plant roots.
- E Horizon: Leached layer where minerals like clay and iron are washed out, leaving sand/silt.
- B Horizon (Subsoil): Accumulates material from above—dense with clay, iron, and organic deposits.
- C Horizon: Made of weathered parent rock (regolith); base material for soil formation.
- Bedrock: Hard, unweathered rock beneath the soil.

1.6.2. Soil Degradation and Conservation

Soil degradation refers to the decline in soil quality due to loss of fertility, structure, organic matter, and nutrient-holding capacity. This deterioration affects agricultural productivity, disrupts ecosystems, and intensifies issues like desertification, food insecurity, and climate change. Globally, around 33% of soils are already degraded, with projections suggesting this could rise to over 90% by 2050 if current trends persist.

Major Types of Soil Degradation

- Soil Erosion: The most widespread form, caused by wind, water, or human actions. For example, deforestation in Madagascar and overgrazing in Australia have stripped topsoil and decreased land productivity.
- Nutrient Depletion: Seen in places like Punjab, where excessive fertilizer use and monocropping have led to loss of key nutrients like nitrogen, phosphorus, and potassium.
- Salinization: Common in arid areas like the Aral Sea Basin due to poor irrigation and evaporation, leading to salt accumulation that inhibits plant growth.
- Acidification: Triggered by overuse of ammonium fertilizers and acid rain, reducing microbial activity and nutrient availability, as seen in Assam's tea gardens.
- Physical Degradation: Includes compaction from machinery or overgrazing, and surface sealing due to raindrop impact. This reduces water infiltration and root penetration.

- Soil Contamination: Industrial waste, mining, and pesticide overuse lead to chemical pollution, harming soil biota and making land toxic, as seen in Uzbekistan's uranium mining zones.

How has climate change intensified soil degradation?

Climate change profoundly intensifies soil degradation by altering its physical, chemical, and biological properties.

- Increased Soil Erosion: Intensified rainfall and extreme weather events boost water runoff, leading to higher rates of soil erosion.
- Loss of Soil Organic Carbon (SOC): Rising temperatures accelerate organic matter decomposition, directly reducing vital SOC levels and diminishing soil fertility.

Soil Organic Carbon (SOC): SOC is carbon stored in soil organic matter, originating from decomposed plant and animal residues. Soils globally store 2-3 times more carbon than the atmosphere, underscoring their critical role in climate regulation.

Student Notes:

- Conservation Aim: Protecting and increasing SOC is crucial for soil health and combating climate change. The "4 per 1000" initiative, launched at COP21 in 2015, aims to boost SOC stocks by 0.4% annually.
- Altered Soil Moisture Regimes: Higher temperatures increase evaporation, and irregular precipitation disrupts the delicate soil moisture balance. Droughts in semi-arid regions (e.g., the Sahel) reduce soil moisture, making soils more prone to compaction and erosion.

1.6.3. Soil Conservation Strategies

To prevent further degradation, a mix of farming and non-farming strategies is used.

Farming-Based Methods

- Contour Cropping and Strip Cropping: Slow down water runoff and protect topsoil.
- Terracing: Controls erosion on slopes.
- Windbreaks: Tree rows that reduce wind speed and soil loss.
- Cover Crops and No-till Farming: Maintain soil cover year-round, enhancing moisture and structure.

Non-Farming-Based Methods

- Afforestation and Reforestation: Restore vegetation cover.
- Buffer Strips and Grassed Waterways: Reduce erosion near rivers and fields.
- Biochar Application: Improves soil fertility and microbial activity.

- Check Dams and Rock Barriers: Slow down water flow in hilly areas.

Student Notes:

2. CLIMATOLOGY

Previous year questions (PYQs)

- Major hot deserts in the northern hemisphere are located between 20-30 degrees north and on the western side of the continents. Why?(2013)
- The recent cyclone on the east coast of India was called “Phailin”. How are tropical cyclones named across the world?(2013)
- What do you understand about the phenomenon of temperature inversion in meteorology? How does it affect the weather and the habitants of the place?(2013)
- Bring out the causes for the formation of heat islands in the urban habitat of the world.(2013)
- Most of the unusual climatic happenings are explained as an outcome of the El-Nino effect. Do you agree?(2014)
- Tropical cyclones are largely confined to the South China Sea, Bay of Bengal and Gulf of Mexico. Why?(2014)
- How far do you agree that the behaviour of the Indian monsoon has been changing due to humanizing landscapes? Discuss(2015)
- Discuss the concept of air mass and explain its role in macro-climatic changes.(2016)
- What characteristics can be assigned to the monsoon climate that succeeds in feeding more than 50 percent of the world population residing in Monsoon Asia? (2017)
- How does the cryosphere affect global climate? (2017)
- Discuss the meaning of color-coded weather warnings for cyclone-prone areas given by the India Meteorological Department.(2022)
- The troposphere is a very significant atmospheric layer that determines weather processes. How ?(2022)
- Why is the South-West Monsoon called 'Purvaiya' (easterly) in Bhojpur Region? How has this directional seasonal wind system influenced the cultural ethos of the region? (2023)
- What is the phenomenon of ‘cloudbursts’? Explain. (2024)
- What is a twister? Why are the majority of twisters observed in areas around the Gulf of Mexico? (2024)

PYQs Analysis

UPSC’s GS questions on Climatology have consistently tested aspirants on both fundamental atmospheric processes and their real-world climatic implications. The focus isn’t limited to “what happens” but more on “why it happens, where, and with impact.”.

For example:

•
Atmospheric Dynamics & Circulation: Core concepts like temperature inversion (2013), troposphere's significance (2022), and air masses (2016) indicate clarity on structure, layering, and movement of air that drives weather patterns.
•
Weather Phenomena & Hazards: From cloudbursts (2024) and twisters (2024) to cyclones (2013, 2014, 2022), the paper often probes climate events that have significant societal consequences. Questions here focus on mechanisms, spatial distribution, and institutional responses (e.g., IMD color-coded alerts).
•
Monsoons & Climatic Variability: The Indian monsoon remains a favorite—with questions exploring its changing behavior due to land-use (2015), its climatic significance in Asia (2017), or even its cultural relevance (2023).
•
Global Climate Drivers: The El Niño effect (2014) and humanizing landscapes have been used to explore broader climatic anomalies and trends.

Student Notes:
2.1. Earth’s Atmosphere
The atmosphere is made up of different types of gases, water vapour and dust particles. The composition of the atmosphere is not static. It changes according to the time and place. Nitrogen and Oxygen are the two main gases in the atmosphere. 99 per cent part of it is made up of these two gases. Other gases like organs, carbon dioxide, hydrogen, Neon, helium etc. form the remaining part of the atmosphere.
2.1.1. Structure Of Atmosphere
Layer
Description
Height
Range
(km)
Temperature
Trend
Key Features
Troposphere
The lowest
layer, where we
live and
experience
weather.
0 - 13
(Thicker
at
equator,
thinner at
poles)
Decreases
with height
(normal
lapse rate)
•
Contains 75% of
atmospheric mass.
•
Responsible for all

weather phenomena.
•
Clouds, precipitation,
wind all occur here
Stratosphere
The calm layer
above the
troposphere.
13 - 50
Increases
with height
due to ozone
absorption
•
Contains the ozone
layer, which protects us
from harmful UV
radiation.
•
Ideal for air travel due
to stable conditions.
•
Some cirrus clouds may
be present
Mesosphere
The middle layer
where
temperatures
plummet.
50 - 85
Decreases
with height
•
Most meteors burn up
here due to thin air.
•
Polar mesospheric
noctilucent clouds form
due to extreme cold
Thermosphere The upper layer
where
temperatures
soar due to
solar radiation.
85 - 600
Increases
with height
due to UV
and X-ray
absorption
•
The International Space
Station and satellites
orbit here.
•
Kármán Line (100 km)
defines the edge of

Student Notes:
space
Ionosphere
(Within
Thermosphere
)
A region with
charged
particles that
affect radio
waves.
80 - 400
Varies
•
Electrically charged
particles (ions) present.
•
Reflects radio waves,
enabling
communication
Exosphere
The outermost
layer, where
particles escape
to space.
400+
Gradually
increases
•
Very thin and sparse
atmosphere.
•
Transition zone to
outer space
•
pen_spark
Polar Stratospheric Clouds (PSCs) and Their Role in Ozone Depletion
The stratosphere, situated approximately 15–50 km above Earth's surface, is typically too dry to support cloud formation.
However, during the polar winters, extremely low temperatures allow the formation of Polar Stratospheric Clouds (PSCs) at altitudes between 15 and 25 km. These clouds are crucial in the seasonal depletion of the ozone layer, especially over Antarctica.
Role in Ozone Depletion:
PSCs facilitate chemical reactions
that
convert
stable
chlorine
compounds into reactive forms,
such as chlorine monoxide (ClO)
and atomic chlorine (Cl).
These reactive chlorine species
are highly effective in breaking

down ozone molecules when
exposed to sunlight in the spring,
leading to significant ozone depletion.

Student Notes:

Recent Observations:

In recent years, the occurrence of PSCs has been linked to colder stratospheric temperatures, which may be influenced by climate change. Anomalously cold conditions can lead to more frequent and intense PSC formation, potentially delaying the recovery of the ozone layer. Understanding the dynamics of PSCs is essential for assessing the health of the ozone layer and predicting future ozone depletion events.

2.2. Temperature Distribution On Earth

The Sun stands as the primary source of heat for our planet. The varying amounts of solar energy received by different regions of the Earth result in the diverse climatic features we observe. This differential heating is fundamental to the formation of wind systems, pressure zones, precipitation patterns, and other weather phenomena.

Factors Affecting Distribution Of Temperature

Angle of Incidence
Higher latitudes receive slanting rays, resulting in less effective heating. Tropics are hotter; poles are colder.

Atmospheric Transparency
Dust, smoke, and clouds scatter, reflect, or absorb solar radiation, affecting surface heating.

Land-Sea Differential
Land heats/cools faster

due to lower specific heat. Oceans regulate coastal temperatures via circulation. Prevailing Winds Winds redistribute heat; e.g., westerlies bring warm maritime air to Europe, moderating its climate. Ocean Currents Warm currents (e.g., Gulf Stream) raise temperatures; cold currents (e.g., California Current) lower them. Altitude Temperature decreases with height due to lower air pressure and

reduced
greenhous
e effect.
Earth–Sun
Distance
Slight
orbital
variation
affects
solar
radiation
marginally
compared
to
other
dominant
factors.

2.2.1. Heat Budget

A heat budget is a perfect balance between incoming heat (insolation) absorbed by the earth and outgoing heat (terrestrial radiation) escaping it in the form of radiation.

Student Notes:

- If the incoming heat and the outgoing heat are not balanced, then Earth would be getting either too warmer or cooler. Since these are perfectly balanced the earth is neither too warm nor too cold.
- When 100% of insolation reaches the top of Earth's atmosphere, about 35% is reflected back to space (27% by clouds and 2% by snow/ice, known as Earth's albedo).
- The remaining 65% is absorbed, with 14% absorbed by the atmosphere and 51% by Earth's surface.
- The Earth radiates 51% back as terrestrial radiation; 17% goes directly to space, and 34% is absorbed by the atmosphere.
- The atmosphere, in turn, radiates 48% back to space, ensuring that the total outgoing radiation (17% + 48%) balances the 65% received from the Sun.

Heat Balance of Earth

The Earth's heat balance is governed by the distribution of solar radiation, which varies across the planet's surface. Some regions experience a surplus of heat, while others face a deficit.

- The areas between 40°N and 40°S receive more solar radiation than they lose, creating a radiation surplus, whereas regions near the poles experience a radiation deficit due to the more oblique angle of the sun's rays.

This surplus heat from the tropics is redistributed toward the poles, helping prevent extreme heating in the tropics and permanent freezing at higher latitudes.

To understand the energy balance, it's important to consider net radiation, which is the difference between the incoming solar radiation and the outgoing terrestrial radiation. Net radiation can be positive or negative:

- Positive Net Radiation occurs
when a region receives more
energy than it loses, resulting in

an energy surplus. This typically
happens near the equator, where
the sunlight is more direct.

- Negative Net Radiation happens when a region loses more energy than it receives, creating an energy deficit. This is common in polar regions where sunlight is oblique.

In order to maintain equilibrium, energy from surplus regions (such as the tropics) is transferred to deficit regions (such as the poles), ensuring that overall net radiation for the entire Earth remains balanced over the course of a year.

Impact on Earth's heat balance: Natural & Anthropogenic

Natural
Anthropogenic
Solar
Variability
Changes in
solar output
(sunspot
cycles) alter
the amount
of energy
Volcanic
Eruptions
Ash and
aerosols
increase
atmospher
ic albedo,
leading to
Ocean-
Atmosphere
Interactions
Phenomena
like El
Niño/La Niña
redistribute
heat,
Greenhouse
Gas Emissions
CO■, CH■, N■O
emissions
from industry,
transport, and
agriculture
intensify the
Aerosol
Emissions
Industrial
pollutants
increase
atmospheri
c
reflectivity,
Land Use
Changes

Deforestatio
n reduces
carbon sinks
and alters
albedo;
urbanization

Student Notes:
Earth
receives.
short-term
cooling.
affecting
global
temperature
patterns.
greenhouse
effect, leading
to warming.
causing
regional
cooling but
disrupting
natural
feedbacks.
creates heat
islands.

Horizontal Distribution of Temperature

The horizontal distribution of temperature in the Earth's atmosphere refers to how temperature varies across different regions at the same altitude. Below image shows a decrease in temperature from the equator to the poles, with significant variations influenced by local factors like altitude, ocean currents, and land-sea distribution.

Vertical distribution of temperature

Vertical temperature distribution refers to how temperature changes as you move up through the Earth's atmosphere. In general, temperature tends to decrease with increasing altitude. This decrease is called the environmental lapse rate or the vertical temperature gradient.

The normal lapse rate is not always the same, but it differs depending upon height, season, latitude or other numerous local factors. Such as:

- Latitude: Tropics receive more sunlight, so the lapse rate might be higher there compared to Polar Regions.
- Season: Summer sun heats the surface more, leading to a steeper lapse rate compared to winter.
- Local conditions: Presence of clouds, water bodies, and atmospheric pressure can also influence the lapse rate.

Greenhouse Effect

The Sun is the primary energy source for Earth’s climate, emitting energy in short wavelengths, mostly in the visible and ultraviolet spectrum.

To maintain energy balance, the Earth radiates this absorbed energy back into space as infrared radiation.

However, a significant portion of this outgoing heat is absorbed by greenhouse gases and reradiated back to the surface, warming the planet—this is known as the greenhouse effect.

Student Notes:

Why It Matters?

- Without the natural greenhouse effect, Earth's surface would be below freezing, making life impossible.
- Human activities—mainly fossil fuel burning and deforestation—have intensified this natural effect, leading to global warming.

Key Greenhouse Gases:

- Water vapour – most abundant and effective
- Carbon dioxide (CO_2) – second-most significant
- Methane (CH_4), nitrous oxide (N_2O), ozone (O_3) – also contribute despite lower concentrations

In contrast, nitrogen (78%) and oxygen (21%) make up most of the atmosphere but do not trap heat.

Regional Sensitivity:

- In humid tropics, extra CO_2 has limited additional warming effect.
- In cold, dry regions (like the poles and upper atmosphere), even small increases in GHGs have greater warming impact.

Feedback Mechanisms:

1. Water Vapour Feedback

Warming increases water vapour → enhances greenhouse effect → more warming → cycle continues

- Can double the warming caused by CO_2 alone

2. Cloud Feedback

- Clouds can trap heat (warming) and reflect sunlight (cooling)

■
Changes in cloud type, altitude, size, and lifespan can either amplify or reduce global warming
■
Cloud feedbacks are complex and a major area of climate research
Natural vs. Human Role:
•
Natural systems like plants and oceans help regulate GHGs (e.g., through photosynthesis).
•
Since the industrial era, human emissions have overloaded this balance, strengthening the greenhouse effect and driving climate change.
2.2.2. Temperature Inversion
A temperature inversion features a layer of warm air trapped above a layer of cooler air near the ground. A phenomenon that disrupts the normal vertical temperature distribution in the atmosphere.

Student Notes:
Types Of Temperature Inversion
1. Intermontane Valley Inversion
Intermontane Valley Inversion occurs when the lower layers of air cool more quickly than the upper layers on sloping surfaces like mountainsides or valleys.
•
This results in cold air settling near the ground, with warmer air above, reversing the typical temperature gradient.
•
This phenomenon is common in middle and higher latitudes, especially in elevated terrains like the Himalayas.
2. Ground Inversion
Ground inversion is a common occurrence when the air cools upon contact with a colder surface, ultimately becoming cooler than the air above it.
•
This phenomenon often emerges on clear nights, as the ground rapidly cools due to radiation In a relatively short time, the lowest few hundred meters of the troposphere become colder than the air above, and a temperature inversion is in effect.
•
This type of temperature inversion is prevalent in higher latitudes.
•
In lower and middle latitudes, surface temperature inversions typically occur on cold nights and dissipate during daytime.
3. Subsidence Inversions:
These form when a large air mass descends and warms up due to compression. This warm air can then settle over cooler surface air.

Student Notes:

Frontal Inversions:

Although less frequent, these occur when warm and cold air masses meet along a weather front. The temperature difference creates a stable layer where the warmer air overrides the cooler air near the ground.

Effects Of Temperature Inversion

- Impact on Weather: The warm layer acts like a lid, suppressing the natural upward movement of air (convection). This limits the vertical mixing of air masses and restricts cloud formation. This can lead to drier conditions and potentially contribute to drought.
- Reduced Visibility: Cool, moist air trapped near the ground by the warm layer can condense and form fog, particularly

Student Notes:

during radiation inversions at night. This can significantly reduce visibility, impacting transportation and outdoor activities.

- Air Quality: Temperature inversion trapping pollutants from cars, factories, and other sources close to the ground. This can lead to smog and hazy conditions, especially during winter months when inversions are most common.
- Impacts on agriculture: It traps cold air close to the ground, leading to frost formation, which can damage crops, especially during the growing season.
- Disrupted Radio Signals: Inversions can bend radio waves, sometimes causing reception issues or affecting radio communication range.

Wet-Bulb Temperature (WBT)

Wet-bulb temperature is the lowest temperature that can be reached by evaporation of water into the air. It reflects a combination of air temperature and humidity, and is measured using a thermometer wrapped in a wet cloth (hence "wet-bulb") and exposed to air flow. (* Dry-Bulb Temp- Regular air temperature)

- WBT indicates how well sweating can cool the human body. Above 35°C WBT, the body cannot cool itself, even in shade or with water.
- At this point, core body temperature rises, risking heat stroke or death, even with fans or hydration. The threshold of survivability is around 35°C WBT for 6 hours.

Related Concepts:

- The Heat Index expresses how hot it feels by combining air temperature and humidity — relevant when high WBT prevents efficient cooling.
- The Wind Chill Factor represents how cold it feels when wind enhances heat loss from the body — important in low-temperature climates.

Impacts of High Wet-Bulb Temperature

Impact Area	Consequences
Health	Heat stroke, exhaustion, organ failure, deaths
Agriculture	Wilting of crops, water stress, reduced yield
Infrastructure	Overload on cooling systems, power demand spike
Outdoor Work	Inability to carry out physical tasks; training curbed
Urban Life	Intensifies urban heat island effect; poor air quality

2.3. Pressure Belts

Pressure belts are areas on the earth’s surface where the same pressure is distributed differently depending on latitude. These are caused by high or Low-Pressure cells. These high- and low-pressure cells generate high- and low-pressure belts, respectively.

2.3.1. Thermally induced pressure belts

Thermally-induced pressure belts are regions of the Earth's atmosphere where variations influence the air pressure in temperature. These belts are formed due to solar radiation's uneven heating of the Earth's surface.

The Thermally Induced Pressure Belts are further divided into two types:

1. Equatorial Low-Pressure Belts
2. Polar High-Pressure Belts

1. Equatorial Low Pressure Belt or ‘Doldrums’

- This belt happens to be the zone of convergence of trade winds from two hemispheres from sub-tropical high pressure belts. It lies between 10°N and 10°S latitudes.
- This belt is also called the Doldrums, because of the extremely calm air movements. This is because of the absence of Surface winds since winds approaching this belt begin to rise near its margin. Thus, only vertical currents are found.
- Vertical winds (convection) carrying moisture form cumulonimbus clouds and lead to thunderstorms (convectional rainfall).
- In spite of high temperatures, cyclones are not formed at the equator because of ‘zero’ coriolis force.

2. Polar High pressure belt-

- The polar high pressure belts are at 90° N and 90° S latitudes. This zone is commonly referred to as the polar highs.
- Since the Polar Regions receive only slanting rays of the sun, the temperature remains low throughout the year. Thus high pressure is developed over this zone.

•
Also, the subsidence of cold and dry air in this zone increases the pressure. Due to the Coriolis Effect, the subsiding air gets converted into anticyclones and forms gales (very strong winds).

2.3.2. Dynamically Induced Pressure Belts

Dynamically induced pressure belts are regions in the Earth's atmosphere where air pressure is influenced by dynamic factors, particularly the movement and interaction of air masses and the Earth's rotation. Dynamically induced pressure belts are shaped by atmospheric circulation patterns and the Coriolis Effect.

The Dynamically Induced Pressure Belts are further divided into two types:

1. Sub-Tropical High-Pressure Belts
2. Sub-Polar Low-Pressure Belts

Student Notes:

1. Subtropical High Pressure Belt or Horse Latitudes

•
The subtropical highs extend from near the tropics to about 35°N and S.

•
High pressure along this belt is due to subsidence of air coming from the equatorial region which descends after becoming heavy. The high pressure is also due to the blocking effect of air at upper levels because of the Coriolis force.

•
The subsiding air is warm and dry, therefore, most of the deserts are present along this belt, in both hemispheres. For example Sahara Desert (North Africa): The world's largest hot desert, the Sahara exemplifies the impact of descending air currents.

•
A calm condition (anticyclone) with feeble winds is created in this high pressure belt.

•
The descending air currents feed the winds blowing towards adjoining low pressure belts. This belt is frequently invaded by tropical and extra-tropical disturbances.

2. Sub-Polar Low-Pressure Belts

•
The sub-polar low-pressure belts are between 60° to 65° latitudes in both hemispheres.

•
This belt is known as the temperate convergence zone because the warm and cold air masses from the sub-tropical and polar high pressure belts converge at this zone. This, in turn, produces cyclonic storms.

•
It is a dynamically induced pressure belt which is evident from the low pressure over this zone, despite the temperature being low.

•
In the northern hemisphere, the sub-polar low-pressure belts become discontinuous during the summer and continuous during the winter.

Inter-Tropical Convergence Zone (ITCZ) and Its Seasonal Shifts

The Inter-Tropical Convergence Zone (ITCZ) is a narrow zone near the Earth's equator where the trade winds from the Northern Hemisphere and the Southern Hemisphere converge. This region is characterised by warm, moist, rising air, which leads to the formation of clouds and causes heavy rainfall.

Seasonal Shifts of the ITCZ

The position of
the
ITCZ
shifts
throughout

the
year,
mainly
following
the
apparent
movement of the
overhead
Sun.
However, this shift
does not exactly
match the Sun's
position but lags
slightly behind.

During the Northern Hemisphere Summer (Around June Solstice)

- The Sun's rays are directly overhead at the Tropic of Cancer (23.5°N).
- The ITCZ shifts northward towards the Tropic of Cancer.
- Over the Indian subcontinent, the ITCZ can move as far north as 25°N.
- This northward shift is intensified due to the excessive heating of the landmasses in South Asia and Southeast Asia.
- The result is the southwest monsoon season, bringing widespread rainfall to the Indian region.

Student Notes:

During the Northern Hemisphere Winter (Around December Solstice)

- The Sun is directly overhead at the Tropic of Capricorn (23.5°S).
- The ITCZ shifts southward towards the Tropic of Capricorn.
- In the Southern Hemisphere, this southward shift is less intense because the landmasses are smaller and the heating effects are weaker compared to the Northern Hemisphere.
- As a result, the ITCZ does not move as far south as it moves north during the Indian summer.

Impact on Global Pressure Belts

The seasonal movement of the ITCZ is linked to the shifting of pressure belts around the globe:

- Low-pressure belts follow the ITCZ, moving north and south with the seasons.
- High-pressure belts also adjust slightly in response.
- The ITCZ is associated with the Hadley cell circulation, which influences global wind patterns and precipitation.

Importance of ITCZ Shifts

- The migration of the ITCZ plays a critical role in determining the rainfall patterns of tropical regions.

•
When the ITCZ moves over an area, it brings thunderstorms, heavy rainfall, and monsoonal winds.

2.4. Atmospheric Circulation

World atmospheric circulation is the large-scale movement of air around the planet. This circulation is primarily driven by the uneven heating of the Earth's surface by the sun. The structure of atmospheric circulation remains consistent annually, despite variations in specific details.

Atmospheric circulation is classified into three types:

1. Primary or General Circulation:

•
Primary winds, also known as planetary, permanent, global, invariable, or prevailing winds, blow constantly throughout the year.

•
Three types of primary winds: Trade Winds, Westerlies, and Easterlies.

2. Secondary Circulation

•
This circulation is also called seasonal, periodic, variable, and regional winds.

•
These winds change direction with different seasons, exemplified by monsoons.

3. Tertiary Circulation:

•
Formed due to local pressure gradients resulting from differences in the Earth's surface heating and cooling, tertiary winds, such as Harmattan and Chinook, blow only during specific periods in a small area, confined to the lower levels of the troposphere.

2.4.1. Planetary Winds

They are also called primary winds or permanent winds because they remain the same throughout the year and are distributed across the globe. These winds are related to thermally and dynamically induced pressure belts and rotation of the earth.

Tropical Easterlies:

•
They blow from the sub-tropical high-pressure areas towards the equatorial low-pressure belt. They flow as the north-eastern trades in the northern hemisphere and the south-eastern trades in the southern hemisphere.

Student Notes:

•
The trade winds from two hemispheres meet at the inter tropical convergence zone, and due to convergence, they rise and cause heavy rainfall.

•
Their off – shore nature on the western side of the continents are one of the reasons behind formation of deserts in those areas.

Subtropical Westerlies:

•
They blow from the subtropical high - pressure belts towards the sub polar low-pressure belts. They blow from southwest

to north-east in the northern hemisphere and north-west to south-east in the southern hemisphere.

- These winds produce wet spells and variability in weather.

Polar Easterlies:

- They blow from the polar high-pressure areas of the sub-polar lows. The Polar easterlies are dry, cold prevailing winds blowing from north-east to south-west direction in the Northern Hemisphere and south-east to north-west in the Southern Hemisphere.

Significance Of Planetary Winds

Climatic significance

- Balances the heat budget by transporting the excessive heat of tropics towards poles.
- Form the dynamic pressure belts – Sub Polar low-pressure belt is formed due to convergence and upliftment of sub-tropical westerlies and Polar easterlies.
- Cyclone formation and movement – Their convergence form the fronts at sub polar low-pressure belt and thus create extra tropical cyclone. Trade winds move the Tropical cyclones from west to East.
- Regional Climate- Monsoon in Indian subcontinent is caused due to eastward shift of SE trades after crossing the equator under the effect of Coriolis force.

Oceanic significance

- Movement of oceanic currents- North and South Equatorial currents move east to West under the influence of Trade winds. Gulf Stream moves toward the North-east and hit the NW coast of Europe under the influence of Sub-tropical Westerlies.
- Formation of gyres- Primary winds affected by Coriolis form the circulatory motion of current thereby forming the Gyres.

Geomorphic significance:

- Formation of deserts- Tropical Easterlies form the desert on the western margins of the Continents as they become dry when they reach there and act as offshore winds.

Ecological significance:

- Their effect on Oceanic current movement allows transport of nutrients and thriving biodiversity in the form of fisheries, planktons, and corals.

Student Notes:

Why Are Deserts Found Between 20-30 Degrees North and on the Western Sides of Continents?

The formation of major hot deserts in the Northern Hemisphere, primarily between 20-30 degrees north and on the western side of continents, is influenced by several factors:

Atmospheric Conditions

- Subtropical High-Pressure Belts: These belts, situated around 20-30 degrees north, are characterized by descending air masses. This descending air warms and compresses, inhibiting cloud formation and precipitation, creating arid conditions ideal for desert formation. Examples include the Sahara Desert in Africa and the Arabian Desert in Asia.
- Trade Winds: The easterly winds carry moisture from oceans. While they bring rain to eastern coasts, they become drier inland, contributing to the aridity of western regions.

Geographic Factors

- Rain Shadow Effect: Mountain ranges on western continental sides act as barriers to moisture-laden winds. As air is forced to rise over these mountains, it cools and releases precipitation. The drier air descends on the leeward side, creating desert conditions. The Mojave Desert in North America is a prime example.
- Cold Ocean Currents: Cold ocean currents along western coasts cool the air, reducing its moisture-holding capacity. This leads to less precipitation and contributes to desert formation.

The combination of descending air, dry trade winds, rain shadow effects, and cold ocean currents creates the perfect conditions for the development of major hot deserts in these specific geographic locations.

2.4.2. Seasonal Winds

Winds changing their direction with the shifting seasons are termed seasonal winds. Includes monsoon winds, which alter their direction based on seasonal changes. Other examples of periodic winds include land and sea breeze, mountain and valley breeze, cyclones and anticyclones, and air masses.

- Monsoon winds:
  - Monsoons were traditionally explained as land and sea breezes on a large scale. Thus, they were considered a convectional circulation on a giant scale.
  - The monsoons are characterized by seasonal reversal of wind direction.
  - Monsoon winds blow from sea to land in summer and from land to sea in winter due to differential heating of land and water.

Student Notes:

  - Originating in the trade wind belt between the Tropic of Cancer and the Tropic of Capricorn, these winds are prominent in South and Southeast Asia.
  - The monsoon winds flow over India, Pakistan, and Bangladesh. Myanmar (Burma), Sri Lanka, the Arabian Sea, Bay of Bengal, south-eastern Asia, northern Australia, China
  - Outside India, in the eastern Asiatic countries, such as China and Japan, the winter monsoon is stronger than the summer monsoon. (we will study about monsoons in detail while studying Indian Climate)
- Land and Sea Breezes:
  - During the daytime, the land heats up faster than the adjacent sea, creating low pressure over land and high pressure over the sea. The pressure gradient induces air movement from the high-pressure sea to the low-pressure land, known as a sea

breeze.

- At night, land cools rapidly, becoming cooler than the sea, resulting in a reverse pattern known as land breeze.

• Mountain and Valley Breezes: Mountain and valley breezes are local winds that occur due to differential heating and cooling between mountain slopes and valleys. They are not considered seasonal winds, as they occur daily.

- Valley Breeze: During the day, the sun heats up mountain slopes faster than valleys. This creates a low-pressure area on the mountain, drawing cooler air from the valley upwards - the valley breeze.

- Mountain Breeze: At night, the mountain slopes cool down rapidly, forming denser, cold air. This air flows downhill into the warmer valley, creating a mountain breeze.

These local winds influence local climate, weather patterns, and ecosystems. They can also impact human activities like agriculture and aviation.

Student Notes:

2.4.3. Local Winds

Local winds are those kinds of winds that are solely caused by local conditions. Local winds are caused by the air moving between high and low-pressure systems in confined spaces. Each form of wind differs somewhat from the others since there are various sorts of winds. These local winds play an important role in the weather and climate of a particular location.

Hot Local Winds

Wind Name	Region	Characteristics	Impact on Local Weather
Loo	Northern India and Pakistan	Hot, dry, strong, blows from west to east	High temperatures (45-50°C), heatwaves, reduced visibility
Foehn	Leeward side of Alps	Warm, dry, strong	Snow melt, early pasture growth,

increased fire risk
Chinook
Eastern slopes
of Rockies
Hot, dry, strong,
"snow eater"
Rapid snowmelt, increased
temperatures
Sirocco
Sahara Desert
Hot, dry, dusty
Brings hot, dry conditions,
sometimes cooled by
Mediterranean Sea
Harmattan
Northwest
Africa
Hot, dry, dusty, strong
Relief from moist heat, health
benefits, dry climate
Cold local winds
Wind
Name
Region
Characteristics
Impact on Local Weather
Mistral
Alps, France
Cold, dry, high velocity
Low temperatures, freezing conditions
Bora
Adriatic Sea
region
Cold, dry, high speed
Low temperatures, strong winds
Blizzard
Various
regions
Freezing, wind-laden
with dry snow
Severe winter conditions, low visibility,
transportation disruptions
Some examples of recent local winds:
Local Wind
Region
Year
Led To
Santa
Ana
Winds
Southern
California, USA
2025
Intensified wildfires – rapid spread, massive
displacement, property loss

Student Notes:
Föhn Winds
Swiss
Alps,
Switzerland
2023
Triggered avalanches – fatalities, infrastructure
damage, ski closures
2.4.4. Atmospheric Tricellular Circulation
Atmospheric Tricellular Circulation refers to the three-cell system in each hemisphere: Hadley, Ferrel, and Polar cells. These cells involve large-scale air movement from the equator to the poles and back, driving global wind patterns and influencing climate by distributing heat and moisture across the Earth's surface.
Walker cell
The Walker Cell is an atmospheric circulation pattern found along the equatorial Pacific Ocean.
It involves the movement of air in a loop: warm air rises over the western Pacific, creating low pressure and heavy rainfall, while cooler air sinks over the eastern Pacific, causing high pressure and dry conditions.
(The Walker Cell, a key atmospheric circulation pattern connected to ENSO, will be discussed later in Monsoon topic)
2.4.5. Jet Streams
Jet streams are long, narrow, high-speed, meandering, circumpolar winds that typically flow north-eastward, eastward, and south-eastward in the middle and upper troposphere or lower stratosphere.

Student Notes:
Characteristics of jet streams

- They generally move from west to east in a narrow belt of a few thousands km of length, hundred km of width and few km of thickness moving at the height of 7.5 -14 km in the upper troposphere.
- Generally, their circulation is observed between poles and 20° latitudes in both the hemispheres.
- Their circulation path (trajectory) is wavy and meandering. Meandering jet streams are called Rossby waves.
- Their velocity increases during winter season and the wind velocity becomes twice the velocity during summer season. Maximum wind velocity is 480 km (per hour).
- The extent of jet streams narrows down during the summer season because of their northward shifting while these extend up to 20° latitudes during winter season.

Each type of jet stream influences global and regional weather patterns, playing a critical role in the Earth's climate system.
Significance of jet streams

- Climate: Jet streams can transport weather systems across the world, affecting temperature and precipitation. For E.g. - they carry temperate cyclones from the eastern coast of USA to Western coast of Europe. Their presence & withdrawal over Gangetic planes directly affects the monsoonal pattern in India.
- Predicting weather: Monitoring jet streams can help meteorologists determine where weather systems will move next.
- Ozone layer depletions: Jet streams may transport ozone depleting substances higher up in the atmosphere upto stratosphere. This vertical air circulation causes rapid rate of mixing of air between troposphere and stratosphere, which helps in the transport of anthropogenic pollutants from troposphere to stratosphere.
- Disasters: Recently climate change studies have proved the link of Jet streams and disasters like floods, fires and cyclones.
- Travel & Transportation: If an airplane flies in a powerful jet stream and they are traveling in the same direction, the airplane can get a boost reducing the fuel need. Opposite may lead to turbulence and resistance.

Jet Stream Blocking

It refers to a meteorological phenomenon where the normal west-to-east flow of the jet stream is interrupted by a high-pressure system, called a blocking high. This causes the jet stream to split or form large meanders, creating a pattern that can persist for days or weeks, preventing typical weather system progression.

Student Notes:

Mechanism: Blocking occurs when a strong high-pressure ridge forms in the upper atmosphere, causing the jet stream to loop around it. This traps weather systems in place, leading to prolonged periods of similar weather.

Rossby waves

Rossby waves are large, wavy patterns in the jet stream, which is the fast-flowing air current high in the atmosphere.

- When the temperature contrast weakens, especially due to Arctic warming, the jet stream becomes more wavy. This increased waviness causes the jet stream to dip further south, bringing cold Arctic air into regions like North America.
- As a result, areas that typically have milder winters may experience severe cold spells and winter storms.

Polar Vortex: Formation and Significance

The Polar Vortex is a large area of low pressure and cold air surrounding both the North Pole and South Pole. It is a natural, recurring feature in the atmosphere and plays a key role in shaping winter weather patterns, particularly in the Northern Hemisphere.

Formation

- The polar vortex forms during the winter months as cold, dense air accumulates around the poles.
- It is maintained by the strong jet stream that encircles the polar regions, trapping the cold air.
- The vortex is generally centered over the polar region and extends upward into the stratosphere.
- It is strengthened by the Earth's rotation and the temperature contrast between the polar regions and lower latitudes.

Student Notes:

Significance

-

Cold Weather Patterns: The polar vortex helps to control winter temperatures. When the vortex is strong and stable, it keeps cold air confined near the poles. However, when the vortex weakens or shifts, it can lead to outbreaks of cold air moving into lower latitudes, causing extreme winter weather in places like North America and Europe.

- Severe Weather Events: A weakened or displaced polar vortex is linked to intense cold spells and snowstorms, as the cold air escapes the polar region and moves southward.
- Global Climate Effects: Changes in the polar vortex can also be influenced by larger climate systems, such as El Niño or La Niña, which can affect its behavior and alter weather patterns globally.

Heat dome

A heat dome is a weather phenomenon where a high-pressure system in the atmosphere traps warm air, similar to a lid on a pot, for an extended duration.

How are heat domes and jet streams connected?

While heat domes are a cause of heat waves, it's important to note that heat waves can occur independently of them.

- The formation of a heat dome is linked to the behavior of the jet stream, a high-altitude corridor of fast-moving air that typically steers weather systems across the Earth's surface. The jet stream usually follows a wave-like pattern, oscillating north and south.
- However, when these waves become larger and more stretched out, their movement slows down and can even come to a standstill. This stagnation traps a high-pressure system in place, leading to the emergence of a heat dome.

Student Notes:

Heat Waves and Cold Waves

Heat Wave

A Heat Wave is considered when the maximum temperature at a station reaches or exceeds a certain threshold for at least two consecutive days.

IMD Criteria:

Situation

Heat Wave Criteria

Regions Affected Most

Normal
max
temp < 40°C

Departure from normal ≥ 5°C to 6.4°C =
Heat Wave

- Northwest India (Rajasthan, Punjab, Haryana, Delhi, UP)
- Central India (Madhya Pradesh, Chhattisgarh)
- Eastern India (Odisha, Bihar, Jharkhand)
- Telangana, Vidarbha

in
Maharashtra
Departure from normal ≥ 7°C = Severe
Heat Wave
Normal
max
temp ≥ 40°C
Actual max temp ≥ 45°C = Heat Wave
Actual
max
temp ≥ 47°C
Severe Heat Wave (irrespective of
normal)
Coastal
stations
Heat Wave declared only if temperature
reaches ≥ 37°C and persists
Must persist for 2 or more consecutive days for declaration.
Cold Wave
A Cold Wave occurs when the minimum temperature falls significantly below normal levels in plains or hilly regions, for two or more consecutive days.
IMD Criteria:
Situation
Cold Wave Criteria
Regions Affected Most
Minimum temp ≥
10°C
Departure from normal is -5°C to -6.4°C =
Cold Wave
•
Northwest
and
North India: Punjab,
Haryana, Delhi, UP,
Rajasthan
•
Bihar,
Jharkhand,
parts
of
Madhya
Pradesh
•
Himalayan foothills
and NE India
Departure from normal is ≤ -6.5°C = Severe
Cold Wave
Actual min temp ≤
4°C
Cold Wave is declared, even without large
deviation
Hilly regions
Cold Wave if temp ≤ 0°C

Student Notes:

Why heat waves are becoming frequent in India?

- Global Warming: A rising global average temperature means our starting point for seasonal heat is already higher, making it easier to reach extreme heatwave levels.
- Altered Wind Patterns: Persistent high-pressure systems are becoming more common, trapping hot air over large areas for extended periods.
- Urban Heat Islands: Rapid urbanization with extensive concrete and asphalt traps heat, while deforestation removes natural cooling, making local areas much hotter.
- Drier Conditions: A lack of pre-monsoon showers and drier soil mean the sun's energy heats the air directly instead of evaporating water, causing temperatures to spike more intensely.

2.5. Precipitation

Precipitation is water that falls from the sky, including rain, snow, hail, and sleet. It forms when water droplets or ice crystals in clouds become heavy enough to fall to the Earth's surface.

Formation

- Condensation: Water vapor cools and turns into tiny liquid droplets in the clouds.
- Nucleation: Droplets form around tiny particles like dust or salt.
- Collision and Coalescence: In warmer clouds, droplets collide and merge into larger drops that fall as rain.
- Bergeron Process: In cold clouds, ice crystals grow by taking water vapor from droplets, forming snow that may melt into rain if it warms.

Student Notes:

Types of Precipitation

- Frontal Rainfall: Occurs when warm and cold air meet, often leading to rain. Common in the UK.
- Orographic Rainfall: Moist air is forced up by mountains, causing heavy rain on the windward side. Example: Cherrapunji in India.
- Convectional Rainfall: Sun heats the Earth's surface, causing air to rise, cool, and condense into rain. Common near the equator.

Global Distribution of Precipitation

- Equatorial Regions: High rainfall due to warm temperatures and moisture-rich air.
- Subtropical Regions: Dry due to descending air that prevents cloud formation.
- Mid-Latitudes: Varying precipitation influenced by fronts and cyclone.
- Polar Regions: Low precipitation, mostly snow, due to cold air holding less moisture.

Cloudburst

A cloudburst is an extremely intense and sudden rainfall event, typically over a small geographical area and within a short time—usually less than an hour.

- Rainfall rate: More than 100 mm/hour (can even exceed 200 mm/hour)
- Often leads to flash floods, landslides, and heavy destruction, especially in mountainous regions
- May or may not be accompanied by thunder and lightning.

How Does a Cloudburst Occur?

- It happens when warm, moist air rises rapidly, forming cumulonimbus clouds.
- Due to rapid condensation at high altitudes, massive amounts of moisture get trapped.
- When this saturated cloud cannot hold more moisture, and local conditions prevent it from dispersing, it releases all water at once—causing a cloudburst.

Why Are Himalayan Areas More Prone to Cloudbursts?

- Orographic Effect: Moist winds from the south (monsoon) are forced to rise over steep Himalayan slopes → rapid cooling and condensation → sudden intense rainfall.
- Steep Terrain: Mountains accelerate uplift of moist air and prevent lateral spread of clouds → increases vertical cloud build-up.
- Monsoon Dynamics: Strong monsoonal winds carry abundant moisture from the Bay of Bengal and Arabian Sea → leads to saturated air masses.
- Convective Instability: High surface temperatures during summer create strong upward convection currents, a key trigger for cloudbursts.
- Localized Weather Systems: Himalayas often develop localized low-pressure systems, triggering micro-scale rainfall events.
- Climate Change Link (Emerging Factor): Increasing surface temperatures and erratic monsoon behavior may be making cloudbursts more frequent and intense in recent years.

Example: Uttarakhand (2021) – Cloudburst-triggered floods and landslides

Student Notes:
Atmospheric River
They are long, narrow bands of water vapor in the sky, transporting moisture from the tropics to mid and high latitudes.
These rivers form over warm ocean waters, where evaporation creates high moisture levels.

- Pineapple Express: A well-known atmospheric river that originates near Hawaii and affects the West Coast of North America, bringing heavy precipitation and sometimes causing flooding.
- Recent studies have shown that 70% of India's major flood events between 1985 and 2020 were linked to atmospheric rivers, especially during the summer monsoon. Events like the 2013 Uttarakhand floods and the 2018 Kerala floods were caused by intense AR activity.

2.6. Air Mass

An air mass is a large area of air that has the same temperature and moisture levels throughout. It usually covers a wide region and comes from a specific place known as the source region. Air masses are grouped based on how warm or cold they are and how much moisture they contain.

- Temperature Classification:
  - Polar (P) Air Masses: These are cold air masses.
  - Tropical (T) Air Masses: These are warm air masses.
- Moisture Classification:
  - Maritime (m) Air Masses: These are humid air masses, usually formed over oceans.
  - Continental (c) Air Masses: These are dry air masses, typically formed over land.

Student Notes:
The formation of Air Mass involves several key steps:

- Source Regions: Air masses form over specific areas called source regions. These regions are typically flat and have consistent conditions, like oceans or large plains.
- Stagnation: The air remains stationary over the source region, allowing it to gradually absorb the temperature and moisture characteristics of the surface.
- Characteristics: Once formed, an air mass can be warm or cold, and moist or dry, depending on its source region. For example, air masses over oceans are usually moist, while those over

land are drier.
After formation the air masses can move with the wind, affecting weather patterns in other regions by bringing their specific characteristics with them.
Air Mass Modification
Air mass modification refers to the change in characteristics of an air mass—such as temperature, humidity, and stability—as it moves from its source region to a new region.
How Does Modification Occur?
As an air mass travels, it interacts with new surface conditions (land or water), which alters its original properties:
- Over warmer surfaces → it warms up, may become unstable
- Over colder surfaces → it cools down, may become stable
- Over oceans → it gains moisture
- Over land → it may lose moisture

Air mass modification influences: Local weather patterns, Precipitation and cloud formation, Storm development (especially along fronts).
Examples:
- A continental polar (cP) air mass moving over the ocean becomes warmer and more humid.
- A maritime tropical (mT) air mass moving inland over a cold landmass becomes cooler and drier.

Student Notes:
2.6.1. Fronts
Fronts represent the boundaries between air masses of differing temperatures, acting as zones of transition between these distinct air masses.
2.6.1.1. Types of Fronts
1. Cold Front:
A cold front occurs when a cold air mass moves into a region occupied by a warmer air mass. These fronts tend to move quickly, often at double the speed of warm fronts, resulting in dramatic weather shifts.
- As the denser, cooler air pushes the warmer, lighter air upward into the troposphere, it leads to the development of cumulus or cumulonimbus clouds and can trigger thunderstorms.

Impact on Weather:
- Sudden and significant temperature drop
- Formation of cumulus and cumulonimbus clouds
- Heavy rainfall, often accompanied by thunderstorms, hail, and lightning
- Gusty winds

- Atmospheric pressure transition from falling to rising
- Cooler temperatures following the passage

2. Warm Front:

A warm front is formed when a warm air mass advances into an area of cooler air. These fronts move more slowly than cold fronts due to the difficulty of displacing the denser cold air. As the warm air rises over the cooler air, it results in cloud formation and stormy weather.

Impact on Weather:

- Gradual temperature increase
- Formation of high clouds like cirrus and cirrostratus, followed by lower clouds like altostratus
- Steady and widespread rain or drizzle
- Increased humidity levels
- Winds typically change direction and become gentler

Student Notes:

3. Stationary Front:

A stationary front occurs when a cold or warm front stops moving because neither air mass is strong enough to replace the other. This standstill can last for several days, with winds blowing parallel to the front, helping to maintain its position.

Impact on Weather:

- Persistent cloudiness blocking sunlight and causing overcast conditions.
- Significant temperature differences on either side of the front
- Winds blow parallel to the front, keeping it stationary
- Often associated with low-pressure systems, leading to unsettled weather

4. Occluded Front:

An occluded front forms when a cold front overtakes a warm front. As the faster-moving cold front catches up with the warm front, the cold air mass meets the cooler air mass ahead of the warm front, causing the warm air to rise.

Impact on Weather:

- Precipitation from cumulonimbus or nimbostratus clouds
- Temperature changes, either warming or cooling
- Post-front conditions often include clearer skies and drier air

2.7. Cyclones

A cyclone is a large rotating air mass around a low-pressure center, with inward spiraling winds. It brings severe weather, with counterclockwise winds in the Northern Hemisphere and clockwise winds in the Southern Hemisphere.

How are cyclones named and what are the guidelines on adopting their names?

- In 2000, a group of nations called WMO/ESCAP (World Meteorological Organisation/United Nations Economic and Social Commission for Asia and the Pacific), which comprised Bangladesh, India, the Maldives, Myanmar, Oman, Pakistan, Sri Lanka and Thailand, decided to start naming cyclones in the region.
- After each country sent in suggestions, the WMO/ESCAP Panel on Tropical Cyclones (PTC) finalized the list.

Why is it important to name cyclones?

- Adopting names for cyclones makes it easier for people to remember
- With a name, it is also easy to identify individual cyclones, create awareness of its development, rapidly disseminate warnings to increase community preparedness and remove confusion where there are multiple cyclonic systems over a region.

Student Notes:

Based on location, cyclones are classified in two major types:

- Tropical cyclones
- Temperate Cyclones

2.7.1. Tropical Cyclones vs Temperate Cyclones

	Tropical Cyclones	Temperate Cyclones
Location and Formation	Form between the Tropic of Capricorn and Tropic of Cancer over	

warm oceans.
Develop
due
to
warm
sea
temperatures, Coriolis force, and a
pre-existing low-pressure area.
Occur
between
35°
and
65°
latitude, especially in winter.
Form from the convergence of polar
and tropical air masses, explained
by the Polar Front theory.
Size, Front and
Duration
Smaller: about 150–300 km in
diameter, No fronts involved and
Short-lived: usually a few days
Larger: about 1000–2000 km in
diameter, Involves both warm and
cold frontsan Longer duration: 5 to
7 days or more
Structure and
Characteristics
Mature cyclones have a warm
center called the 'Eye.'
Around the Eye, there are bands of
clouds.
These cyclones are known for
strong winds, heavy rain, and high
sea waves.
Consist of various fronts from
colliding air masses.
Less intense than tropical cyclones,
lacking a warm 'Eye.'
Intensity and
Impact
More intense, causing significant
destruction through violent winds,
heavy rainfall, and storm surges.
Weaken after landfall or over cooler
waters.
Less intense, usually causing milder
weather with rain and moderate
winds.
The impact is more consistent and
generally less severe than tropical
cyclones.
Movement
Patterns
Move from east to west, influenced
by trade winds and Coriolis effect.
Curve northward in the Northern

Hemisphere, southward in the Southern Hemisphere. Slower, with possible direction changes.
Move predominantly from west to east, driven by westerlies. Movement is consistent and faster, guided by the jet stream.
Example
Cyclone Tauktae, Cyclone Yaas
Cyclones in North Atlantic

In essence, both tropical and temperate cyclones are powerful rotating weather systems driven by low pressure, characterized by strong winds, and influenced by the Earth's rotation. While their formation mechanisms and structure differ, their ability to generate destructive winds is a common trait.

Changing Nature of Tropical Cyclones in the Indian Ocean

Tropical cyclones in the Indian Ocean are becoming more intense, longer-lasting, and increasingly frequent in the Arabian Sea, driven by rising sea surface temperatures and climate change. While the Bay of Bengal remains cyclone-prone, the Arabian Sea is witnessing a sharp surge in severe cyclones

Causes Behind the Change

Cause	Explanation
Warming Sea Surface Temperatures	Rising SST (>28°C) provides more energy, especially in the Arabian Sea.
Climate Change	Global warming has increased cyclone intensity and unpredictability.
Reduced Vertical Wind Shear	Especially in pre- and post-monsoon periods in Arabian Sea, aiding cyclone formation.
Indian Ocean Dipole (IOD)	Positive IOD years enhance cyclone activity in the Arabian Sea.
Madden-Julian Oscillation (MJO)	Influences intraseasonal cyclone frequency and movement.

Arabian Sea vs Bay of Bengal

Parameter	Bay of Bengal	Arabian Sea
Traditional Activity	~80% of Indian cyclones occur here	Historically less active (~20%)
Recent Trends	No. remains high but intensity more variable	Sharp rise in frequency & intensity since 1990s
Reasons		

Warm waters, funnel shape,
riverine inflow
Rapid warming, lower wind shear,
less aerosols
Examples
Cyclone Amphan (2020), Mocha
(2023)
Cyclone Tauktae (2021), Biparjoy
(2023)
Seasonality
Mainly pre- and post-monsoon
Increasing post-monsoon activity
Direction Shift
Sometimes recurves toward
Bangladesh
More westward tracks toward
Gujarat & Oman

Student Notes:

Recent unique cyclonic phenomenon in Indian ocean

The Indian Ocean has witnessed several unique cyclonic phenomena in recent years, each characterized by distinct patterns and developments:

1. Cyclone Asna (August 2024)
   - It marked a rare late-monsoon event in the Arabian Sea, fueled by SSTs of 29–30°C and low wind shear, impacting Oman and Gujarat
2. Twin Cyclones Asani and Karim (May 2022):
   - In May 2022, twin cyclones, Asani in the Northern Hemisphere and Karim in the Southern Hemisphere, developed simultaneously. This rare occurrence was fueled by the Madden-Julian Oscillation (MJO), which promoted convection and strong westerly winds, aiding the formation of these storms on either side of the equator.
3. Cyclone Gulab's Transition (September 2021):
   - Cyclone Gulab originated in the Bay of Bengal and later shifted to the Arabian Sea under the influence of trade winds. This unusual cross-basin movement highlighted the complex interactions between regional wind patterns and cyclone trajectories.
4. Super Cyclonic Storm Amphan (May 2020):
   - Amphan, a super cyclonic storm in the Bay of Bengal, was one of the most intense storms in recent history. Its rapid intensification and devastating impact underscored the increasing severity of cyclones in the region.
5. Cyclone Fani's Long Life Span (May 2019):
   - Cyclone Fani had an unusually long lifespan, lasting more than 10 days. It developed close to the equator, making it a unique example of a long-lived and powerful cyclone in the region.

Fujiwhara Effect

The Fujiwhara Effect occurs when two cyclones, such as hurricanes or typhoons, move in the same direction and interact closely. This causes the cyclones to rotate around a common center, leading to different possible outcomes depending on their relative strengths.

Outcomes of the Fujiwhara Effect:

- Weaker Cyclone Absorption: If one cyclone is weaker, it may get absorbed into the stronger one, losing its identity.
- Cyclones of Similar Strength: Cyclones of similar strength may rotate around each other, potentially merging into a larger system or separating.
- Intense Cyclone Merging: In rare cases, two strong cyclones may merge, forming a "mega cyclone" with increased destructive power.

In March 2023, the Fujiwhara Effect was observed in the Bay Area and Southern California, leading to strong winds and damage.

What is a colour-coded weather warning?

India Meteorological Department (IMD) issues color-coded weather warnings for cyclone-prone areas in India to alert people about the potential danger from cyclones.

Student Notes:

These color codes represent the intensity of the cyclone and the likely impact on people and property in the affected areas.

Color-coded warnings issued by the IMD for cyclones:

What is a bomb cyclone?

A bomb cyclone is a rapidly intensifying storm that occurs when a mid-latitude cyclone's atmospheric pressure drops significantly within 24 hours, leading to powerful winds and severe weather. Bomb cyclones are most common in winter and can cause severe weather conditions, especially in coastal regions.

Bomb cyclones in North America, especially in the northeastern U.S. and coastal areas, bring powerful winds, heavy snowfall, and intense cold, often causing blizzards. They lead to major disruptions, including power outages, halted transportation, and coastal flooding from storm surges.

Student Notes:
Twisters - Tornadoes
A twister, commonly known as a tornado, is a violently rotating column of air that extends from a thunderstorm to the ground. It is one of nature's most intense weather phenomena, known for its destructive winds and localized damage.
Formation of Tornadoes
Tornadoes form under specific atmospheric conditions, particularly within supercell thunderstorms, which are thunderstorms with a rotating updraft called a mesocyclone.
Key Conditions for Tornado Formation:

- Abundant moisture in the lower atmosphere
- Atmospheric instability, which allows air to rise rapidly
- Wind shear (changes in wind speed and direction with height), which initiates rotation
- Lift provided by fronts or dry lines, triggering thunderstorm development

As the storm matures, a funnel cloud may form when the rotation intensifies and stretches downward. If it touches the ground, it becomes a tornado.
Tornado Characteristics

- Wind Speed: Ranges from 105 km/h to over 480 km/h
- Size: Typically 200–500 meters wide, but can exceed 1 km
- Path Length: May travel several kilometers, though most last only a few minutes

Student Notes:

- Eye: Unlike tropical cyclones, tornadoes do not have a defined 'eye', but the center has very low pressure
- Duration: Most tornadoes last a few minutes; some can persist over an hour

Why Twisters Are Common Around the Gulf of Mexico?
The region near the Gulf of Mexico, particularly the central United States (also known as Tornado Alley), sees a high frequency of tornadoes due to a unique combination of climatic and geographic factors:

- Warm, Moist Air from the Gulf: Acts as the fuel for thunderstorm development.
- Cold, Dry Air from the Rockies or Canada: Collides with warm air to create strong atmospheric instability.
- Wind Shear: Supports rotating updrafts, critical for tornado formation.
- Jet Stream Dips: Enhance wind shear and help organize storms.
- Flat Terrain: The Great Plains allow mixing of air masses, increasing storm severity.

2.7.2. Anticyclones
An anticyclone is a large-scale system of high atmospheric pressure in which air descends and diverges outward from the center. This is opposite to a cyclone (low-pressure system), where air converges and rises.
Characteristics of Anticyclones:

Feature	Description
Pressure	High-pressure system (center has the highest pressure)
Air Motion (Northern Hemisphere)	Air moves clockwise and outward due to the Coriolis force
Air Motion (Southern Hemisphere)	Air moves anticlockwise and outward
Vertical Movement	Subsidence (sinking air) that warms adiabatically
Weather	Generally clear skies, calm winds, and dry weather
Associated Fronts	Usually no fronts; stable air mass dominates

Anticyclones form when:

- Air cools and sinks, increasing surface pressure.
- Cooling may happen due to radiative heat loss from the Earth's surface (e.g., over land during winters).
- Subtropical high-pressure zones are major global anticyclonic belts (e.g., Horse Latitudes at ~30°N/S).

Impacts of Anti-cyclones

Positive Impacts:

- Stable weather ideal for outdoor activities and agriculture during harvest season.
- Associated with clear skies, allowing for solar heating.

Negative Impacts:

- Can cause drought due to prolonged absence of rain (e.g., in Indian monsoon break period).
- Air pollution and smog build-up in urban areas due to stagnant air (e.g., Delhi winter smog).

Student Notes:

- Can block cyclones or storms, leading to floods or heatwaves in other areas (e.g., European blocking highs).

Global Examples:

- Siberian High (Winter anticyclone)
- Azores High / Bermuda High (Subtropical warm-core anticyclone over Atlantic)

2.8. Indian Monsoons

Monsoons are seasonal winds which reverse their direction with the change of season. The monsoon is a double system of seasonal winds – They flow from sea to land during the summer and from land to sea during winter. India receives south-west monsoon winds in summer and north-east monsoon winds in winter.

Factors Affecting Indian Monsoon

Factor	Impact on Monsoon
Differential Heating of	

Land and Sea
Creates a low-pressure zone over land and high-pressure over the ocean. This pressure gradient drives moist winds from the Indian Ocean toward the subcontinent. Stronger heating usually strengthens monsoon winds.
Tibetan Plateau
Heating
Acts as an elevated heat source, intensifying upper-tropospheric circulation. This strengthens the monsoon trough and favors earlier and stronger onset of the monsoon.
El Niño (ENSO)
Warms central Pacific Ocean and shifts atmospheric circulation patterns. Weakens the monsoon flow, leading to deficient rainfall and droughts in India (e.g., 2015, 2002).
La Niña (ENSO)
Cools the Pacific Ocean and strengthens trade winds. Generally results in stronger monsoon winds and above-normal rainfall in India (e.g., 2022).

Indian Ocean Dipole
(IOD)
A positive IOD (warm west Indian Ocean) enhances cross-equatorial flow, boosting monsoon rains. A negative IOD can suppress rainfall, especially in southern India.
Madden-Julian
Oscillation (MJO)
A moving pulse of convection that brings temporary enhancement or suppression of rainfall. If MJO is over the Indian Ocean, it can intensify low-pressure systems and increase rainfall.
Bay of Bengal/Arabian
Sea SSTs
Warm waters increase evaporation and fuel monsoon depressions. Especially critical for low-pressure formation over Bay of Bengal, driving rainfall in eastern and central India.
Jet Streams (STWJ &
TEJ)
A shift in the Subtropical Westerly Jet northward is a sign of monsoon onset. Tropical Easterly Jet strengthens upper-level divergence, favoring rainfall.
Arctic Amplification
Rapid warming in the Arctic disrupts mid-latitude and subtropical circulation. This can shift the monsoon trough or delay the onset, leading to erratic rainfall patterns.
Atlantic Meridional
Overturning
Circulation (AMOC)
Weakening of AMOC alters heat distribution and global circulation. Long-term weakening can reduce the monsoon's strength by disrupting the Walker and Hadley cells.
The Indian monsoon is influenced by a complex interplay of global, regional, and local factors, each with varying degrees of influence on onset, distribution, and intensity. These factors are not only variable in space and time, but also interact in non-linear ways, making prediction and management challenging.

For example, in 2023, despite the development of an El Niño, monsoon rainfall remained close to normal in many regions due to favorable intra-seasonal oscillations like the Madden-Julian Oscillation (MJO) and localized SST anomalies.

Variability in Indian Monsoon

The Indian monsoon is influenced by multiple complex weather systems, such as the El Niño effect, the Indian Ocean Dipole etc, leading to its unpredictable nature.

Features of Monsoon Variability

- Burst of Monsoon: The monsoon's sudden heavy rainfall marks its arrival, driven by the intensifying Somali Jet and moisture from the Arabian Sea. It usually begins around June 1 in Kerala, though it can vary.
  - A 2018 study linked burst strength to the Madden-Julian Oscillation (MJO), with the strong MJO phase in 2020 causing intense rainfall (200 mm in 48 hours) in Kerala.
- Delay in Onset: The normal onset is June 1 in Kerala, but delays of 7–15 days can happen.
  - For example, in 2019, the onset was delayed to June 8 due to a weak monsoon vortex and El Niño influence.
- Breaks in Monsoon: The monsoon experiences periods of reduced rainfall, lasting 3–15 days, often due to the shifting monsoon trough.
  - These breaks are frequent in northwest India; in 2021, a 12-day break in Rajasthan led to drought-like conditions, while the Western Ghats stayed wet.

Student Notes:

- Early Withdrawal: The monsoon generally withdraws by late September. Early retreats, like in mid-September 2015 due to El Niño, reduce rainfall totals, with 2015 seeing a 14% drop.
  - In Tamil Nadu, early withdrawal in December 2019 resulted in 20% below-average rainfall, affecting groundwater recharge. A study connected early withdrawal to warming in the northwest Indian Ocean.
- Rainfall Intensity: Short, intense rainfall events are increasing.
  - IMD data (1901–2020) shows a 50% rise in extreme rainfall events (>100 mm/day) in central India, linked to a 0.6°C increase in sea surface temperatures in the Arabian Sea since 1980.

2.8.1. ENSO (El Niño–Southern Oscillation)

ENSO is a coupled ocean-atmosphere phenomenon in the tropical Pacific Ocean that leads to global climatic changes, especially affecting tropical regions like India.

It includes two opposite phases:

- El Niño (warm phase)
- La Niña (cold phase)

It also involves changes in atmospheric pressure known as the Southern Oscillation.

El Niño – El Niño is the abnormal warming of sea surface temperatures (SSTs) in the central and eastern Pacific Ocean near the equator.

Key Features:

-

Occurs every 2–7 years
La Niña : La Niña is the abnormal cooling of SSTs in the equatorial central and eastern Pacific.
Key Features:

- Strengthening of trade winds

Student Notes:

- Weakening or reversal of trade winds
- Warm water moves eastward from Indonesia to Peru
- Associated with suppressed convection (cloud formation) in western Pacific
- Leads to shifts in jet streams, weather anomalies, and droughts/floods globally
- Enhanced upwelling of cold water off South America
- Stronger convection in the western Pacific, including near India
- Typically follows an El Niño event

Southern Oscillation: A seesaw pattern of atmospheric pressure between Tahiti (eastern Pacific) and Darwin, Australia (western Pacific).

- Measured by the Southern Oscillation Index (SOI)
  - Positive SOI → La Niña-like conditions
  - Negative SOI → El Niño-like conditions

Together with ocean temperature changes, this forms the ENSO cycle.
Impact of El Niño

- Weather Patterns:
  - Global Temperature Anomalies: El Niño typically leads to warmer global temperatures, as it disrupts normal weather patterns. This can result in increased temperatures across various regions, contributing to global warming trends.
  - Altered Precipitation: El Niño often causes heavy rainfall and flooding in some areas, particularly in the eastern Pacific and parts of South America, while inducing droughts in other regions, such as Southeast Asia, Australia, and parts of Africa.
- Ecosystems and Biodiversity:
  - Coral Bleaching: The warming of ocean waters during El Niño events often leads to coral bleaching, threatening coral reefs and the diverse marine life they support.
  -

Forest Fires: The drier conditions in some regions can increase the frequency and intensity of forest fires, leading to loss of biodiversity and habitat destruction.

- Economic and Social Impacts:
  - Global Economic Disruptions: The agricultural and environmental impacts of El Niño can lead to significant economic losses, particularly in sectors like agriculture, fisheries, and insurance. Fluctuations in food production and commodity prices can destabilize economies, especially in developing countries.
  - Public Health: Changes in temperature and precipitation patterns can exacerbate the spread of diseases such as malaria, dengue, and cholera, particularly in regions already vulnerable to such diseases.

2.8.2. Indian Ocean Dipole (IOD) and Its Impact

The Indian Ocean Dipole (IOD) is a significant climate phenomenon in the equatorial Indian Ocean, similar to the El Niño-Southern Oscillation (ENSO) in the Pacific Ocean.

- It is defined by the variation in sea surface temperatures between two regions: the western Indian Ocean, particularly in the Arabian Sea, and the eastern Indian Ocean, south of Indonesia. These regions, or "poles," show opposite temperature patterns during IOD events.

Phases of IOD

- Positive IOD Phase:
  - Characterized by warmer sea surface temperatures in the western Indian Ocean compared to the east.
  - Results in easterly wind anomalies across the Indian Ocean and reduced cloudiness to the northwest of Australia.

Student Notes:

  - Leads to less rainfall over southern Australia , potentially causing droughts and bushfires, as seen during the 2020 Australian bushfires.
  - In the Indian subcontinent, a Positive IOD can intensify the monsoon, bringing above-normal rainfall. For example, the simultaneous occurrence of Positive IOD and El Niño in 2019 led to above-normal monsoon rainfall in India.

- Negative IOD Phase:
  - Marked by cooler sea surface temperatures in the western Indian Ocean relative to the east.
  - Westerly winds bring increased cloudiness to Australia's northwest, resulting in more rainfall in southern Australia and the Top End.
  - When coupled with El Niño, a Negative IOD can exacerbate the negative impacts on the Indian monsoon, leading to deficient rainfall, as observed in 1992.

Overall, the IOD is a critical factor in understanding regional climate variability, particularly in terms of its influence on monsoon patterns in the Indian subcontinent. Its interactions with other climate phenomena, such as El Niño, play a significant role in shaping weather patterns across the Indian Ocean and surrounding regions.

How climate change is altering the Indian monsoons?

Climate change has increased the fluctuations in the Indian monsoons- increase in the intense short spells and long dry spells. Following are the impacts of climate change on the Indian monsoons-

- Altered Intensity and Distribution of Rainfall
  - Climate change has led to changes in the intensity and spatial distribution of monsoon rainfall across India.
  - Some regions are experiencing more intense and erratic rainfall, while others are facing reduced precipitation.
- Increase in Extreme Weather Events
  - There has been an observed increase in the frequency and intensity of extreme weather events, such as heavy rainfall and intense cyclones, during the monsoon season.
- Warming of the Indian Ocean
  - The Indian Ocean has been warming, which is influencing the temperature gradient between the land and the ocean. This temperature difference is crucial for the onset and sustenance of the monsoon, and any changes can affect its behaviour.
- Delayed Onset and Extended Withdrawal
  - Climate change contributes to a delay in the onset of the monsoon, affecting the timing of sowing and agricultural activities.
  - Changes in the withdrawal of the monsoon may lead to prolonged rainy seasons or delayed transitions to the dry season, impacting crop cycles.

While these shifts in the Indian monsoon are influenced by climate change, it is important to recognize that the increasing incidences of climate change are largely driven by human activities. These anthropogenic interventions are not only fueling climate change but are also directly contributing to alterations in the monsoon patterns across India.

Frequent thunderstorms in Northern India in 2025

Northern India in 2025 has witnessed an unusually high frequency of thunderstorms, especially during the pre-monsoon season. This spike is the result of a complex interaction between meteorological disturbances, climate change, and local geographic factors.

Increased Frequency and Intensity of Western Disturbances

- In 2025, the India Meteorological Department (IMD) recorded an exceptional number of seven active western disturbances in May alone.
- These Mediterranean-origin low-pressure systems traversed northern and central India, enhancing atmospheric instability and triggering widespread pre-monsoon thunderstorms.

Persistent Moisture Influx from Surrounding Seas

- Warm winds carrying moisture from the Arabian Sea and Bay of Bengal have interacted with incoming western disturbances.
- This created high latent heat release in the atmosphere—an essential condition for thundercloud formation and frequent lightning.

Role of Climate Change and Global Warming

- Warming oceans have led to increased evaporation and atmospheric humidity.
- According to recent studies, rainfall events are becoming shorter but more intense, often resulting in violent convective thunderstorms.
- Global warming has also caused erratic weather patterns, fueling storm variability.

Local and Topographical Influences

- In foothill and orographic regions, rising air due to terrain features supports cloud development and localized thunderstorms.

Melting of Cryosphere - a manifestation of climate change

The melting of the cryosphere—comprising glaciers, ice sheets, sea ice, and permafrost—is one of the most visible and alarming manifestations of climate change.

Consequences of Cryospheric Decline

- Sea Level Rise: Melting glaciers and ice sheets contribute to rising sea levels. The mean rise was 1.6–1.8 mm/year in the 20th century, but recent rates are higher.
- Ocean Circulation Disruption: Freshwater from melting ice disrupts ocean circulation patterns. The Atlantic Meridional Overturning Circulation (AMOC) has slowed by 30% from 1994 to 2017, with global climate implications.
- Glacial Lake Outburst Floods (GLOFs): Over 5,000 glacial lakes have formed in the Himalayas, with 200 identified as potentially dangerous in Uttarakhand, Himachal Pradesh, Sikkim, and Jammu and Kashmir. These pose significant risks to downstream communities and infrastructure.

Glacial lake Outburst Flood (GLOF)
Sudden release of water from a lake formed at the side, in front of, within, beneath, or on the surface of a glacier, due to glacier melt.

Student Notes:

- Recently, GLOF from Lhonak Lake caused massive flooding and destruction in North Sikkim (2023).

Mitigation and Management Strategies:

- Government Measures: NDMA prepared national guidelines on GLOF management → Implementation of land-use regulations in GLOF-prone areas.
- Early Warning Systems (EWS): Installation of sensors and seismic monitors for real-time data collection. → Sikkim's early warning system at South Lhonak Lake.
- Technical Measures: Construction of controlled drainage channels, tunnels, and spillways to reduce lake volumes → Artificial lowering of lake levels in high-risk areas.

Student Notes:

3. OCEANOGRAPHY

Previous year questions (PYQs)

- Critically evaluate the various ocean resources that can be harnessed to address the world's resource crisis. (2014)
- What factors cause ocean currents? How do they influence regional climates, fishing, and navigation? (2015)
- Explain the variations in ocean salinity and discuss its multifaceted effects.(2017)
- What are the consequences of spreading of 'Dead Zones' on marine ecosystem?(2018)
- How do ocean currents and water masses differ in their impacts on marine life and coastal environments? Provide relevant examples. (2019)
- Mention the significance of straits and isthmus in international trade. (2022)
- What forces influence ocean currents? Describe their role in the global fishing industry. (2022)

PYQs Analysis

The questions in Oceanography reflect broad concepts intertwined with global issues. Whether it's ocean currents or marine pollution, questions reflect the move beyond static knowledge.

For example:

- Ocean Circulation & Marine Influence: Core ideas like forces influencing ocean currents (2015, 2022), water masses (2019), and variations in salinity (2017) show physical processes with regional impacts on climate, fisheries, and maritime navigation.
- Environmental Concerns & Ecosystem Health: Questions on Dead Zones (2018) or marine resource utilization (2014) reflect growing concerns about oceanic resource and stress.

3.1. Ocean Relief Features

Oceans are large saltwater bodies covering over 70% of Earth, crucial for climate regulation and marine life. It is divided into five principal oceans viz. the Pacific, Atlantic, Indian, Southern, and Arctic Oceans.

Strong forces have shaped the ocean floor, which has terrain like mountains, plains, and trenches that mirror the Earth's surface above.

Major Ocean Relief Features	Description
Continental Shelf	• The continental shelf is a gently sloping extension of a continental plate that stretches into the sea. • These shelves are typically 70 to 80 kilometers wide, though they can vary, like the wide Siberian shelf (up to 1,500 kilometers) and the narrower eastern USA shelf (up to 120 kilometers). • Continental shelves form due to factors like submerged continent parts, sea-level rise, sediment deposits, and wave erosion. • Significance of Continental Shelves. ■ u

Student Notes:

Major Ocean Relief Features	Description
Continental Slope	• The continental slope is the area that connects the continental shelf to the ocean basins. • The depth of the slope is between 200 and 3,000 meters. Features like canyons and trenches are found here.
Continental Rise	•

When the slope reaches a level of between 0.5° and 1°, it is referred to as the continental rise.

- With increasing depth the rise becomes virtually flat and merges with the abyssal plain.

Deep Ocean Plains
(Abyssal Plain)

- These are the flattest and smoothest regions of the world because of terrigenous and shallow water sediments that buries the irregular topography.
- The depths vary between 3,000 and 6,000 m.
- These plains are covered with fine-grained sediments like clay and silt.

Oceanic Ridges

- A mid-oceanic ridge is composed of two chains of mountains separated by a large depression. [Divergent Boundary]
- These oceanic ridge systems are of tectonic origin and provide evidence in support of the theory of Plate Tectonics.
- Iceland, a part of the mid-Atlantic Ridge, is an example.

Hydrothermal Vents

Hydrothermal vents are fissures on the ocean floor near mid-ocean ridges through which geothermally heated water is expelled into the cold deep ocean.

Formation:

- Seawater seeps into cracks in the oceanic crust.
- It is heated by underlying magma, reacts with minerals, and becomes rich in dissolved metals and sulfides.
- The superheated fluid then rises back through the crust and erupts at the sea floor, forming vents.

Ecological, Scientific & Economic Importance:

- Support unique chemosynthetic ecosystems, independent of sunlight. Bacteria and archaea use hydrogen sulfide to produce energy (chemosynthesis).
- Provide insights into origin of life theories (life in extreme environments).
- Rich in polymetallic sulfides – potential source for deep-sea mining (e.g., copper, zinc, gold)

Following ocean relief features, it’s essential to understand related surface features like isthmuses, straits, bays, and gulfs, which influence navigation and coastal processes.

Difference between Isthmus and Strait
Feature
Isthmus
Strait
Definition A narrow strip of land connecting
two larger land areas and separating
two bodies of water.
A narrow body of water connecting two
larger bodies of water and separating
two land masses.
Importan
ce/Signifi
cance
•
Strategic military and economic
routes (e.g., Panama Canal)
•
Facilitates land-based
transportation and trade
between continents
•
Influences ocean circulation,
which in turn affects weather
patterns on both sides.
•
Development of ports and harbours,
maritime routes for global shipping
and trade (e.g., Suez Canal)
•
Strategic military chokepoints, e.g.,
Straits of Malacca.
•
Biodiversity hotspots due to mixing
of different marine environments.
e.g., the Coral Triangle in Southeast
Asia, where Indian Ocean and
Pacific meet.
Difference between Bay and Gulf
Feature
Bay
Gulf

Definition
A bay is a large body of water partially
enclosed by land but with a wide
mouth, providing access to the sea.
Example- Bay of Bengal
A gulf is a large body of sea or

ocean, partially enclosed by land,
typically with a narrower opening
compared to a bay. Example-
Persian Gulf
Formation
Bays are formed due to the erosion of
coastlines and the subsidence of land.
Formed by tectonic activity, such as
the movement of plates, which
creates larger indentations in the
land.
Significanc
e
Bays often serve as excellent harbours
and fishing grounds, providing safe
anchorage and shelter from storms.
Gulfs are significant for
international shipping routes, rich
marine biodiversity, and oil
reserves.
3.1.1. Ocean Floor Mapping
Ocean floor mapping, known as bathymetry, is essential for understanding the topography,
geological features, and ecosystems of
Earth's oceans. Remotely operated vehicles
(ROVs)
and
autonomous
underwater
vehicles (AUVs) equipped with sonar and
cameras are used for detailed mapping.

- It identifies underwater features like ridges, trenches, and seamounts, providing insights into tectonic activity and natural resource formation.
- Mapping helps locate fishing zones, identify mineral deposits, and assess the environmental impact of human activities like oil exploration and deep-sea mining.

International Projects:

- The General Bathymetric Chart of the Oceans (GEBCO) provides global bathymetric data.
- Seabed 2030 aims to map the entire

ocean floor by 2030.

- Many countries have national programs for ocean floor mapping.

India's Samudrayaan: Initiated in 2021, this deep ocean mission aims to explore the ocean bed at 6,000 meters depth in the central Indian Ocean. The mission uses the Matsya6000 submersible to study the deep ocean environment, focusing on resource exploration and marine research.

Indian Ocean Basin

Student Notes:

3.2. Properties of Ocean Water

Ocean water has unique physical characteristics that affect weather, marine life, and climate systems. The three main properties are temperature, salinity, and density. These are closely connected and influence ocean behavior on a global scale.

3.2.1. Temperature

Ocean surface temperatures can range from about -2°C in Polar Regions to over 30°C in equatorial regions. The distribution of ocean temperature is influenced by several factors that include both natural processes and geographic features.

Vertical variation in oceanic temperature

The vertical distribution of temperature in the deep ocean is influenced by density-driven water movements.

- The maximum temperature of oceans is found at the surface due to direct solar energy.
- Heat conduction alone transfers only a small proportion of heat downward; convection plays a crucial role in transmitting heat to lower sections of the oceans.

1. Surface Layer (Mixed Layer):
   - Depth: Extends from the ocean surface to about 200 meters.
   - Temperature: Warmer due to sunlight and mixing by wind and waves.
   - Variation: Changes with seasons as it interacts with the atmosphere.
2. Thermocline:
   - Depth: From about 200 meters to 1,000 meters.
   - Temperature: Rapid decrease with depth, less pronounced in polar regions.
   - Stability: Acts as a barrier to mixing, separating warm surface water from cold deep

water.
Variation of Temperature with depth at various
latitudes

3. Deep Ocean:

- Depth: Below 1,000 meters to the ocean floor.
- Temperature: Cold and uniform, typically between 0°C and 3°C.
- Stability: Very stable with little temperature change over time.

Horizontal Distribution of Ocean Temperatures

- Ocean temperatures are warmest near the equator, ranging from 26°C to 28°C, and decrease by about 0.5°C per degree of latitude as you move toward the poles, where temperatures approach freezing.
- Ocean regions in the Northern Hemisphere are slightly warmer due to greater landmass, which heats and cools faster, while the Southern Hemisphere has more stable and cooler temperatures due to larger ocean expanses.
- Regional variations occur as warm currents like the Gulf Stream and cold currents like the California Current create temperature differences.

3.2.2 Salinity

Ocean salinity measures the amount of dissolved salts in seawater, expressed in parts per thousand (ppt). For example, a salinity of 35 ppt means there are 35 parts of salt in every 1,000 parts of water. Water with salinity above 24.7 ppt is considered brackish.
Isohalines are lines on maps connecting locations with equal salinity, helping visualize salinity distribution.

Factors determining ocean salinity

- Freshwater Influx: The inflow of freshwater from rivers and melting glaciers dilutes ocean salinity. For example, Polar Regions have lower salinity compared to equatorial regions due to less evaporation and the mixing of fresh water from ice melt.
- Evaporation: Arid regions and subtropical high-pressure zones, such as the Mediterranean Sea, experience higher evaporation rates, which increases salinity.
- Ocean Currents: Ocean currents redistribute water with varying salinity levels. The Gulf Stream, for instance, elevates salinity along the western margins of the North Atlantic Ocean.
- Temperature: Salinity, temperature, and water density are interconnected. High temperatures generally correlate with high salinity regions. For example, tropical areas typically have higher salinity due to increased evaporation rates.

Understanding these factors is crucial as they play a significant role in ocean circulation, marine ecosystems, and global climate patterns.

Principle of Constant Proportion in Ocean Salinity

The Principle of Constant Proportion, also known as Forchhammer’s Principle, states that while the total salinity of seawater may vary from place to place, the relative proportion of major dissolved salts remains nearly constant throughout the ocean.

In simpler terms, even if one sample of seawater has 34 parts per thousand (ppt) of salt and another has 36 ppt, the ratios of the key ions (like chloride, sodium, sulfate, magnesium, etc.) stay nearly the same in both.

Why Is This Important?

- This principle allows scientists to measure only one major salt ion (typically chloride) and then calculate the total salinity from it.
- The ratio of chloride to total salinity is usually around 55%.

The total salinity can vary due to evaporation, precipitation, river inflow, or ice melting, but the salt composition (ratios) remains remarkably uniform globally in the open ocean.

Exceptions can occur in semi-enclosed or isolated seas (e.g., the Baltic Sea or Dead Sea), where salinity is influenced by restricted mixing.

Applications:

- Used to determine salinity by measuring only chloride concentration (via titration or instruments).
- Helps in studying water masses and tracking ocean currents.

Horizontal Distribution of Ocean Salinity:

- Tropical Regions: Near the equator and in tropical regions, the ocean tends to be more saline due to high evaporation rates, leaving the salts behind and increasing the salinity.

Student Notes:

- Subtropical High-Pressure Belts are characterized by sinking air, clear skies & low precipitation leading to high salinity levels.
- Sub polar Regions experience influx of freshwater from melting glaciers leading to lower salinity levels.

Vertical Distribution of Ocean Salinity:

- Surface Salinity: Influenced by processes of evaporation, precipitation, and freshwater input from rivers and melting ice. These processes can lead to higher or lower salinity levels at the ocean's surface.
- Halocline: This zone is characterized by a significant decrease in salinity due to the mixing of more saline surface waters with deeper, less saline waters.
- Deep Ocean Salinity: In the deep ocean, salinity does not vary much with depth.

Ocean Salinity: A Regional Look

Here's a quick dive into how it varies across different regions:

Indian Ocean

Pacific Ocean
Atlantic Ocean

- Overall, it averages around 35 parts per thousand.
- The Bay of Bengal sees lower salinity due to freshwater influx from mighty rivers like the Ganges.
- In contrast, the Arabian Sea boasts higher salinity due to high evaporation and minimal freshwater input.
- Its vast size and unique shape play a key role in salinity variation.
- Upwelling in the eastern Pacific lowers surface salinity.
- Warmer, tropical and subtropical regions in the west experience high evaporation, leading to higher salinity.
- Northern regions, like the subpolar North Atlantic, have lower salinity due to melting ice and precipitation.
- As water travels south, evaporation rates increase,

and warm currents like the
Gulf Stream contribute to
higher salinity.

- The saltiest pockets are often found in subtropical high-pressure zones like the Sargasso Sea.

Student Notes:

3.2.3. Density

Density is defined as the mass of a substance per unit volume, and it determines how heavy or light a substance is relative to its volume. In practical terms, density affects whether something sinks or floats—denser objects sink, while less dense ones float.

The average density of ocean water is approximately 1.025 g/cm³ (grams per cubic centimeter), though this can slightly vary depending on environmental and regional conditions.

In the case of ocean water, density is not constant; it varies depending on three major factors: temperature, salinity, and pressure.

Factors Controlling Ocean Water Density

- Temperature: Temperature has a significant effect on seawater density. When ocean water is heated by solar radiation, it expands, becoming less dense. On the other hand, cooling leads to contraction, increasing the water's density.
  - This relationship explains why warmer tropical waters are generally less dense than the cooler waters found in higher latitudes.
  - The effect of temperature on density is more pronounced in equatorial and tropical regions due to greater variations in surface heating.
- Salinity: Salinity refers to the concentration of dissolved salts in water. When more salt is present, the mass per volume increases, making the water denser.
  - Salt also affects the freezing point and temperature of maximum density. In pure water, maximum density occurs at 4°C. However, the addition of salt lowers this point; in typical seawater, the temperature of maximum density coincides with the freezing point at about –1.3°C.
  - Thus, high salinity contributes to higher water density, especially in regions where evaporation rates are high.
- Pressure: As we go deeper into the ocean, the pressure increases due to the weight of the overlying water.
  - This increased pressure compresses water molecules, making them more tightly packed and hence increasing the density.
  - Although the impact of pressure on density is relatively small at the surface, it becomes more significant at great depths and contributes to the overall density gradient in the ocean.

These three factors—temperature, salinity, and pressure—interact to create a layered structure in the ocean, a process known as ocean stratification, where denser water lies beneath less dense layers.

Vertical Variation in Ocean Water Density

The density of seawater increases with depth, but the pattern of increase is not uniform. Based on these variations, the ocean is generally divided into three vertical layers:

Student Notes:

Layer
Depth
Range
Key Features
Regional Variations
Mixing Behavior
Surface
Layer
(Photic
Zone)
0 – 200
meters
- Exposed to sunlight,
warm and less dense
-
Most
dynamic;
interacts
with
atmosphere
- Tropics: Very warm, light
water due to high solar
radiation
-
Subtropics:
High
evaporation raises salinity
slightly
High mixing due
to wind, waves,
and
solar
heating
Pycnocline
Layer
300 –
1000
meters
-
Sharp
density
increase with depth
- Due to thermocline
(temperature
drop)
and halocline (salinity
rise)
-
Tropics/Subtropics:
Pycnocline overlaps with

thermocline and halocline
-
Mid-latitudes:
More
influenced
by
salinity
changes
Acts as a barrier
to
vertical
mixing
Deep/Bott
om Layer
Below
1000
meters
to
ocean
floor
- Cold, dense, and
stable water
- Little variation in
temp/salinity
- Comprises ~80% of
ocean volume
- Polar regions: Surface
already cold → entire
column
nearly
uniform
(isopycnal),
promoting
mixing
-
Tropics:
Strong
stratification
inhibits
mixing
Minimal mixing;
stable
stratification,
except in polar
regions

Student Notes:
3.3. Movement of ocean water
The movement of ocean water is a complex process driven by various forces and factors. Understanding these movements is crucial for comprehending marine ecosystems, climate patterns, and navigation. The major types of ocean water movement include:
1. Waves: Waves are the oscillating
movements of water caused mainly by
wind blowing across the surface of the

sea.
The most common cause of ocean waves is wind blowing across the surface of the water. As the wind moves, it pushes on the ocean's surface, creating small ripples. With continued wind and time, these ripples grow into larger waves.
The size and strength of waves depend on three main factors:
1. Wind speed – Stronger winds push harder on the surface.
2. Wind duration – Longer winds have more time to transfer energy.
3. Fetch – The distance over which the wind blows across the open water.
In deeper waters, the water particles under a wave don't travel forward. They move in circular orbits, rising and falling as the energy passes through. It's this motion that gives waves their rolling form. However, not all waves are caused by wind, some are triggered by much larger natural events like underwater earthquakes or volcanic eruptions (Tsunami Waves).
2. Tides: Tides involve the rhythmic rise and fall of entire sea levels. This occurs roughly once or twice daily due to the gravitational pull of the moon, influenced by the sun and Earth's rotation.
Tides can be categorized in two ways:
- Frequency:
  - Semi-diurnal: Two high tides and two low tides occur in a 24-hour period.
  - Diurnal: Only one high tide and one low tide occur in a day.
- Sun-Moon Alignment:
  - Spring tides: When the sun, moon, and Earth are aligned, their combined gravity creates more extreme high and low tides.
  - Neap tides: When the sun and moon are at right angles to Earth, their opposing forces produce less dramatic tidal changes.

Student Notes:
3. Ocean currents: Ocean currents are large, continuous movements of seawater that flow through the world's oceans. They are driven by factors such as wind, the Earth's rotation, temperature differences, and salinity levels. Notably, ocean currents play a critical role in regulating Earth's climate by transporting heat around the globe.
3.3.1. Types of ocean currents
Ocean Currents based on Depth:

Type	Description	Location	Percent age of volume
Surface currents	Driven by wind and friction, these currents flow in the upper 400 meters of the ocean, influencing weather patterns and marine life. For example Kuroshio Current.	Uppermost layer of the ocean	10%
Deep water currents diagram	These massive currents move slowly throughout the ocean basins, primarily influenced by differences in water density and gravity. They play a crucial role in global heat distribution. For example Atlantic Meridional Overturning Circulation (AMOC)	Ocean basins at various depths	90%

Ocean Currents based on Temperature:

Type	Description
Cold currents	Transporting cold water from polar regions towards the equator, often found along the west coasts of continents. For example North equatorial current
Warm currents	Carrying warm water from near the equator towards higher latitudes, these currents have a significant impact on global climate and influence marine life. They are commonly found along the east coasts of continents. For Example- Gulf stream

Student Notes:

Factors Responsible for the Formation of Ocean Currents

1. Insolation: Solar radiation heats the equator, causing water to expand and bulge slightly

compared to cooler poles. This creates a subtle slope, influencing water movement.
2. Atmospheric Circulation: Winds blow across the ocean surface, pulling the water along through friction. The direction and strength of the wind determine the path and intensity of the currents, reflecting the patterns of atmospheric circulation.

■ For example- The North Atlantic Drift in the Atlantic and the North Pacific current in the Pacific move in the northeast direction under the influence of westerlies.

3. Coriolis Force: The Earth's rotation bends the path of moving currents. In the Northern Hemisphere, currents deflect to the right (e.g., Gulf Stream), while in the South, they deflect left (e.g., Brazilian Current).
4. Salinity: Variations in water density due to salinity differences influence vertical movements within currents. Denser, saltier water tends to sink, while lighter, fresher water rises, creating a circulation pattern.
5. Land Masses: Continents and islands act as barriers, deflecting and shaping currents. For example, the tip of South America redirects the West Wind Drift northward, forming the Peru Current.
6. Seasonal Changes and Monsoon Winds This factor is particularly important in the Indian Ocean region, where the monsoon system causes seasonal reversal of wind direction and therefore current flow:

■ During the Southwest Monsoon (June–Sept), winds blow from the southwest, forming the Somali Current (a strong seasonal current).

■ During the Northeast Monsoon (Oct–Feb), the current reverses direction. Such seasonal variations do not occur in other oceans to the same extent and highlight the uniqueness of the Indian Ocean current system.

By understanding these forces, we gain a deeper appreciation for the ocean's dynamic nature and its profound impact on our planet's climate.

Impact of Ocean currents on Climate and Geography

- Desert Formation: Cold ocean currents contribute significantly to the formation of deserts along the west coasts of tropical and subtropical continents. They cause fog and aridity by reducing moisture content and drying out the areas. for Example Namib Desert
- Rainfall: Warm ocean currents bring rainfall to coastal areas and interiors. Warm currents flowing parallel to the east coasts of tropical and subtropical continents result in warm and

Student Notes:

rainy climates. For example, Kuroshio Current brings warm and humid air, contributing to a warm and rainy climate in the region

- Moderating Effect: Ocean currents moderate temperatures along coasts. The North Atlantic Drift brings warmth to England, while the Canary cold current cools Spain and Portugal.
- Fishing: The mixing of cold and warm ocean currents creates rich fishing grounds, such as the Grand Banks near Newfoundland, Canada, and the northeastern coast of Japan. This interaction replenishes oxygen and promotes plankton growth, the primary food source for fish, making these mixing zones the best fishing grounds.
- Tropical Cyclones: Warm water accumulated by ocean currents in the tropics serves as a major force behind tropical cyclones.
- Navigation: Ocean currents assist in navigation by providing predictable pathways that can speed up or slow down ships, aiding in efficient maritime travel.

Connection Between Ocean Currents and Major Fishing Grounds

Ocean currents play a crucial role in shaping marine ecosystems and fisheries. The movement of cold and warm waters, driven by wind, salinity, temperature differences, and Earth's rotation, not only redistributes heat and nutrients but also determines the location and productivity of global fishing zones. Areas influenced by cold ocean currents and upwelling are particularly rich in plankton and fish, making them the world's major fishing grounds.

How Ocean Currents Influence Fishing Grounds?

1. Upwelling Brings Nutrients to the Surface

- In regions where cold deep water rises to the surface, nutrients from decomposed organic matter are brought upward.
- This fertilizes phytoplankton blooms, which serve as the base of the food chain for fish and marine mammals.

2. Cold Currents Enhance Oxygen Content

- Cold currents carry more dissolved oxygen, essential for the survival of fish species in dense populations.
- They also regulate sea temperatures, making the environment suitable for spawning and growth.

3. Convergence Zones Attract Fish

- Where warm and cold currents meet, water layers mix, creating biologically rich zones.
- These areas support a wide variety of fish species, both pelagic (open water) and demersal (bottom dwellers).

Major Fishing Grounds

Here are some of the world's richest fishing zones directly influenced by ocean currents:

For example: Grand Banks – Off Newfoundland

- Currents Involved: Cold Labrador Current and warm Gulf Stream
- Mechanism: Convergence zone creates nutrient-rich conditions and supports upwelling.
- Fish Caught: Cod, haddock, halibut
- Significance: Historically among the richest fishing grounds, though overfishing led to its decline in the late 20th century.

Ocean Gyres

Ocean gyres are large systems of rotating ocean currents formed due to the combined effect of global wind patterns, Coriolis force, and continental boundaries. They typically move in clockwise direction in the Northern Hemisphere and anticlockwise in the Southern Hemisphere.

Gyres help in redistributing heat, transporting nutrients, and driving the Earth's climate engine.

Major Ocean Gyres of the World

3.3.2. Deep Ocean Water Circulation

Deep ocean water circulation, also known as thermohaline circulation, refers to the global movement of ocean water in the deep layers of the ocean, primarily driven by differences in water density due to temperature (thermo-) and salinity (-haline).

Unlike surface currents, which are primarily wind-driven, deep ocean currents operate on a much slower timescale and involve vertical and horizontal movement of water masses across ocean basins.

This system plays a critical role in regulating Earth's climate, distributing heat, nutrients, carbon, and oxygen throughout the ocean.

Formation

The formation of deep ocean currents is rooted in the concept of density-driven movement:

1. Surface Cooling and Evaporation at High Latitudes
    - In regions like the North Atlantic or around Antarctica, surface water becomes very cold and salty due to:
        - Low temperatures
        - High evaporation
        - Sea ice formation, which leaves salt behind (increasing salinity)
    - This water becomes denser than the layers below and begins to sink.
2. Sinking of Dense Water (Deep Water Formation)
    - This dense water sinks to the bottom of the ocean and starts spreading horizontally, forming deep ocean currents.
4. Global Conveyor Belt Movement
    - Once the cold, dense water sinks, it flows along the ocean floor, gradually moving towards the equator.
    - In other parts of the world, especially in the Indian and Pacific Oceans, this deep water rises (upwelling) due to mixing, turbulence, or wind divergence.
    - The water is then warmed and returns to the surface, where it flows back toward polar regions, completing a global loop called the Global Conveyor Belt or Thermohaline Circulation.

Student Notes:

CONCEPT OF WATER MASS

A water mass is a body of water with distinct physical and chemical characteristics, formed due to specific processes in the ocean or other large water bodies. These characteristics remain relatively stable over a significant depth range, making it identifiable from surrounding water. Examples of Water Masses are

- North Atlantic Deep Water (NADW): Formed in the North Atlantic Ocean, it is characterized by cold temperatures and high salinity. NADW sinks to great depths and spreads southward, influencing global ocean circulation.
- Antarctic Bottom Water (AABW): This water mass forms around Antarctica through processes like sea ice formation.

Characteristics of Water Masses

1. Temperature and Salinity: Water masses have unique temperature and salinity values,

which are relatively stable over time and distinguish them from adjacent water.
2. Density: The combination of temperature and salinity determines the density of a water mass. Differences in density influence vertical and horizontal movement within the ocean.
3. Formation Region: Water masses are formed in specific regions where conditions like evaporation, precipitation, ice formation, and freshwater input significantly influence their properties.
4. Depth Range: Water masses typically occupy distinct depth ranges. For example, some water masses form at the surface, while others form in deeper layers.
5. Stability: Once formed, water masses can remain stable and retain their characteristics over long periods, allowing them to be tracked across the ocean.

Water masses are integral components of the ocean's structure and dynamics, affecting global climate patterns, marine ecosystems, and ocean circulation. Understanding their characteristics and distribution helps in studying the ocean's role in the Earth's climate system.

Significance of Deep water Circulations (DWC):
1. Global Heat Distribution: DWC aids in the global distribution of heat, regulating Earth's temperature and mitigating extreme temperatures across different regions.
2. Carbon Dioxide Regulation: It plays a crucial role in controlling atmospheric carbon dioxide by transporting carbon from the surface to the deep ocean for long-term storage.
3. Influence on Ocean Currents: DWC shapes ocean currents and circulation patterns, impacting marine ecosystems, weather patterns, and coastal regions.
4. Sea Level Regulation: It affects sea levels by redistributing heat and influencing thermal expansion, as warm water is less dense than cold water.

Student Notes:

Weakening Deep water Circulation

In recent decades, climate scientists have observed clear signs that deep ocean circulation systems, particularly in the Atlantic, are weakening. The causes and consequences are alarming:

Causes of Weakening:

- Global Warming
  - Increased melting of Greenland ice sheet and Arctic sea ice adds freshwater into the North Atlantic, reducing salinity and hence density—preventing sinking.
- Increased Precipitation and River Runoff
  - Contributes further freshwater into critical deep water formation zones.
- Ocean Warming
  - Warmer water is less dense, which interferes with the normal process of water sinking at high latitudes.

Scientific Findings:

- The Atlantic Meridional Overturning Circulation (AMOC) has slowed by 15–20% since the mid-20th century, according to several studies.
- The IPCC AR6 report (2021) also confirms strong evidence of weakening and very high confidence that it will continue to decline if global warming persists.

3.4. Sea level changes

Sea level changes refer to the fluctuations in the average level of the Earth's oceans relative to the land. These changes can occur

on both short-term and long-term scales
and are influenced by a variety of natural
and human-driven factors.
They are critical indicators of climate
change and have significant impacts on
coastal areas, ecosystems, and human
infrastructure.
Comparison of Isostatic and Eustatic Sea Level Changes
Aspect
Isostatic Sea Level Change
Eustatic Sea Level Change
Definition
Changes in sea level relative to the
land, caused by vertical movements of
the Earth's crust.
Changes in global sea level due to
variations in the amount of water
in the oceans.
Causes
Glacial Isostatic Adjustment (GIA): The
Earth's crust rebounding after being
depressed by ice sheets.
Tectonic Activity: Movements of the
Earth's crust due to plate tectonics.
Melting
of
Ice
Sheets
and
Glaciers:
Increases
in
water
volume from melting ice
Thermal
Expansion:
Water
expands as it warms, increasing
sea levels.
Time Scale
•
Thousands to millions of years for
significant changes.
•
Can be rapid during post-glacial
rebound periods.
•
Decades to centuries for
noticeable changes.
•
Faster changes in response to
recent global warming.
Geographical
Impact
•
Localized: Affects specific regions
depending on crustal movements.

•
Global: Affects sea levels
worldwide uniformly.

•
Examples: Post-glacial rebound in
Scandinavia and Canada.
•
Examples: Global sea level rise
due to melting polar ice caps.
Implications
for Coastal
Areas
Can lead to either relative sea level rise
or fall, depending on the direction of
crustal movement.
Consistent global sea level rise
threatens
coastal
regions
worldwide.

3.5. Ocean Deposits

Ocean deposits are accumulations of material that have settled on the seafloor. These materials come from various sources, both living and nonliving. Here's a quick breakdown of the main types:

- Terrigenous Deposits: These are land-derived sediments transported to the ocean by rivers, wind, and glaciers. Their composition varies depending on the source.
- Biogenous Sediments: These originate from the remains of dead marine organisms. The two main types are:
  - Siliceous Ooze: Formed from the silica shells of tiny organisms like diatoms and radiolarians.
  - Calcareous Ooze: Formed from the calcium carbonate shells of organisms like foraminifera and coccolithophores.
- Cosmogenous Sediments: These rare deposits come from outer space, including micrometeorites, meteorite fragments, and tektites.
- Pelagic Deposits: These offer a glimpse into life in the deep ocean and consist of:
  - Ooze: A soft, mud-like substance made from microscopic shells.
  - Deep-sea Clay: Extremely fine particles that settle from the water column.
- Hydrogenous Deposits: These form through chemical reactions in seawater, with minerals like manganese nodules and phosphorites precipitating and settling on the ocean floor.

Minerals present in seabed

The seabed contains three main types of mineral deposits that are being considered for commercial exploitation:

•

Polymetallic nodules: These small lumps are found scattered across the ocean floor, often partially buried in sediments. They contain a variety of metals including manganese, iron, copper, nickel, cobalt, lead, and zinc.(Note:-Detailed discussion of polymetallic nodules is covered in the resource topic)

Student Notes:

- Seafloor massive sulfides (SMS): Also known as polymetallic sulfides, these deposits are rich in copper, iron, zinc, silver, and gold. They form through hydrothermal processes along mid-ocean ridges and volcanic arcs.
- Cobalt-rich ferromanganese crusts: These crusts precipitate minerals from seawater onto seamounts and ridges at depths between 400 and 7,000 meters. They contain iron, manganese, nickel, cobalt, copper, and rare earth elements.

The International Seabed Authority (ISA) has so far approved 28 exploration contracts covering over 1.3 million square kilometers of seafloor to study these mineral deposits. However, the environmental impacts of deep-sea mining remain poorly understood and are a major concern.

The significance of ocean deposits:

- Scientific Research: Ocean deposits provide insights into Earth's geological history and climate, helping scientists understand past events, environmental changes, and the formation and evolution of oceans and continents.
- Resource Availability: Ocean deposits can indicate potential mineral resources, such as manganese nodules rich in nickel, copper, and cobalt, which form over millions of years. Economically, the extraction of these deposits significantly contributes to the global economy.
- Biodiversity: Ocean deposits provide habitats for diverse marine life. Coral reefs, for example, support a wide range of species and play a vital role in marine ecosystems.
- Climate Regulation: Sediments in ocean deposits store carbon and help regulate the Earth's climate by controlling the carbon cycle and influencing oceanic carbon sequestration.

3.6. Marine Resources

Marine resources refer to the natural wealth derived from oceans and seas, encompassing a vast range of living (biotic) and non-living (abiotic) materials. These resources extend from the shallow coastal waters to the deep ocean basins, and include everything from fisheries and minerals to energy and transport routes.

Oceans cover over 70% of the Earth’s surface and are crucial to the planet’s ecological balance, economic development, and human survival, particularly for nations with extensive coastlines like India.

Types of Marine Resources

Marine resources are broadly classified into the following categories:

1. Biotic Resources (Living Resources)

These are derived from marine flora and fauna:

- Fish and shellfish: Provide protein-rich food to billions and are a major source of employment.
-

- Seaweeds and algae: Used in food additives, pharmaceuticals, cosmetics, and fertilizers.
- Marine mammals: Historically exploited but now largely protected due to conservation efforts.
- Corals and sponges: Source of calcium carbonate, natural habitat for biodiversity, and useful in medical research.

2. Abiotic Resources (Non-Living Resources)

These include materials that do not come from living organisms:

- Minerals: Such as polymetallic nodules (rich in manganese, nickel, cobalt), sand, and gravel.
- Salt: Extracted through evaporation of seawater, crucial for human consumption and industries.

3. Energy Resources

- Offshore oil and natural gas: Major source of energy; India's Mumbai High and KG Basin are notable reserves.
- Tidal and wave energy: Renewable and predictable, though yet to be fully tapped.
- Offshore wind farms: A growing area in marine renewable energy, especially in Europe and increasingly in Asia.

Importance of Marine Resources

Marine resources are indispensable for both development and sustainability. Their importance spans across various domains:

Sector	Contribution
Economic	Fisheries, minerals, offshore drilling, shipping, and tourism contribute billions to GDP.
Livelihood	Over 200 million people globally rely on fishing and marine-related activities.
Ecological	Oceans regulate the Earth's climate system, absorb carbon dioxide, and maintain biodiversity.
Energy	Provides both conventional (oil, gas) and renewable energy (tidal, wave).

Sector	Contribution
Scientific	Supports bioprospecting and climate research, offering insights into new medicines and Earth's systems.

Threats to Marine Resources

- Overfishing: Leads to collapse of fish populations and loss of livelihoods.
- Marine Pollution: From plastic waste, oil spills, sewage, and industrial runoff.

- Habitat Destruction: Mangroves, coral reefs, and estuaries are being degraded rapidly.
- Climate Change: Ocean warming, sea level rise, and acidification affect marine life and ecosystems.
- Deep-sea Mining: May lead to irreversible ecological damage if not regulated properly.

Conservation of Marine Resources

Conserving marine resources is essential for long-term sustainability, food security, and climate resilience. Key strategies include:

1. Sustainable Fishing Practices

- Use of eco-friendly fishing methods.
- Enforcing fishing quotas and seasonal bans to allow fish stocks to replenish.

2. Marine Protected Areas (MPAs)

- Designated zones where human activity is restricted or monitored to preserve ecosystems and biodiversity (e.g., Gulf of Mannar Biosphere Reserve in India).

3. Pollution Control Measures

- Implementing bans on single-use plastics.
- Treating industrial and domestic effluents before discharge into the sea.

4. Habitat Restoration

- Restoration of mangroves, seagrass beds, and coral reefs to protect coasts and support marine life.

5. Marine Spatial Planning

- Strategic zoning of marine areas to balance economic use with environmental protection.

Initiatives for Conservation of Marine Resources

In India:

- Integrated Coastal Zone Management Programme (ICZMP): Aims to balance conservation with livelihoods in coastal areas.
- Deep Ocean Mission: Supports deep-sea exploration, biodiversity study, and technology development.
- Sagar Mala Project: Focuses on port-led development while incorporating environmental safeguards.
- Blue Flag Beaches: Promotes eco-friendly tourism by certifying clean and sustainable beach practices.
- Marine Fishing Regulation Act and PM Matsya Sampada Yojana: Encourage sustainable fishing and support coastal communities.

Global Initiatives:

- SDG 14 (Life Below Water): Calls for the conservation and sustainable use of oceans and marine resources.
- UNCLOS (United Nations Convention on the Law of the Sea): Provides a legal framework for ocean governance.
- Ocean Cleanup Project: Targets removal of plastic from the Great Pacific Garbage Patch and

beyond.

•

Convention on Biological Diversity (CBD): Addresses conservation of marine species and habitats.

Student Notes:

Coral Reefs

Complex marine ecosystems, often called the "rainforests of the sea". These limestone structures, formed by coral polyps, cover less than 1% of the ocean floor but support about 25% of all marine species.

3.6.1. Distribution of Coral Reefs

India

Gulf of Kutch (Gujarat), Gulf of Mannar (Tamil Nadu), Andaman and Nicobar Islands, and Lakshadweep Islands.

Minor coral formations are also found off the coasts of Maharashtra, Kerala, and parts of the east coast.

Global:

located in tropical oceans. Some of the largest coral reefs are the Great Barrier Reef (Australia), the Belize Barrier Reef, and the Red Sea Coral Reef.

3.6.2. Major Threats to Coral Reefs

•

Climate Change:

o Ocean Acidification: Corals absorb around 48% of global CO■ emissions, leading to increasingly acidic oceans that hamper coral growth.

o Rising Temperatures: Warmer sea temperatures cause coral bleaching.

o Sea Level Rise: Corals in deeper water, reducing their access to essential sunlight.

o Altered Ocean Currents: Changes in sea temperature and salinity → disrupt nutrient distribution and coral reproduction.

•

Pollution and Sedimentation: → Affects approx. 25% of reefs globally, introducing harmful nutrients and chemicals. → Sedimentation, Prevents coral larvae settlement.

•

Coral Mining: Extraction for construction materials, in regions like Sri Lanka and southern India, leads to direct habitat destruction.

Ideal Conditions for Coral Growth

Corals require specific conditions for optimal growth:

Temperature: 23–29°C (Warm tropical waters)

Salinity: 32–35 PSU (Stable salinity levels)

Sunlight: For photosynthesis (found in depths up to 50 meters)

Clear Water: Low turbidity for maximum light penetration

Stable Substrate: Hard surfaces for coral larvae settlement

Student Notes:
Fourth
Global
Mass
Coral Bleaching
The fourth global mass
coral bleaching event
has been triggered by
unprecedented
ocean
temperatures,
as
reported by the US
National Oceanic and
Atmospheric
Administration
(NOAA).
•
Since
mid-March
2023, the average
sea
surface
temperature
has
been
abnormally
high, reaching a record of 21.07°C in March 2024.
•
This extreme heat has led to widespread coral bleaching across multiple regions, including the Great Barrier Reef, where severe bleaching has been observed in a third of the reefs surveyed.
•
Over 54% of the world's coral areas have experienced bleaching-level heat stress in the past year, with this number rising weekly. The current bleaching event is exacerbated by the El Niño weather pattern, which contributes to warmer ocean conditions.
Major Coral Bleaching Events
1998: First
Mass
Bleaching
•
Triggered by El Niño-induced sea surface temperature rise in
Pacific Ocean
•
Resulted in mortality of 8% of global coral population
2010: Second
Mass
Bleaching
Intensified coral destruction, affecting 35% of coral reefs worldwide
2014-2017:
Third Mass
Bleaching
Widespread impact across multiple oceanic regions:
•
Western Pacific (including Guam), North and South Pacific, Indian
Ocean.
•

Affected 56% of coral reefs globally
To protect coral reefs, we should limit unplanned coastal development, promote sustainable fishing, reduce harmful chemical use, and prioritize climate action.

3.7. Marine Pollution

Marine pollution refers to the introduction of harmful substances or energy into the ocean, either directly or indirectly by human activities, that result in negative impacts on marine life, water quality, and human health. These pollutants may be chemical, physical, biological, or noise-

Student Notes:

based, and they enter the ocean through rivers, coastal discharge, atmospheric deposition, oil spills, or dumping of waste.

Marine pollution has reached crisis levels globally:

- According to the IUCN, 80% of marine debris is plastic.
- Microplastics are now found in human blood, lungs, brain tissue, and seafood, making marine pollution a human health concern.

Student Notes:

- Dead zones — areas with no oxygen where marine life cannot survive — are increasing rapidly due to agricultural runoff.

Key Sources and Types of Marine Pollution

- Oil and Hydrocarbon Pollution: It occurs primarily due to accidental spills from oil tankers, leaks from offshore drilling platforms, and ballast water discharge from ships.
  - When oil spreads across the ocean surface, it forms a slick that blocks oxygen exchange, harming plankton, fish, birds, and marine mammals. Over time, hydrocarbons enter the food chain through bioaccumulation.
  - Major examples include the Exxon Valdez spill (Alaska, 1989) and the Deepwater Horizon disaster (Gulf of Mexico, 2010).
- Plastic and Microplastic Pollution: This arises from the widespread use and careless disposal of single-use plastic items such as bags, bottles, wrappers, and straws. Fishing gear like nets and ropes, when lost or discarded, become "ghost gear" that entangles marine organisms.
  - Plastic pollution severely affects marine food chains, coral reefs, and nutrient cycling. Example: Great Pacific Garbage Patch, located in the North Pacific Gyre.
- Chemical Pollution (Toxic and Industrial Waste): This type of pollution results from the discharge of toxic substances such as mercury, lead, arsenic, cadmium, and other industrial

chemicals into the sea. These often originate from factories, chemical plants, tanneries, and mining operations located near rivers or coastlines.

■ Minamata disease in Japan, caused by mercury poisoning from industrial effluents dumped into the sea.

- Radioactive Pollution: Radioactive waste enters the oceans through discharges from nuclear power plants, submarine operations, and nuclear accidents. These wastes often contain isotopes such as cesium-137 and iodine-131, which persist in the environment for decades.

■ Example: Fukushima Daiichi disaster in Japan (2011), where radioactive water was released into the Pacific Ocean after an earthquake and tsunami.

- Noise Pollution: This pollution in marine environments is caused by commercial shipping, sonar from naval operations, underwater blasting, and deep-sea mining. Marine mammals like whales and dolphins, which rely on echolocation for navigation and communication, are particularly vulnerable.

- Light Pollution: Light from coastal infrastructure, offshore oil rigs, and ships interferes with the natural behavior of marine organisms. It disrupts the reproductive cycles of corals, confuses the navigation of sea turtles, and alters the vertical migration patterns of zooplankton and fish.

International Efforts to Combat Marine Pollution

Several multilateral agreements and global frameworks have been established under the auspices of the United Nations and international maritime organizations to protect the world's oceans.

MARPOL Convention (1973/78)

The International Convention for the Prevention of Pollution from Ships (MARPOL) is the most comprehensive global treaty to prevent marine pollution from ships.

It covers pollution by oil, sewage, garbage, air emissions, and harmful substances in packaged form.

London Convention (1972) & London Protocol (1996)

These instruments aim to control dumping of waste and other matter into the sea.

Bans the dumping of industrial waste, radioactive material, and persistent plastics in marine areas.

Student Notes:

Establishes obligations for states to protect and preserve the marine environment

Empowers coastal nations to regulate marine pollution within their Exclusive Economic Zones (EEZs).

UNEP's Clean Seas Campaign (2017–Present)

A global campaign to reduce plastic pollution, especially microplastics, by engaging governments, industries, and citizens.

Promotes bans on single-use plastics and investment in circular economy models.

Efforts by India to Tackle Marine Pollution

India, with its 7,500 km long coastline and growing maritime economy, has adopted multiple legal, regulatory, and programmatic measures to address marine pollution.

Coastal Regulation Zone (CRZ) Notifications

Issued under the Environment Protection Act, 1986, CRZ rules regulate construction and industrial activity within sensitive coastal areas.

Aim to protect mangroves, estuaries, coral reefs, and prevent coastal erosion and pollution.

Single-Use Plastic Ban (2022)

Prohibits the manufacture, sale, and use of single-use plastic items below 75 microns, which are common marine pollutants.

Aims to reduce land-based plastic leakage into rivers and oceans.

Blue Flag Beach Certification

Beaches are certified by the Foundation for Environmental Education (FEE) based on cleanliness, waste management, and eco-tourism standards.

India now has 12 Blue Flag beaches, promoting clean coastal practices.

For real, lasting change, marine pollution control must go beyond regulation — it requires systemic changes in production and consumption, stronger community participation, and innovation in waste management and ocean governance.

3.8. Some Additional Topics

Ocean Warming:

Absorption of over 93% of excess heat from greenhouse gas emissions since the 1970s (IPCC SROCC, 2019) → Impacts:

- Coral bleaching: 50% decline in living corals in Great Barrier Reef over past three decades.
- Species migration: Poleward shift of marine species (e.g., Indian oil sardine moving northward along Indian coasts).
- Polar ice melting: Affecting biodiversity from plankton to polar bears.
- Impacts on India: Increased frequency of cyclones in the North Indian Ocean basin → Due to Rising sea surface temperatures in the Arabian Sea and Bay of Bengal.

Ocean Acidification:

Increased absorption of atmospheric CO_2, which dissolves in seawater and forms carbonic acid → lowering the pH of ocean waters → Impacts:

Student Notes:

- Chemical Composition Changes: Acidic waters lead to → Dissolution of calcium carbonate structures, affecting organisms like corals, shellfish, and plankton.
- Ecosystem Alterations: Ecosystem alterations affecting fisheries and coastal protection for e.g., Weakening of coral reefs (e.g., Gulf of Mannar, Lakshadweep)

Ocean Deoxygenation:

Caused by rising temperatures and nutrient pollution → results in decreased oxygen levels in seawater (Warm waters hold less oxygen, contributing to hypoxic conditions in various marine areas) → Impacts:

- Altered Marine Life Balance: Hypoxia-tolerant species, such as jellyfish, grow in low-oxygen environments → forced into oxygen-rich areas.
- Global Warming Contribution: Deoxygenated waters produce greenhouse gases → like nitrous oxide and methane → contribute to climate change.
- Impacts on India: Expanding Oxygen Minimum Zones (OMZ) in the Arabian Sea affecting fisheries.

Additional Phenomena:

- Marine Heatwaves (MHWs): Defined as period where sea surface temperatures are 5-7°C above average for at least five consecutive days → Causes:
  - o Local Processes: Ocean-atmosphere interactions and water mixing contribute to MHWs.
  - o El Niño: Increases sea surface temperatures in the Pacific, influencing MHWs in tropical regions.
  - o Human Activities: Greenhouse gas emissions from burning fossil fuels and deforestation increase ocean temperatures.
- Impacts on India: Affects Southwest Monsoon patterns → Increases extreme weather events (e.g., 2020 Cyclone Amphan intensification).
- Atlantification of Arctic Basin: Arctic Ocean resembling Atlantic Ocean → due to reduced sea ice and increased warm water inflow. Key aspects include:
  - o Process: Less sea ice allows warmer Atlantic water to rise to the surface, accelerating ice melt and warming the region.
  - o Ecological Impacts:
    - > Reduced Ice and Freshwater: Increased mixing with Atlantic water reduces ice cover and freshwater availability.
    - > Altered thermohaline circulation, potential changes in Indian monsoon patterns
    - > Ecosystem Disruption: Changes in fish species and food webs impact Arctic wildlife and ecosystems.

Student Notes:

Student Notes:

4. PHYSIOGRAPHY OF INDIA

Previous year questions (PYQs)

- There is no formation of deltas by rivers of the Western Ghats. Why (2013)
- Whereas the British planters had developed tea gardens all along the Shivaliks and Lesser Himalayas from Assam to Himachal Pradesh, in effect they did not succeed beyond the Darjeeling area. Explain. (2014)
- Bring out the relationship between the shrinking Himalayan glaciers and the symptoms of climate change in the Indian sub-continent. (2014)
- In what way can floods be converted into a sustainable source of irrigation and all-weather

inland navigation in India? (2017)

- The interlinking of rivers can provide viable solutions to the multi-dimensional inter-related problems of droughts, floods and interrupted navigation. Critically examine. (2020)
- How will the melting of Himalayan glaciers have a far-reaching impact on the water resources of India? (2020)
- What are the environmental implications of the reclamation of water bodies into urban land use? Explain with examples. (2021)
- Identify and discuss the factors responsible for diversity of natural vegetation in India. Assess the significance of wildlife sanctuaries in rain forest regions of India. (2023)

PYQs Analysis

UPSC’s questions on the physiography of India consistently reveal an interdisciplinary approach, where physical landscapes are assessed not only for their structure but also for their impact on human activity, resource management, and ecological sustainability. The focus is on understanding why India’s landforms behave the way they do—and how that influences everything from agriculture and vegetation to transport and conservation.

For example:

- Structural & Geomorphic Logic: The repeated question on why rivers from the Western Ghats don’t form deltas (2013) and why Eastern Northern Plains are broader demand a functional understanding of slope, flow velocity, sedimentation, and drainage evolution.
- Human-Landform Interaction: Whether it's tea cultivation failure beyond Darjeeling (2014) or the role of floods in inland navigation (2017), the questions often link physiographic settings with developmental constraints and innovations.
- Resource, Vegetation & Ecosystem Linkages: From natural vegetation diversity and the role of wildlife sanctuaries (2023) to river interlinking as a multi-pronged solution (2020), UPSC clearly expects aspirants to tie physiographic understanding.

In this document, we’ve covered all the key topics of Indian Physiography in depth—from the structural evolution of the Himalayas and Peninsular Plateaus to the dynamics of river systems, coastal plains, and islands—while integrating recent geographical developments and region-specific concerns.

4.1. The Himalayas

Himalayas are the young fold mountains. They run from west-east direction from Indus to Brahmaputra covering a distance of 2500 KM. The Himalayas may be divided into three parallel ranges:

(a) Greater Himalayas or Himadari
(b) Lesser Himalayas or Himachal
(c) Outer Himalayas or Shivaliks

Student Notes:

Greater Himalayas (Himadri):

Elevation: Average of 6,000 meters, with peaks like Mount Everest, Kanchenjunga, Makalu, Dhaulagiri, and Nanga Parbat. Its width varies from 120 to 190 km.

Features: Home to key mountain passes such as Bara Lacha-La, Shipki-La, Nathu-La, and Zoji-La. The Ganges and Yamuna rivers originate here.

Lesser/Middle Himalayas (Himachal):

Elevation: Ranges from 1,000 to 4,500 meters, with an average width of 50 km.

Features: Includes the Pir Panjal, Dhaula Dhar, and Mahabharata ranges. Known for hill stations like Shimla, Darjeeling, and Mussoorie. Notable valleys include Kashmir, Kullu, and

Kangra.

Outer Himalayas (Shivaliks):

Elevation: Ranges from 900 to 1,100 meters, with a width of 10 to 50 km.

Features: Forms the foothills with valleys called 'Duns,' such as Dehradun and Kotli Dun.

Beyond the Main Himalayan Ranges:

Trans-Himalayan Ranges: North of the Greater Himalayas are the Zaskar and Ladakh ranges, with the Indus River in between. The Karakoram range, home to K2, is further north.

Purvanchal Hills: Located in the eastern Himalayas, includes the Mishami, Patkoi, Naga, Mizo hills, and the Meghalaya plateau with Garo, Khasi, and Jaintia hills.

Difference between Western Himalayas and Eastern Himalayas

Parameters	Western Himalayas	Eastern Himalayas
Extent	Stretch from the Indus River in the west to the Kali River in Nepal, covering the northwestern part of the Himalayas.	Extend from the Tista River in the west to the easternmost reaches of the Himalayas.

Student Notes:

Gradient	Features a gradual ascent from the plains, with higher ranges situated further from the plains.	Rises abruptly from the plains, with peaks such as Kanchenjunga situated close to the foothills.
Precipitation	Receives relatively less rainfall, about one-fourth of what the Eastern Himalayas experience.	Receives high rainfall, resulting in dense forest coverage throughout the region.
Vegetation	Predominantly consists of Coniferous Forests and Alpine Vegetation, adapted to drier conditions.	Dominated by Evergreen Forests along the foothills, Temperate Broadleaf Forests, and Alpine Forests, thriving in the moist climate.

Biodiversity
Has
lower
biodiversity
compared to the Eastern
Himalayas due to less varied
forest types.
Boasts high biodiversity, including Tropical
Evergreen Forests, and is recognized as a
Biodiversity Hotspot in India.

Major Land Use Changes in the Himalayas in Recent Years

The Himalayan region is undergoing rapid and significant land use transformations driven by a variety of human-led activities. These changes range from deforestation and the expansion of terraced farming to unchecked urbanization and the development of large-scale infrastructure projects.

- Deforestation: Forests, particularly at lower altitudes, have been significantly reduced. For example, the Kumaon region in Uttarakhand, India, has lost much of its forest cover due to timber extraction and land conversion.
- Agricultural Expansion: Forests have been cleared for terraced farming. In Himachal Pradesh, India, areas like Kullu and Mandi have seen forest loss for agricultural use.
- Urbanization: Towns and cities have expanded into previously undeveloped areas. Dharamshala, India, is a case where urban growth has encroached on forest land.
- Infrastructure Development: Roads, hydroelectric projects, and tourist facilities have altered land use. In Sikkim, India, projects like the Teesta hydroelectric plant have impacted land patterns.
- Pasture Degradation: Overgrazing has led to pasture loss. In Uttarakhand, India, high-altitude meadows like Bugyals are suffering from soil erosion and vegetation loss.
- Abandonment of Traditional Agricultural Lands: Economic changes and outmigration have led to the neglect of traditional farmlands. Sikkim, India, shows how remote villages are seeing abandoned agricultural areas

How do the Himalayas influence the climate in South Asia?

- Differential Heating: Temperature contrasts between the Himalayas and the Indian Ocean influence the reversal of wind patterns, crucial for monsoon onset and retreat.
- Obstruction of Winds: The Himalayas block the northward movement of monsoon winds, causing them to rise and cool, leading to heavy rainfall in the Indian subcontinent.
- Protection from Cold Air: They block cold Central Asian winds, maintaining warmer temperatures that support monsoon circulation.
- Jet Streams Influence: The Himalayas affect the subtropical jet streams, impacting the timing and intensity of the monsoon.

Student Notes:

Shrinking Himalayan Glaciers

In recent decades, these glaciers have been melting at an accelerated pace, becoming both a consequence of global climate change and a trigger for new environmental crises, particularly in the Indian subcontinent.

- ISRO & Wadia Institute of Himalayan Geology have confirmed that over 80% of monitored glaciers are retreating, with smaller and lower-altitude glaciers shrinking more rapidly.

Key Causes of Glacial Retreat

Rising Global Temperatures
Changing Precipitation Patterns
Anthropogenic Pressure

The Himalayas are warming at ~0.3°C per decade, faster than the global average.
Even a 1.5°C rise (as warned by IPCC) could cause the loss of ~36% of glacier volume by 2100.
Glaciers rely on winter snowfall for accumulation. But changing monsoon dynamics have reduced snowfall and increased rainfall at higher altitudes, hastening melting.
Infrastructure (e.g., roads, tunnels, hydroelectric dams) and tourism disrupt glacial ecosystems.
Deforestation in the Himalayan foothills reduces local cooling and snow retention.

Impacts

- River Discharge Variability: Himalayan glaciers feed major perennial rivers like Ganga, Yamuna, Satluj, and Teesta.
  - Initially, melting increases discharge and flooding; eventually, rivers face reduced base flow, especially during dry seasons.
- Groundwater Recharge Decline: Glaciers support stream-aquifer interactions, which help replenish alluvial aquifers in Indo-Gangetic plains.
  - Reduced glacial flow decreases natural recharge, worsening India’s existing groundwater crisis—already the world’s largest extractor.
- Irrigation and Food Security Risks: Over 60% of India’s irrigated land depends directly or

indirectly on glacier-fed river systems.

■ Declining flows and increased drought risks threaten cropping patterns, especially rabi crops.

• Hydropower and Energy Disruptions: Melting glaciers cause flash floods and increase sediment load, damaging hydropower infrastructure.

• Urban Water Stress: Cities like Shimla, Srinagar, Dehradun, and Delhi depend on glacier-fed rivers.

■ Decreasing flows can cause seasonal scarcity and conflict over municipal water supply.

4.2. Northern Plains of India

The northern plains are located between south of the Himalayas and north of the Peninsular plateau. These are formed by the deposition of the sediments brought by three main river systems namely: the Indus, the Ganga and the Brahmaputra.

• It is one of the largest and most fertile plains of the world. Major crops such as wheat, rice, sugarcane, pulses, oil seeds and jute are grown here.

Regional Divisions:

1. Categorization based on the dominant river systems:

• Punjab Plains: The western section is shaped by the Indus River and its tributaries—Jhelum, Chenab, Ravi, Beas, and Sutlej—featuring fertile "doabs" between confluent rivers.

Student Notes:

• Ganga Plains: This vast central region stretches between the Ghaggar and Tista rivers, covering Haryana, Uttar Pradesh, Delhi, Bihar, parts of Jharkhand, and West Bengal.

• Brahmaputra Plains: The easternmost section in Assam is shaped by the Brahmaputra River.

2. Sub-regions of northern plains based on Relief Features:

The northern plains can be further distinguished based on their unique topographic features:

• Bhabar: As rivers descend from the Himalayas, they shed coarse pebbles in a narrow belt close to the foothills. This zone, typically 8-16 kilometers wide, is known as the Bhabar. Notably, streams tend to disappear within the Bhabar region.

•

Terai: South of the Bhabar lies the Terai, a region where the vanished streams reappear, creating a characteristically wet, marshy, and swampy area.

- Bhangar: This region forms the most extensive part of the northern plains, consisting of the oldest alluvial deposits. Bhangar lies above the floodplains, resembling elevated terraces. The soil here, known locally as "kankar," is rich in calcium carbonate.
- Khadar: The fertile floodplains formed by younger alluvium are called Khadar. The soil in this region is renewed periodically by floods, leading to its exceptional fertility.

Significance of the Northern Plains

- Agricultural Productivity: The Great Plains have fertile alluvial soil, making them a prime agricultural region. For instance, around 50% of India's wheat and more than 90% of its rice are grown in these plains.
- High Population Density: This region is one of the most densely populated in India, with states like Punjab, Haryana, Uttar Pradesh, Bihar, and West Bengal having large populations due to the fertile land and abundant water resources.
- Economic Significance: The Great Plains support a variety of industries, including textiles and food processing. Their flat terrain and navigability make it easier to develop infrastructure like roads and railways, which further enhance economic growth.
- Cultural and Historical Importance: The plains have been central to Indian civilization, with cities such as Delhi and Kolkata having historical significance. The sacred Ganges River enhances the region's cultural and religious importance.

Why is the eastern northern plain wider than the western plain?

- River Systems and Sediment Load: The Ganga-Brahmaputra river system in the east carries more water and sediment because these rivers have longer courses. This results in extensive sediment deposition, forming a broad floodplain in the east.
- Himalayan Topography and Tectonic: In the Himalayas, the western side has a steep slope, making rivers flow faster and deposit less sediment, leading to a narrower plain. Meanwhile, the eastern Himalayas have experienced more tectonic uplift, creating more sediment, which helps form a wider plain.
- Climatic Factors: Additionally, the eastern region receives more rainfall, which increases erosion and the amount of sediment rivers can transport and deposit, further expanding the plains.

Student Notes:

Floods in the Northern Plain

Flooding is a recurring issue in the Great Northern Plain, especially in states like Bihar, Uttar Pradesh, and Assam. Several factors contribute to flooding in this region:

1. Monsoonal Rains: The heavy monsoon rains significantly increase the water levels in rivers, leading to overflow and flooding.
2. Sediment Deposition and River Dynamics:
   a. Major rivers like the Ganga, Brahmaputra, and their tributaries often carry high sediment loads, which form sandbars and raise riverbeds.
   b. This reduces the rivers capacity to hold water, causing them to overflow, change course. This leads to widespread flooding and displacement, as seen with the Kosi River in Bihar.
3. Anthropogenic causes:
   a. Unscientific River Management: Lack of proper river management, including inadequate

dredging and embankment maintenance, contributes to flooding.
b. Deforestation: In the catchment areas, deforestation reduces the land's ability to absorb rainwater, increasing runoff into rivers.
c. Encroachment on Riverbeds: Construction and settlements on riverbeds obstruct the natural flow of water, aggravating floods.
d. Urbanization: Rapid urbanization leads to increased impervious surfaces, reducing infiltration and accelerating runoff.

Mitigation Measures and Government Efforts

Government efforts to mitigate floods involve both structural and non-structural measures which are as follows:

- Structural Measures: The Flood Management Programme (FMP), launched during the XI Plan, including anti-erosion and embankment construction.
- Non-Structural Measures: Flood forecasting and early warning by CWC and IMD, flood zoning, and afforestation are part of strategies, as per NDMA guidelines
  - Recent initiatives include the MISHTI Initiative (2023-24) for mangrove plantation to manage coastal floods, and the InterLinking of Rivers (ILR) programme, e.g., Ken-Betwa project.
  - NDMA conducts awareness campaigns and training, but only 7% of dams have Emergency Action Plans, per CAG report, indicating gaps
- International Cooperation: Data sharing with Nepal for Kosi and China for Brahmaputra is crucial, though implementation challenges persist, as noted in transboundary river discussions

Brahmaputra Floods

The Brahmaputra, flowing through Assam, floods annually due to heavy monsoon rainfall (70% in four months), Himalayan snowmelt, and high sedimentation, with its basin receiving intense rains, as per NDMA reports.

- Climate change intensifies rainfall, with 2024 floods showing 436% above normal in some areas, as per research.

Student Notes:

Impacts: It affects 40% of Assam’s arable land, leading to crop damage, displacement of millions, and economic losses estimated in billions annually, with historical floods like 2012 and 2017 causing significant devastation.

Urban Flooding in India
Urban flooding differs from rural flooding by not only heavy rain but also unplanned urbanization, which can increase flood peaks by 1.8 to 8 times and flood volumes by up to 6 times.
Causes of Urban Flooding

- Climate Change and Extreme Weather Events: The IPCC 2023 report confirms that global warming is causing more intense monsoon rains in South Asia.
- Rapid Urbanization and Poor Planning: Led to encroachment on natural drainage systems and floodplains → Increase in impervious surfaces → reduces natural water infiltration. For ex., Bengaluru Floods (2022).
- Outdated Drainage Systems: Designed for lower rainfall intensities. Example: Mumbai's drainage system can handle only 25 mm of rain per hour.
- Environmental Degradation: Loss of water bodies and wetlands that act as natural flood buffers.
  - Encroachment of 300 inland water bodies, illegal construction → Chennai Floods.
- Unplanned Dam Releases: Sudden water releases from dams, like in Chennai 2015, can cause flooding without adequate warnings.

Way Forward

- Build Climate-Resilient Infrastructure (SDG 11): Design infrastructure to withstand climate impacts.
- Improve Drainage Systems: Regular monsoon audits and investment in drainage infrastructure, like Tamil Nadu's Tirupugazh Committee, are crucial.
- Develop Green Infrastructure: Use wetlands and other green solutions for natural flood

defence and environmental benefits.

- Flood Plain Mapping: Create detailed flood maps to enhance management and community awareness. For ex., Chennai (C-FLOWS) for Flood warning system for heavy rain.
- Adopt Rainwater Harvesting: Integrate RWH systems into construction → Construct Bioswales → launch of the "Bengaluru Water Solutions" campaign.

Global Best Practices

- Sponge Cities (China): Aims to absorb and reuse 70% of rainwater → Implemented in 30 cities, including Wuhan and Xiamen
- Room for the River (Netherlands): Gives rivers more space to manage higher water levels.
- Tokyo's Underground Discharge Channel: World's largest underground flood water diversion facility → Significantly reduced flood risks in metropolitan Tokyo.

Student Notes:

India's Urban Wetlands: A Call for Urgent Protection

India has lost nearly a third of its natural wetlands over the last three decades to unsustainable urbanization, illegal construction, and pollution. The loss in major cities is staggering: Chennai has lost 90% of its wetlands, Mumbai 71%, Bengaluru 56%, and the Delhi-NCR 38%.

Why Wetlands Matter?

- Wetlands are biodiversity hotspots that provide essential resources and ecosystem services.
- They are crucial for water security, acting as a source of food and water, and recharging groundwater.
- They act as natural sponges, providing flood moderation, storm protection, and erosion control.
- They are critical for climate regulation, purifying water and storing vast amounts of carbon.

Recent Initiatives to protect the wetlands

- The National Mission for Clean Ganga has formulated a toolkit for managing urban wetlands and water bodies.
- The Union Ministry of Jal Shakti has launched a program to develop health cards and management plans for wetlands in over 50 Ganga districts.
- Delhi's draft Master Plan 2041 proposes to protect and develop an integrated network of 'green and blue assets' (wetlands and green spaces).

4.3. Thar Desert

The Thar Desert, also known as the Great Indian Desert, is located along the western margins of the Aravalli Hills. Characterised by shifting sand dunes and barchans, the desert extends into the Indian states of Rajasthan and Gujarat.

The region has a semi-arid to arid climate, with annual rainfall of less than 150 mm. Vegetation is sparse, primarily consisting of thorny bushes and shrubs, with the Luni

River as the main river system.
Features Contributing to the Formation of the Thar Desert
The location of the Thar Desert in the western part of India is primarily influenced by several geographical factors:
1. Rain Shadow Effect: The Aravalli Mountains run in a southwest to northeast direction, blocking the moisture-laden winds coming from the southwest monsoon. This results in very little rainfall reaching the Thar region.
2. Proximity to the Tropic of Cancer: The Thar Desert is situated close to the Tropic of Cancer, which results in high temperatures and low humidity. This geographical position contributes to the high evaporation rates and limited precipitation, both characteristic of desert climates.
3. Atmospheric Circulation: The prevailing wind patterns in the region, which include the northeast trade winds and dry westerlies, contribute to the arid conditions by bringing dry air and limiting moisture.

Student Notes:
Thar Desert's Expanding Boundaries and Associated Land Degradation
Several studies have predicted that sandstorms from the Thar Desert will eventually reach the National Capital Region (NCR).
- Destruction of Aravali Ranges
  - Unchecked Mining Activities: Extensive mining in the Aravali hills has led to their gradual destruction. The Aravalis act as a natural barrier, preventing the spread of desert sands towards the east.
  - Deforestation: Clearing trees for fuel, timber, and agriculture reduces soil stability.
- Changing Rainfall Patterns: Alterations in rainfall distribution have resulted in less precipitation in the region, exacerbating arid conditions.
- Agricultural Practices:
  - Unscientific and intensive agricultural practices degrade the soil quality and lead to the loss of vegetation cover.
  - Overexploitation of Groundwater: Depletion of water resources causes land to become arid.
- Spread of Sand Dunes
  - Uncontrolled Movement: Lack of mechanisms to control the spread of sand dunes allows them to encroach upon fertile land, furthering desertification.

The Great Green Wall of India
This is an ambitious initiative to create a 1,400 km long and 5 km wide green belt from Gujarat to the Delhi-Haryana border. It is a proposed ecological barrier designed to combat the growing threat of desertification.
Significance of the project
- Halting Desertification: The primary goal is to create a massive green barrier that will prevent the Thar Desert from expanding further east, protecting fertile agricultural lands in Rajasthan, Haryana, Punjab, and Uttar Pradesh.
-

Restoring the Aravalli Ecosystem: The project aims to rejuvenate the degraded Aravalli hills through large-scale afforestation using native species. This will help restore the region's biodiversity, improve soil health, and recharge depleted groundwater tables.

- Combating Climate Change: The vast green belt will act as a significant carbon sink, absorbing millions of tonnes of carbon dioxide and helping India meet its climate goals.

In essence, the Great Green Wall is India's ambitious ecological defence against desertification and land degradation.

4.4. The Peninsular Plateau

Peninsular plateau is a triangular shaped table land. It is part of ancient land mass called Gondwana level. It covers an area of nearly 5 lakh sq.km. It is spread over the states of Gujarat, Maharashtra, Bihar, Karnataka and Andhra Pradesh.

River Narmada divides the peninsular plateau into two parts:

(i) The central highlands and

(ii) Deccan Plateau

Student Notes:

Central Highlands

Deccan Plateau

- Lies north of the Narmada River.
- Includes Malwa Plateau, Bundelkhand, Baghelkhand, and Chotanagpur Plateau.
- Slopes towards the north and east, forming the watershed of many rivers.
- Lies south of the Narmada River.
- Composed of Deccan Traps (Basaltic lava flows).
- Includes plateaus of Maharashtra, Karnataka, Telangana, and Andhra Pradesh.
- Slopes eastward, making the rivers Godavari, Krishna, and Kaveri flow towards the Bay of Bengal.

Why Chotanagpur Plateau is Rich in Minerals?

The Chotanagpur Plateau, often called as the 'Ruhr of India', owes its immense mineral wealth to its ancient and complex geological history.

- Rock Composition: The area is dominated by metamorphic and igneous rocks. These rock types are often associated with various mineral deposits.
- Geological History: It has undergone multiple cycles of geological activities, including

metamorphism and magmatism, which are conducive to mineral formation.

- Weathering and Erosion: Long periods of weathering and erosion have exposed mineral-rich rock layers. This process has also led to the concentration of certain minerals in placer deposits.
- Coal Formation: During the Carboniferous period (359-299 million years ago), dense forests in the Chotanagpur region were buried under sediments. Over millions of years, heat and pressure transformed this plant matter into the coal deposits found today.

Formation and Features of the Meghalaya Plateau

- The Meghalaya Plateau extends from the Deccan Plateau and was shaped by the north-eastward movement of the Indian plate during the formation of the Himalayas.
- This movement created a fault between the Rajmahal Hills and the Meghalaya Plateau, forming the Malda Gap, which is a significant lowland area that allowed for the depression to be filled by river sediments.
- Like the Chotanagpur Plateau, the Meghalaya Plateau is rich in minerals such as coal, iron ore, sillimanite, limestone, and uranium.
- The Meghalayan Plateau is a part of the Peninsular Plateau because it is composed of the same ancient granites and gneisses, which are structurally separated from the main block by the Malda Gap—a down-faulted trough filled with recent river sediments.

Deccan Plateau's Stability Compared to the Himalayas

1. Less Tectonic Activity: The Deccan Plateau is made of ancient, solid volcanic rock, which makes it stable, whereas the Himalayas are still forming due to ongoing tectonic collisions.
2. No Major Fault Lines: The Deccan plateau lacks major active fault lines, while the Himalayas have significant fault zones that cause frequent seismic activity.
3. Thicker Crust: The Deccan Plateau has a thicker, more rigid crust, whereas the Himalayas have a thinner and more dynamic crust.

4.4.1. The Western and Eastern Ghats

The Western and Eastern Ghats are two prominent mountain ranges that flank the Peninsular Plateau of India, running along the western and eastern coasts, respectively. These ranges play a crucial role in shaping the climate, drainage, and biodiversity of the region.

Student Notes:

Aspect	Western Ghats	Eastern Ghats
Location Structural Features	Characterized by a continuous escarpment with steep slopes and numerous passes (ghats) facilitating east-west movement.	Broken into discontinuous ranges due to erosion by major rivers like the Mahanadi, Godavari, Krishna, and Kaveri.
Elevation	Average elevation around 1,000 meters, with peaks like Anai Mudi	

(2,695 meters) in Kerala being the highest.
Average elevation is around 600 meters, with peaks like Arma Konda (1,690 meters) in Andhra Pradesh being the highest.
Climate
Receives heavy rainfall on the western slopes due to orographic lift, leading to tropical and subtropical moist broadleaf forests.
Receives less rainfall, resulting in dry deciduous forests and a drier climate compared to the Western Ghats.
Biodiversity
Recognized as one of the world's eight "hottest hotspots" of biological diversity, hosting numerous endemic species due to varied climatic conditions and habitats.
Less rich in biodiversity with fewer endemic species compared to the Western Ghats, attributed to its drier climate and fragmented habitats.

4.5. Coastal Plains of India

The coastal plains in India run parallel to the Arabian Sea & Bay of Bengal along the Peninsular Plateau.

Student Notes:
West Coast Plains Vs East Coast Plains
West coast plains
East coast plains

- The Western Coastal Plains are Formed by rivers like Narmada, Tapi, and Sabarmati.
- It is Divided into Kachchh, Kathiawar, and Konkan coast.
- The Eastern Coastal Plains are formed by Ganga, Brahmaputra, Mahanadi, Godavari, Krishna, Kaveri.
- It is Divided into Utkal, Northern Circars, and Coromandel Plains.
- Submerged coastal plains can be found throughout the western coast as steep gradients and subsidence of western part of deccan plateau which can lead to faster erosion and less sediment accumulation along the shore.
-

The eastern coastal plain is broader and represents an emerging coast as rivers flowing from the interior of the continent deposit sediments along the coast, building up broad alluvial plains.

- Except for the Malabar Coast in the south, the Western Coastal Plain is unsuitable for agriculture.
- Due to the alluvial soil, the Eastern Coastal Plain is quite fruitful.
- Less Vulnerable to coastal erosion and cyclones as compared to the east coast.
- Vulnerable to tropical cyclones and flooding

Vulnerability of Indian coastline to erosion

The National Centre for Coastal Research (NCCR) has monitored Indian coastal areas from 1990-2018 and they have found that 33.6 percent of the Indian coastline is vulnerable to erosion.

Impact of Coastal Erosion:

- Land and Infrastructure Loss: Erosion eats away at land, causing the loss of valuable real estate, agricultural fields, and critical infrastructure.
- Ecosystem Degradation: Erosion damages coastal ecosystems like mangroves, coral reefs, and seagrass beds.
- Increased Vulnerability: Eroded coastlines become more susceptible to the damaging effects of cyclones, storm surges, and tsunamis.
- Saline water intrusion: Erosion can lead to saltwater intrusion into freshwater aquifers, contaminating drinking water supplies and affecting agriculture.

Resource Potential of India's Coastal Plains

The coastal plains of India possess a wide array of resources crucial for the nation's economy. These range from fertile deltas supporting agriculture and vast fishing grounds to significant mineral and energy reserves.

- Agriculture: The fertile alluvial deltas support a highly productive agricultural base, especially for rice cultivation.
- Fisheries: The long coastline with its numerous backwaters and estuaries sustains a massive fishing and aquaculture industry.
- Minerals & Energy: The plains hold significant resources like offshore oil and gas reserves, and valuable beach sand minerals like monazite (a source of thorium).
- Trade & Ports: The coastline is ideal for maritime trade, hosting major ports that handle the majority of India's international commerce.

Geographical Reasons for Fewer Natural Harbours on the Eastern Coast
1. Coastal Configuration
■
The eastern coast along the Bay of Bengal is relatively straight and smooth, limiting natural harbors like Chennai's artificial port, which needs extensive infrastructure.
■
In contrast, the western coast has natural indentations and estuaries, with Mumbai's port benefiting from these geographic features.
2. Continental Shelf
■
The eastern coast has a wide, gently sloping continental shelf, resulting in shallower waters that require extensive dredging for deep-water harbors like Kolkata.
■
The western coast has a narrower shelf that quickly drops into deeper waters, allowing natural harbors like Mormugao in Goa to accommodate large ships closer to shore.
3. River Mouths and Sedimentation
■
The eastern coast, with major rivers like the Ganges and Godavari, deposits large amounts of sediment into the Bay of Bengal, creating extensive deltas and shallow waters, causing silting issues at ports like Kolkata.
■
On the other hand, the western coast has fewer large river deltas, resulting in less sediment and deeper waters, which benefits ports like Cochin.
4. Cyclonic Activity
■
The eastern coast is highly vulnerable to cyclones from the Bay of Bengal, which cause erosion and damage, making it difficult to maintain natural harbors, as seen with the Odisha coast.

■
In contrast, the western coast experiences fewer cyclones, resulting in more stable natural harbors, such as the port of Mangalore, which faces fewer disruptions.
The implication of the absesnce of natural harbours on the eastern coasts is that the development of maritime trade and infrastructure on the East Coast has required significant human intervention and massive capital investment.
It necessitates the creation of artificial harbors and a continuous financial commitment to dredging and maintenance to keep the ports operational, shaping India's port development strategies and trade logistics.
4.6. Drainage system of India
The movement of water through well-defined channels is referred to as drainage. The geological history, type, and structure of rocks, as well as the terrain, slope, and other factors, all affect how a river drains.

Himalayan vs Peninsular drainage system
Feature
Himalayan Rivers
Peninsular Rivers
Origin
Originate from glaciers and snow-

capped peaks of the Himalayan and
Karakoram
ranges
(e.g.,
Ganges,
Yamuna)
Originate from lower elevations of
the Western Ghats, Vindhya-Satpura
ranges, and central highlands (e.g.,
Godavari, Krishna)
Flow
Perennial, with substantial water flow
year-round due to melting snow and
glaciers
Seasonal, primarily dependent on
monsoon rains, often drying up
partially in summer (e.g., Tapi, Mahi)
Nature of
Valley
Deep, V-shaped valleys with steep
gradients, often forming gorges (e.g.,
Rishikesh-Gangotri)
Broad, U-shaped valleys with gentle
slopes and mature profiles (e.g.,
Godavari Basin)
Drainage
Pattern
Typically dendritic (tree-like) or trellis
patterns (e.g., Ganges Basin)
Often rectangular, trellis, or radial
patterns (e.g., Krishna Basin)
Sediment
Load
High sediment load, carrying large
amounts of
silt
and
sand
(e.g.,
Brahmaputra)
Lower sediment load, mostly carrying
finer sediments (e.g., Tapi)
River
Course
Long courses, traveling great distances
across the Indo-Gangetic plains.
Shorter courses, often flowing into
the Bay of Bengal or the Arabian Sea.

Why do the Western coast has more estuaries and fewer river deltas?

The predominance of estuaries over deltas in the Western Ghats is primarily due to the unique geological and climatic conditions of the region.

- Nature of rivers: The rivers that originate in the Western Ghats do not have a long course to travel, and they quickly reach the sea. As a result, they do not have enough time to deposit sediments and form a delta.
- Coastline: The coastline of the Western Coastal Plain is characterised by a steep gradient,

and there are no shallow bays where rivers can deposit their sediments. The steep coastline also results in strong wave action, which prevents the formation of a delta.

- Tidal influence: The Arabian Sea experiences a high tidal range, which prevents the formation of a delta by constantly moving the sediments away from the river mouth.
- Geological factors: The Western Coastal Plain is a region that is characterised by hard rocks that do not erode easily. As a result, there are no loose sediments available for the rivers to deposit and form a delta.

Transboundary Water Disputes in Himalayan Rivers

The Indus, Ganges, and Brahmaputra rivers, originating in the Himalayas, are crucial lifelines for India, supporting agriculture, hydropower, and the livelihoods of millions. Their transboundary nature, however, often leads to complex disputes among riparian nations.

Key Transboundary River Disputes:

- Indus (India-Pakistan): Governed by the Indus Waters Treaty (1960), which dictates water sharing. Despite the treaty, disputes persist over water use and the construction of dam projects, impacting bilateral relations.
- Teesta (India-Bangladesh): Disputes primarily revolve around India's upstream water diversion projects and Bangladesh's demand for a larger share of the river's flow,

Student Notes:

especially during the dry season.

- Brahmaputra (India-China): China's upstream dam projects on the Brahmaputra are a significant concern for India. These projects raise potential impacts on downstream water flow and availability in India and Bangladesh.

Implications of These Disputes:

These transboundary water disputes carry significant ramifications, extending beyond mere water sharing:

- Geopolitical Rivalries: Water disputes often intensify India’s strategic concerns, particularly with Pakistan and China, adding another layer to existing geopolitical complexities.
- Diplomacy and Regional Cooperation: The management of water-sharing agreements profoundly influences the scope of regional cooperation and bilateral negotiations between riparian states.
- National Security: Control over and access to water resources are increasingly tied to national security and stability, making water a strategic asset.
- Environmental Impact: Climate change exacerbates these issues by affecting water availability and increasing the risks of both floods and droughts, intensifying the strain on shared resources.
- Social Impact: Rising population pressure across riparian nations further escalates the demand for water, exacerbating competition and potential conflict over limited resources.

4.6.1. Inland water based transport in India

Inland Water Transport (IWT) is the mode of transportation that utilizes India's vast network of rivers, canals, and backwaters for moving cargo and passengers. Under the National Waterways Act, 2016, a total of 111 waterways have been declared as National Waterways (NWs) to boost their development and operationalize them for transport.

Student Notes:

Untapped Potential of Water based transport for India

The development of inland waterways holds immense potential for India's economy and logistics sector:

- Cost-Effective and Fuel Efficient: IWT is the most economical mode for bulk transport. The cost per tonne-kilometre is significantly lower compared to railways and road transport.
- Environmentally Friendly: This mode is far less polluting and more fuel-efficient compared to road and rail.
- Decongestion of Infrastructure: Shifting cargo to waterways can significantly reduce the burden on India's overcrowded road and rail networks, decreasing traffic congestion and logistics bottlenecks.
- Balanced Regional Development: Developing National Waterways can provide crucial connectivity to remote and landlocked regions. For example, NW-1 (Ganga) from Haldia to Varanasi enhances trade access for northern states.

Barriers to the Growth of Water-Based Transport in India’s River Systems

1. Geographical Limitations: Many Indian rivers have a variable flow, with significant seasonal variations due to the monsoon. This makes navigation unpredictable and challenging.
2. Silting and Sedimentation: Many rivers in India are prone to silting and sedimentation, which can obstruct navigation channels and require regular dredging. This maintenance is costly and often neglected.
3. Competition from Road and Rail: India's road and rail networks are more developed and widely used for freight and passenger transport. These modes are often faster and more reliable, reducing the demand for water transport.
4. Infrastructure Deficiency: There is a lack of adequate infrastructure, such as ports, docks, and navigation aids, which are necessary for efficient water transport.
5. Environmental Concerns: Preserving river ecosystems is often prioritized over developing navigation channels.

Watershed

It is a natural drainage basin where all surface water converges.

A watershed acts as a single, interconnected geo-hydrological unit for the management of land and water resources.

Benefits of Watershed Management

Proper management of a watershed provides significant environmental and economic benefits:

- Water Conservation: It enhances rainwater harvesting and increases groundwater recharge, improving water availability for drinking and irrigation, especially in rainfed areas.

- Soil Health: By implementing measures like contour bunding and afforestation, it controls soil erosion, prevents land degradation, and improves soil fertility.
- Increased Productivity: Improved soil and water resources lead to higher agricultural productivity, crop diversification, and increased farm incomes.
- Ecological Restoration: It helps restore ecological balance by regenerating vegetation, which in turn supports biodiversity and creates a more resilient ecosystem against climate shocks like droughts and floods.

Watershed Development Programmes in India

- Integrated Watershed Management Programme (IWMP): Launched in 2009, this programme integrated the various earlier schemes into a single, unified approach.

  - Its core objective was to restore ecological balance by harnessing, conserving, and developing degraded natural resources with a strong focus on community participation.
- Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) - Watershed Development Component (WDC): In 2015, the IWMP was amalgamated into the larger PMKSY (Pradhan Mantri Krishi Sinchai Yojana) scheme.

4.6.2. Interlinkage of Rivers

The interlinking of rivers in India aims to balance water distribution by redirecting excess water from flood-prone areas to drought-affected regions, addressing both floods and droughts.

Benefits of the Interlinking of rivers

- Water and Agriculture Benefits: River interlinking balances water availability by transferring surplus water to drought-prone areas, enhancing agricultural productivity. For example, the Ken-Betwa link aids Bundelkhand, and the Indira Gandhi Canal has turned desert land in Rajasthan into fertile farmland.

- Hydroelectric Power: Building dams and reservoirs as part of the project can produce hydroelectric power. This can help reduce the use of fossil fuels and support clean energy initiatives.
- Economic Growth through Waterways: Creating inland waterways can improve the movement of goods and boost trade, especially in areas with limited road and rail access. For example, the Ganga-Bhagirathi-Hooghly river system is already used for transporting goods and could be expanded with interlinking.
- Environmental and Flood Control: The project can help manage floods and reduce water pollution and salinity, benefiting local ecosystems. Projects like the Polavaram Dam are designed to prevent flooding while also supporting irrigation and water supply.
- Job Opportunities and Rural Development: Building and maintaining canals and infrastructure can create many jobs, especially in rural areas. This can improve living

standards, reduce migration to cities, and support the economic development of rural communities.

Challenges in the River Interlinking

- Massive Cost and Effort: The project requires a huge amount of money (estimated at Rs. 5.6 lakh crores) and significant engineering expertise to build the canals and structures needed. This raises questions about affordability and feasibility.
- Social Impact and Displacement: Large dams and reservoirs often displace communities living near the rivers. These people would need to be resettled and adequately compensated, causing social disruption.
- Environmental Concerns: Building dams and canals can disrupt ecosystems, harm wildlife habitats, and potentially reduce the flow of freshwater into oceans, impacting marine life. National parks and sanctuaries along the rivers could be affected.
- Flood Control Doubts: While the project aims to control floods by diverting excess water, some experts question its effectiveness. Past experiences with large dams in India suggest they may not always prevent flooding.
- Interstate and International Disputes: States with surplus water may be hesitant to share it with others, leading to conflicts. Additionally, the Himalayan component of the project could impact neighboring countries like Bangladesh, requiring international agreements.

National River Linking Project

Plan envisages the transfer of water from water surplus basins where there is flooding to water-deficit basins.

The two components of the project are:

1. Himalayan Component
2. Peninsular Component

Himalayan Component has 14 projects in the pipeline:

- Storage dams are to be constructed on the rivers Ganga and Brahmaputra and their tributaries.
- Linking of ganga and Yamuna
- Connecting Brahmaputra and ganga basins to the Mahanadi basin.
- Connecting eastern tributaries of the Ganga with the Sabarmati and Chambal river systems.

Peninsular Component projects linking 16 rivers in southern India:

- Surplus water from Mahanadi and Godavari will be transferred to Krishna, Kaveri, Pennar, and Vaigai rivers.
- Linking Mahanadi and Godavari river basins to Kaveri, Krishna, and Vaigai river systems.
- The project connects the Ken and Betwa Rivers and links the Parbati and Kalisindh Rivers to the Chambal River to enhance water distribution in these areas.

Student Notes:

4.7. Islands of India

India has two main group of islands:

1. Andaman and Nicobar archipelago in the Bay of Bengal - Andaman and Nicobar Islands were

formed due to a collision between the Indian Plate and Burma Minor Plate.

2. The Lakshadweep Islands in the Arabian Sea - Lakshadweep Islands are coral islands. These islands are part of reunion hotspot volcanism.

4.7.1. Andaman and Nicobar group of islands vs Lakshadweep islands

Feature	Lakshadweep Islands	Andaman and Nicobar Islands
Formation	Formed by coral activity on volcanic tops of the Indian Ocean ridge.	Formed by the collision of the Indian plate with the Burma plate.
Relief features	Extremely low elevation (up to 5 meters above sea level), lacking hills and valleys.	Characterised by peaks and valleys (e.g., saddle peak), with waterfalls (e.g., rangat, whisper wave).
Drainage	Lacks significant rivers and lakes due to low elevation and porous terrain.	Includes several rivers (e.g., Kalpong) with various drainage patterns.
Climate	Tropical wet and dry or savanna climate (Koppen classification:Aw).	Tropical monsoon climate (Koppen classification: Am).
Precipitation	Receives 100-200 cm of rainfall annually.	Receives 300-350 cm of rainfall mainly from the southwest monsoon.
Soil types	Coral limestone-derived soils: coral sands, lagoonal sands, and mud.	Varied soils: heavy clayey, clayey loams, loams, sandy loam, and marine alluvium.

Strategic importance of island territories of India

For a maritime nation like India, its island territories are not peripheral lands but crucial strategic assets.

- Control over Global Chokepoints: The islands give India direct oversight of the world's most critical Sea Lanes of Communication (SLOCs).

■
For example-The Andaman & Nicobar Islands dominate the approaches to the Malacca Strait in the east, while the Lakshadweep Islands monitor the Nine Degree Channel in the Arabian Sea.
•
Forward Military Power Projection: They serve as natural, unsinkable aircraft carriers that extend India's military reach.
■
For example- The Andaman and Nicobar Command (ANC), India's only tri-service command, is a pivot to project power into Southeast Asia
•
Geo-Economic and Diplomatic Leverage: The islands provide India with a vast Exclusive Economic Zone (EEZ), rich in marine and potential energy resources. They are also key to India's foreign policy ambitions, with the A&N; Islands being central to the 'Act East' Policy for engaging with ASEAN nations.
4.8. Natural Vegetation of India
India's natural vegetation is a reflection of its diverse climatic conditions, topography, and soil types, resulting in a rich tapestry of flora across the country.

Student Notes:
4.8.1. Types of Vegetation in India
Forest Type
Distribution
Rainfall and Specific
Details
Flora and Fauna
Moist Tropical Forests
Tropical Wet
Evergreen
Western Ghats,
Andaman & Nicobar
Islands, NE India
200-400 cm; High
biodiversity; dense
undergrowth
Mahogany, Rosewood;
Elephants, Tigers, Various
birds and insects
Tropical Semi
Evergreen
NE India, Western
Ghats, Eastern coast
150-250 cm; Mix of
evergreen and
deciduous
vegetation
Evergreen and deciduous
trees like Sal, Teak;
Leopards, Deer, Various
birds
Tropical Moist
Deciduous

Central India
(Madhya Pradesh,
Odisha, Chhattisgarh)
100-200 cm; Trees
shed leaves during
dry season
Sal, Teak, Bamboo; Sloth
bears, Wild boars, Various
birds
Littoral and
Swamp
Sunderbans,
Andaman Islands
>200 cm; Coastal
and swamp
ecosystems; highly
productive
Mangrove species like
Sundari, Rhizophora;
Saltwater crocodiles,
Mudskippers, Migratory
birds
Dry Tropical Forests
Tropical Dry
Evergreen
Tamil Nadu, Andhra
Pradesh
80-150 cm; Adapted
to dry conditions;
drought-resistant
species
Ebony, Palmyra palm;
Jackals, Various reptiles
Tropical Dry
Deciduous
Rajasthan, Gujarat,
UP
70-120 cm;
Deciduous trees
shed leaves to
conserve water
Babul, Acacia, Tendu; Deer,
Wild boars, Various birds
Tropical Thorn
Rajasthan, Gujarat
20-80 cm; Extremely
arid conditions;
adapted to low
water
Cacti, Thorny shrubs;
Indian gazelle, Foxes,
Various reptiles
Montane Forests
Sub-tropical
Broad-leaved
Hill
Eastern himalayas,

Western Ghats
120-250 cm; Found
at lower elevations;
diverse vegetation
Oak, Rhododendron; Red
panda, Various birds
Sub-tropical
Moist Hill
(Pine)
himalayas, Western
Ghats
150-300 cm;
Dominated by pine;
high rainfall areas
Pine, Deodar; Himalayan
tahr etc.
Sub-tropical
Dry Evergreen
Himalayas, Deccan
Plateau
100-200 cm; Dry
evergreen species;
varied terrain
Oak, Evergreen shrubs;
Leopards etc.
Alpine Forests
Sub-alpine
Higher altitudes of
himalayas
100-200 cm; Found
in high-altitude
areas; hardy
vegetation
Juniper, Rhododendron;
Himalayan ibex, Snow
leopards
Moist Alpine
Higher elevations of
himalayas
>200 cm; High
rainfall; lush
vegetation in alpine
zones
Alpine herbs, Grasses;
Himalayan tahr, Various
high-altitude birds
Dry Alpine
Driest high-altitude
<100 cm; Extremely
Hardy shrubs, Drought-

Scrub
regions of himalayas

dry conditions;
adapted to harsh
climates
resistant grasses; Tibetan
antelope etc.

India State of Forest Report (ISFR) 2023

The India State of Forest Report (ISFR) 2023, published by the Forest Survey of India (FSI), provides a comprehensive assessment of the country's forest and tree resources. This biennial report offers valuable insights into the current status and trends of forest cover across India.

Key Highlights from ISFR 2023:

- Total Forest and Tree Cover: The combined forest and tree cover in India is estimated at 827,357 square kilometres, accounting for 25.17% of the nation's geographical area.
  - Forest Cover: represents 21.76% of India's geographical area.
  - Tree Cover: It accounts for 3.41% of the geographical area.
- Increase in Cover: Since the previous assessment in 2021, there has been an overall increase of 1,445 square kilometers in forest and tree cover. This includes a 156 square kilometer rise in forest cover and a 1,289 square kilometer increase in tree cover.
- States with Largest Forest Cover (Area-wise):
  - Madhya Pradesh: 85,724 square kilometers.
  - Arunachal Pradesh: 67,083 square kilometers.
  - Maharashtra: 65,383 square kilometers.
- Carbon Stock: India's forest carbon stock is estimated at 7,285.5 million tonnes, reflecting an increase of 81.5 million tonnes compared to the previous assessment. This growth contributes to India's commitment to its Nationally Determined Contributions (NDCs) under the Paris Agreement, with the total carbon stock reaching 30.43 billion tonnes of CO■ equivalent, surpassing the 2030 target of an additional 2.29 billion tonnes.

Student Notes:

4.8.2. Mangroves

Salt-tolerant trees and shrubs growing in coastal intertidal zones, forming unique ecosystems crucial for ecological balance and coastal protection.

Global Distribution:

- Present in 118 countries, covering 10-24 million hectares,
- Six main biogeographical regions, primarily in tropical areas.
- India: 0.15% of total geographical area → Key areas: Sundarbans (West Bengal), Bhitarkanika (Odisha), Gujarat coast.

Importance of Mangroves:

→ Coastal protection against storms and erosion → Carbon sequestration and climate regulation → Habitat for diverse flora and fauna → Support for local livelihoods through fishing and tourism.

Threats to Mangroves:

- Climate Change Impacts: Rising temperatures (0.5°C per decade) affecting growth and biodiversity → Sea-level rise challenging mangrove survival → Increasing cyclone intensity → Rising salinity levels.

- Anthropogenic: Deforestation (5% loss from 1989-2009) for agriculture and aquaculture → Pollution from industrial effluents.
- Natural Disasters: Intensifying storms causing erosion and uprooting → Increased flooding affecting oxygen availability.
- Socio-economic: Human-wildlife conflict, especially with Bengal Tigers → Lack of effective disaster management → Spread of waterborne diseases.

Indian Conservation Schemes:

- National Mangrove Committee (established 1976),
- National Afforestation Programme: Includes mangrove restoration.
- Integrated Coastal Zone Management Project: World Bank-supported. for ex, UNESCO World Heritage Sites (e.g., Sundarbans),

- Mangrove Initiative for Shoreline Habitats and Tangible Incomes (MISHTI): aimed at increasing mangrove coverage,
- Green India Mission: Aims to increase forest/tree cover, including mangroves.

Mangroves require integrated conservation approaches balancing ecological preservation with sustainable development, aligning with global and national efforts.

Vulnerability of Indian forests to fires

There is significant increase in fire incidents, with states like Uttarakhand, Odisha, Madhya Pradesh, and those in the Northeast.

Causes of forest fires

- Shifting Cultivation: The practice of 'slash and burn' or Jhum cultivation, especially in Northeast India, is a primary cause.
- Collection of Forest Produce: Fires are often deliberately set by locals to clear the ground for easier collection of non-timber forest products like mahua flowers and tendu leaves, particularly in Central India.
- Negligence: Unattended campfires, carelessly thrown cigarette butts, or sparks from electrical transformers are significant sources of accidental fires.
- Land Clearing & Encroachment: Deliberate fires are sometimes set to clear forest land for agricultural purposes, construction, or other illegal activities.

Effective implementation of the National Action Plan on Forest Fires (NAPFF) is need of hour. Empowering and involving local communities is the most effective measure. Successful models include Van Panchayats in Uttarakhand and Community Forest User Groups, which engage locals in prevention and response.

Student Notes:

4.9. Soils of India

India's diverse climate, topography, and vegetation result in a variety of soil types, which play a significant role in determining agricultural productivity.

4.9.1. Types of soils

Soil type
Distribution
(crops & industrial use)
Alluvial soil
Indo-Gangetic-brahmaputra plains
40% of India's total land area- punjab, haryana, uttar pradesh, bihar, west bengal
Crops: rice, wheat, sugarcane, cotton, jute
Industrial: brick-making, pottery.

Student Notes:

Black cotton soil (regur soil)
Deccan trap: Maharashtra, Madhya pradesh, Gujarat, andhra pradesh
Also in Tamil nadu, Uttar pradesh, Chhattisgarh
Crops: cotton, wheat, jowar, linseed, virginia tobacco, castor, sunflower
Industrial: cement industry
Red soil
Peninsular India: Tamil nadu, Karnataka, Maharashtra, Andhra pradesh, Madhya pradesh, Orissa, Jharkhand
Crops: groundnut, potato, maize, ragi, rice, wheat, sugarcane, pulses
Industrial: brick-making, pottery
Laterite soil
Western ghats, eastern ghats, Rajmahal hills
Parts of Odisha, West Bengal, Andhra pradesh, Kerala, Karnataka, Assam
Crops: cashew, tea, coffee, rubber, coconut
Industrial: construction material (when hardened)
Mountainous or forest soils

Himalayan region, western and eastern
ghats
Forested areas across India.
Crops: temperate fruits, potato,
tea, coffee
Industrial: limited; mostly forest
products
Arid or desert
soil
Rajasthan, northern Gujarat, southern
Punjab, Haryana.
Crops: drought-resistant crops
(pearl millet, sorghum, guar)
Industrial: limited; some
traditional crafts
Saline and
alkaline soil
Arid and semi-arid regions: Rajasthan,
Punjab, Haryana, Uttar Pradesh, Bihar
Coastal areas
Crops: salt-tolerant varieties of
rice, wheat, barley
Industrial: limited due to high
salt content
Peaty and
marshy
soil/bog soil
Kerala,
Coastal areas of Odisha and Oamil nadu
Sundarbans of West Bengal
Crops: paddy, jute
Industrial: fuel (peat),
horticulture

Critical issues with the soils of India

- Widespread Nutrient Deficiency: Nationwide studies show that a majority of soils are deficient in key nutrients like Sulfur (S) and Zinc (Zn).
  - This is like a widespread malnutrition problem for crops, leading to poor yields. In states like Karnataka, the loss of soil organic carbon—a key ingredient for fertile soil—is severely threatening farm productivity.
- Soils Turning Acidic: Factors like heavy rainfall and industrial pollution are making India's soil more acidic, which is harmful to agriculture and the environment.
  - Acidic soil damages crop health and hinders growth. It also causes the soil to release massive amounts of stored carbon into the atmosphere, contributing to climate change. Regions like Assam's tea gardens are prime examples facing this issue.
- Harmful Impact of Pesticides: While used to protect crops, the overuse of chemical pesticides is poisoning the soil across the country. These chemicals can build up in the soil over time, contaminating the land and potentially entering the food chain.

■
A tragic real-world example is from Kerala's Kasaragod district, where the extensive use of the pesticide endosulfan led to long-term soil contamination and severe health issues for the local people.

- Salinization and Alkalinization: Poor irrigation practices, especially in arid and semi-arid regions, combined with high evaporation rates, lead to the accumulation of salts or alkali in the topsoil. This makes vast tracts of land unproductive, a significant issue in states like Punjab and Haryana.

Steps Taken by India to Tackle Soil Issues:

India has initiated several programs and policies to address these critical soil health challenges:

- Soil Health Card Scheme (2015): A flagship program providing farmers with soil nutrient status cards, offering recommendations on the optimal dosage of fertilizers and micronutrients needed for their farms. This directly aims to combat widespread nutrient deficiency and promotes balanced fertilization.
- Neem-Coated Urea (NCU): Introduced to reduce nitrogen loss from urea, improve nitrogen use efficiency by crops, and mitigate negative environmental impacts, thereby addressing nutrient depletion.
- Pradhan Mantri Krishi Sinchayee Yojana (PMKSY): Focuses on "Per Drop More Crop," promoting efficient irrigation methods like micro-irrigation. This helps in combating salinization and waterlogging by preventing over-irrigation.
- National Mission for Sustainable Agriculture (NMSA): Promotes climate-resilient agriculture, including strategies for sustainable soil management, water use efficiency, and soil organic carbon enhancement.

Student Notes:

5. DISTRIBUTION OF KEY NATURAL RESOURCES

Previous year questions (PYQs)

- With growing scarcity of fossil fuels, the atomic energy is gaining more and more significance in India. Discuss the availability of raw material required for the generation of atomic energy in India and in the world. (2013)
- It is said the India has substantial reserves of shale oil and gas, which can feed the needs of country for quarter century. However, tapping of the resources doesn’t appear to be high on the agenda. Discuss critically the availability and issues involved. (2013)
- In spite of adverse environmental impact, coal mining is still inevitable for development.” Discuss. (2017)
- What is water stress? How and why does it differ regionally in India? (2019)
- India has immense potential of solar energy though there are regional variations in its development. Elaborate. (2020)
- The process of desertification does not have climatic boundaries. Justify with examples (2020)
- Can the strategy of regional-resource based manufacturing help in promoting

employment in India? (2021)

- Discuss the multidimensional implications of uneven distribution of mineral oil in the world. (2021)
- Examine the potential of wind energy in India and explain the reasons for their limited spatial spread. (2022)
- Why is the world today confronted with a crisis of availability of and access to freshwater resources? (2023)

PYQs Analysis

UPSC's GS questions on resource distribution reflect a clear trend—not just locating where resources are, but understanding their presence or absence. Topic needs understanding the interlinakges between different resources.

For example:

- Energy Geographies & Transition Challenges: From atomic energy raw material availability (2013) to shale oil and gas potential (2013) and solar and wind energy patterns (2020, 2022).
- Regional Planning & Resource-Based Development: Whether it's resource-led manufacturing for employment generation (2021) or the regional variation in solar potential (2020).

In this document we have discussed the distribution of minerals, water resources and all the important sources of energy in detail. These topics have been linked with probable themes which can be asked in the paper.

5.1. Mineral

A mineral is a natural substance of organic or inorganic origin with definite chemical and physical properties.

Types of Mineral Resources

On the basis of chemical and physical properties, minerals may be grouped under two main categories of metallics and non-metallics which may further be classified as follows :

Student Notes:

5.1.1. Mineral distribution across the world

- Iron Ore: The primary raw material for making steel, iron ore is foundational to global industry and infrastructure. Its largest deposits are found in ancient sedimentary rock formations.
  - The largest producer is Australia. Other major producing countries include Brazil, China, and India.
- Bauxite: The main source of aluminum, bauxite is a sedimentary rock formed over long periods from the weathering of aluminum-rich rocks in tropical and subtropical climates.
  - The world's leading producer is Australia. Significant production also comes from Guinea, China, and Brazil.
- Copper: Essential for electrical wiring, electronics, and construction, copper deposits are often associated with volcanic and tectonic activity along plate boundaries.
  - The top producer is Chile. Other key producing nations are Peru, the Democratic Republic of Congo (DRC), and China.

- Manganese: A critical alloy used to make steel stronger and more resistant to wear. More than 80% of the world's known reserves are in just two countries.
  - The largest producer by a significant margin is South Africa. Other major producers are Australia, Gabon, and China.
- Diamond: The hardest known natural material, valued for both industrial applications and jewelry. Major deposits are found in ancient, stable continental crusts known as cratons, within volcanic pipes called kimberlites.
  - The leading producer by volume is Russia. Botswana, Canada, and the Democratic Republic of Congo (DRC) are also major producers.
- Gold: A precious metal used in jewelry, finance, and electronics. It is found in a wide variety of geological settings, including quartz veins (lode deposits) and river beds (placer deposits).
  - The world's top producer is China. Other significant gold-producing countries include Australia, Russia, and the United States.

Student Notes:

5.1.2. Mineral Resources in India (Mineral Rich Regions)

India has five major mineral belts, each with different mineral deposits and geological formations. Detailed overview:

Mineral Belt	Geological Structure	Mineral Deposits	Key Regions
Northern Belt	Ancient crystalline rocks, primarily from the Precambrian era	Iron ore, Manganese, Bauxite, Coal	Chhotanagpur Plateau (Jharkhand, Odisha, West Bengal, Chhattisgarh)
Central Belt	Deccan Trap and Gondwana rocks	Coal, Iron ore, Manganese	Jharkhand, Odisha, Chhattisgarh, Madhya Pradesh
Southern Eastern Region	Sedimentary rocks and volcanic formations	Iron ore, Manganese, Bauxite, Coal	Odisha, Chhattisgarh, Andhra Pradesh

South Western
Region
Dharwar system of
rocks
Bauxite, Ferrous
metals, Coal
Karnataka, Goa, Uplands
of Tamil Nadu and Kerala
North-Western
Region
Rocks from the
Aravali mountain
range
Sandstone, Granite,
Marble, Gypsum,
Fuller earth
Rajasthan, Gujarat

Student Notes:

5.1.3. Critical minerals

A mineral is labelled as critical when the risk of supply shortage and associated impact on the economy is (relatively) higher than the other raw materials.

India has identified a list of 30 critical minerals essential for its economic growth and technological development. Some of these minerals are Antimony, beryllium, cobalt, copper, graphite etc.

Among these India has sufficient reserves for copper, graphite, rare earths etc. However it is dependent on the imports for Lithium, cobalt, germanium, Indium, Selenium etc.

Student Notes:

How India can secure the supply chain of Critical minerals?

- Accelerate Domestic Mining: India is auctioning critical mineral blocks (e.g., lithium in Jammu & Kashmir, rare earths in Karnataka and Rajasthan) to attract both public and private investment in exploration and extraction.

- Bilateral and Multilateral Agreements: Secure long-term supply through joint ventures, and diplomatic engagement with resource-rich countries such as Australia, Argentina, Chile, and African nations.
  - Example: The Khanij Bidesh India Ltd. (KABIL) joint venture is acquiring stakes in lithium and cobalt mines in Australia and Argentina to ensure steady supply.

Other approach to reduce the supply side risk-

The UK provides another example, focusing on reducing demand for critical minerals through recycling, reuse, and design innovation. The UK's National Engineering Policy Centre recommends halving the country's critical materials footprint by 2040 through:

- Increased recycling and recovery of materials from end-of-life products,
- Reducing the size and material intensity of products (e.g., smaller EV batteries),
- Promoting repair and reuse of electronics.

Key Concerns in Mining critical minerals

- Ecosystem Disruption: Mining for critical minerals often leads to the destruction of natural habitats and landscapes. Additionally, extraction and processing activities can release pollutants, contaminating local soil and water resources and threatening biodiversity.
- Radiation Hazards: Some critical minerals contain radioactive elements, exposing workers to potential health risks during mining and processing.
- Energy-Intensive Processing: Processing many critical minerals requires high-temperature technologies, which are highly energy-demanding. This results in a larger carbon footprint and raises concerns about the sustainability of mineral supply chains.

Student Notes:

Initiatives by Government to Strengthen the Critical Minerals Sector:

- National Critical Mineral Mission (2025): Launched to secure India's clean energy future by ensuring availability of 30 identified critical minerals vital for solar, wind, EVs, and battery storage.
- Amendments to Mines and Minerals Act, 1957: To allow for the mining of critical minerals like lithium, niobium, and rare earth elements (REEs) and auction of 5.9 million tonnes of lithium reserves in J&K.;
- Increased Exploration: The Geological Survey of India (GSI) has taken up 125 projects to explore critical mineral reserves in the country.
- Khanij Bidesh India Ltd. (KABIL) for overseas acquisition (focus on Australia, Argentina, Bolivia).

•
India-Australia critical minerals investment partnership ($5.8 billion commitment).
Lithium deposits in india
Lithium, a critical component for the production of
batteries, particularly for electric vehicles (EVs) and
renewable energy storage.
Distribution of Lithium Deposits
Location
Reserves
Jammu & Kashmir
(J&K;)
Estimated at 5.9 million tonnes.
Rajasthan
Likely larger than J&K;, meeting about 80% of India's lithium demand.
Karnataka
Estimated 14,100 tonnes, additional resources in Marlagalla area.
Other States
Smaller reserves identified in Jharkhand, Andhra Pradesh, and
others.
Case Study: Reasi Lithium Block, Jammu & Kashmir
•
The Reasi Lithium Block in Jammu and Kashmir has 5.9 million tonnes of lithium
reserves, identified by the Geological Survey of India (GSI).
•
At the time of discovery, the Reasi block was considered the seventh-largest lithium
reserve in the world, highlighting its potential strategic value for India’s ambitions in
clean energy and battery manufacturing.

Student Notes:
•
However, the lack of sufficient data on the resource's viability and extraction challenges
led to the annulment of both the first and second auctions, as fewer than three bidders
qualified.
•
To address these issues, GSI is conducting further exploration to assess the deposit's
viability.
Successful mining could significantly reduce India’s lithium import dependence and
support the electric vehicle industry.
5.2. Water Resources
Water is a finite and essential natural resource, yet its availability is uneven across time, space,
and regions. Despite being termed a "blue planet," less than 1% of Earth's water is accessible and
usable for human needs.
Issues related to water resources
•
Urbanization and Land Use Change: Rapid urban growth leads to less land available for water
absorption, increasing runoff and flood risks while reducing groundwater recharge.
•
Surface Water Pollution: Rivers and lakes are polluted by untreated sewage, industrial waste,
and agricultural runoff, compromising water quality and ecosystem health.
■
Examples: The Ganga and Yamuna rivers are among the most polluted, with the Yamuna
in Delhi recording 7,500 coliform bacteria per 100cc of water—far above safe limits.
•
Inefficient Water Use in Agriculture: Outdated irrigation methods waste significant amounts

of water, worsening scarcity and limiting availability for other needs.

■

Example: Agriculture consumes about 80–85% of India's freshwater, but water use efficiency is very low—only 25–35% in conventional irrigation, meaning up to 75% is wasted.

•

Climate Change and Erratic Monsoons: Shifting monsoon patterns result in more frequent droughts and unpredictable water availability, disrupting agriculture and water supply.

■

Example: India's water resources heavily depend on monsoon rains, which are becoming increasingly erratic due to climate change.

•

Groundwater Depletion: Excessive extraction for irrigation and industry is causing groundwater levels to fall rapidly, threatening long-term water security.

5.2.1. Groundwater and its management in India

India is the largest user of groundwater and has the largest area under groundwater irrigation in the world. 87% of extracted groundwater is used in agriculture and 11% is used for domestic purposes.

Key challenges to India's groundwater

•

Over-Extraction and Depletion: One of the primary issues is the unregulated and excessive withdrawal of groundwater, particularly for irrigation purposes.

■

A 2021 CAG report noted that groundwater extraction in India rose from 58% to 63% between 2004 and 2017, surpassing the natural rate of recharge.

•

Gaps in Management and Monitoring: There are significant deficiencies in the systems for managing and monitoring groundwater.

■

Data on groundwater levels is currently gathered manually by technicians only a few times each year, which hampers effective, real-time monitoring and management.

•

Widespread Contamination: According to the Central Ground Water Board (CGWB), portions of nearly 409 districts are affected by fluoride contamination, while parts of 209 districts are impacted by arsenic contamination.

Key Factors behind Groundwater Pollution

•

Industrial Pollution: Discharge of untreated industrial waste (heavy metals, chemicals, solvents) contaminates groundwater.

•

Harmful Agricultural Practices: Excessive fertilizers and pesticides lead to nitrate contamination. Over-extraction for irrigation depletes aquifers and increases salinity.

•

Urbanization & Waste Mismanagement: Sewage leaks, landfill runoff, and industrial effluents pollute shallow aquifers.

•

Climate Change Impact: Altered rainfall patterns and overuse hinder aquifer replenishment, worsening water quality.

•

Institutional and Management Gaps: Multiple agencies and outdated laws (1882 Indian Easement Act) result in fragmented policies and unregulated private wells.

■

Poor data and unclear aquifer boundaries make management difficult.

Steps Taken for Groundwater Management in India

- Atal Bhujal Yojana (ATAL JAL): Focuses on community participation and demand-side interventions for sustainable groundwater management in water-stressed Gram Panchayats across 7 states.
- Jal Shakti Abhiyan: this initiative focused on water conservation and rainwater harvesting in water-stressed districts. It expanded as "Catch the Rain" in 2021, covering all districts nationwide.
- Mission Amrit Sarovar (2022): To create or rejuvenate 75 Amrit Sarovars in every district to enhance water harvesting and conservation.
- "Bhu-Neer" Portal: Provides detailed information on the legal framework for groundwater extraction, including state and national regulations
- National Aquifer Mapping & Management Programme (NAQUIM): CGWB maps major aquifers, creates sustainable use plans.

5.3. Land Resources

Land resources are vital for food production, biodiversity, and human settlement. Globally, about 38% of the world's land is used for agriculture, with cropland and pastures covering over 48 million square kilometers. However, up to 40% of land is degraded (UNCCD), threatening livelihoods and ecosystem health.

5.3.1. Land degradation

Land degradation is the decline in the quality and productivity of land due to a combination of natural processes and human activities. This degradation directly affects over 3 billion people worldwide.

Causes of Land Degradation

The causes can be broadly categorized into natural and human-induced factors, with human activities being the primary driver.

- Deforestation: This is one of the most significant causes. Forests are cleared for agriculture, logging, and urbanization, which removes the protective vegetation cover and exposes the soil to erosion by wind and water.
  - Example: The large-scale clearing of the Amazon rainforest for cattle ranching and soybean cultivation has led to irreversible soil degradation.
- Unsustainable Agricultural Practices:
  - Overgrazing: When livestock graze too intensively on a piece of land, they strip it of vegetation, leaving the soil compacted and vulnerable to erosion.
    > Example: Large areas of the Sahel region in Africa have been degraded due to overgrazing, contributing to desertification.
  - Improper Irrigation: Poorly managed irrigation can lead to waterlogging and salinization, where salts accumulate in the soil, making it toxic for most plants.
    > Example: The Aral Sea basin saw vast areas of land turn into salt flats after the rivers feeding it were diverted for cotton cultivation.
- Urbanization and Industrial Pollution: The expansion of cities and industrial activities leads

to the clearing of land and can cause severe soil contamination from chemical waste and
pollutants, rendering the land barren.

Desertification

According to the United Nations Convention to Combat Desertification (UNCCD):
"Desertification is the degradation of land in arid, semi-arid and dry sub-humid areas resulting
from various factors, including climatic variations and human activities."

Student Notes:

Climatic Causes

Cause
Description
Examples
Climate Change
& Global
Warming
Rising
temperatures
increase
evapotranspiration, reduce
soil moisture, and intensify
droughts.
- Horn of Africa Drought (2020–24):
Longest drought in 40 years → degraded
over 10 million hectares in Somalia,
Kenya.
-
Bundelkhand
(India):
Frequent
droughts, drying of soil due to high
temperature variability.
Erratic Rainfall &
Droughts
Decrease
in
rainfall
frequency
and
intensity
causes dryland stress.
- Sahel Region (Africa): Decreased
rainfall since 1970s caused 65 million
hectares of land degradation.
- Rajasthan (India): Shift in monsoon
patterns leads to aridity and sand dune
advancement.

Anthropogenic Causes (Human-Induced)

Cause
Description
Examples
Deforestation
Forests are cleared for
timber,
fuelwood,

agriculture,
and
development, exposing
topsoil to erosion.
- Shivalik Hills (Uttarakhand): Deforestation
for settlements and tourism has caused
rapid topsoil loss.
- Amazon Basin: Logging and slash-burn
agriculture contribute to savannization.
Unsustainable
Agriculture
Practices
like
monoculture,
excessive
irrigation,
and use of chemicals
degrade soil structure
and fertility.
- Punjab-Haryana Indo-Gangetic Belt:
Overuse of fertilizers and tube wells has led
to salinization and decline in productivity.
- Central Asia (Aral Sea): Cotton irrigation
caused
massive
salinity
and
land
degradation.
Mining and
Industrial Activity
Mining exposes land
surfaces,
removes
vegetation, and alters
- Aravalli Hills (Rajasthan, Haryana): Illegal
stone mining led to deforestation, water
stress, and sand drift into fertile areas.

Student Notes:
hydrology.
- Chhattisgarh-Jharkhand: Open-cast coal
mining has degraded large swathes of
forested land.
Water
Mismanagement
Over-extraction
of
groundwater,
canal
overuse, and improper
drainage
cause
waterlogging

and
salinity.
- Indira Gandhi Canal (Rajasthan): Faulty irrigation caused salinization in command areas.
- Kutch (Gujarat): Exploitation of groundwater and salt farming degraded surface and subsoil.

Impacts of Desertification

Impact Area	Explanation
Agriculture & Livelihoods	Decrease in soil fertility → Declining yields → Food insecurity, especially in rural India & Sub-Saharan Africa
Water Resources	Loss of vegetation reduces groundwater recharge → Surface runoff increases → Water scarcity
Biodiversity Loss	Degraded habitats cause extinction of flora and fauna adapted to drylands
Human Health	Dust storms (e.g., from Thar Desert) cause respiratory diseases, eye irritation
Migration & Conflicts	Land degradation often forces rural-urban migration and fuels disputes over dwindling resources

Global Initiatives to Combat Desertification

- UNCCD (United Nations Convention to Combat Desertification)
  - Established in 1994, it is the only legally binding global treaty focused on land degradation.
  - Promotes Land Degradation Neutrality (LDN)—restoring as much land as is degraded.
- Bonn Challenge
  - Global effort to restore 350 million hectares of degraded land by 2030.
  - Supported by countries, NGOs, and UN bodies.
- COP16 – Riyadh Declaration (2024)
  - Called for $2.6 trillion in investment for land restoration.
  - Introduced early-warning systems and drought-resilience technologies.
- Sustainable Development Goals (SDGs)
  - o SDG 15.3 aims to achieve land degradation neutrality by 2030.

5.4. Energy Resources

Depending upon its source and utilization, energy can be divided into two major classifications:

•
Conventional energy sources: Coal, Petroleum, Natural Gas etc.
•
Non-Conventional energy sources: Solar, Wind, Biogas, and Geothermal energy etc.

Student Notes:
Key Data:
India Rankings:
•
Producer: 3rd largest
•
Consumer: 3rd largest
•
Installed Capacity: 5th largest
Per Capita Energy Consumption: India's per capita energy consumption is about 1/3rd of the world's average.
Energy Mix of India
Panchamrit Targets:
•
Reach a non-fossil fuel energy capacity of 500 GW by 2030.
•
Fulfil at least 50% of energy requirements via renewable energy by 2030.
•
Reduce CO2 emissions by 1 billion tons by 2030.
•
Reduce carbon intensity below 45% by 2030.
•
Achieve Net-Zero emissions by 2070.
5.4.1. Coal
Coal accounts for 55% of India's energy needs and fuels 74% of power generation. Projected to remain critical until 2030–2035, with demand peaking as renewable integration accelerates.
Problems related to coal in India:
•
Shortage of High-Grade Coking Coal: India lacks sufficient high-grade coking coal, essential for the steel industry, leading to imports from Australia, Canada, South Africa, and Indonesia.
o
For example, Indian coal has high ash content and low caloric value, causing significant pollution when burned.
•
Deep Mining Techniques: Lack of advanced deep mining technology leads to high casualties and inefficiencies.
o
For example, In January 2021 six miners died in an incident in a rat-hole mines in the East Jaintia Hills (Meghalaya).

Student Notes:
•
High Demand from Captive Power Plants: Industrial users such as aluminium smelters and cement makers, often imports when Coal India cannot meet their demands.
o
According to the IEA’s Coal Report 2021, India’s coal consumption is expected to increase

at an average annual rate of 3.9%.
Government steps:

- To support this increase in steel production and blending percentage, the Ministry of Coal (MoC) has established Mission Coking Coal to create a roadmap for boosting the production and utilization of domestic coking coal in India.
- Mission Coking Coal recommended new exploration, enhancing production, enhancing washing capacity, auction of new coking coal mines.
- Coal Gasification Scheme: Scheme was launched, aiming to gasify 100 million tonnes of coal by 2030, thereby maximizing the value and utility of this vital resource.

5.4.2. Petroleum or Mineral Oil

Extracted from sedimentary rocks. Primarily consists of 90-95% hydrocarbons, remaining 5-10% made up of organic compounds containing oxygen, nitrogen, sulphur, etc.

The Uneven Distribution of Mineral Oil and its Global Impact

Middle East alone holds nearly half of the world's proven oil reserves, while just five countries control over 60% of the total.

- Geopolitical Power and Conflict: The concentration of oil gives immense geopolitical leverage to producing nations and creates strategic vulnerabilities for consumers, often leading to conflict.
  - Example: The Persian Gulf has been a global hotspot for decades. The 1973 oil crisis, where OPEC countries imposed an embargo, and the subsequent Gulf Wars, were directly linked to the control and security of oil supplies, showing how oil can be used as a political weapon.
- Economic Disparity and the 'Resource Curse': The uneven distribution creates vast economic inequalities. However, this wealth can lead to the "resource curse," where an over-reliance on oil revenues cripples other sectors of the economy.

- Uneven Environmental Burden: The environmental costs of oil are not shared equally. Producing regions suffer immediate consequences like oil spills, while the climate change effects from oil consumption disproportionately harm vulnerable nations that are not major consumers.

Oil Production in India

India's mineral oil production occurs in both on-shore and off-shore locations across the country.

- On-shore production is concentrated in several key states.
  - In Northeast India, Assam

is a significant producer with its historic Digboi field.

■ In the west, major oilfields are located in Gujarat (Ankleshwar and Khambhat) while Rajasthan (Barmer region).

• India's off-shore oil production is carried out along both its western and eastern coasts.

■ Key sites on the Western Coast include the Bassein and Aliabet fields, while the Eastern Coast features in the Krishna-Godavari Basin.

What are Strategic Petroleum Reserves (SPR)? Why are SPRs Important for India?

Strategic Petroleum Reserves are massive underground stockpiles of crude oil maintained by the government for emergency situations. India has established these reserves in large underground rock caverns at locations like Visakhapatnam (Andhra Pradesh) and Mangalore & Padur (Karnataka).

1. Energy Security: They act as a crucial energy buffer, ensuring India has a ready supply of crude oil to fall back on during global crises, such as wars or major supply disruptions, which could otherwise halt the country's economy.
2. Price Stability: They help the government manage and stabilize domestic fuel prices. By releasing oil from these reserves during times of high global prices, the government can cushion the public from sudden and extreme price hikes.

5.4.3. Natural Gas

Natural Gas primarily consists of methane and ethane, with smaller amounts of propane, butane, pentane, and hexane also present. Russia’s reserves accounts for almost a quarter of the total global gas reserves.

Natural gas contributes 6.2% in India’s energy basket. (NITI ayog)

India's Plan for a Gas-Based Economy

India is actively transitioning towards a gas-based economy to reduce import dependence on crude oil and enhance energy security.

Student Notes:

Key Objectives

• Reducing Import Dependence: India currently imports ~50% of its natural gas;

focus on boosting domestic production and exploration.

- Increasing Gas Share: Targeting 15% share in the energy mix by 2030 to lower emissions and support economic growth.
- Diversifying Energy Sources: Reducing coal and oil dependency by promoting natural gas as a cleaner alternative.

Hurdles in Expanding the India's Natural Gas Sector

- Expensive Imports: India imports nearly half of its gas, making it vulnerable to volatile global prices. This often makes gas-based power too expensive and unpredictable compared to other energy sources like coal.
- Low Domestic Production: The country's own natural gas production is not keeping up with its growing demand. This is due to challenges in discovering and developing new gas fields, which forces more reliance on costly imports.
- Lack of Pipelines: There aren't enough pipelines to transport gas efficiently across the country. This means many expensive gas-based power plants remain idle because they cannot get a steady and affordable supply of fuel.

Policies to Boost India's Natural Gas Production

The Government of India has introduced several key policies to increase domestic natural gas production, attract investment, and reduce reliance on imports:

Hydrocarbon Exploration and Licensing Policy (HELP)

- Introduced a simpler revenue-sharing model with the government.
- Provides a single license to explore and produce all forms of hydrocarbons (oil, gas, shale gas, etc.).

Open Acreage Licensing Policy (OALP)

-

Allows companies to choose their own exploration blocks anytime during the year.

- Makes the process faster and more industry-driven, moving away from government-selected blocks.

Student Notes:

Unlocking Stranded Resources & Building Infrastructure

- Discovered Small Fields (DSF) Policy: Auctions small, unused gas fields to private players to bring them into production.
- National Gas Grid Expansion: Aggressively building a nationwide pipeline network to transport gas from production sites to consumers, which is crucial to support increased production.

5.4.4. Solar Energy

As of March 2025, the country's installed capacity stands at 105 GW, with solar power contributing over 32% to India's total renewable energy generation. India targets 450 GW solar capacity by 2030 for climate goals, less fuel reliance, and social inclusion (SDG 10).

- Leading States: Rajasthan, Gujarat, and Karnataka.
- Major Solar Parks: Bhadla (Rajasthan), Pavagada (Karnataka).

Student Notes:

Challenges

- Land Acquisition: Large-scale solar farms require vast, contiguous tracts of land, which are often difficult to acquire due to competing demands for agriculture and other uses.
- Import Dependence: The sector is heavily reliant on imported solar cells and modules, primarily from China, creating supply chain vulnerabilities and economic risks.
- Grid Integration and Stability: Solar power is intermittent (only generated during the day) and variable (affected by clouds). Integrating this fluctuating power into a grid designed for stable, 24/7 supply creates instability.
- Looming Waste Management Crisis: Solar panels have a lifespan of 25-30 years. With the solar boom having started over a decade ago, India faces a massive wave of solar panel waste in the near future.

Why is there regional variation in solar power development in India?

Solar power development in India is highly concentrated, with western and southern states like Rajasthan, Gujarat, and Karnataka being clear leaders, while eastern and northeastern states have significantly lower installed capacities.

- State-Level Policy and Investment Climate: State-level policies are crucial for attracting investment. Leading states were early movers in creating investor-friendly solar policies, offering streamlined land acquisition, subsidies, and stable power purchase agreements.

● Solar Insolation and Irradiation: The intensity and duration of sunlight are not uniform across the country. Western regions like Rajasthan and Gujarat, along with parts of the Deccan Plateau, receive the highest solar irradiation, making them naturally more efficient and cost-effective for solar power generation.

Government Initiatives:

● Green Energy Corridors: This initiative focuses on developing dedicated transmission infrastructure to ensure that the power generated from large solar parks can be efficiently transported to the national grid.

● Production Linked Incentive (PLI) Scheme: This scheme aims to boost the domestic manufacturing of solar components like cells and modules, thereby reducing India's dependence on imports.

● Rooftop and Agricultural Solar Schemes: Programmes like the PM-Surya Ghar: Muft Bijli Yojana (for rooftop solar) and PM-KUSUM (for solar agricultural pumps) are promoting decentralized solar energy generation.

What is One Sun One World One Grid (OSOWOG)?

The One Sun One World One Grid (OSOWOG) is an initiative first proposed by the Prime Minister of India to create a trans-national electricity grid for supplying solar power across borders. The vision is to generate round-the-clock clean energy by connecting regions where the sun is shining to regions where it has set.

Student Notes:

Significance of the Initiative

1. Overcoming Solar Power's Limitation: It directly addresses the main challenge of solar energy—that it is only available during the daytime and depends on the weather—by enabling the transmission of clean energy anywhere and anytime through a worldwide grid.
2. Accelerating Global Infrastructure: It aims to speed up the construction of essential new infrastructure, such as electricity interconnectors and flexible grids, which are needed to deliver reliable and secure power across the globe.
3. Enabling Round-the-Clock Clean Energy: The initiative's core vision is to harness the fact that "The Sun Never Sets" for the entire Earth. This allows for a continuous supply of solar power by transmitting it from regions experiencing daylight to those experiencing night.

5.4.5. Wind Energy

India has a vast wind energy potential of over 300 GW, concentrated primarily in coastal states like Tamil Nadu, Gujarat, Maharashtra, and Karnataka.

As of 2024, the country has an installed capacity of 47.96 GW, with key wind farm sites such as Muppandal in Tamil Nadu and the Kutch and Saurashtra regions in Gujarat playing a crucial role in harnessing this clean energy resource

Student Notes:

Challenges Faced by the Wind Energy Sector:

- Higher Installation Costs: Lack of local manufacturers and trained workers increases installation costs.
- Land and site development delays:

acquiring
suitable
land is difficult due
to
fragmented land.

- Transmission challenges: India’s grid faces bottlenecks in evacuating wind power due to inadequate transmission lines.
- Seasonal variability in wind speeds poses challenge for consistent wind energy production.

Why there is no offshore wind energy production in India?

- High Costs: The cost of generating electricity from offshore wind is currently 2-3 times higher than from onshore wind and solar energy in India.
- Lack of Infrastructure: India's port infrastructure is not yet equipped to handle the manufacturing, storage, and transport of the massive components required for offshore turbines.

Government Initiatives to Promote Wind Energy

- National Offshore Wind Energy Policy: Targets the development of offshore wind energy.
- Guidelines for Onshore Wind Power Projects: Streamlines the development process for efficiency and minimal environmental impact.
- Renewable Purchase Obligation (RPO) Mandate: Mandates power utilities to procure a certain percentage of electricity from renewables, encouraging wind energy expansion.
- Green Energy Corridors Project: Strengthens power evacuation and transmission infrastructure for integrating wind and other renewables into the national grid.
- National Wind-Solar Hybrid Policy (2018) and National Offshore Wind Energy Policy (2015): Promote renewable energy.

5.4.6. Nuclear energy

Driven by the need for clean and reliable energy, there is a global resurgence in nuclear power. India is also planning a major expansion, aiming to increase its nuclear capacity from the current 7.5 GW to an ambitious 100 GW by 2047.

India currently has 23 operational reactors with a combined capacity of about 7,480 MW. At present, nuclear energy constitutes just over 3% of India's total electricity generation.

Benefits of Nuclear Energy

- Clean Source of Energy: It has a minimal carbon footprint, with greenhouse gas emissions that are about 100 times lower than those from coal-fired electricity.

- Reliable and Continuous Power: Unlike wind or solar, nuclear power is not dependent on weather conditions and can provide a stable and perennial supply of electricity.
- Avoids Massive CO2 Emissions: Globally, nuclear power generation prevents the emission of more than 1 billion tonnes of CO2 equivalent every year.
- No Air Pollutants: Nuclear power does not emit harmful air pollutants like fine particles, nitrogen dioxide, or sulfur dioxide into the atmosphere, unlike fossil fuels.

Challenges of Nuclear Energy

- Lack of an Independent Regulator: India's Atomic Energy Regulatory Board (AERB) operates under the Department of Atomic Energy (DAE), which raises concerns about its autonomy and transparent oversight.
- Nuclear Waste Management: There is a lack of long-term disposal solutions for highly radioactive waste in India, which currently relies on temporary storage methods like cooling pools and dry casks.
- High Capital Costs: Nuclear power plants require massive upfront financial investments and have very long payback periods, making financing a major challenge.
- Limited Domestic Fuel: India has scarce domestic uranium resources, which are insufficient to meet the demand of its nuclear power plants,

leading to a reliance on imports.

Availability of raw material for the generation of nuclear energy in India

- Uranium: India's limited uranium deposits are primarily located in the Singhbhum belt of Jharkhand, the Cuddapah basin of Andhra Pradesh, and parts of Meghalaya.

Student Notes:

■ India has agreements for uranium purchases with Canada, Kazakhstan, Russia, and Uzbekistan.

- Thorium: Abundant reserves of thorium are found within the monazite sands along the country's coastlines, with the highest concentrations on the beaches of Kerala and Tamil Nadu.

5.4.7. Bio-energy in India

India has a significant biomass energy potential, estimated to be between 28–32 GW. As of March 2025, the total installed capacity for biomass energy stands at 11.58 GW, with leading states in its production being Punjab, Maharashtra, Uttar Pradesh, Karnataka, and Tamil Nadu.

Key Challenges for Biomass Energy:

- Supply Chain Constraints: Biomass resources are often scattered, bulky, and vary by season, which makes their collection, storage, and transport logistically difficult and expensive.
- Land Use Conflicts: Creating large-scale biomass plantations can compete with land needed for food crops, potentially impacting biodiversity and soil health.
- Low Energy Density: The raw biomass has a low energy density, which increases transportation costs and requires significant investment in pre-treatment technologies.

Government initiative for biomass based energy:

- National Bioenergy Programme: The Ministry of New & Renewable Energy (MNRE) is implementing the National Bioenergy Programme (2022–2026) covering three sub-schemes: Waste to Energy, Biomass, and Biogas.
- SATAT (Sustainable Alternative Towards Affordable Transportation) Scheme: Launched by the Ministry of Petroleum and Natural Gas, SATAT

aims to set up 5,000 BioCNG (CBG) plants with a target of producing 15 million metric tonnes (MMT) of BioCNG annually.

- Mandatory Biomass Co-firing Policy: The Ministry of Power has mandated that all coal-based thermal power plants must use a blend of 5-10% biomass pellets along with coal for electricity generation. This policy creates a large and steady demand for agricultural residue, helps reduce stubble burning.

Bioeconomy's Role in Combining Economic Growth with Ecological Sustainability

- Reducing Carbon Footprint: Ethanol blending increased from 1.53% in 2014 to 15% in 2024, cutting 519 lakh metric tons of CO■ emissions and reducing crude oil imports.
- Sustainable Agriculture: Biofertilizers and biopesticides reduce chemical inputs, enhancing soil health. For example, bioremediation technologies degrade pesticide residues and restore ecosystems.
- Green Industrial Transition: The BioE Policy promotes shifting chemical industries to bio-based alternatives (e.g., bioplastics, enzymes), targeting a 5–6% GDP growth by 2030 through sustainable manufacturing.

Student Notes:

5.4.8. Geothermal energy

It is natural heat from within the Earth used for electricity and heating. Magma beneath the crust generates continuous heat from radioactive decay.

Geothermal Energy Potential in India: estimated potential in India is 10GW.

- Potential Sites:
  - Puga Valley (Ladakh): Promising site with significant geothermal potential.
  - Geothermal Provinces: Himalayas,

Sohana,
West Coast, Cambay,
and Godavari regions.

Key Challenges:

- High Cost: Development costs range from $2 million to $7 million per megawatt, which is a significant financial barrier.
- Infrastructure Issues: High costs and specialized skills required for drilling and plant setup.
- Environmental Concerns: Drilling can release harmful gases and may trigger minor seismic activity.
- Sustainability: Requires careful management to reinject fluids and maintain reservoir pressure, preventing resource depletion and geological hazards such as sinkholes.

5.4.9. Alternate sources of energy

With conventional fuels limited and non-renewable, the government aims to boost alternative hydrocarbon sources like coal-bed methane, gas hydrates, oil shales, and underground coal gasification to reduce reliance on petroleum imports and address environmental concerns.

Resource Type	Description
Coal-bed Methane (CBM)	• Natural gas stored within coal seams, formed during the coalification process and absorbed into the solid matrix of coal. • Classified as an unconventional source of natural gas due to its unique occurrence. India, the fifth-largest proven coal reserve,

Student Notes:

aims to reduce hydrocarbon imports and transition towards a gas-based economy.

- Estimated CBM resources for 2020-21 are 2,600 billion cu. m spread over 11 states; Andhra Pradesh, Assam, Chhattisgarh, Gujarat, Jharkhand, Madhya Pradesh, Maharashtra, Odisha, Rajasthan, Tamil Nadu and West Bengal.

Gas Hydrates

- Created when gas and water mix under high pressure and low temperature conditions, typically found in ocean depths exceeding 800 meters and in sediments just below the seafloor.
- Also formed in certain permafrost regions globally.
- US Geological Survey states that India has the second largest gas hydrates in World.
- Gas hydrate zones in Krishna–Godavari, Kerala, Konkan, Mahanadi and Andaman offshore areas.
- Also established in Krishna–Godavari, Mahanadi and Andaman Basin, but, were non-exploitable with available technologies.

Shale Oil/Shale Gas

- Extracted from organic-rich sedimentary rocks known as oil shales, trapped within the pores and fractures of source rocks, primarily shale.
- Unconventional resources due to their unique occurrence and extraction methods. Hydraulic fracturing is used for commercial production.
- Shale gas formations in various sedimentary basins in India such as Gangetic plain, Gujarat, Rajasthan, Andhra Pradesh, and coastal areas.
- Hydrocarbon-rich basins like Cambay, Assam-Arkan, and Damodar Basins hold large shale gas deposits.

Student Notes:

5.5. Mining & Exploration

Minerals are crucial for industrial development, serving as essential raw materials. India's mining sector is vital for driving GDP growth, foreign exchange earnings.

Challenges:

- Regulatory Bottlenecks: Evolving regulations cause delays and uncertainty, affecting operational efficiency.
  - Example: The Mines and Minerals (Development and Regulation) Amendment Act, 2021, aiming to boost private investment, led to implementation delays due to complex transition rules.
- Environmental Impact: Mining leads to deforestation, biodiversity loss, and pollution, necessitating sustainable practices.
- Infrastructure Deficiencies: Poor infrastructure hampers extraction and processing; upgrades are needed for improved productivity.
- Illegal Mining: Unregulated activities cause environmental harm and revenue loss, requiring stringent enforcement.
- Land Acquisition Issues: Complex land rights and compensation issues result in conflicts and delays.

What is rat hole mining and why it is dangerous?

Rat-hole mining is a primitive, dangerous, and often illegal method of extracting coal from narrow, horizontal seams.

Rat-hole mining is widely condemned and has been banned by India's National Green Tribunal (NGT) since 2014 due to its severe risks to both human life and the environment.

- Tunnel Collapse: The narrow tunnels lack any structural support, making them extremely prone to caving in and trapping miners.
- Flooding: The tunnels can flood instantly during heavy rains or if miners accidentally puncture an underground aquifer, leaving no chance for escape. A tragic incident in Meghalaya in 2018 saw several miners trapped and killed in a flooded rat-hole mine.
- Water Pollution: The practice causes Acid Mine Drainage, where sulfur-rich coal mixes with water, making nearby rivers and streams highly acidic.

5.5.1. Deep sea mining

Deep-sea mining is the process of extracting mineral deposits from the deep seabed, typically at depths below 200 meters.

Importance of Deep-Sea Mining for India

- By exploring and extracting resources from the seabed, India aims to reduce its significant import dependency on minerals like nickel, cobalt, copper, and manganese. These minerals are vital for manufacturing everything from electric vehicle batteries and solar panels to advanced electronics and smartphones.
- India's Deep Ocean Mission, which includes the development of a manned submersible (Matsya 6000) and mining technologies, underscores this commitment to harnessing oceanic resources for economic growth and energy security.

Student Notes:
Challenges and Limitations of deep sea mining
- Environmental Impact: Risks to fragile ecosystems and biodiversity are significant and not fully understood.
- Technological Hurdles: Operating at extreme depths requires complex, durable machinery.
- Regulatory Framework: Lack of an international regulatory framework raises concerns about resource distribution and environmental protection.
- Economic Viability: High initial investment costs require careful assessment of potential benefits and financial feasibility.

Polymetallic nodules
Polymetallic nodules, also known as manganese nodules, are rock concretions found lying on the deep-sea floor, typically at depths of around 4,000 to 6,000 meters. These nodules contain valuable metals such as manganese, nickel, cobalt, and copper.
Exploration of deep sea minerals
These resources are managed by the International Seabed Authority (ISA), which signs contr their exploration. India, for instance, signed a 15-year contract with the ISA in 2002 for the exp of nodules in the Central Indian Ocean Basin (CIOB).
Strategic Significance: The mining of these nodules is driven by the global need for critical metals. These metals are essential for high-technology applications and the green energy economy, including the production of electronics, smartphones, batteries, and solar panels.
The Mines and Minerals (Development and Regulation) Amendment Act 2023
The MMDR Amendment Act, 2023, was introduced to accelerate the exploration and mining of critical and deep-seated minerals essential for India's clean energy goals and national security.
Why the Amendment Was Needed?
Under the previous law, the exploration and mining of key minerals were riddled with two major problems:
- Government Monopoly on Strategic Minerals: Twelve "atomic minerals," including many that are critical for technology and green energy (like lithium, beryllium, titanium), were reserved exclusively for government companies. This severely limited the scope and speed of exploration.

Student Notes:
- Lack of Incentive for Private Exploration: Private companies were hesitant to invest in high-risk, capital-intensive exploration for deep-seated minerals (like gold, copper) because there was no clear mechanism to benefit from their discoveries.

Key provisions of the Amendment
- Delisting of Key Atomic Minerals: Six minerals, including lithium, beryllium, titanium, niobium, tantalum, and zirconium, have been removed from the "atomic minerals" list. This crucial change opens them up for exploration and mining by the private sector.
- Introduction of an Exploration Licence (EL): A new type of single license has been introduced specifically for private companies to undertake reconnaissance and exploration for 29 critical and deep-seated minerals.
- Auction of Exploration Licences: These new Exploration Licences will be granted through a transparent and competitive bidding process, allowing the most capable private players to

participate.

National Mineral Policy, 2019

Aims to ensure effective regulation and sustainable development of the mining sector in India.

Impacts of NMP

- Cheaper and more economical transportation of minerals through waterways and dedicated corridors,
- Development of mineral-rich but underdeveloped regions through the District Mineral Fund,
- Increased private investment and financing in the mining sector,
- Better planning and stability for the private sector through long-term import-export policies,
- Reduced environmental impact through sustainable mining practices.

Overall, the NMP 2019 aims to bring in greater transparency, regulation, and sustainable development in the mining sector, while also boosting private investment and reducing import dependence. It is a key policy that addresses several challenges faced by the mining industry in India.

Student Notes:

6. INDUSTRIES

Previous year questions (PYQs)

- Describing the distribution of rubber producing countries, indicate the major environmental issues faced by them. (2022)
- Account for the present location of iron and steel industries away from the source of raw material, by giving examples. (2020)
- Discuss the factors for localisation of agro-based food processing industries of North-West India (2019)
- Can the strategy of regional-resource based manufacturing help in promoting employment in India? (2019)
- What is the significance of Industrial Corridors in India? Identifying industrial corridors, explain their main characteristics. (2018)
-

Petroleum refineries are not necessarily located nearer to crude oil producing areas, particularly in many of the developing countries. Explain its implications. (2017)

- Account for the change in the spatial pattern of the Iron and Steel industry in the world. (2014)
- Do you agree that there is a growing trend of opening new sugar mills in the southern States of India? Discuss with justification. (2013)
- Analyze the factors for the highly decentralized cotton textile industry in India. (2013)

PYQs Analysis

UPSC's GS mains questions on industries go far beyond textbook location theories. The focus is not merely on "where industries are," but "why they are moving, evolving, or becoming decentralized."

For example:

- Location Dynamics & Changing Patterns: Questions like why iron and steel industries are moving away from raw material sources (2020) or the spatial shift in sugar mills to southern states (2013) test aspirants on both traditional locational and contemporary deviations driven by market and policies.
- Resource Linkages & Regional Employment: Repeated focus on agro-based industries in North-West India (2019) and regional-resource based manufacturing (2019) indicates question's interest in how industries support regional development.
- Infrastructure & Corridors: The question on industrial corridors (2018) and refinery location away from oil fields (2017) reveals an awareness of how logistics, trade routes, and port connectivity increasingly define industrial siting in both developing and developed economies.

Keeping above trend in mind all important topics like industrial corridors, and comprehensive industry discussion has been done in the chapter.

6.1 Industries

Industries refer to organized economic activities that transform raw materials or components into finished goods through physical or chemical processes. It includes activities like refining natural resources, making electronic parts, and assembling final products for consumer use or further production.

Student Notes:

6.1.1. Classification of Industries

Classification	Types	Explanation	Examples
Source of Raw Materials Used	Agro-based	Industries using agricultural products as raw materials.	Cotton, woollen, jute, silk textile, rubber, sugar, tea, coffee, edible oil
	Mineral-based	Industries using minerals as raw materials.	

Iron and steel, cement,
aluminium, machine
tools, petrochemicals
Main Role
Basic or Key
Industries
Industries
supplying
raw
materials to manufacture
other goods.
Iron and steel, copper
smelting, aluminium
smelting
Consumer
Industries
Industries producing goods
for direct use by consumers.
Sugar, toothpaste,
paper, sewing machines,
fans
Capital
Investment
Small Scale
Industry
Industries defined by the
maximum
investment
allowed on the assets.
Max investment: ■1
crore
Ownership
Public Sector
Industries
owned
and
operated
by
government
agencies.
BHEL, SAIL
Private Sector
Industries
owned
and
operated by individuals or
groups of individuals.
TISCO, Bajaj Auto Ltd.,
Dabur Industries
Joint Sector
Industries jointly run by the
state and individuals or
groups of individuals.
Oil India Ltd. (OIL)
Cooperative
Sector
Industries

owned
and
operated by producers or
suppliers of raw materials,
workers, or both, sharing
profits
or
losses
proportionately.
Sugar industry in
Maharashtra, coir
industry in Kerala
Bulk
and
Weight of Raw
Materials
&
Products
Heavy
Industries
Industries using heavy raw
materials
and
producing
heavy goods.
Iron and steel
Light Industries
Industries using light raw
materials and producing light
goods.
Electrical goods
industries
6.1.1.1. Footloose Industry
A footloose industry can be located anywhere without being affected by resources, land, labour, and capital. Key characteristics include:

- Location Flexibility: Can be set up anywhere.
- Fixed Costs: Costs remain constant regardless of location.

Student Notes:

- Raw Materials: Use small, light, easily transportable raw materials.
- Skilled Labour: Require skilled workers due to advanced industrial processes.
- Output: Produce lightweight, high-value products.
- Environmental Impact: Generally non-polluting with less carbon footprint.
- Preferred Locations: Peaceful, cost-effective areas with good connectivity for transportation.
- Examples: Diamonds, computer chips, mobile manufacturing, honey processing.

Non-Footloose Industries

- Non-footloose industries need to be near raw materials due to time-sensitive production. Examples include: Sugar, Jute and Tea Industry etc.
- Non-footloose industries are dependent on the proximity to raw materials to minimize transportation costs and time.

Importance of Footloose Industries in India's Development:

- Job Creation & Skill Enhancement
  Employment generation, reduced migration, workforce upskilling
  Examples: IT parks in Bengaluru, Hyderabad; Technical training centers in Pune.
- Economic Diversification & Regional Balance
  Reduced agriculture dependence, economic resilience, inclusive growth
  Examples: BPO in Jaipur, Bhopal; Pharmaceuticals in Visakhapatnam; Tourism in Udaipur
- Infrastructure Development & Connectivity
  Transport, telecommunications, utilities improvement, regional linkages
  Examples: IT corridors in Hyderabad (roads, telecom); SEZs in Gujarat (ports); Agro-processing units in Madhya Pradesh (rural roads).
- Technology Transfer & Innovation Boost
  Knowledge sharing, expertise diffusion, R&D; promotion
  Examples: Biotech in Kerala; Aerospace in Bengaluru; Renewable energy in Rajasthan.
- Investment Attraction & Export Growth
  Foreign/domestic capital inflow, global market integration, forex generation
  Examples: Auto components in Tier-II/III cities; Electronics in Noida; Textiles in Tirupur; Gems and jewellery in Jaipur.

6.2. Location of Industries

Location of industries is influenced by factors like access to raw materials power, market, capital, transport and labour, etc. The factors affecting can be divided into two broad categories:

6.2.1. Geographical Factors:

- Raw Materials → Industry Location: Proximity to sources, crucial for heavy/perishable materials → e.g., sugar mills near sugarcane fields, copper smelting near ore deposits.
- Power Sources → Energy-Intensive Industries: Steady supply (coal, oil, hydro) essential → e.g., aluminium and synthetic nitrogen plants cluster near power sources.
- Labour Availability → Manufacturing Centers: Access to skilled, cost-effective workforce → e.g., light consumer goods and agro-based industries grow in populous regions.
- Transport → Industrial Efficiency: Well-developed land/water connectivity → Brings raw material inflow and product distribution, supporting industrial growth.
- Market Proximity → Reduced transport costs → competitive pricing → e.g., textile industries in Mumbai, Ahmedabad; refineries near consumption centers.

Alfred Weber's Theory of Industrial Location

He developed a theory to explain where industries should be located to minimize costs.

His theory focuses on three main
factors: transportation cost, labour
cost, and agglomeration cost (the
benefits of having industries close
together).

- Site → Industrial Setup: Flat terrain, good connectivity, enough space → ideal for factory establishment; trend of rural relocation due to urban land costs.
- Climate Influence → Sector-Specific Locations: Moderate conditions preferred → e.g., humid climate in Maharashtra, Gujarat fosters cotton textile industry, preventing thread breakage.

6.2.2. Non – Geographical Factors:

- Capital Availability → High investment needs → industries concentrate in finance-rich urban centers → e.g., Mumbai's finance and textile industries.
- Government Policies → Strategic policies shape industrial locations → aimed at balanced growth, pollution control → e.g., Bengaluru's IT hub emergence.
- Industrial Inertia → Historical Centers: Industries grow in original locations → e.g., Ahmedabad's continued prominence in textiles.
- Banking Infrastructure → Robust financial services → Support daily operations → e.g., Delhi NCR's strong banking infrastructure supports various industries.

6.2.3. World Industrial Regions

Major industrial regions of the world are eastern North America, western and central Europe, eastern Europe and eastern Asia. Major industrial regions tend to be located in the temperate areas, near sea ports and especially near coal fields.

6.3. Industrial Regions of India

Industrial regions are zones of planned industrial development that integrate infrastructure, utilities, and institutional support to promote large-scale manufacturing, foster innovation, and enable competitiveness in domestic and export markets.

Industrial regions can be classified into two types:

- Major Industrial Regions,
- Minor Industrial Regions

Characteristics of Industrial Regions of India

Feature	Explanation
Concentration of Industries	Clustering of core industries like iron and steel, engineering, chemicals, textiles, etc.
Resource-based Localization	

Proximity to raw materials—coal in Dhanbad-Bokaro, cotton in Mumbai-Pune, iron ore in Chhattisgarh.
Urban Agglomeration
Industrial growth supports urbanization—e.g., Kolkata, Mumbai, Bengaluru.
Transport Connectivity
Well-connected via rail, road, and port facilities—e.g., Mumbai and Chennai belts.
Labour Force Availability
Dense labor supply—both skilled and unskilled—supporting diverse manufacturing.
Mixed Industrial Typology
Includes large-scale, MSMEs, traditional industries, and SEZs.

Significance of Industrial Regions of India

- Catalysts of Economic Growth: Industrial regions contribute significantly to the Gross Domestic Product (GDP).
  - Example: The Mumbai-Pune Industrial Region contributes a large share to Maharashtra’s GSDP, housing major automobile (Tata, Mahindra) and pharmaceutical hubs (Serum Institute).
- Employment Generation and Skill Development: These regions generate both direct and indirect employment across formal and informal sectors.
  - Example: The Bengaluru-Tamil Nadu Industrial Region has enabled large-scale employment in the IT, electronics, and textile sectors. It has also fostered technical skill development in Tier-2 cities like Coimbatore and Hosur.
- Urbanization and City Development: Industrial growth accelerates urban development and expands urban infrastructure.
  - Example: Gurgaon (now Gurugram), once a rural town, transformed into a modern city due to the growth of the Delhi-Gurgaon industrial-IT corridor.
- Promotion of Ancillary Industries and MSMEs: Clusters attract SMEs and service sectors, supporting local entrepreneurship.
  - Example: Ludhiana in Punjab, part of the Delhi-Ludhiana belt, has emerged as a hub of bicycle parts and woolen garments, largely due to small-scale industry growth.
- Export Competitiveness: Regions near ports help in enhancing India's export capabilities.
  - Example: Chennai-Bengaluru Industrial Corridor, with access to the Chennai Port, is an export hub for automobiles and electronics.
- Regional Economic Transformation: Industrial regions uplift backward regions.
  - Example: Bhilai and Rourkela, once tribal areas, became urban-industrial centres due to steel plants and mining, boosting regional development.

Challenges of Industrial Regions in India

- Environmental Degradation: Industrial activity causes air, water, and soil pollution; unsustainable resource use.
  - Example: The Hugli Industrial Belt in West Bengal suffers from jute mill effluents polluting the Ganga River, impacting both ecology and human health. Delhi-NCR suffers from severe air pollution exacerbated by industries, particularly during winter.

- Urban Infrastructure Strain and Congestion: Overcrowding, traffic bottlenecks, housing shortages, and pressure on civic amenities.
    - o Example: Mumbai's Dharavi slum, located near industrial units, highlights how unchecked industrialization causes poor living conditions.
- Inter-regional Disparities: Most industrial development is concentrated in the western and southern parts of India.
    - o Example: States like Gujarat, Maharashtra, and Tamil Nadu dominate industrial output, while some states like Bihar, Madhya Pradesh lag due to lack of investment and infrastructure.
- Inadequate Infrastructure in Emerging Regions: Power shortages, poor connectivity hinder new industrial regions.
    - o Example: Industrial growth in Jharkhand and Chhattisgarh is impeded by power cuts and poor road-rail infrastructure, despite being rich in minerals.
- Obsolete Technology and Poor Productivity: Many Indian industries still use outdated technology, leading to inefficiency.
    - o Example: Jute mills in West Bengal face decline due to failure to modernize, unlike synthetic fiber industries in Gujarat.
- Labor-related Challenges: Labor unrest, low productivity, and inadequate social security are major hurdles.

Student Notes:

- o Example: Periodic strikes in Haryana's Manesar belt (e.g., Maruti Suzuki) reveal industrial tension due to wage and safety issues.
- Land Acquisition and Policy Uncertainty: Acquiring land for industries is difficult due to socio-political resistance and policy vagueness.
    - o Example: Tata Nano's failed project in Singur, West Bengal, due to land acquisition protests, discouraged industrial investment in the region.
- Environmental and Industrial Disasters: Poor regulation leads to frequent accidents.
    - o Example: The Vizag gas leak (LG Polymers, 2020) from an industrial unit in Andhra Pradesh caused several deaths, highlighting regulatory gaps in industrial safety.

6.3.1. Industrial Corridors

Industrial corridors in India were developed post-2000 to reduce regional disparities and promote manufacturing growth. They connect major industrial regions through improved transport and logistics infrastructure. This fosters economic integration and addresses key spatial and developmental challenges.

Benefits

- Regional Economic Integration: Better connects different regions economically.
- Improved Connectivity: Faster and more efficient transport.
- Enhanced Export Competitiveness: For example, the Krishnapatnam Port in CBIC.
- Balanced Regional Development: Reduces disparities between regions.
- Job Creation: DMIC alone is expected to create 100 million jobs by 2040.

Student Notes:

Challenges

- Land Acquisition: Difficulties in acquiring land for projects.
- Environmental Concerns: Impact on local ecosystems.
- Funding Constraints: High costs and

need for innovative funding.

- Inter-State Coordination: Effective collaboration between states.

Impact

- Contribution to 'Make in India': Promotes manufacturing in India.
- Sustainable Urbanization: Develops smart, sustainable cities.
- Economic Growth: Accelerates overall economic development.
- Foreign Investment Attraction: For example, Japan's $4.5 billion investment in DMIC

How Do Industrial Corridors Differ from Special Economic Zones (SEZs) in India?

Aspect
Industrial Corridors
Special Economic Zones (SEZs)
Purpose
Broad industrial development and job creation across large areas {e.g., Delhi-Mumbai Industrial Corridor (DMIC)}
Promote exports and attract FDI with tax incentives (e.g., Jawaharlal Nehru Port SEZ).
Scale and Scope
Large-scale projects spanning multiple states (e.g., DMIC covers 1,483 km across six states.).
Smaller, duty-free zones for specific industries (e.g., Mundra SEZ).

Student Notes:
Infrastructure
High-speed transport, logistics hubs, and smart cities {e.g., Chennai-

Bengaluru Industrial Corridor (CBIC)
with 500 km expressway}.
Basic infrastructure for export-
oriented industries (e.g., Noida
SEZ).
Governance
Managed
by
National
Industrial
Corridor
Development
and
Implementation Trust (NICDIT) with
state partnerships.
Governed by SEZ Act, 2005, and
Development Commissioners.

Defence Industrial Corridors in India

India’s Defence Industrial Corridors (DICs) are being developed to promote indigenous defence manufacturing, reduce import dependency, and transform India into a global defence export hub. These corridors aim to create a synergistic ecosystem of private and public sector enterprises, R&D; institutions, and MSMEs.

Regions and Corridors

India has announced two major Defence Industrial Corridors:

1. Uttar Pradesh Defence Corridor (UPDIC)

•
Nodes: Aligarh, Agra, Jhansi, Kanpur,
Chitrakoot, and Lucknow.

2. Tamil Nadu Defence Corridor (TNDIC)

•
Nodes: Chennai, Coimbatore, Salem,
Tiruchirappalli, and Hosur.

Why These Regions? (Locational Factors)

Factor
Uttar Pradesh DIC
Tamil Nadu DIC
Existing Base
Ordinance
factories,
DRDO
units
Engineering clusters, PSU factories
Workforce
Abundant
semi-skilled
and
skilled labour
Technically skilled workforce from
IIT Madras, NITs
Connectivity
Expressways, Eastern Freight
Corridor
Chennai Port, major airports, road-
rail network
Industrial
Ecosystem
Auto,

MSMEs,
engineering
hubs
Aerospace
and
electronics
industries

Student Notes:

Land Availability
Ample land in semi-urban areas Industrial parks and SIPCOT zones
Policy Push
UP Defence & Aerospace Policy 2018
Tamil Nadu Aerospace & Defence Industrial Policy 2019

Future Outlook

- Part of India's push for Atmanirbhar Bharat in defence.
- Encouraging FDI in defence (now up to 74% via automatic route).
- Potential to become nodes of geoeconomic strength, with India emerging as a hub for MRO (Maintenance, Repair & Overhaul), unmanned systems, and defence electronics.

6.3.2. Emerging Industrial Clusters in Tier-2 and Tier-3 Cities in India

India's industrial landscape is undergoing a transformation with the rise of new clusters in tier-2 and tier-3 cities, fostering regional growth and reducing reliance on metropolitan areas.

Key Drivers:

- Cost Advantage: Lower land and labour costs.
- Government Initiatives: Programs like Smart Cities Mission and state-specific policies.
- Improved Connectivity: Enhanced road and air connectivity through projects like Bharatmala and UDAN.
- Digital Infrastructure: Increasing internet penetration supporting tech-based industries.
- Skilled Workforce: Educational institutions and reverse migration trends.

Challenges:

- Infrastructure Gaps: Inadequate physical and digital infrastructure in some regions.
- Skill Mismatch: Aligning local skill development with industry needs.
- Environmental Sustainability: Balancing industrial growth with ecological concerns.
- Uneven Development: Risk of creating new intra-state disparities.

Government Initiatives:

- Atmanirbhar Bharat Abhiyan: Encouraging local manufacturing and self-reliance.

● Production Linked Incentive (PLI) Scheme: Boosting manufacturing across various sectors and regions.
● National Logistics Policy 2022: Aiming to reduce logistics costs and improve the competitiveness of smaller cities.

As India aims to become a $5 trillion economy, these emerging clusters will be important in driving inclusive and sustainable growth. This promotes balanced regional growth, support local economy, and reduced strain on overburdened metropolitan areas.

6.4. Mineral-based Industry

6.4.1. Iron and Steel Industry

The Indian iron and steel industry stands as a global powerhouse, ranking as the world's second-largest producer of crude steel.

Emerging Clusters:

- Coimbatore (Tamil Nadu): Textile machinery, auto components, IT.
- Indore (Madhya Pradesh): Pharmaceuticals, automobiles, IT.
- Visakhapatnam (Andhra Pradesh): Pharmaceuticals, defence manufacturing, IT.
- Chandigarh-Mohali-Panchkula: IT, biotechnology, education.

Student Notes:

Locational Factors of Iron and Steel Industry

Primary Factor: Raw material proximity → Proximity to iron ore, coal, limestone—key for minimizing transport costs. Example: Bhilai plant near Dalli Rajhara iron ore mines

Secondary Factors:

- Market access → Reduced finished product transport costs → Competitiveness. Example: Tata Steel's scrap-based plant in Rohtak (near auto industry),
- Transportation infrastructure → Efficient logistics → Operational efficiency → Stimulates regional infrastructure development,
- Port access → Easy import/export → Global competitiveness. Example: Vizag Steel Plant near Vizag port,
- Government policies → Strategic plant locations → Balanced regional growth.

Types of Steel Plants

Large Integrated Plants: Iron ore + Coal → Crude steel → Finished steel products

Advantages:

Large-scale
production, full control over process
Mini Steel Plants: Utilizing scrap
iron/Pig iron → Catering to local
demand → Steel products Advantages:
Lower capital requirement → Easier
establishment,
Shorter production cycle → Quick
market response,
Urban/semi-urban
locations
→
Decentralized industrialization,
Flexibility → Meet local demands
efficiently.

Student Notes:
Major Iron and Steel Industry Locations – India
Region
Key Plants
Locational Basis
Chotanagpur
Plateau
Jamshedpur
(Tata),
Bokaro,
Durgapur, Rourkela, Burnpur
Close
to
iron
ore
(Odisha,
Jharkhand), coal (Raniganj, Jharia)
Odisha Region
Kalinganagar, Angul, Jharsuguda
Iron ore belt, power, mineral-rich
zone
Maharashtra-
Gujarat Belt
Bhadravati, Wardha, Hazira
Market proximity, port access,
natural gas
Southern India
Salem, Vijayanagar, Bhadravati
Local ore (low grade), imported coal,
regional market
Western Coast
Mangalore, Ratnagiri
Port-based
steel
plants
using
imported raw materials
Punjab-Haryana

Gobindgarh
Scrap-based
mini
steel
plants,
market-oriented

Challenges Confronting the Industry:

- Raw material dependence → Imported coking coal → Higher production costs (India imports 85% of coking coal due to limited domestic reserves; imported coal has lower ash content ~10% vs. domestic ~25-30%, crucial for quality steel).
- Infrastructure bottlenecks → Inefficient logistics → Increased operational costs (E.g., congested railways, inadequate port facilities; average logistics cost in India: 14% of GDP vs global average of 8%).
- Regulatory hurdles → Project delays → Reduced competitiveness (Multiple clearances needed for mining: environmental, forest, land acquisition; average time for clearances: 2-3 years).
- Global competition (e.g., China) → Price pressure → Profit margin squeeze (China produces 50% of world's steel; Indian steel often 15-20% costlier than Chinese imports).
- Technological lag → Limited high-grade steel production → Reduced global market share (India's R&D; spending in steel: 0.05-0.5% of turnover vs. 1-2% in advanced countries; limits production of automotive and electrical steels).

Government Initiatives: Boosting the Steel Sector

- National Steel Policy 2017: Aims for 300MT crude steel capacity by 2030-31 (current capacity: 179.515 MT in 2023-24)
- DMI&SP; Policy: Preference for domestically manufactured iron and steel in government projects (minimum 15-50% domestic content requirement),
- Steel Scrap Recycling Policy: Aims to reduce scrap imports (~7 MT/year); current scrap usage ~30 MT/year.
- Steel Quality Control Orders (QCOs): 145 steel products under mandatory BIS certification.
- Strategic Trade Measures: Raised import duties; ferro-nickel duty cut and scrap duty exemption till March 2026.
- National Green Hydrogen Mission: Integrates steel sector into green hydrogen use for low-carbon steelmaking.

Student Notes:

6.5. Service/Technology Industries

6.5.1. IT Industry

The IT and ITeS (IT-enabled Services) sector
covers services like software development,
R&D;,
engineering
design,
hardware

manufacturing,
and
BPO.
As
of
2023,
accounting for approx. 8% of the India's GDP
and employs over 5 million people.
Factors Influencing Location of IT Industries
•
Climate: Cities like Bengaluru and Pune
offer a moderate climate conducive to
establishing IT infrastructure.
•
Natural Disaster Risk: Bengaluru and
Hyderabad have lower risks of natural
disasters, making them attractive locations.
•
Water
Availability
and
Digital
Infrastructure: These cities also provide
better water availability and quality digital
infrastructure.
•
Urban Agglomerations: The presence of a
skilled workforce in urban agglomerations is a
significant factor.
•
Government Policies and Tax Incentives: Favourable
policies and incentives further attract IT industries.
Global Distribution of IT Industries
•
Silicon Valley, USA: Home to giants like Apple, Google,
and Facebook.
•
Beijing, China: Known as Zhongguancun or "China's
Silicon Valley," hosting companies like Baidu, Xiaomi,
and Lenovo.
•
London, UK: Focuses on fintech, AI, and cybersecurity.
•
Tokyo, Japan: Known for hardware and robotics with
companies like Sony, Panasonic, and Softbank.
Figure: Distribution of IT Industry in World and India

Student Notes:
Major Challenges
•
Urban Concentration: About 70% of IT exports come from seven cities → Regional imbalance
and Urban strain → Bangalore: accounting 38% exports.
•
Digital Divide: Urban-rural connectivity gap → Limited rural IT growth → NE states, central

India affected.

- Climate Vulnerability: Coastal IT hubs are at risk, as evidenced by the Chennai floods in 2015, with Mumbai and Kolkata also exposed.
- Resource Scarcity: Water stress in IT clusters → Bangalore water crisis → Sustainability challenges for IT parks.
- Talent Distribution: Skills are concentrated in metropolitan areas → Brain drain from Tier-2/3 cities → Bihar, Jharkhand struggling.
- Infrastructure Disparity: Tier-1 cities have better infrastructure compared to Tier-2/3 cities, resulting in → Uneven IT growth → STPI (Software Technology Parks of India) scheme addressing gap.

Government Initiatives

- Development of Tier-2 and Tier-3 Cities: Efforts to decentralize IT industry growth.
- Software Technology Parks of India (STPI) Scheme: Focused on promoting IT/ITES in smaller cities.
- Special Economic Zones (SEZs): Providing benefits to IT/ITES sectors.
- Digital India Program: Includes projects like BharatNet for rural connectivity enhancement.

6.5.2. Semiconductor Industries

Semiconductors, known as integrated circuits or "computer chips," are crucial for modern electronics and computing. Silicon (Si) is the most widely used material due to its abundance and stability.

Bengaluru: Case Study of an IT Hub

Bengaluru, often referred to as the "Silicon Valley of India," stands out as a premier IT hub due to various factors:

Policies: Karnataka's IT Policy (1997) and the establishment of 62 operational Special Economic Zones (SEZs) by 2021.

MNC Presence: Early presence of multinational companies like Texas Instruments (1985), IBM, Intel, and Microsoft.

Education Ecosystem: Home to premier institutions like IISc, IIIT-B, and over 320 engineering colleges.

Infrastructure: Dedicated IT corridors and the Namma Metro enhance connectivity.

Startup Culture: Houses over 5,000 active tech startups (2020).

Challenges: Faces issues like traffic congestion, water scarcity, and urban sprawl.

Way Forward: By improving infrastructure, sustainable urban planning, and managing resources effectively, the city can overcome these obstacles and enhance the overall quality of life for its residents.

Future Trends in IT Industry Distribution

Rise of Tier-2 and Tier-3 Cities: Coimbatore,
Mangaluru,

Mysuru,
Kochi,
Bhubaneswar,
Indore, Jaipur
Factors: Lower costs, government incentives, quality of life
Focus on Emerging Technologies: Increased emphasis on AI, IoT, and Blockchain.
Growth of Remote Work: Leading to decentralization of IT operations.
Sector-Specific IT Clusters: Development of clusters focused on sectors like fintech and healthtech.
Academia-Industry Collaboration: Enhanced partnerships in smaller cities to foster innovation and skill development.

Student Notes:
Location Factors:

- Availability of Raw Materials: Proximity to silicon mines, such as those in Silicon Valley, USA, is essential for semiconductor production.
- Skilled Workforce: Regions like Hsinchu, Taiwan, benefit from the presence of top tech universities and a highly skilled labour force.
- Infrastructure: Advanced facilities and clean rooms, as seen in Dresden, Germany, are crucial for semiconductor manufacturing.
- Government Policies: Tax incentives and subsidies in countries like South Korea support semiconductor industry growth.
- Market Proximity: Being close to major tech markets, such as Shenzhen, China, helps companies reach consumers and partners more effectively.

Global Distribution:

- Key players: Japan, Taiwan, the United States, China, Germany, and South Korea.
- India is developing its semiconductor industry with projects in:
  - Dholera, Gujarat: Tata Electronics is partnering with Powerchip Semiconductor.
  - Morigaon, Assam: Tata Semiconductor Assembly and Test is setting up operations.
  -

Sanand, Gujarat: CG Power is collaborating with Renesas Electronics and Stars Microelectronics.

Challenges:

- Supply Chain Dependencies: Heavy reliance on specific regions like Taiwan (which produces 60% of global semiconductors) and South Korea (which provides 100% of advanced chips).
- Resource Constraints: Issues include the need for ultra-pure water, stable power sources, and specialized gases.
- Infrastructure Development Needs: Significant investment in facilities and technology is required.
- Geographical Disparities: Unequal access to technology across different regions of India.
- Shortage of Skilled Workforce: There is a need for more trained professionals in the sector.
- Regulatory and Policy Hurdles: Complex regulations and policies can impede progress.

Case Study: Diversifying Semiconductor Supply Chains Recent disruptions have highlighted the need for diversified supply chains:

Pandemic: Shortages arose due to production issues in China.

Geopolitical Tensions:

Russia-Ukraine: Disruptions due to Ukraine's neon supply.

Trade Restrictions:

EU & US: Limitations on semiconductor sales to China.

China: Export controls on critical materials like gallium and germanium.

Way Forward:

- Regional Balancing: → Promote semiconductor hubs in different geographical regions → Reduce concentration in traditional tech centers (e.g., Bangalore, Hyderabad).
- Resource Management: → Develop water-efficient technologies for semiconductor manufacturing → Focus on regions with stable water supply (e.g., riverine areas, high rainfall zones).

Student Notes:

- Energy Security: → Locate facilities near renewable energy sources (solar parks, wind farms) → Promote green energy corridors for semiconductor clusters.
- Urban-Rural Integration: → Create semiconductor satellite towns to reduce urban congestion → Promote rural areas with good connectivity for ancillary industries.
- Ecosystem Development: → Create region-specific semiconductor ecosystems based on local strengths → Integrate with existing industrial clusters (e.g., electronics manufacturing hubs).

6.6. Agro-based Industries

6.6.1. Sugar Industry

Sugar is country's second largest agro-based industry, next to cotton. India emerged world's largest producer and consumer of sugar as well as the world's 2nd largest

exporter of sugar after Brazil.
Geographical Distribution:
Largest sugar producing countries: India > Brazil >
Thailand > China > United States of America.
In India Uttar Pradesh (35%) is the largest sugarcane producer, with two belts – the Ganga-Yamuna doab and the Tarai region. Followed by Maharashtra (22%), Karnataka (10%), and Tamil Nadu (8%).
Factors Influencing Location:

- Close to Sugarcane Fields: Sugarcane, the primary raw material for sugar production, is highly perishable and cannot be stored post-maturity.
- low sugar yield: Sugarcane has low sugar yield (9-12% of cane weight) and need Immediate processing.
- Transportation costs: Mills are located near sugarcane fields (about 20 km) to minimize costs.
- Mills achieve energy self-sufficiency by using bagasse as fuel.

Steps Toward Self-Reliance (India):
→ Approval of three semiconductor fabrication units (March 2024) →
Total investment: ■1.26 lakh crore ($15.2 billion) → Key locations:
Dholera (Gujarat),
Morigaon (Assam), Sanand (Gujarat)
Sugarcane Cultivation:
Key Requirements
Temperature: 28-32°C.
Rainfall: 75-120 cm annually.
Humidity: 70-85% during growth; 55-75% during ripening.
Soil: Well-drained, fertile soils.
Irrigation: Adequate and timely irrigation during the grand growth phase (121-210 days).
Current Status:
Annual production: Approximately 30-35 million tonnes.
Contributes about 1.1% to India's GDP.
Over 500 operational sugar mills across the country.

Student Notes:
Key Challenges:

- Low yield: India's average yield (64.5 tonnes/hectare) is significantly lower than global leaders (e.g., Hawaii: 121 tonnes/hectare).
- Short crushing season: 4-7 months, leading to under-utilization of capacity.
- High production costs: Due to inefficient technology and high sugarcane prices.
- High Water Footprint: Producing 1 kg of sugar requires ~1,500–2,000 litres of water.
  - This leads to groundwater depletion, especially in Maharashtra and Karnataka.

FRP vs. SAP Pricing Conflicts in Sugarcane Issues

Fair and Remunerative Price (FRP): Set by the Central Government, FRP is the minimum price that sugar mills must pay to sugarcane farmers.

State Advised Price (SAP): Set by individual state governments, SAP is often higher than the FRP to provide additional benefits to local farmers.

Conflict:

Financial Strain: Sugar mills face financial stress due to the obligation to pay higher SAP, affecting their profitability and operations.

Farmer's Interests: Farmers prefer SAP as it guarantees higher income, leading to tensions between their interests and the financial viability of sugar mills.

Student Notes:

- Low per capita consumption: 19 kg in India vs. global average of 23 kg (2020).
- FRP vs. SAP pricing conflicts.
-

Unpaid dues to farmers: As of 2021, over Rs. 22,000 crore in arrears.
North India and South India sugar industries:
Recent Developments and Government Initiatives:

- Ethanol Blending Program: 20% ethanol blending in petrol by 2025. Sugarcane-based derivatives are expected to account for 54% of ethanol requirement.
- Technology Upgradation: Scheme for Extending Financial Assistance to Sugar Mills for Enhancement and Augmentation of Ethanol Production Capacity.
- Sustainable Sugarcane Initiative (SSI): Promotes water-efficient cultivation techniques.
- Sugar Development Fund: Provides loans for modernization and expansion of sugar factories.

Minimum Distance Criteria for Sugarcane: Under the Sugarcane Control Order, the central government mandate a specific minimum distance between two sugar mills to ensures that each mill has an adequate catchment area for sourcing sugarcane. This tends to provide a steady supply of raw material for production. Drawbacks of this system is mentioned below:
Reduced Competition: Limits competition among mills, potentially leading to complacency and inefficiency.
Farmer Disadvantage: Farmers may receive lower prices for their sugarcane due to a lack of competition between mills.
Discourages New Mills: Restricts the establishment of new mills, potentially hindering industrial growth and investment in the sector.
Way Forward:

- Implement Rangarajan Committee recommendations:
  - o Revenue sharing model (70:30 for farmers and mills).
  - o Removal of distance criterion between mills.
- Promote crop diversification in water-stressed regions.
- Encourage adoption of precision agriculture techniques.
- Invest in R&D; for developing high-yielding, drought-resistant varieties.
- Facilitate technology transfer for improving mill efficiency.
- Develop a comprehensive export strategy to manage surplus production.

Aspect	South India	North India
Yield (tonnes/hectare)	Higher yield: - Tamil Nadu: 105	Lower yield: - Uttar Pradesh: 81
Crushing Season (days)	Longer season: - Tamil Nadu: 200-250 days	Shorter season: - Uttar Pradesh: 150-180 days
Cooperative Mills	Better-managed Machines	Older machinery: - Many mills over 40 years old

Irrigation Methods
Extensive drip irrigation:
- Maharashtra: 65% coverage
Limited drip irrigation:
- Uttar Pradesh: 10% coverage
Technology Adoption
Modern technology:
- Example: 70% mills use diffuser technology
Traditional technology:
- Example: 30% mills use diffuser technology

Student Notes:

6.6.2. Cotton Industry

India, with its tropical climate and abundant cotton crop, became a significant centre for fine cotton cloth production.

Current status: India is the largest producer of cotton globally, accounting for 23% of total global cotton production. Cotton grows over 13.06 million hectares in India compared to 33.1 million hectares globally.

Geographical Distribution

- Initially concentrated in Mumbai, the industry expanded to regions like Rajasthan, Maharashtra, and Gujarat.
- Factors such as raw material availability, power supply, and proximity to markets influenced mill locations.
- Expansion continued with mills moving closer to urban centres and ports for better market access.

Structure of the Industry

The Indian cotton textiles industry comprises three tiers: hand-spun khadi sector, handlooms, and power looms, and large-scale capital-intensive mills.

Factors Affecting location of Cotton Industry

- Raw Material
    - Industry location traditionally aligned with cotton-growing areas like Ahmedabad, Nagpur, and Coimbatore.
    - Not strictly bound to proximity due to the industry's nature as non-weight losing.
- Transportation:
Ideal

locations are well-connected to both cotton-producing regions and markets to minimize transport costs.

- Access to Market: India's diverse climate supports widespread market potential, even in non-cotton-growing regions.
- Power: Early mills relied on water and steam power; later benefited from hydroelectricity and now from electricity-based climate control.
- Climate: Coastal regions with tropical/subtropical climates are favoured due to textile production requirements.
- Labour: Shift from high-labour-cost regions to low-labour-cost areas like India and Bangladesh has shaped industry dynamics.

Cotton Cultivation: Key Requirements

Temperature: Cotton thrives in 70-100°F (21-37°C) temperatures.

Rainfall: Needs 500-700 mm of evenly distributed annual rainfall.

Soil: Prefers deep, well-drained sandy loam with pH 5.8-8.0.

Other Factors: Requires a frost-free period of 180-200 days, abundant sunshine, and warm, humid conditions for optimal growth.

Student Notes:

Challenges Facing the Industry

- Cotton Availability: Dependency on monsoon for cotton crop.
- Labour Productivity: Lower compared to global standards due to out-dated machinery and practices which impacts productivity and quality.
- Global Competition: Facing competition from cheaper and higher-quality textile goods from countries like Taiwan, South Korea, and Japan.

Case Study: Global Competition in the Cotton Industry: China and Vietnam vs India

The textile industry has seen a significant shift, with Vietnam's export growth rate of 37% over five years outpacing India's 22%, indicating dynamic changes in the global market. Vietnam

attracted $19 billion in FDI for textiles (2011-2021),
Factors Contributing to Vietnam's Success:
Location → Trade Efficiency: Vietnam's Southeast Asian position → Better access to Asian markets → Enhanced export competitiveness vs. India,
Climate → Industry Specialization: India's diverse climate → Cotton cultivation → Cotton-based textiles. Vietnam's tropical climate → Focus on synthetic fibers → Fast fashion production (e.g., Zara, H&M;),
Industries→ Supply Chain: Vietnam: Concentrated textile clusters → Efficient supply chains while in India: Dispersed industry → Logistical challenges,
Infrastructure → Export Costs: Vietnam's modern ports and transportation → Lower export costs. India's infrastructural bottlenecks → Higher logistics expenses,
Regional Integration → Market Access: Vietnam in ASEAN and CPTPP → Stronger East Asian economic ties. India's RCEP withdrawal → Limited regional market integration
China's Evolving Role: China is transitioning to higher-value products and investing in Vietnam and Bangladesh, intensifying competition for India in the region.
Government Initiatives

- Market Access Initiative (MAI) Scheme: Aims to Supports textile exporters through rebates on state and central taxes.
- SAMARTH Scheme: Aims to train 10 lakh people to meet industry demand for skilled labour.
- Cott-Ally Mobile App: Assists cotton farmers by providing information on MSP, procurement centres, payments, and best farming practices.
- Mega Investment Textiles Parks (MITRA): Establishes seven textile parks to boost industry competitiveness and attract investments.
- Confederation of Indian Textile Industry (CITI) Initiatives: Improves cotton yield and production sustainability in collaboration with farmers.

6.6.3. Jute Industry
India is the world's largest producer of jute. The jute textile industry holds significant importance in India, ranking second only to cotton. As of 2023, India have 97 jute mills, primarily located in West Bengal (71) and Andhra Pradesh (12). The mills in West Bengal are concentrated along a 100 km stretch along the Hooghly River.
Factors affecting location of the Industry

- Raw Material: West Bengal’s delta soil and climatic conditions are ideal for jute cultivation.
- Transportation: The Hooghly River serves as a crucial waterway, facilitating transport from jute-growing areas. Kolkata port aids in machinery imports and finished product exports.
- Market Access: There is a robust domestic market across India for jute products, particularly gunny bags.

Student Notes:

- Labour: The densely populated Ganga-Brahmaputra Delta region provides a ready workforce, including from neighbouring Bihar and Uttar Pradesh.

Challenges

- Historical Factors: Post-partition, many jute-producing areas went to Bangladesh, while the mills remained in India. This imbalance necessitates jute fibre imports from Bangladesh to meet demand.

- Technological Obsolescence: Outdated machinery, power shortages, and industrial inefficiencies hinder production.
- Competition and Alternatives: Newly established mills in Bangladesh pose competitive challenges, while synthetic materials like polythene and nylon are replacing traditional jute products.

Government Initiatives for the Jute Industry in India

- Jute Diversification Scheme: Encourages diversification of jute products to expand market opportunities.
- Domestic Market Promotion Activities (DMPA): Promotes jute products within India to increase domestic sales.
- Mandated Jute Packaging: The Cabinet Committee on Economic Affairs approved reservation norms mandating:
  - 100% packaging of foodgrains and
  - 20% of sugar in jute bags for the Jute Year 2023-24.

Student Notes:

6.6.4. Tea Industry

India is the second-largest producer of tea globally. India is also among the world's top tea-consuming countries, with 80% of the tea produced in the country consumed by the domestic population.

Distribution of the Industry

- Regions: Assam (83% of national production) and West Bengal are the primary tea-producing states. The southern states of Tamil Nadu, Kerala, and Karnataka contribute 17% of production. Other regions include Tripura, Himachal Pradesh, and the North-Eastern states.
- Varieties: Assam is known for Camellia Assamica, with a unique malty and earthy flavour. Darjeeling is famous for its floral aroma and has GI tag recognition.
- Export: India is 4th largest tea exporter, with major markets including Russia, Iran, UAE, USA, UK, Germany, and China. Black tea constitutes 96% of exports.

Challenges

The industry faces several challenges, including:

- Crisis and Abandonment: Low productivity, thin margins, and lesser export levels have led to the abandonment of tea estates.
- Competition: India faces stiff competition from

Sri Lanka, Kenya, China, and Indonesia.

o Demand for organic tea have further affected India’s market position

- Working Conditions and Small Tea Growers: Tea workers face deeply embedded human rights and gender issues, such as low wages and poor working conditions, exacerbated by globally low prices.
- Climate Change impact: This has led to an increase in pest incidents in plantations, resulting in extensive pesticide use and subsequently raising the input costs of tea production.
- External Factors: The Russia-Ukraine war has worsened industry problems by disrupting supply chains and reducing tea imports from Russia, a major buyer of Indian tea.

Government Initiatives

- Tea Board of India: Offers various schemes like the Tea Development and Promotion Scheme (2021-26) and the Chai Sahyog Mobile App for small growers.
- Promotion and Subsidies: Assistance for promotional campaigns and subsidies for exporters to participate in international fairs.
- Regulatory Reforms: Online Licensing System and worker welfare initiatives.
- Setting up of Mini tea factories to encourage entrepreneurs and unemployed youth.

Growth Conditions for Tea Cultivation

Climate: Hot and humid conditions.

Temperature: 20°-30°C; harmful at above 35°C and below 10°C.

Rainfall: 150-300 cm annually, evenly distributed.

Soil: Slightly acidic, calcium-free, with porous sub-soil for good water percolation.

Regulating Authority: Tea Board of India

Establishment: Set up in 1953 under the Ministry of Commerce

Objective: To make India a leading global tea producer through various programs and schemes.

Offices:

India: Headquarters in Kolkata with 17 additional offices.

Abroad: Two offices located in Dubai and Moscow.

Student Notes:
Way Forward:
To enhance the sector's profitability and sustainability, the following steps are crucial:

- ODOP (One district One Product) Scheme: Promote tea as a unique product from different districts.
- AROMA Strategy:

The tea industry remains vital to India's economy and cultural heritage. Addressing current challenges through strategic initiatives and support systems will ensure its sustainable growth.

6.6.5. Coffee Industry

India became the world's eighth largest coffee grower during 2022-2023. India exports 70-80% of its coffee production, with major markets in Italy, Germany, Russia, and Belgium.

India produces two types of coffee:

- Arabica: 30% of production, higher quality.
- Robusta: 70% of production, more disease-resistant.

Geographical Distribution

- Major Producing Regions:
    - Karnataka: 71% of total production.
    - Kerala: 21% of total production.
    - Tamil Nadu: 5% of total production (Nilgiri district).

Factors Determining the Location of Coffee Industry

- Climate: Requires a hot and humid climate (15-28°C, 150-250 cm rainfall).
- Vegetation: Grown under shady trees.
- Topography: Hill slopes at elevations of 600-1,600 meters above sea level.
- Soil: Well-drained, rich in humus and minerals.
-

Capital and Labour: Capital-intensive, labour-intensive industry requiring abundant, cheap, and skilled labour.

Why is Coffee Cultivation Restricted to the Bean Belt?

Coffee cultivation is restricted to the "bean belt" region around the equator, between the Tropics of Cancer and Capricorn, due to its ideal growing conditions. These include:

Geographical Indications (GI)

Coorg Arabica Coffee (Karnataka)

Wayanad Robusta Coffee (Kerala)

Chikmagalur Arabica Coffee (Karnataka)

Araku Valley Arabica Coffee (Andhra Pradesh)

Student Notes:

Challenges

- Climate Change: Erratic rainfall patterns and increased pest and disease incidence.
- Small Holdings: 98% of coffee growers are small farmers with an average farm size of 2-3 hectares.
- Price Fluctuations: Vulnerability to international market price volatility.
- Labour Shortage: Migration of workers to urban areas.
- Competition: From major producers like Brazil and Vietnam.

Case Study: Rising Coffee Prices

Global coffee prices surged in 2024–25 due to severe droughts and frosts in Brazil and El Niño impacts in Vietnam, cutting supplies of Arabica and Robusta beans. As a ripple effect, Indian growers witnessed record domestic prices (Arabica ~■600/kg), boosting incomes.

- India's exports dipped 10% amid high domestic holding.
- Retail prices rose globally with an 8–11 month lag (FAO).
- Climate volatility and input cost inflation remain key risks.

India benefits short-term but needs long-term reforms in plantation rejuvenation, processing infrastructure, and climate resilience.

Government Initiatives

- Coffee Board of India: Established in 1942 to develop the coffee industry, providing research, financial assistance, and marketing support.
- Integrated Coffee Development Project: Launched in 2014-15 to improve replantation, quality, and market development.
- National policy of tribal development encouraged coffee cultivation in non-traditional areas.
- Export Promotion: Market Development Assistance Scheme and brand promotion in international markets.

Coffee Board of India
Establishment: Statutory organization, constituted under Coffee Act, 1942. HQ: Bangalore.
Function: Under the administrative control of the Ministry of Commerce and Industry.
Objectives: Mainly focuses its activities in the areas of research, extension, development, market intelligence, external & internal promotion for coffee.

6.6.6. Rubber Industry

India is the sixth largest producer of natural rubber (NR) in the world and second largest consumer of NR.

- Distribution: Kerala (the largest producer), Tamil Nadu, Karnataka, Tripura, Assam, Andaman and Nicobar, and Goa.
- World (major producers): Thailand, Indonesia, Malaysia.

Factors Responsible the Location of Natural Rubber Industry

- Climatic Conditions: Favourable warm, humid tropical climate, Lateritic soils rich in iron.
- Labour: Need skilled labour to collect Latex,

Favourable Conditions for Rubber
Age: around 32 years in plantations.
Soil: Well-drained and well-weathered soils e.g., Lateritic type, alluvial, sedimentary types
Precipitation and Temperature: An evenly distributed rainfall with at least 100 rainy days a year and a temperature range of about 20 to 34°C.
Conditions: A humidity of around 80%, 2000 hours of sunshine, and absence of strong winds

- Disease Resistance: High-yielding varieties resistant to fungal infections.
- Yield and Quality Control: Regular replanting maintained high yield and quality; strong focus on quality control.

Challenges Facing the Rubber Industry:

- High Labour Costs: Expensive skilled labour for rubber tapping makes plantations financially unsustainable.

- Import Competition: Cheaper imported rubber lowers domestic prices, further discouraging local production.
- Production-Consumption Gap: Increasing tire industry demand widens the gap between rubber production and consumption.
- Climate Change: Changing weather, especially in traditional areas like Kerala, poses challenges for rubber cultivation.
- Technological Lag: Limited adoption of advanced technology reduces productivity and global competitiveness.

Government Initiatives in the Rubber Sector:

- Rubber Plantation Development Scheme: Provides financial assistance to farmers to develop rubber plantations.
- Rubber Group Planting Scheme: Offers financial incentives for forming rubber farmer groups and societies.
- National Rubber Policy 2019: Supports the entire rubber industry value chain, including natural rubber production.
- Sustainable and Inclusive Development of the Natural Rubber Sector
- To encourage investment 100% FDI permitted.

Why Did the Southeast Asian Rubber Industry Rise and the South American Industry Fall?

The Southeast Asian rubber industry rose since 1930s due to Favourable climate, successful domestication, abundant labour, political stability, disease resistance, technological advances, and quality control. Conversely, the South American industry collapsed due to wild tree reliance, labour shortages, political instability, disease susceptibility, technological and competition from Southeast Asia.

The Rubber Board of India, established in 1955 and headquartered in Kottayam, Kerala, operates under the Ministry of Commerce and Industry. Its primary objective is to foster the growth and advancement of the rubber industry across India.

6.7. Other Industries

6.7.1. Pharmaceutical Industry

India's pharmaceutical industry has emerged as a "pharmacy of the world". The Indian pharmaceutical industry is the world’s 3rd largest by volume and 14th largest in terms of value.

Location Factors of Pharmaceutical Industries in India

Market:

- Large domestic market,
- West coast location advantageous for exports to Africa and Europe.

Government Policy:

- 100% FDI allowance attracts foreign investments,
- Strong IP protection under Indian Patents Act, 1970,

Infrastructure: Availability of power, transport, and communication,

Labour Skills:

- Availability of skilled labour,
- Contributes to industry decentralization across the country,

Raw Materials: Proximity to petrochemical hubs (e.g., Jamnagar, Gujarat; Bombay High, Maharashtra).

Capital Availability: Western India's traditional role as a trade and capital hub.

Problems of Pharmaceutical Industries in India

Technology Gap:

- Lagging in R&D; for new medicine development
- Limited focus on research and innovation

Raw Material Dependence:

- High reliance on China for Active Pharmaceutical Ingredients (APIs)
- Import of ~70% of bulk drug requirements from China

Global Competition:

- Stiff competition from China, Israel, and Japan
- Accusations of patent violations by big players
- Weakening intellectual property environment
post-TRIPS implementation

Quality Issues:

- Adulteration and piracy concerns,
- Proliferation of duplicate manufacturers.

International Pressure:

- U.S. Trade Representative's 2024 Special 301 Report includes India in the 'Priority Watch List' along with China, Russia, Venezuela, Indonesia, Chile, and Argentina. (Reason behind this related to Intellectual Property (IP) protection and enforcement),
- Lead to negative impact on industry reputation and exports.

These challenges highlight the need for strategic interventions to enhance India's pharmaceutical industry competitiveness and self-reliance.

Recent Government Initiatives:

- Scheme for Development of Pharma industry – Umbrella Scheme such as Assistance to Pharmaceutical Industry (CDP-PS).

Student Notes:

- Production Linked Incentive (PLI) Scheme: Rs. 15,000 crore allocated to boost domestic manufacturing of APIs and medical devices.
- Bulk Drug Parks Scheme: Rs. 1,000 crore for the promotion of bulk drug parks for FY25,
- R&D; and Biotech Focus: National Biopharma Mission to accelerate biopharmaceutical development.
- Efforts like Mission COVID Suraksha and the resumption of vaccine exports to COVAX highlight India's role in global health security.

6.7.2. Automobile Industry

India has emerged as Asia's fourth largest exporter of automobiles, following Japan, South Korea, and Thailand. This growth underscores its potential to lead in global car volumes, projected to reach approximately 611 million vehicles on Indian roads by 2050.

Location Factors of Automobile Industries

- Proximity to Raw Materials: Requires a steady supply of raw materials such as steel, nonferrous metals, plastics, rubber, and electronics. Proximity to steel-producing centres is crucial due to the high demand for steel in vehicle manufacturing.
- Access to Ports: Port cities like Mumbai, Chennai, and Kolkata are favoured due to their logistical advantages for importing raw materials and exporting finished vehicles.
- Market-Oriented Locations: Urban centres like Delhi-NCR, Mumbai, Chennai, and Pune not only offer large consumer markets but also provide access

to
skilled
labour
and
supporting industries.

- Government Policy and Initiatives:
The Auto Policy has positioned India as a hub for small car production, focusing on quality and affordability.

Challenges Faced by the Industry

- Environmental Regulations Stringent environmental safeguards, including emission standards, fuel categorizations, and promotion of biofuels and electric vehicles, pose regulatory challenges.
- Infrastructure Constraints Automobile plants require substantial investments in land, capital, and skilled labour. Challenges in land acquisition, as seen in Bengal and Orissa, hinder industry growth.
- Diverse Market Dynamics India's diverse consumer base, influenced by varying socio-economic factors, demands a versatile product portfolio that caters to both urban middle-income groups and rural populations.
- Research and Development Insufficient focus on research and development in fuel-efficient technologies, emission standards, and cost-effective production methods hampers technological advancement and competitiveness.

Government Initiatives

- FDI and NATRIP: India allows 100% FDI in automobiles and established NATRIP for testing and R&D; since 2015.
- PLI Scheme: Extended PLI Scheme for Auto and Auto Components till March 2028 to boost manufacturing incentives.
- Automotive Mission Plan 2016-26 (AMP 2026): Aims for four-fold growth in auto sector over next decade.
- FAME Scheme: New scheme to promote electric vehicles and enhance charging infrastructure with US$ 321.5 million budget allocation for 2024-25.

Global Automobile Industry: Restructuring & Reorganization
The global automobile industry is undergoing a profound transformation driven by technological shifts, policy imperatives, and supply chain recalibrations. This restructuring reflects a transition toward sustainability, digitalization, and geopolitical realignments.

Key Dimensions of Restructuring
Aspect
Changes
Electrification

Automakers are transitioning from internal combustion engines
(ICE) to electric vehicles (EVs). Companies like Volkswagen, GM,
and Hyundai are phasing out ICE production and investing in EV
platforms.
Supply Chain
Realignment
Dependence on China-dominated supply chains for rare earths,
chips, and batteries is being reduced. The US, EU, and India are
encouraging "China+1" strategies and nearshoring.
Platform
Consolidation
Manufacturers are moving toward shared modular platforms (e.g.,
VW's MEB, Toyota's e-TNGA) to improve efficiency and reduce
production costs across EV models.
Digital
Manufacturing
Integration of Industry 4.0, AI, IoT, and robotics in production lines
to achieve real-time monitoring, customization, and predictive
maintenance.
Mobility-as-a-
Service (MaaS)
Shift in business models from vehicle ownership to shared
mobility, ride-hailing, and subscription-based services (Uber, Ola,
Zipcar).
Sustainability
Regulations
Tighter emission norms (Euro 7, CAFE standards) and carbon
neutrality targets are pushing automakers to redesign operations
and reduce lifecycle emissions.

Emerging Geographies & Decentralization

- Asia's Rise: China leads in EV production and innovation; India, Vietnam, and Thailand are emerging as low-cost manufacturing hubs.
- Regional Hubs: Shift from single-nation dependence to regional hubs (e.g., Mexico for US market, Eastern Europe for EU, Vietnam/India for APAC) to mitigate geopolitical and logistical risks.
- Gigafactories: Rise of battery gigafactories (Tesla, CATL, Panasonic, Reliance) to reduce battery import dependency and lower EV costs.

Case Study: BYD – Restructuring Global Auto Industry

BYD has disrupted the EV sector by adopting a vertically integrated model—manufacturing batteries, chips, and EV components. With innovations like the Blade Battery and global exp into Europe, Asia, and Latin America,showcasing a cost-efficient, scalable blueprint for the fu mobility.

India in the Changing Landscape

- EV Push: India aims for 30% EV sales by 2030 (under FAME-II, PLI-Auto, and Battery Storage schemes).
- New Hubs: Tamil Nadu, UP, Gujarat, and Karnataka are emerging as EV and component manufacturing centers.
- Localisation Drive: Government incentives for semiconductors, Li-ion batteries, and auto-electronics to reduce import dependence.

6.7.3. Shipbuilding Industry

Shipbuilding refers to the construction, repair, and maintenance of vessels used for transportation, defense, and trade. It includes a range of ships, from small boats to large tankers and warships. Shipbuilding is carried out in specialised facilities called shipyards, which are equipped to handle large-scale projects and complex assembly processes.

Location Factors of the Shipbuilding Industry

Factor	Explanation	Examples
Proximity to Deep Water	Requires calm, deep harbours for launching and repairing large vessels.	Visakhapatnam, Cochin, Kattupalli (India); Busan (S. Korea)
Coastal Access	Sea access is vital for testing and operational deployment.	Mumbai, Goa, Chennai
Raw Material Access	Close to steel plants, heavy engineering, and electrical industries.	Gujarat (steel), Maharashtra (components)
Skilled Workforce	Requires engineers, naval architects, and welders.	Presence of IITs, Naval Academies, training institutes
Port Connectivity	Shipyards benefit from being near major commercial ports.	Cochin Port, Kandla Port, Chennai Port
Naval and Defence Demand	Defence sector demand drives shipyard expansion.	Mazagon Dock, GRSE, Garden Reach

Government
Policy Support
Financial incentives, FDI allowance,
and public procurement policies
encourage growth.
Shipbuilding Financial Assistance
Policy (SFAP)
Characteristics of the Shipbuilding Industry

- Capital and Technology Intensive: Requires large infrastructure, skilled labor, and precision engineering.
- High Employment Multiplier: Supports steel, paints, electronics, logistics, and ancillary sectors.
- Strategic for Defence: Supports navy modernization and maritime dominance.
- Dual-Use Capacity: Builds both civilian (cargo, cruise, fishing) and military vessels.
- Long Gestation Period: Projects take 1–3 years, depending on ship size and complexity.

India's Growth in Shipbuilding Capacity

- Shipbuilding Financial Assistance Policy (2021–2031): Offers 20% subsidy for domestically built ships.
- Sagarmala Project: Enhances port connectivity, logistics parks, and coastal infrastructure.
- FDI Policy: Allows 100% FDI in shipbuilding and repair.
- Green Shipbuilding: Focus on LNG-fueled vessels and decarbonized propulsion systems.

6.7.4. Space Industry

India's space industry, primarily driven by the Indian Space Research Organisation (ISRO), has evolved into a strategic and innovation-driven sector. The spatial distribution of its facilities is not random but shaped by a blend of physical, technical, strategic, and institutional locational factors.

Student Notes:
Locational factors influencing the Space Industry in India
India's space industry, primarily driven by the Indian Space Research Organisation (ISRO), has evolved into a strategic and innovation-driven sector.
The spatial distribution of its facilities is not random but shaped by a blend of physical, technical, strategic, and institutional locational factors. With the rise of private space players under IN-SPACe, these locational dynamics are becoming even more crucial.
Locational Factors Influencing India's Space Industry
Factor
Influence on Location
Examples
1. Proximity to the
Equator
Closer to the equator allows more
efficient
launches
into
geostationary orbits due to Earth's

rotation.
Satish Dhawan Space Centre (SHAR), Sriharikota (13.7°N) – India’s primary launch site
2. Coastal Access
Ensures safety during launches (over the sea) and ease of transporting large components via ports.
SHAR (Andhra Pradesh), Thumba Equatorial Rocket Launching Station (Kerala)
3. Skilled Human Capital
Presence of premier scientific institutions and engineering colleges provides R&D; talent.
Bengaluru – ISRO HQ, URSC, NSIL; IITs, IISc, HAL ecosystem
4. Historical and Institutional Legacy
Locations chosen for early scientific research or military R&D; often developed into full-scale space hubs.
Thiruvananthapuram – Vikram Sarabhai Space Centre; legacy of space science since 1960s
5. Supporting Infrastructure
Need for clean rooms, testing facilities, telemetry stations, wind tunnels, etc.
Ahmedabad – SAC (payload design), Mahendragiri – IPRC (propulsion testing)
6. Policy & Regulatory Ecosystem
Government support, reforms (e.g., Indian Space Policy 2023), and ease of private participation influence clustering.
IN-SPACe HQ in Ahmedabad; emerging space startup hubs in Hyderabad, Chennai, Bengaluru
7. Land Availability & Safety Zones
Large, isolated land tracts are needed for launchpads, tracking stations, and rocket testing to

prevent risk to population.
Challakere
(Karnataka)
–
astronaut training & human
spaceflight support
8. Strategic &
Defence Linkages
Some locations are chosen based
on proximity to DRDO labs, defence
PSUs, or missile testing ranges.
Hyderabad
(NRSC,
BDL),
Balasore (Odisha) – missile
testing zone

Student Notes:
Emerging Private Ecosystem in India

- Startups like Skyroot, Agnikul, Bellatrix, Pixxel are emerging in Hyderabad, Chennai, Bengaluru.
- IN-SPACe and the Indian Space Policy 2023 allow non-government entities to build and operate satellites and launch vehicles—spurring regional innovation hubs.
- New industrial parks and space-tech zones are being planned near Bengaluru, Chennai, and Hyderabad, driven by startup agglomeration.

6.8. Evolving Global Supply Chains: A Geographical Perspective
Globalization led to the creation of complex, interconnected supply chains spanning continents. For instance:

- Electronics industry: Components manufactured in Asia, assembled in Mexico, and sold in North America and Europe.
- Textile industry: Cotton grown in India, processed in Bangladesh, and finished products sold globally.

These patterns resulted in:

- Specialized industrial clusters (e.g., Silicon Valley for tech, Guangdong for electronics manufacturing)
- Development of major shipping routes and ports (e.g., Port of Shanghai, Rotterdam)
- Emergence of global cities as coordination centers (e.g., London, Singapore)

But now, Deglobalization is reshaping supply
chain patterns by driving a shift from global networks to more localized structures that prioritize risk mitigation and local sourcing. Key Reasons are given below:

Supply Chain

It is the network that connects the production and distribution of goods from raw materials to final consumers. For example: Smartphone Production.

Rare earth minerals (e.g., from China) → Chip manufacturing (e.g., in Taiwan) → Assembly (e.g., in Vietnam) → Global retail distribution.

Student Notes:

6.8.1. Geographical Impacts of Supply Chain Disruptions

Recent events have exposed vulnerabilities in this global system:

US-China Trade War:

- Shifted soybean trade patterns: US exports to China decreased, while Brazil's increased,
- Relocation of manufacturing from China to countries like Vietnam and Mexico.

COVID-19 Pandemic:

- Disrupted pharmaceutical supply chains, heavily dependent on China and India,
- Exposed vulnerabilities in just-in-time manufacturing, particularly in automotive and electronics industries.

Russia-Ukraine War:

- Europe's reliance on Russian natural gas has led to energy shortages and price hikes due to sanctions and supply interruptions.
- Example: Germany faced significant increases in energy costs due to reduced gas supplies from Russia.

6.8.2. Emerging Geographical Patterns in Supply Chain Strategies

- Friend Shoring: Relocating production to allied or friendly countries to reduce reliance on geopolitical rivals.
  - Japan offering incentives for companies to relocate production from China to Southeast Asia or India.
  - Geographical Impact: Strengthening of regional economic blocs and potential emergence of new industrial clusters.
- Nearshoring: Moving production closer to home to reduce transportation costs and improve supply chain resilience.
  - US companies moving production from China to Mexico.
  - Geographical Impact: Revitalization of manufacturing in proximity to major markets, potentially altering urbanization patterns in border regions.
- Onshoring: Bringing production back to the company's home country to enhance control

over the supply chain.
o
India's push for domestic semiconductor manufacturing under the "Make in India" initiative.
o
Geographical Impact: Reindustrialization of developed economies and potential for new domestic industrial zones.

6.8.3. From Just-in-Time to Just-in-Case: Spatial Implications

The shift from JIT to JIC inventory systems has significant geographical implications:

● Increased demand for warehousing and storage facilities near major urban centers,
● Development of secondary and tertiary ports to diversify supply routes,
● Renewed focus on strategic stockpiling locations for critical goods (e.g., medical supplies, rare earth elements).

Key Highlight:
The shift from just-in-time (JIT) to just-in-case (JIC), highlighted by S. Jaishankar, reflects a broader trend in global supply chain management due to COVID-19 and trade tensions. Geographical implications:
Reshoring and Nearshoring: Moving production closer to home or friendly nations, changing global production patterns.
Stockpiling Locations: Strategically placing inventory stockpiles closer to end markets.
Supply Diversification: Sourcing from multiple locations to mitigate risks.

Student Notes:
Example: The EU's strategy to stockpile rare earth elements, crucial for green technology, to reduce dependence on China.

6.8.4. Decoupling and De-risking: Reshaping Economic Geography

•
Decoupling: Efforts to create parallel supply chains for critical technologies (e.g., 5G networks) independent of China.
o
Geographical Impact: Potential emergence of parallel economic spheres with

distinct production and trade networks.

- De-risking: Diversification of automobile chip suppliers beyond Taiwan and South Korea.
  - Geographical Impact: More distributed network of specialized suppliers, potentially benefiting secondary economic centres.

The evolution of global supply chains, from just-in-time (JIT) to just-in-case (JIC) and the rise of strategies like friend shoring, nearshoring, and onshoring, is reshaping economic geography. This shift prioritizes resilience and strategic autonomy, leading to:

- More regionalized production and trade,
- Increased importance of geographical proximity,
- Emergence of new industrial clusters and potential decline of other.

What is China Plus One Strategy?

Global shift away from sole reliance on China for manufacturing.

Driven by COVID-19 disruptions, US-China tensions, and rising costs in China.

Companies diversifying production to countries like Mexico, Thailand, and Vietnam.