Unit 1: Introduction to Environmental Sustainability, Ecosystem and Biodiversity

Environmental Sustainability — DI02000051

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Unit 1 — Syllabus Coverage

Topics (Weightage: 10% | Hours: 4)

1.1 Definition & Scope of Sustainability
Structure and Function of Ecosystems
Food Chain, Food Web, Ecological Pyramids

1.2 Biogeochemical Cycles: Carbon, Nitrogen, Sulphur, Phosphorus

1.3 Importance of Biodiversity
Threats to Biodiversity
Conservation Strategies (in-situ & ex-situ)

GTU PYQ: Su'25, W'25 — MCQs + 4M + 7M descriptive

1.1 Environmental Sustainability

Definition · Scope · Ecosystems

What is Sustainability? (W'25, Su'25 MCQ — 1M)

Brundtland Definition (1987)

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Environmental

Protect natural resources, reduce pollution

Economic

Long-term growth without resource depletion

Social

Equity, health, well-being for all

Three Pillars of Sustainability: Environment + Economy + Society

Scope of Environmental Sustainability (W'25 — 4M)

Area	Scope / Focus
Natural Resources	Conservation of forests, water, soil, minerals
Energy	Shift to renewable; reduce fossil fuel dependence
Waste Management	Reduce, Reuse, Recycle (3R/5R)
Pollution Control	Air, water, soil, noise, e-waste management
Climate Change	Reduce GHG emissions; carbon neutrality
Biodiversity	Protect species, habitats, ecosystems
Policy & Law	Environmental acts, ISO 14000, green building

➥ **Goal**: Balance human development with ecological health for long-term survival.

Sustainable Development Goals (SDGs) (General — 3M)

UN SDGs 2030 — 17 Goals

Adopted by UN in 2015. Key environment-related goals:

SDG 6 — Clean Water & Sanitation
SDG 7 — Affordable Clean Energy
SDG 11 — Sustainable Cities
SDG 12 — Responsible Consumption
SDG 13 — Climate Action
SDG 14 — Life Below Water
SDG 15 — Life on Land

India's Steps:

- ➥ National Solar Mission
- ➥ Swachh Bharat Abhiyan
- ➥ FAME (Electric Vehicles)
- ➥ Namami Gange project
- ➥ National Action Plan on Climate Change (NAPCC)

What is an Ecosystem? (Su'25 MCQ, W'25 — 3M)

Definition

An **ecosystem** is a community of living organisms (*biotic*) interacting with each other and their non-living environment (*abiotic*) as a functional unit.

Biotic Components

- ➥ Producers (Plants)
- ➥ Consumers (Animals)
- ➥ Decomposers (Fungi, Bacteria)

Abiotic Components

- ➥ Sunlight, Temperature
- ➥ Water, Wind, Soil
- ➥ Minerals, Gases (CO_2, O_2)

Largest ecosystem on Earth = **Oceans** (Su'25 MCQ Answer: B)

Abiotic Components of an Ecosystem (W'25 — 3M)

Category	Components	Role
Climatic	Sunlight, Temperature, Rain	Energy source, habitat
Edaphic	Soil, Minerals, pH	Anchoring, nutrient supply
Aquatic	Water (rivers, lakes, sea)	Medium for life
Atmospheric	O_2, CO_2, N_2	Respiration, photosynthesis
Topographic	Altitude, Slope, Aspect	Microclimate variation

Key Point: Abiotic factors determine which organisms can survive in an ecosystem. They set the **physical limits** (temperature range, water availability, soil type).

Biotic Components: Producers, Consumers, Decomposers (Su'25 MCQ)

Producers

Autotrophs
Make own food via photosynthesis
Examples:
Green plants, Algae, Phytoplankton

Consumers

Heterotrophs
Primary: Herbivores
Secondary: Carnivores
Tertiary: Top predators

Humans = Primary & Secondary (Su'25 MCQ: C)

Decomposers

Saprotrophs
Break down dead organic matter
Examples:
Fungi, Bacteria
(Su'25 MCQ: C — Decomposers)

➥ **Most important element in biotic components** = **Carbon** (Su'25 MCQ: C)

Structure and Function of Ecosystem (W'25 — 4M)

Two Key Aspects

Structure	The composition of biotic & abiotic components and their arrangement
Function	Energy flow, nutrient cycling and population regulation

Functions of an Ecosystem

- **Energy Flow** — Sun → Producers → Consumers → Decomposers
- **Nutrient Cycling** — Biogeochemical cycles (C, N, S, P)
- **Productivity** — Primary (plants) & Secondary (animals)
- **Decomposition** — Breakdown of dead matter; nutrient return
- **Regulation** — Population control; disease regulation

Food Chain (Su’25, W’25 — 3M)

Definition

A **food chain** is the linear sequence of organisms through which energy and nutrients pass as one organism eats another.

Grass	← Grasshoppe	← Frog	← Snake	← Eagle
Producer	1° Consumer	2° Consumer	3° Consumer	4° Consumer

Types: (1) **Grazing food chain** — starts with green plants. (2) **Detritus food chain** — starts with dead organic matter (detritus) → decomposers.

Food Web (Su'25, W'25 — 3M)

Definition

A **food web** is a network of interconnected food chains in an ecosystem. It shows the complex feeding relationships.

Food Chain vs Food Web

Food Chain	**Food Web**
Linear	Network
Single path	Multiple paths
Unstable	More stable
Few organisms	Many organisms

Significance

- ➡ Reflects real ecosystem complexity
- ➡ Removal of one organism affects many
- ➡ Provides alternative energy pathways
- ➡ More resilient to disturbance

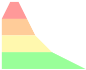
Humans in food web:
Primary AND secondary consumer
(omnivores — eat plants & animals)

Ecological Pyramids (W'25 — 4M)

Definition

A graphical representation of the number, biomass, or energy at each trophic level. Always wider at base (producers) and narrower at top.

Type	Represents	Shape
Pyramid of Numbers	Count of individuals	Usually upright
Pyramid of Biomass	Total dry weight	Usually upright
Pyramid of Energy	Energy (kcal) at each level	Always upright



Energy Flow in Ecosystem — 10% Law (W'25, Su'25 — 3M)

Lindeman's 10% Law (1942)

Only **10%** of the energy stored at one trophic level is transferred to the next level. The remaining **90%** is lost as heat (respiration, excretion, etc.).

Producers 10,000 kcal $\xleftarrow{10\%}$ Herbivores 1,000 kcal $\xleftarrow{10\%}$ Carnivores 100 kcal $\xleftarrow{10\%}$ Top Predator 10 kcal

➥ This is why food chains rarely exceed **4–5 trophic levels**.

➥ Sun provides the initial energy via **photosynthesis** (only ∼1% used by plants).

Type	Sub-type	Key Feature
Terrestrial	Forest	High biodiversity, dense canopy
	Grassland	Moderate rainfall, grasses dominant
	Desert	Low rainfall, extreme temperature
Aquatic	Freshwater	Rivers, lakes, ponds
	Marine	Oceans — **largest ecosystem on Earth**
	Wetlands	Swamps, marshes; high productivity
Artificial	Cropland, Aquarium	Human-managed systems

Amazon Rainforest releases ≈20% of Earth's total oxygen (Su'25 MCQ: C).
Wetlands = "Kidneys of the Earth" due to natural water filtering.

1.2 Biogeochemical Cycles

Carbon · Nitrogen · Sulphur · Phosphorus

Biogeochemical Cycles — Overview (W'25 MCQ — 1M)

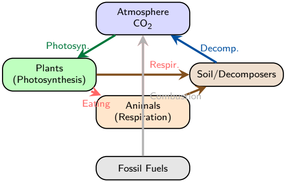
Definition

A **biogeochemical cycle** is the pathway by which a chemical element or molecule moves through both the biotic (biological) and abiotic (geological, hydrological, atmospheric) components of an ecosystem.

Cycle	**Reservoir**	**Key Process**
Carbon	Atmosphere, Oceans	Photosynthesis / Respiration
Nitrogen	Atmosphere (78% N_2)	Fixation / Denitrification
Sulphur	Rocks, Ocean sediments	Weathering / Decomposition
Phosphorus	Rocks, Soil, Sediments	Weathering / Uptake by plants

➥ **Nitrogen in atmosphere** $\approx$ **78%** (Su'25 MCQ: C)

(Su'25, W'25 — 4M)



Key Processes

- **Photosynthesis:** Plants absorb CO_2
- **Respiration:** All organisms release CO_2
- **Decomposition:** Microbes release CO_2 from dead matter
- **Combustion:** Burning fossil fuels adds CO_2
- **Ocean uptake:** Oceans absorb CO_2

Human Impact

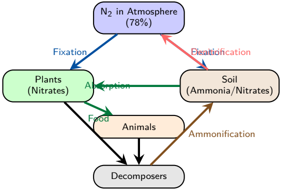
Burning coal/oil raises atmospheric CO_2 $\rightarrow$ Global Warming

Carbon Cycle — Steps & Facts (Exam Guide — 4M)

Step	Process	Description
1	Photosynthesis	$CO_2 + H_2O \xrightarrow{\text{sunlight}} \text{Glucose} + O_2$
2	Respiration	Organisms oxidise glucose → release CO_2
3	Decomposition	Bacteria/fungi break down dead matter → CO_2
4	Combustion	Fossil fuels burn → CO_2 to atmosphere
5	Carbon sequestration	Oceans, forests, soil store carbon
6	Fossilization	Dead organic matter → coal, oil (millions of yrs)

Carbon reservoirs: Atmosphere, Biosphere, Hydrosphere (oceans), Lithosphere (rocks/fossil fuels)
Pre-industrial CO_2: 280 ppm **Current:** >420 ppm (2024)

Nitrogen Cycle (Su'25, W'25 — 7M)



Key Steps

1. **Fixation:** $N_2 \rightarrow NH_3$ (Rhizobium bacteria)
2. **Nitrification:** $NH_3 \rightarrow NO_2^- \rightarrow NO_3^-$
3. **Assimilation:** Plants absorb NO_3^-
4. **Ammonification:** Dead matter $\rightarrow NH_3$
5. **Denitrification:** $NO_3^- \rightarrow N_2$ (back to air)

- N_2 = 78% of atmosphere
- Essential for proteins, DNA
- *Rhizobium* fixes N in legumes
- Lightning also fixes N

Nitrogen Cycle — Processes in Detail (W'25, Su'25 — 4M)

Process	Organism	Reaction / Description
Nitrogen Fixation	Rhizobium, Azotobacter	$N_2 \rightarrow NH_3$ (ammonia)
Ammonification	Decomposers	Dead organics $\rightarrow NH_4^+$
Nitrification	Nitrosomonas	$NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$
Assimilation	Green plants	NO_3^- absorbed as nutrients
Denitrification	Pseudomonas	$NO_3^- \rightarrow N_2$ released to air

Exam Quick Points

- **N_2 in atmosphere** = **78%** (Su'25 MCQ: C)
- Most plants CANNOT use N_2 directly — needs fixation
- Legumes (beans, peas) have root nodules with *Rhizobium*

Sulphur Cycle (Su'25, W'25 — 4M)

Key Processes

1. Weathering: Rocks release SO_4^{2-} into soil

2. Assimilation: Plants absorb SO_4^{2-} $\rightarrow$ amino acids (cysteine, methionine)

3. Decomposition: Dead matter $\rightarrow$ H_2S (hydrogen sulphide)

4. Oxidation: $H_2S + O_2 \rightarrow SO_4^{2-}$ (by bacteria)

5. Combustion: Fossil fuels $\rightarrow$ SO_2 (acid rain precursor)

6. Volcanic: Volcanoes release SO_2 to atmosphere

Human Impact

➥ Burning coal releases SO_2
➥ $SO_2 + H_2O \rightarrow H_2SO_4$ (Sulphuric Acid Rain)
➥ Acid rain: damages forests, corrodes buildings, acidifies water bodies

Reservoir

Main reservoir: Rocks & sediments (lithosphere)
Atmospheric form: SO_2 gas

Phosphorus Cycle (Su'25, W'25 — 4M)

Key Processes

1. Weathering: Rocks → phosphate ions (PO_4^{3-}) in soil

2. Uptake: Plant roots absorb PO_4^{3-}

3. Consumption: Animals eat plants → phosphorus in bones, DNA, ATP

4. Decomposition: Dead matter → phosphate returns to soil

5. Runoff: Rain carries phosphates to water bodies

6. Sedimentation: Aquatic phosphate settles as rock

Key Facts

- **No atmospheric phase** (unlike C, N, S)
- Slowest of all biogeochemical cycles
- Essential for: DNA, RNA, ATP, bones, teeth
- Main reservoir: Rocks (phosphate rock)

Human Impact

Excess fertilizer runoff → **Eutrophication** (algal bloom, O_2 depletion in water)

Comparison of Biogeochemical Cycles (W'25, Su'25 — 7M)

Feature	Carbon	Nitrogen	Sulphur	Phosphorus
Reservoir	Atmosphere/Oceans	Atmosphere	Rocks/Sediments	Rocks
Atmospheric form	CO_2	N_2 (78%)	SO_2	**None**
Key process	Photosynthesis	Fixation	Weathering	Weathering
Key organisms	Plants, Decomposers	*Rhizobium*	Bacteria	Plants, Decomposers
Human impact	Greenhouse effect	Acid rain (NO_x)	Acid rain (SO_2)	Eutrophication
Essential for	Energy (carbohydrates)	Proteins, DNA	Amino acids	DNA, ATP, bones
Cycle speed	Moderate	Fast	Moderate	Very slow

Phosphorus is unique — only cycle with NO atmospheric phase. All others (C, N, S) have gaseous form.

Human Disruption of Biogeochemical Cycles (Exam Guide — 4M)

Cycle	Human Activity	Impact
Carbon	Burning fossil fuels, deforestation	$\uparrow CO_2 \rightarrow$ Global warming
Nitrogen	Synthetic fertilizers, vehicle exhaust	$\uparrow NO_x \rightarrow$ Acid rain, Eutrophicati
Sulphur	Coal burning, smelting	$\uparrow SO_2 \rightarrow$ Acid rain
Phosphorus	Fertilizer runoff, detergents	Eutrophication in water bodies

Mitigation Strategies

- Reduce fossil fuel use, switch to renewables
- Use nitrogen-fixing plants instead of synthetic fertilizers
- Install scrubbers in industries to capture SO_2
- Regulate agricultural runoff to prevent eutrophication

1.3 Biodiversity

Importance · Threats · Conservation

Biodiversity — Definition & Types (W'25, Su'25 — 4M)

Definition (Convention on Biological Diversity, 1992)

Biodiversity is the variety and variability of all life on Earth — including the diversity within species, between species, and of ecosystems.

Genetic Diversity

Variation in genes within a species

E.g. Different rice varieties, dog breeds

Species Diversity

Variety of species in an area

E.g. Tropical forests have thousands of species

Ecosystem Diversity

Variety of habitats & ecosystems

E.g. forests, wetlands, deserts, oceans

Importance of Biodiversity (Su'25, W'25 — 4M)

Category	Importance
Ecological	Maintains ecosystem stability; food webs; pollination; seed dispersal
Economic	Food, medicine, timber, fibre, raw materials worth billions
Medical	25% of medicines derived from plants; wild species = drug sources
Agricultural	Genetic diversity of crops → disease resistance, yield improvement
Cultural	Spiritual, aesthetic, recreational value; ecotourism
Climate	Forests absorb CO_2; regulate rainfall and temperature
Soil	Plants prevent erosion; root microbes fix nutrients

➥ **Ecosystem services** (clean water, clean air, soil formation) depend entirely on biodiversity.

Threats to Biodiversity (Su'25, W'25 — 7M)

Major Threats (Mnemonic: **HIPCC**)

Threat	Cause	Example
Habitat loss	Deforestation, urbanisation	Loss of Amazon, mangroves
Invasive species	Non-native species dominate	Water hyacinth chokes lakes
Pollution	Air, water, soil, noise	Pesticides kill pollinators
Climate change	Global warming, drought	Coral bleaching, species shift
Consumption	Overexploitation, poaching	Tiger, rhino, elephant decline

- ➥ **85%** of threatened species are affected by habitat destruction
- ➥ Current extinction rate is **1000×** faster than natural background rate

Causes of Biodiversity Loss (W'25, Su'25 — 4M)

Direct Causes

- Deforestation & land clearing
- Hunting & poaching
- Over-fishing
- Collection of wild plants
- Introduction of invasive species
- Draining of wetlands

Indirect Causes

- Population growth
- Industrialisation & urbanisation
- Agricultural expansion
- Climate change
- Poor environmental policy
- Lack of awareness

Fragmentation: Large habitats split into small patches → populations isolated → inbreeding → extinction.
Edge effect: Fragmented patches expose more species to disturbance at boundaries.

In-situ Conservation Strategies (Su'25, W'25 — 7M)

Definition

In-situ conservation = Protecting species in their **natural habitat**.

Method	**Description**	**India Example**
National Parks	Strictly protected; no human activity	Jim Corbett, Gir
Wildlife Sanctuaries	Some human use permitted	Bharatpur, Chilika
Biosphere Reserves	Large area; core + buffer zones	Sundarbans, Nilgiris
Reserved Forests	Protected forests	Across all states
Sacred Groves	Community-protected forest patches	Meghalaya, Kerala

➥ India has **106 National Parks**, **567 Wildlife Sanctuaries**, **18 Biosphere Reserves**.

Ex-situ Conservation Strategies (Su'25, W'25 — 7M)

Definition

Ex-situ conservation = Protecting species **outside their natural habitat**.

Method	Description	Example
Zoos	Captive breeding, public education	Delhi Zoo
Botanical Gardens	Living plant collection	Sanjay Gandhi NP
Seed Banks	Seeds preserved at low temp	Svalbard (Norway)
Gene Banks	Genetic material stored	NBPGR, New Delhi
Tissue Culture	Lab propagation of plants	Orchid conservation
Captive Breeding	Breed & reintroduce to wild	Crocodile, Vulture

In-situ vs Ex-situ: In-situ is preferred (natural conditions); Ex-situ used when in-situ is not possible (critically endangered species).

Biodiversity Hotspots (Su'25, W'25 — 4M)

Definition (Norman Myers, 1988)

A **biodiversity hotspot** is a region with exceptionally high species diversity **AND** facing serious threats (at least 70% original habitat lost).

Hotspot	**Location**	**Key Species**
Western Ghats	SW India	Lion-tailed macaque, Nilgiri Tahr
Himalaya	N India	Snow leopard, Red panda
Indo-Burma	NE India, SE Asia	Irrawaddy dolphin, Green peafowl
Sundaland (overlap)	SE Asia	Orangutan, Sumatran tiger

- **India has 4 biodiversity hotspots** out of 36 globally.
- Together cover only 2.5% of Earth's land surface but support **60%** of all species.

Category	India's Share
Land area	2.4% of world's land
Species share	7–8% of all recorded species
Flowering plants	∼47,000 species (known)
Mammals	∼410 species
Birds	∼1,300 species
Reptiles	∼460 species
Tiger population	∼3,167 (2023 census; world's largest)
Elephants	∼30,000 (60% of world's Asian elephants)

- ➥ **Project Tiger (1973):** 50+ tiger reserves; population rose from 1,827 to 3,167
- ➥ **Project Elephant (1992):** 33 elephant reserves in India

Convention on Biological Diversity (CBD) (Su'25 — 4M)

CBD — Earth Summit, Rio de Janeiro (1992)

Three main objectives:

➥ Conservation of biological diversity

➥ Sustainable use of biological resources

➥ Fair and equitable sharing of benefits from genetic resources

Parties: 196 countries (India ratified 1994)

Related Agreements

Nagoya Protocol (2010)	Access & Benefit Sharing (ABS) of genetic resources
Cartagena Protocol (2000)	Safe transfer, handling of GMOs
Kunming-Montreal (2022)	30×30 target: protect 30% land & sea by 2030
CITES	Trade in endangered species regulated

Wildlife Protection Act & Indian Laws (W'25 MCQ — 1M)

Act	Purpose
Wildlife Protection Act, 1972	Protect animals, prevent poaching & trade
Forest Conservation Act, 1980	Regulate diversion of forest land
Environment Protection Act, 1986	Umbrella law for all environmental issues
Biological Diversity Act, 2002	Implement CBD in India; ABS mechanism
Air Prevention Act, 1981	Control air pollution
Water Prevention Act, 1974	Control water pollution

➥ **Wildlife Protection Act 1972** enacted to protect wildlife and prevent poaching and illegal trade (W'25 MCQ: Wildlife Protection Act, 1972).

IUCN Red List — Threat Categories (Exam Guide — 3M)

IUCN = International Union for Conservation of Nature

Category	Code	Example (India)
Extinct	EX	Pink-headed duck
Extinct in Wild	EW	Pygmy hog (reintroduced)
Critically Endangered	CR	Great Indian Bustard
Endangered	EN	Bengal Tiger, Asiatic Lion
Vulnerable	VU	Indian Elephant, Gaur
Near Threatened	NT	Clouded Leopard
Least Concern	LC	Common Myna

- **Red Data Book** = IUCN publication listing threatened species.
- India has >900 species on the IUCN threatened list.

Worked: Draw a Food Chain (Su'25, W'25 — 3M)

Question: Draw and label a terrestrial food chain with 4 trophic levels.

Answer

Grass (Producer) → Rabbit (1° Consumer) → Fox (2° Consumer) → Eagle (3° Consumer)

Energy transfer: Only 10% passes to each next level (10% Law).

Types: Grazing food chain (starts with green plant) vs Detritus food chain (starts with dead matter).

Q: Explain the carbon cycle with a neat diagram.

Answer — 5 key points

1. **Photosynthesis:** $6CO_2 + 6H_2O \xrightarrow{\text{sunlight}} C_6H_{12}O_6 + 6O_2$
2. **Respiration:** $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$
3. **Decomposition:** Dead organisms $\rightarrow$ CO_2 released by microbes
4. **Combustion:** CH_4 / coal $+ O_2 \rightarrow CO_2 + H_2O +$ heat
5. **Ocean absorption:** CO_2 dissolves in sea water $\rightarrow$ carbonic acid (H_2CO_3)

Human impact: Burning fossil fuels has increased atmospheric CO_2 from 280 ppm (pre-industrial) to >420 ppm (2024), driving global warming.

Worked: Explain Nitrogen Cycle (Su'25, W'25 — 7M)

Q: Explain the nitrogen cycle with diagram.

Answer — 5 Steps

Step 1 — Nitrogen Fixation:
N_2 (atmosphere) $\rightarrow$ NH_3 (ammonia) by *Rhizobium*, Azotobacter, lightning

Step 2 — Nitrification:
$NH_3 \xrightarrow{\textit{Nitrosomonas}} NO_2^- \xrightarrow{\textit{Nitrobacter}} NO_3^-$ (nitrate — plant-available form)

Step 3 — Assimilation:
Plants absorb NO_3^- $\rightarrow$ amino acids, proteins; passed to animals via food

Step 4 — Ammonification:
Dead matter decomposed by bacteria/fungi $\rightarrow$ NH_4^+ returned to soil

Step 5 — Denitrification:
Pseudomonas converts NO_3^- $\rightarrow$ N_2 gas, back to atmosphere

Worked: Conservation Strategies (W'25 — 7M)

Q: Explain in-situ and ex-situ conservation with examples.

In-situ (Natural Habitat)

Protects species in own habitat.

➥ National Parks: Jim Corbett (Tiger)
➥ Sanctuaries: Gir (Asiatic Lion)
➥ Biosphere Reserves: Sundarbans
➥ Sacred Groves

Advantage: Natural behaviour preserved; self-sustaining

Ex-situ (Outside Habitat)

Protects species outside habitat.

➥ Zoos: Captive breeding
➥ Botanical Gardens: Plants
➥ Seed Banks: Genetic diversity
➥ Tissue Culture: Rare plants

Advantage: Useful when natural habitat destroyed

PYQ MCQ Practice — Unit 1 (Su'25) (1M each)

Q	Question	Answer
Q1	Largest ecosystem on Earth	**B) Oceans**
Q2	Role of humans in food web	**C) 1° and 2° consumer**
Q3	% O_2 released by Amazon forest	**C) 20%**
Q4	Primary consumer is	**A) Herbivore**
Q5	Fungi and bacteria are called	**C) Decomposers**
Q6	% Nitrogen in atmosphere	**C) 78%**
Q7	Most important element in biotic components	**C) Carbon**

➥ **Tip:** MCQs test definitions and exact numbers — memorise: Oceans = largest, N_2 = 78%, Amazon = 20% O_2.

PYQ MCQ Practice — Unit 1 (W'25) (1M each)

Q	Question	Answer
Q1	Environmental sustainability means	**C) Maintaining resources f**
Q2	Biogeochemical cycle example	**B) Nitrogen cycle**
Q10	Wildlife Protection Act purpose	**Wildlife Protection Act, 19**

Key Definitions to Memorise

- **Sustainability:** Meet present needs without harming future generations
- **Ecosystem:** Community of organisms interacting with their environment
- **Biodiversity:** Variety of life at genetic, species and ecosystem levels
- **Biogeochemical cycle:** Movement of elements through biotic and abiotic spheres

Worked: Ecological Pyramids (W'25 — 4M)

Q: Draw and explain ecological pyramids.

Answer

Type	Unit	Shape	Note
Numbers	Count	Upright	Inverted in parasite chain
Biomass	g/m^2	Upright	Inverted in marine (phyto-plankton)
Energy	$kcal/m^2/yr$	**Always upright**	Based on 10% law

Key

point: Pyramid of energy is ALWAYS upright and is the most accurate representation of trophic structure.

10% Law (Lindeman): Only 10% of energy at each trophic level is available to the next. If grass has 10,000 kcal → rabbit gets 1,000 kcal → fox gets 100 kcal → eagle gets 10 kcal.

Worked: Short Note on Biodiversity Hotspot (Su'25, W'25 — 4M)

Q: Write a short note on Biodiversity Hotspot.

Answer

Definition: Coined by Norman Myers (1988). A biodiversity hotspot is a biogeographic region that:

- ➥ Contains at least **1,500 endemic vascular plant species**
- ➥ Has lost at least **70% of its original habitat**

Global: 36 hotspots worldwide; cover only 2.5% land but hold 60% of all species

India's 4 hotspots:

1. **Western Ghats** & Sri Lanka
2. **Himalayas** (Eastern)
3. **Indo-Burma** (NE India)
4. **Sundaland** (overlaps Andaman)

Significance: Guides conservation funding and international protection efforts.

Ecosystem Services (Exam Guide — 4M)

Definition

Ecosystem services are the benefits that humans receive from ecosystems, free of cost.

Category	Service	Example
Provisioning	Food, water, timber, medicine	Rice, rivers, forests
Regulating	Climate, flood, disease control	Mangroves prevent floods
Supporting	Soil formation, nutrient cycling	Earthworms in soil
Cultural	Recreation, spiritual, tourism	National parks, pilgrimage

➥ Estimated value of global ecosystem services: **\$125–145 trillion/year** (Constanza et al., 2014)

➥ Loss of biodiversity directly reduces ecosystem service capacity.

Invasive Species (Exam Guide — 3M)

Definition

An **invasive species** is a non-native organism introduced to a new habitat where it spreads rapidly, causing ecological or economic harm.

Species	**Origin**	**Impact in India**
Water hyacinth	S. America	Chokes lakes, kills aquatic life
Lantana camara	Americas	Invades forests, reduces native plants
Parthenium	N. America	Causes allergies, kills crops
Common carp	Europe/Asia	Disrupts native fish populations
African catfish	Africa	Threatens native fish in rivers

➥ Control methods: Manual removal, biological control, chemical treatment

Climate Change Impact on Biodiversity (W'25, Su'25 — 4M)

Direct Impacts

- ➥ Habitat shifts poleward / uphill
- ➥ Coral bleaching (ocean warming)
- ➥ Species phenology mismatch
- ➥ Increased drought → forest die-off
- ➥ Sea level rise destroys coastal habitats
- ➥ Arctic ice loss: polar bear habitat

Key Statistics

- ➥ 1°C rise = 10% species lose habitat
- ➥ 2°C rise = coral reefs effectively gone
- ➥ 50% of species may face extinction risk at 4°C rise
- ➥ Amazon: 3–4°C → savannization
- ➥ India: Himalayan glaciers retreating at 40m/year

Solution link: Protecting biodiversity = protecting carbon sinks (forests absorb CO_2) = slowing climate change.

4R Strategy for Ecosystem Conservation

R	Meaning	Example
Reduce	Use fewer resources	Drive less, eat less meat
Reuse	Use items again	Cloth bags, refillable bottles
Recycle	Convert waste to resources	Paper, glass, metal recycling
Restore	Rehabilitate damaged ecosystems	Reforestation, wetland revival

Ecological Restoration Examples

- **Project Tiger:** Restored tiger habitats across India
- **Aravalli Greening:** Afforestation in Rajasthan
- **Chilika Lake:** Restored wetland biodiversity
- **Mangrove replanting:** Tamil Nadu, Odisha coastlines

Worked: Importance of Biodiversity (W'25, Su'25 — 7M)

Q: Explain the importance of biodiversity.

Answer — 7 point coverage

1. **Ecological:** Maintains food webs, pollination, seed dispersal, pest control
2. **Economic:** Agriculture (70 crops from 30 plant species), timber, fisheries, tourism
3. **Medical:** 25,000+ plant species used in medicine; quinine, penicillin, aspirin from nature
4. **Genetic:** Wild varieties provide genes for crop improvement (pest/drought resistance)
5. **Cultural:** Sacred groves, eco-tourism, aesthetic value
6. **Climate:** Forests absorb CO_2; regulate rainfall, temperature, humidity
7. **Soil & Water:** Plants prevent erosion; root systems recharge groundwater

Worked: Structure & Function of Ecosystem (W'25 — 4M)

Q: Explain structure and function of an ecosystem.

Structure

Two components:

Abiotic: Soil, water, climate, gases
Biotic:
➥ Producers (autotrophs)
➥ Consumers (heterotrophs)
- Primary (herbivores)
- Secondary (carnivores)
- Tertiary (top predators)
➥ Decomposers (bacteria, fungi)

Function

1. Energy flow:
Sun → Plants → Consumers → Decomposers (one-way)

2. Nutrient cycling:
C, N, S, P cycle through biotic and abiotic components (circular)

3. Productivity:
Primary (GPP) and Net (NPP)

4. Decomposition:
Recycling of organic matter

Worked: Short Notes on Sulphur & Phosphorus Cycle

(Su'25 — 4M)

Sulphur Cycle

Reservoir: Rocks, ocean sediments
Atmospheric form: SO_2

Key steps:
1. Rock weathering → SO_4^{2-} in soil
2. Plants absorb SO_4^{2-}
3. Dead matter → H_2S
4. H_2S oxidised → SO_4^{2-}
5. Combustion releases SO_2

Impact: $SO_2 + H_2O \rightarrow H_2SO_4$ (Acid rain)

Phosphorus Cycle

Reservoir: Rocks (lithosphere)
No atmospheric phase!

Key steps:
1. Rock weathering → PO_4^{3-}
2. Plants absorb PO_4^{3-}
3. Animals eat plants (bones, ATP, DNA)
4. Dead matter → PO_4^{3-} in soil
5. Runoff → water bodies → sediment

Impact: Fertilizer runoff → Eutrophication

Flash Revision — Sustainability & Ecosystems

Term	Key Fact
Sustainability	Meet present needs without harming future generations
Three Pillars	Environment + Economy + Society
Ecosystem	Biotic + Abiotic components interacting
Largest ecosystem	Oceans (marine)
Amazon O_2	20% of Earth's oxygen
Producers	Autotrophs; photosynthesis
Decomposers	Fungi and bacteria
Food chain type	Grazing (plant start) or Detritus (dead matter start)
10% Law	Only 10% energy transferred per trophic level
Pyramid of energy	Always upright

Flash Revision — Biogeochemical Cycles

Cycle	Key Fact	Human Impact
Carbon	CO_2 in atmosphere; photosynthesis/respiration	Fossil fuels → global warr
Nitrogen	$N_2 = 78\%$; Rhizobium fixes N_2	Fertilizers → eutrophicati
Sulphur	Reservoir: rocks; SO_2 from combustion	SO_2 → acid rain
Phosphorus	No atmosphere; slowest cycle	Fertilizer runoff → algal b

Unique facts: Phosphorus = ONLY cycle with NO atmospheric phase.
Carbon current level: >420 ppm CO_2 (was 280 ppm pre-industrial).
Nitrification: $NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$ (by Nitrosomonas & Nitrobacter)

Flash Revision — Biodiversity

Term	Key Fact
Biodiversity types	Genetic, Species, Ecosystem
India's hotspots	4: Western Ghats, Himalayas, Indo-Burma, Sundaland
Global hotspots	36; cover 2.5% land, hold 60% species
In-situ conservation	In natural habitat: National Parks, Sanctuaries, Biosphere Reser
Ex-situ conservation	Outside habitat: Zoos, Seed Banks, Botanical Gardens
India NP count	106 National Parks
Project Tiger	1973; tiger count now 3,167
CBD	Convention on Bio Diversity, Rio 1992
CITES	Regulates trade in endangered species
Wildlife Protection Act	1972 — prevents poaching & illegal trade

Mistakes to Avoid

- **Oceans**, NOT forests, are the largest ecosystem
- **Amazon** releases 20% of O_2, NOT 50%
- **Decomposers** are bacteria/fungi, NOT producers
- Pyramid of **energy** is ALWAYS upright — not sometimes
- **Phosphorus cycle** has NO atmospheric phase (unlike C, N, S)
- **In-situ** = protect in natural habitat; **Ex-situ** = outside habitat
- $\mathbf{N_2}$ = 78%, $\mathbf{O_2}$ = 21%, CO_2 = 0.04% of atmosphere
- CBD was at **Rio 1992**, not Kyoto (1997)
- **Wildlife Protection Act** = 1972, Environment Protection Act = 1986

Worked: Define Sustainability & SDGs (W'25 — 4M)

Q: Define environmental sustainability. List 3 SDGs related to environment.

Answer

Definition (Brundtland, 1987):
"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Three Pillars: Environmental + Economic + Social sustainability

Three relevant SDGs:
➥ **SDG 13 — Climate Action:** Reduce GHG emissions; adapt to climate change
➥ **SDG 15 — Life on Land:** Protect forests, combat desertification, halt biodiversity loss
➥ **SDG 14 — Life Below Water:** Protect oceans, prevent marine pollution

India's contribution: National Solar Mission, Namami Gange, FAME scheme.

Worked: Threats to Biodiversity (Su'25 — 7M)

Q: Explain various threats to biodiversity.

Answer — 5 Major Threats (HIPCC)

1. Habitat Loss: Deforestation, urbanisation, agriculture expansion destroy natural habitats. 85% of threatened species affected.

2. Invasive Species: Non-native species outcompete and displace native species (e.g., water hyacinth in Indian lakes).

3. Pollution: Pesticides, industrial effluents, plastic kill organisms across food chains.

4. Climate Change: Rising temperatures shift habitats, cause coral bleaching, increase drought/floods.

5. Over-exploitation: Poaching (tiger, elephant), overfishing, illegal timber trade deplete populations.

Conservation solution: Wildlife Protection Act 1972; Project Tiger; CBD; Protected Areas.

Rapid Revision — Unit 1 Complete (Before Exam)

Ecosystem & Sustainability

Sustainability = 3 pillars (Env+Eco+Social)
Ecosystem = biotic + abiotic
Oceans = largest ecosystem
Amazon = 20% O_2
Producers = autotrophs (plants)
Consumers = herbivore/carnivore
Decomposers = fungi, bacteria
10% law = only 10% energy transferred
Food web = multiple food chains
Pyramid of energy = always upright

Cycles & Biodiversity

C cycle: photosyn./respir./decomp./combustion
N cycle: fix.→nitrify→assimilate→denitrify
S cycle: rocks→SO_4^{2-}→plant→H_2S→SO_2
P cycle: NO atmosphere; eutrophication risk
N_2 = 78%; O_2 = 21% of atmosphere
Biodiversity: genetic/species/ecosystem
India: 4 hotspots, 106 NPs, 567 sanctuaries
In-situ: NP, Biosphere Reserve
Ex-situ: Zoo, seed bank
CBD: Rio 1992; WPA: 1972

Unit 1 — Summary

Sustainability & Ecosystems

- ➥ Sustainability: present needs without harming future
- ➥ 3 pillars: Environmental, Economic, Social
- ➥ Ecosystem: biotic + abiotic interactions
- ➥ Food chain → food web (real ecosystems)
- ➥ 10% energy law (Lindeman, 1942)
- ➥ Types: terrestrial, aquatic, artificial

Cycles & Biodiversity

- ➥ 4 cycles: C, N, S, P (P = no atmosphere)
- ➥ N_2=78%; 10% law governs energy
- ➥ Biodiversity: genetic, species, ecosystem
- ➥ Threats: HIPCC mnemonic
- ➥ In-situ: NP, Sanctuary, BR
- ➥ Ex-situ: Zoo, Seed bank, tissue culture
- ➥ India: 4 hotspots, Project Tiger 1973

Weightage: 10% | Hours: 4 | GTU: 4M + 7M descriptive expected

Unit 2: Waste Management and Pollution Control

Environmental Sustainability — DI02000051

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April 2, 2026

Unit 2 — Syllabus Coverage

Topics (Weightage: 25% | Hours: 7)

2.1	Air pollution: classification, sources, control equipment
2.2	Water pollution parameters: BOD, COD, pH, TSS, Turbidity
2.3	Wastewater treatment (primary, secondary, tertiary)
	Solid waste: generation, sources, characteristics
2.4	Municipal solid waste (MSW) collection & disposal
	Hazardous waste collection & disposal
2.5	Noise pollution and effects
	Plastic waste hazards; E-waste hazards

GTU PYQ: Su'25, W'25 — MCQs + 4M + 8M descriptive (highest weightage unit)

2.1 Air Pollution

Classification · Sources · Control Equipment

Air Pollution — Definition & Pollutants (Su'25 — 4M)

Definition

Air pollution is the presence of one or more contaminants (solid, liquid or gas) in the atmosphere in concentrations sufficient to cause harm to humans, animals, plants or materials.

Pollutant

A **pollutant** is any substance or energy form that causes harmful changes in the environment.

Types:

➥ **Primary:** Directly emitted (CO, SO_2, smoke)

➥ **Secondary:** Formed by reactions (ozone, H_2SO_4)

Key Air Pollutants

CO, CO_2, SO_2, NO_x, O_3 (Ozone)

Particulate matter ($PM_{2.5}$, PM_{10})

Hydrocarbons, CFCs

Lead (Pb), Mercury vapour

➥ **CO_2** from factories/power plants/population = most damaging gas (Su'25 MCQ: D)

Classification of Air Pollutants (W'25, Su'25 — 4M)

Basis	Type	Examples
Origin	Primary	CO, SO_2, NO_x (emitted directly)
	Secondary	O_3, SO_3, HNO_3 (formed in air)
Physical State	Gas/Vapour	CO, SO_2, HF, H_2S
	Liquid droplets	Mist, Aerosol, Fog
	Solid particles	Dust, Fumes, Smoke, Soot
Source	Natural	Volcanic ash, pollen, sea spray
	Anthropogenic	Factory emissions, vehicles

Definitions (Su'25 Q): Mist = liquid droplets 40–500 μm. **Aerosol** = solid/liquid particles 0.01–10 μm suspended in gas. **Dust** = solid particles >1 μm from mechanical action.

Sources of Air Pollution (W'25 — 4M)

Natural Sources

- Volcanic eruptions (SO_2, ash)
- Forest fires (CO, smoke)
- Dust storms (PM)
- Pollen, spores
- Marsh gas (CH_4)
- Sea spray (salt particles)
- Radon gas (from soil)

Anthropogenic Sources

- **Transport:** CO, NO_x, HC from vehicles
- **Industry:** SO_2, HF, particulates
- **Power plants:** SO_2, CO_2, fly ash
- **Agriculture:** NH_3, pesticide spray
- **Mining:** Dust, toxic gases
- **Household:** Cooking smoke, LPG
- **Waste burning:** Dioxins, furans

- **Vehicles** are the single largest source of air pollution in Indian cities.
- **WHO:** 9 out of 10 people breathe polluted air globally (W'25 MCQ: vehicle exhaust = air pollution source).

Effects of Air Pollution (Exam Guide — 4M)

Pollutant	Source	Effect
CO	Vehicles, stoves	Prevents O_2 transport in blood; death
SO_2	Coal combustion	Acid rain; respiratory irritation
NO_x	Vehicles, industry	Smog, acid rain, ozone depletion
$PM_{2.5}$	Factories, vehicles	Lung disease, cancer
O_3 (ground)	Photochemical smog	Eye/lung irritation
CFCs	AC, refrigerators	Ozone layer depletion
Pb (lead)	Old petrol, paint	Neurological damage, especially children

➥ **Great London Smog (1952):** 12,000 deaths in 5 days; triggered UK Clean Air Act 1956.

Smog — Types and Formation (Exam Guide — 3M)

London Smog (Classical)

Composition: SO_2 + smoke + fog
Conditions: Cool, damp winters
Source: Coal burning
Effect: Reduces visibility; respiratory diseases; 12,000 deaths in London 1952

Photochemical Smog

Composition: O_3 + PAN (peroxyacyl nitrate) + NO_2
Conditions: Sunny, warm, stagnant air
Source: Vehicle exhaust + sunlight
Effect: Eye irritation, asthma, rubber cracking, crop damage

Photochemical smog formation:

NO_x + Hydrocarbons $\xrightarrow{\text{UV light}}$ O_3 + PAN + Brown haze

Formation

$SO_2 + H_2O \rightarrow H_2SO_3$ (sulphurous acid) $\rightarrow H_2SO_4$ (sulphuric acid)
$NO_2 + H_2O \rightarrow HNO_3$ (nitric acid)
Normal rain: pH 5.6 Acid rain: pH < 5.6

Effects

- Damages forests and crops
- Acidifies lakes; kills fish
- Corrodes monuments (Taj Mahal)
- Damages soil nutrients
- Human respiratory problems

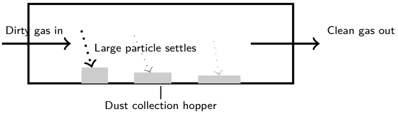
Control

- Reduce coal/oil combustion
- Use flue gas desulphurisation
- Catalytic converters in vehicles
- Switch to natural gas or renewables
- Use limestone ($CaCO_3$) to neutralise acidified lakes

Air Pollution Control Methods (W'25 — 4M)

Approach	Method	Example
Source Control	Fuel change Process change Maintenance	Switch coal $\rightarrow$ gas/solar Use cleaner technology Regular engine tuning
Equipment	Gravity settling Cyclone separator Fabric filter (Baghouse) Electrostatic precipitator Wet scrubber	Large particles ($>$75 μm) Medium particles (5–50 μm) Fine particles ($<$1 μm) Very fine particles Gases + particles
Legislation	Standards, monitoring	CPCB norms, BS-VI

Gravity Settling Chamber (W'25 — 4M)



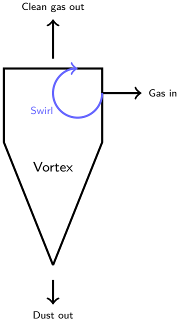
Principle & Details

Principle: Gravity makes large particles settle as gas velocity slows in wide chamber.

Particle size: > 75 μm
Efficiency: 50–70%
Used for: Pre-cleaning before other devices; cement, steel, mining

Advantage: Simple, low cost, no moving parts
Limitation: Cannot remove fine particles

Cyclone Separator (Exam Guide — 4M)



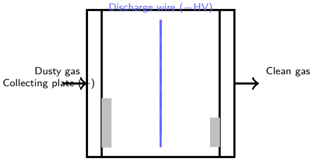
Principle & Details

Principle: Centrifugal force throws particles outward; they fall to hopper. Clean gas exits from top.

Particle size: 5–50 μm
Efficiency: 70–90%
Used for: Sawdust, grain dust, cement, chemical plants

Advantage: No moving parts, handles hot gas
Limitation: Not effective for very fine particles

Electrostatic Precipitator (ESP) (Exam Guide — 4M)

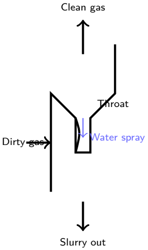


Principle & Details

Principle: High-voltage discharge wire ionises particles (negative charge). They are attracted to positive collecting plates and fall off when plates are rapped.

Particle size: 0.01–10 μm
Efficiency: 99–99.9%
Used for: Thermal power stations, cement, steel

Advantage: Handles very fine particles; low pressure drop
Limitation: High capital cost; not for flammable gases



Principle & Details

Principle: Dirty gas passes through a Venturi throat at high velocity. Water spray collides with particles and absorbs gases. Slurry collected at bottom.

Removes: Both particulates AND gases (SO_2, HF, HCl)
Efficiency: 70–99%
Used for: Chemical plants, fertilizer, steel

Advantage: Removes gases + particles together
Limitation: Produces liquid waste (slurry) needing treatment

Air Pollution Control Equipment — Comparison (W'25 — 7M)

Equipment	Principle	Particle Size	Efficiency	Cost	Use
Gravity Settling	Gravity	$>75\ \mu$m	50–70%	Low	Pre-cleaning
Cyclone	Centrifugal	5–50 μm	70–90%	Low–Med	Cement, grain
Fabric Filter	Filtration	$<1\ \mu$m	>99%	Med	Pharma, food
ESP	Electrostatic	0.01–10 μm	99–99.9%	High	Power plants
Wet Scrubber	Impaction	Particles + gases	70–99%	Med	Chemical plants

Exam tip: ESP = highest efficiency (99.9%) for very fine particles. Gravity settling = simplest, cheapest, for large particles. Wet scrubber = only one that removes gases AND particles.

Water Pollution — Sources & Types (Exam Guide — 3M)

Definition

Water pollution is any physical, chemical or biological change in water quality that adversely affects living organisms or makes water unsuitable for its intended uses.

Point Sources

- Industrial effluents (factories)
- Sewage treatment plants
- Power plant cooling water
- Mine drainage
- *Identifiable single location*

Non-Point Sources

- Agricultural runoff (pesticides, fertilizers)
- Urban stormwater
- Atmospheric deposition
- Livestock waste
- *Diffuse, harder to control*

BOD — Biochemical Oxygen Demand (Su'25, W'25 — 4M)

Definition

BOD is the amount of dissolved oxygen (in mg/L) required by aerobic microorganisms to decompose organic matter in water at **20°C over 5 days.**

Significance

- **Clean water:** BOD < 1 mg/L
- **Slightly polluted:** 1–2 mg/L
- **Moderately polluted:** 3–5 mg/L
- **Heavily polluted:** > 10 mg/L

Higher BOD $\Rightarrow$ more organic pollution $\Rightarrow$ less dissolved oxygen $\Rightarrow$ fish die

Key Points

- Measures **biodegradable** organic matter
- Standard test: BOD_5 at 20°C
- Used for sewage strength and treatment effectiveness
- Cannot detect non-biodegradable pollutants

COD — Chemical Oxygen Demand (Su'25, W'25 — 4M)

Definition

COD is the amount of oxygen (in mg/L) required to chemically oxidise **all** organic matter (biodegradable + non-biodegradable) using a strong chemical oxidant ($\mathbf{K_2Cr_2O_7}$).

Significance

- **Clean water:** COD near 0
- **Industrial effluent:** Very high COD
- Industrial discharge limits set by CPCB

Higher COD $\Rightarrow$ high total organic load

Key Points

- Measures **all organic matter** (biodegradable + toxic)
- Test time: 2–3 hours (faster than BOD)
- COD $>$ BOD always
- Industrial wastewater: COD very important
- Oxidant: potassium dichromate in acid medium

BOD vs COD — Comparison (Su'25, W'25 — 4M)

Parameter	BOD	COD
Full form	Biochemical Oxygen Demand	Chemical Oxygen Demand
Method	Biological (microorganisms)	Chemical ($K_2Cr_2O_7$)
Measures	Biodegradable organic matter	All organic matter
Time	5 days at 20°C	2–3 hours
Value	Lower	Higher (COD $\geq$ BOD)
Application	Sewage, domestic wastewater	Industrial wastewater
Interference	Toxic substances affect	Not affected by toxic matter

- For a purely biodegradable sample: COD $\approx$ BOD (ratio $\approx$ 1.4–2.0)
- High COD but low BOD $\Rightarrow$ toxic/non-biodegradable industrial waste

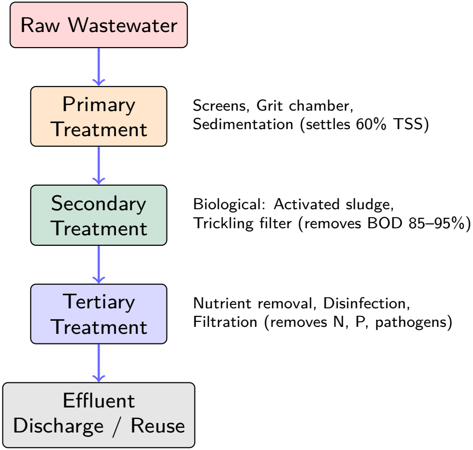
Water Quality Parameters — pH, TSS, Turbidity

(Exam — 4M)

Parameter	Definition	Significance
pH	Measure of hydrogen ion concentration. Scale 0–14. Neutral = 7.	Drinking water: 6.5–8.5. A fects aquatic life.
TSS (Total Suspended Solids)	Mass of solids (mg/L) retained on filter paper.	Clogs gills; blocks sunlig settles as sludge.
Turbidity	Cloudiness/haziness of water due to suspended particles (measured in NTU).	Drinking water $<$ 1 NTU; duces photosynthesis.
Total Solids (TS)	All dissolved + suspended solids. TS = TDS + TSS.	High TS makes water tas bad; industrial scaling.
DO (Dissolved Oxygen)	Oxygen dissolved in water (mg/L).	$>$ 6 mg/L needed for healt aquatic life.

➥ **NTU** = Nephelometric Turbidity Unit. **TDS** = Total Dissolved Solids.

Wastewater Treatment — Overview (Exam Guide — 4–8M)



Primary Treatment of Wastewater (Exam Guide — 4M)

Purpose: Remove suspended solids and floating matter

Unit Process	Description
Screening	Bar screens/fine screens remove large debris (rags, tics, wood)
Grit Chamber	Slows wastewater; heavy grit (sand, gravel) settles
Sedimentation Tank (Clarifier)	Allows suspended particles to settle by gravity hours)
Grease/Oil Trap	Skimmers remove floating grease/oil

Output: Primary effluent (reduces TSS 50–65%, BOD 30–40%)
Sludge: Settled solids sent for further treatment / drying beds

Secondary Treatment of Wastewater (Exam Guide — 4M)

Purpose: Remove dissolved organic matter (BOD) by biological action

Process	Description
Activated Sludge	Wastewater aerated with microbial sludge; bacteria gest organics; sludge recycled
Trickling Filter	Wastewater trickles over rock/plastic media with bio organic matter absorbed
Oxidation Pond	Shallow lagoon; sunlight + algae + bacteria remove ganic matter
Rotating Biological Contactor	Slowly rotating discs with biofilm alternately con wastewater and air

Output: Removes 85–95% BOD, 85–90% TSS
Activated sludge = most common secondary treatment worldwide

Tertiary Treatment of Wastewater (Exam Guide — 4M)

Purpose: Remove nutrients, pathogens and trace pollutants for reuse

Process	Removes
Sand/Membrane Filtration	Fine suspended solids, turbidity
Chlorination	Pathogens (bacteria, viruses)
UV Disinfection	Pathogens without chemicals
Reverse Osmosis	Dissolved salts, heavy metals
Nutrient Removal (BNR)	Nitrogen (nitrification/denitrification), Phosphorus
Activated Carbon Adsorption	Trace organics, colour, odour

Output: High-quality effluent suitable for industrial reuse, irrigation or groundwater recharge. Required for ZERO LIQUID DISCHARGE (ZLD) compliance.

Solid Waste — Definition, Generation & Sources

(Exam — 3M)

Definition

Solid waste is any solid, semi-solid, or liquid material discarded from residential, commercial, industrial or agricultural activities that has no further use.

Sources

- ➥ **Residential:** Food waste, paper, plastics
- ➥ **Commercial:** Packaging, e-waste
- ➥ **Industrial:** Fly ash, slag, chemicals
- ➥ **Agricultural:** Crop residue, animal dung
- ➥ **Biomedical:** Needles, dressings
- ➥ **Construction:** Debris, concrete

Generation in India

- ➥ India generates ≈ **62 million tonnes** per year
- ➥ Only **75–80%** collected
- ➥ Only **22–28%** processed/treated
- ➥ Urban India: 0.3–0.6 kg/person/day
- ➥ Growing 1.3% per year

Solid Waste — Characteristics (Exam — 3M)

Characteristic	Parameter	Significance
Moisture Content	% water by weight	High moisture ⇒ slower decomposition; le
Calorific Value	kJ/kg	Determines suitability for incineration
Organic Content	% volatile solids	Determines biodegradability and composti
Bulk Density	kg/m^3	Affects collection, transport, landfill volum
Particle Size	mm	Affects sorting, processing
Compressibility	Volume reduction	Collection efficiency

Indian MSW characteristics: High moisture (45–60%), high organic content (40–50%), low calorific value ⇒ best suited for composting rather than incineration.

Types of Solid Waste (Exam Guide — 3M)

Classification by Degradability

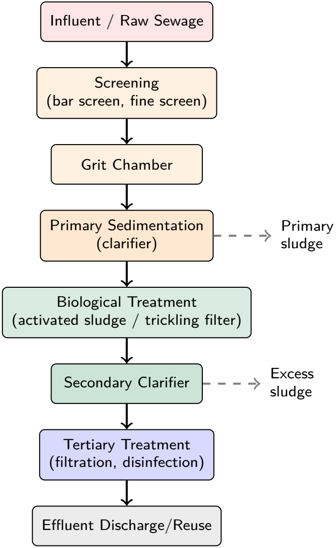
Biodegradable: Food scraps, yard waste, paper
Non-biodegradable: Plastics, glass, metals
Recyclable: Paper, metals, glass, some plastics
Hazardous: Chemicals, batteries, pesticide containers

Classification by Source

MSW: Household + commercial
Industrial: Fly ash, bottom ash, slags
Biomedical: See Schedule 1, BMW Rules 2016
E-waste: Computers, mobiles, TVs
C&D Waste: Construction debris
Radioactive: Nuclear power plants

➥ **Swachh Bharat Mission (2014):** Target: Open Defecation Free India + scientific solid waste disposal.
➥ **SWM Rules 2016:** Source segregation mandatory: Wet waste (green) | Dry waste (blue) | Hazardous (red).

Wastewater Treatment — Complete Flow (Exam — 8M)



Wastewater Treatment — Comparison (Exam — 7M)

Feature	Primary	Secondary	Tertiary
Purpose	Remove suspended solids	Remove dissolved organics	Remove N, P, pathogens
Method	Physical	Biological	Chemical / Physical / Advanc
Key Processes	Sedimentation, screening	Activated sludge, trickling filter	Chlorination, RO, membrane
BOD Removal	30–40%	85–95%	>99%
TSS Removal	50–65%	85–90%	>99%
Cost	Low	Medium	High
Output Quality	Moderate	Good	Very high (reuse quality)

All three stages together = **Complete Wastewater Treatment**. Sludge from primary and secondary treated separately (thickening, digestion, dewatering, drying beds / landfill).

Ozone Layer Depletion (Exam Guide — 3M)

Mechanism

CFCs (chlorofluorocarbons) from ACs and refrigerators rise to stratosphere.

UV light breaks CFCs → releases Cl·

$Cl\cdot + O_3 \rightarrow ClO + O_2$
$ClO + O \rightarrow Cl\cdot + O_2$

One Cl atom destroys 100,000 O_3 molecules!

Effects & Control

Effects:

➥ Increased UV-B radiation
➥ Skin cancer, cataracts in humans
➥ Phytoplankton, marine ecosystem damage
➥ Crop damage

Control:

➥ **Montreal Protocol (1987):** Phase out CFCs
➥ Use HFCs, natural refrigerants
➥ Ozone hole over Antarctica slowly recovering

2.4 MSW & Hazardous Waste

Collection · Disposal · Management

Municipal Solid Waste (MSW)

Solid waste generated from households, markets, commercial establishments and street sweepings in a city/town.

Collection Methods

- ➥ **House-to-house:** Door-to-door collection by municipality
- ➥ **Communal bins:** Residents deposit at fixed points
- ➥ **Segregated bins:** 3-bin system (wet/dry/hazardous)
- ➥ **Transfer stations:** Collection → transfer → final disposal

SWM Rules 2016

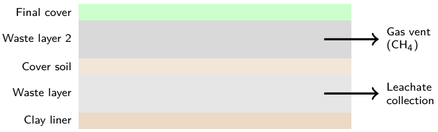
- ➥ Source segregation mandatory
- ➥ **Green bin:** Wet/organic waste
- ➥ **Blue bin:** Dry/recyclable waste
- ➥ **Red bin:** Domestic hazardous waste
- ➥ Bulk generators handle own waste

MSW Disposal Methods (Exam Guide — 4M)

Method	Principle	Best For
Landfill	Engineered burial	Non-recyclable, no
Composting	Aerobic decomposition	Organic/food wast
Vermicomposting	Worm-aided decomposition	Garden, food wast
Incineration	Combustion at 850–1100°C	High calorific, dry
Pyrolysis / Gasification	Thermal conversion without O_2	Plastics, tyres
Recycling	Material recovery	Paper, metals, gla
Biogas / Anaerobic Digestion	Microbial digestion	Wet organic waste

➥ **Hierarchy (preferred order):** Reduce > Reuse > Recycle > Recover > Dispose

Sanitary Landfill (Exam Guide — 4M)



Key Features

- ➥ Engineered clay/HDPE liner prevents leachate seepage
- ➥ Leachate collection and treatment system
- ➥ Daily soil cover (compaction)
- ➥ Biogas (CH_4) vents or captured for energy
- ➥ Groundwater monitoring wells

Merits: High volume; all waste types

Demerits: Large land; leachate risk; gas

Composting (Exam Guide — 3M)

Composting = Aerobic biological decomposition of organic waste

Microorganisms (bacteria, fungi) break down organic matter into **humus-rich compost** (natural fertilizer).

Process

1. Collect organic waste (food, garden)
2. Arrange in windrows/bins
3. Maintain moisture (50–60%) + aerate
4. Temperature rises 55–65°C (kills pathogens)
5. Curing: 4–8 weeks
6. Mature compost ready (dark, earthy)

Benefits

- ➥ Reduces landfill waste 40–60%
- ➥ Produces organic fertiliser (saves chemical fertiliser)
- ➥ Improves soil structure and water retention
- ➥ Low cost if done at source
- ➥ **Vermicomposting:** Uses earthworms; faster; better quality

Process

Controlled combustion at **850–1100°C** reduces waste volume by 90% and weight by 75%.

Waste to Energy (WtE): Steam from combustion drives turbines to generate electricity.

Residue: Ash (2–5% original weight) disposed in landfill.

Pros & Cons

Advantages:
- ➥ Max volume reduction
- ➥ Energy recovery
- ➥ Destroys pathogens

Disadvantages:
- ➥ High cost
- ➥ Air pollutants (dioxins, HCl) if uncontrolled
- ➥ Needs dry, high-calorific waste
- ➥ Not suitable for Indian MSW (high moisture)

Hazardous Waste — Definition & Classification (Exam — 3M)

Definition

Waste that exhibits one or more characteristics: **Ignitability, Corrosivity, Reactivity, Toxicity** (ICRT) and poses a **substantial hazard** to human health or the environment.

Sources

- ➥ Petroleum refining (spent catalyst)
- ➥ Metal processing (heavy metals)
- ➥ Pesticide manufacturing (organochlorines)
- ➥ Electroplating (cyanide, chromium)
- ➥ Paint, solvent industries
- ➥ Hospitals (cytotoxic, sharps)

Disposal Methods

- ➥ **Secured landfill:** Multiple clay/HDPE liner barriers
- ➥ **Incineration (HT):** High-temperature (>1200°C)
- ➥ **Deep well injection:** Inject into sealed rock formations
- ➥ **Chemical stabilisation:** Immobilise metals in cement/polymer
- ➥ **Bio-remediation:** Microbes

2.5 Noise, Plastic & E-Waste

Pollution · Hazards · Management

Noise Pollution — Sources & Levels (Su'25 — 8M, W'25 — 4M)

Definition

Noise pollution is any unwanted, disturbing or harmful sound that impairs health, well-being or communication. Measured in **decibels (dB)**.

Sound Levels

Noise Source	Level
Whisper	30 dB
Normal conversation	60 dB
Traffic	70–90 dB
Factory noise	90–100 dB
Rock concert	110–120 dB
Jet engine	140 dB

Sources

Transport: Road, rail, aircraft
Industry: Heavy machinery
Construction: Drilling, blasting
Social: Loudspeakers, festivals
Household: Music, appliances

Threshold: $>$ 85 dB for $>$ 8 hrs/day causes hearing loss

Effects of Noise Pollution (Su'25 — 8M)

Category	Effect	Details
Auditory	Noise Induced Hearing Loss (NIHL)	Irreversible at >85 dB
	Tinnitus	Constant ringing in ears
	Temporary Threshold Shift	Temporary hearing loss
Health	Hypertension	Elevated blood pressure
	Cardiovascular stress	Heart disease risk
	Sleep disturbance	Fatigue, mental health
Psychological	Stress, anxiety, irritability	Reduces productivity
Communication	Impairs speech perception	Accidents in industry
Wildlife	Disturbs animals' navigation	Bird disorientation (airports)

➥ **WHO:** Noise is the second largest environmental cause of health problems after air pollution in Europe.

Noise Pollution Control (Exam Guide — 3M)

Engineering Controls

➥ **Silencers/mufflers** on engines
➥ **Sound insulation** (walls, floors, ceilings)
➥ **Noise barriers** (walls along highways)
➥ **Vibration isolation** (rubber mounts)
➥ **Acoustic enclosures** around noisy machinery
➥ **Tree belts:** Absorb noise near roads

Administrative & PPE

➥ **Ear plugs / ear muffs** in factory (personal protection)
➥ Limit hours of exposure
➥ **Noise standards** (India: Noise Rules 2000): Industrial 75 dB, Commercial 65 dB, Residential 55 dB (day)
➥ Ban on loudspeakers at night
➥ Regular hearing tests for workers

Plastic Waste — Types & Hazards (Su'25 — 8M)

Types of Plastic

Single-use: Bags, straws, cups (banned in India 2022)
PET: Bottles (recyclable)
HDPE: Pipes, jerry cans
PVC: Cables, flooring
Microplastics: <5 mm particles from degradation

India generates $\approx$ 9.4 million tonnes plastic/year. Only 30% recycled.

Hazards

- ➥ **Marine:** Entangles sea turtles, dolphins; enters food chain
- ➥ **Microplastics:** Found in human blood, lung tissue
- ➥ **Soil:** Blocks water infiltration; crop damage
- ➥ **Animals:** Cattle ingest and die
- ➥ **Leaches toxins:** BPA, phthalates (endocrine disruptors)
- ➥ **Non-biodegradable:** 400–1000 year persistence

➥ **Plastic Waste Mgmt Rules 2016:** Min 50 micron thickness; EPR by producers.

E-Waste — Definition & Composition (Su'25 — 8M)

Definition

E-waste (Electronic waste) is discarded electrical and electronic equipment (EEE) including computers, mobiles, TVs, refrigerators, ACs and peripherals.

Composition

Valuable metals (recover):
Gold, silver, copper, palladium, platinum

Hazardous substances:
Lead (solder, CRT glass), Mercury (lamps), Cadmium (batteries), Chromium VI (coatings), Flame retardants (PCBs, BFRs)

Global & India Facts

- World: 53.6 million tonnes e-waste/year (2019)
- India: 3rd largest e-waste generator
- Only 20% formally recycled globally
- India: E-Waste Rules 2016; EPR obligation on producers
- Urban mining: 1 tonne mobile = 30× more gold than 1 tonne ore

E-Waste Hazards (Su'25 — 8M)

Substance	Source	Health/Environmental Impact
Lead (Pb)	Solder, CRT screens	Brain damage, kidney failure (especi
Mercury (Hg)	Fluorescent lamps, switches	Neurological disorders, Minamata dis
Cadmium (Cd)	Batteries, pigments	Kidney damage, bone disease (Itai-it
Chromium VI	Metal coatings	Lung cancer, skin ulcers
BFRs	Printed circuit boards	Liver damage, thyroid disruption
Beryllium	Motherboards	Lung disease (berylliosis)

Informal recycling hazards (Guiyu, China; Agra, India): Workers burn circuit boards, use acid baths to recover metals ⇒ highly toxic fumes; groundwater and soil contamination.

Proper Management Steps

1. **Collection:** Authorised take-back schemes, drop-off centres
2. **Dismantling:** Manual disassembly; remove batteries, CRTs
3. **Sorting:** Segregate metals, plastics, glass
4. **Refurbishment:** Reuse working components
5. **Recycling:** Shredding + metal recovery
6. **Safe disposal:** Hazardous residues to CHWTSF

India E-Waste Rules 2016

- **EPR (Extended Producer Responsibility):** Producers must take back e-waste
- Collection targets set annually
- Only authorised dismantlers/recyclers can process
- Basel Convention: Ban informal export to developing countries
- 4R: Reduce, Reuse, Recycle, Recover

PYQ Worked — Gravity Settling Chamber (W'25 — 4M)

Q: Draw and explain Gravity Settling Chamber (4M)

Definition: A large rectangular chamber that reduces gas velocity, allowing particles to settle under gravity.

Working: Polluted gas enters the chamber; velocity reduces; particles >75 μm settle to the hopper floor; clean gas exits.

Diagram: See Frame 11 (rectangular box with arrows showing gas flow + settled dust).

Efficiency: 50–70% **Particle size:** >75 μm

Application: Pre-cleaner before ESP or cyclone; cement plants, foundries, grain handling.

Advantages: Simple construction, no moving parts, low maintenance, handles high temperature and large volume gas.

Limitations: Cannot remove fine particles; large space required.

PYQ Worked — BOD and COD (Su'25, W'25 — 4M)

Q: Define BOD and COD. Compare them. (4M)

BOD (Biochemical Oxygen Demand): Amount of dissolved oxygen (mg/L) consumed by microorganism to decompose organic matter at 20°C in 5 days. Measures biodegradable matter only. Used for: domestic sewage, river quality assessment.

COD (Chemical Oxygen Demand): Amount of oxygen (mg/L) required to chemically oxidise ALL organic matter using $K_2Cr_2O_7$ in acid medium. Measures all organic matter (biodegradable + non-biodegradable). Test time: 2–3 hours. Used for: industrial effluent assessment.

Relation: COD $\geq$ BOD always. High BOD/COD ratio = readily biodegradable waste.

Typical values (river): BOD: 1–2 mg/L (clean), >10 mg/L (heavily polluted).

Q: Explain effects of noise pollution on human health (8M)

1. **Auditory Effects:**
➥ NIHL (Noise Induced Hearing Loss) — irreversible hearing damage at >85 dB
➥ Tinnitus — persistent ringing in ears
➥ Temporary Threshold Shift (TTS) after short exposure

2. **Health Effects:**
➥ Hypertension (elevated blood pressure)
➥ Cardiovascular stress — increased heart disease risk
➥ Sleep disturbance — fatigue, reduced immunity
➥ Stress hormones released (adrenaline, cortisol)

3. **Psychological Effects:**
➥ Anxiety, irritability, reduced concentration, mental fatigue

4. **Communication:**
➥ Masking of speech signals — workplace accidents

5. **Wildlife:**
➥ Birds lose navigation; sonar confusion in dolphins/whales (ship noise)

PYQ Worked — E-Waste Impact (Su'25 — 8M)

Q: Explain the impact of e-waste on health and environment (8M)

Health Impacts:

➥ **Lead:** CRT monitors, solder boards ⇒ brain damage, kidney failure (children worst affected)
➥ **Mercury:** Fluorescent lamps ⇒ neurological damage, Minamata disease
➥ **Cadmium:** Li-ion / Ni-Cd batteries ⇒ kidney disease, bone deterioration
➥ **Chromium VI:** Metal coatings ⇒ lung cancer, skin ulcers
➥ **Brominated Flame Retardants (BFRs):** PCBs ⇒ liver cancer, thyroid disruption

Environmental Impacts:

➥ Soil contamination from acid leaching of heavy metals
➥ Groundwater contamination near informal recycling sites
➥ Air pollution from open burning of circuit boards (dioxins, furans)
➥ Bioaccumulation in food chain

Solution: E-Waste Rules 2016 (India); EPR; authorised dismantlers only; Basel Convention.

PYQ Worked — Classify Air Pollutants (W'25 — 4M)

Q: Classify air pollutants with sources (4M)

On the basis of origin:

- **Primary pollutants:** Directly emitted — CO (vehicles), SO_2 (coal), NO_x (combustion), PM (factories), Pb (old petrol)
- **Secondary pollutants:** Formed in atmosphere — O_3 (photochemical smog), $SO_3 + H_2O \rightarrow H_2SO_4$ (acid rain), PAN (peroxyacyl nitrate)

On the basis of physical state:

- **Gaseous:** CO, SO_2, NO_x, HF, H_2S
- **Liquid droplets:** **Mist** (40–500 μm), **Aerosol** (0.01–10 μm), Fog, Smog
- **Solid particles:** **Dust** (>1 μm, mechanical), Fumes (<1 μm, volatilisation), Smoke (carbon), Soot

Important MCQ tip: Mist/aerosol/dust are **particulate** pollutants; they differ by **particle size and state**.

Q: Explain primary, secondary and tertiary wastewater treatment (7M)

Primary Treatment (Physical):
Screening → Grit chamber → Sedimentation tank. Removes: 50–65% TSS, 30–40% BOD. Output: Primary effluent + sludge.

Secondary Treatment (Biological):
Activated sludge process OR Trickling filter. Aerobic microorganisms consume dissolved organics. Removes: 85–95% BOD, 85–90% TSS.

Tertiary Treatment (Advanced):
Sand/membrane filtration, chlorination/UV, nutrient removal (BNR), reverse osmosis. Removes: N, P, pathogens, trace metals. Output: Reclaimed water suitable for reuse.

Key comparison: Primary = physical, Secondary = biological (most BOD removed), Tertiary = chemical/advanced (highest quality, highest cost).

PYQ Worked — MSW Disposal Methods (Exam — 4M)

Q: Explain methods of MSW disposal (4M)

1. Sanitary Landfill:
Engineered site with clay/HDPE liner; daily soil cover; leachate collection; gas venting. Best for non-recyclable waste.

2. Composting:
Aerobic decomposition of organic waste by microorganisms → humus-rich compost. 4–8 weeks. Best for Indian MSW (50% organic). Vermicomposting uses earthworms.

3. Incineration:
Combustion at 850–1100°C. Reduces volume 90%. Generates electricity (WtE). Needs dry, high-calorific waste. Not ideal for India (high moisture organic waste).

4. Recycling:
Paper, metals, glass, plastics sent to recycling facilities. Reduces raw material demand.

Preferred hierarchy: Reduce > Reuse > Recycle > Recover > Dispose

Wrong	Correct
BOD is higher than COD	**COD $\geq$ BOD always**
BOD test takes 2–3 hours	**BOD = 5 days at 20°C**; COD = 2–3 hours
Scrubber only removes gases	**Scrubber removes both gases AND particles**
ESP removes only large particles	**ESP most efficient for very fine particles (0.01–10 μm)**
Composting is anaerobic	**Composting = aerobic**; Anaerobic digestion produces biogas
Incineration best for Indian MSW	**Composting better**; Indian MSW has high moisture
Acid rain has pH < 7	**Acid rain pH < 5.6**; normal rain = 5.6 (CO_2 dissolved)

Flash Revision 1 — Air Pollution (Quick Recall)

Key Facts

- Primary pollutant: directly emitted (CO, SO_2)
- Secondary: formed in air (O_3, H_2SO_4)
- Acid rain: pH < 5.6; $SO_2 + NO_x$ + water
- Photochemical smog: NO_x + HC + UV $\rightarrow$ O_3 + PAN
- London smog: SO_2 + fog; cool, damp
- CFCs $\rightarrow$ ozone depletion; Montreal Protocol 1987
- Vehicles = #1 CO + NO_x source in cities

Control Equipment

- Gravity settling: >75 μm, 50–70%, cheapest
- Cyclone: 5–50 μm, 70–90%
- ESP: 0.01–10 μm, 99.9%, power plants
- Scrubber: gases + particles, 70–99%

Particles Definitions (PYQ)

- **Mist:** Liquid droplets 40–500 μm
- **Aerosol:** Solid/liquid 0.01–10 μm
- **Dust:** Solid >1 μm (mechanical)
- **Fumes:** Solid <1 μm (volatilise)
- **Smoke:** Carbon particles from combustion

Numerical Mnemonics

- EPA standard: $PM_{2.5}$ <12 $\mu g/m^3$
- WHO: 9/10 people breathe polluted air
- Great London Smog: 12,000 deaths, 1952
- Montreal Protocol: 1987

Flash Revision 2 — Water Pollution (Quick Recall)

BOD / COD / Parameters

- BOD: 5 days, 20°C, biodegradable only
- COD: 2–3 hrs, $K_2Cr_2O_7$, all organic
- COD $\geq$ BOD always
- Clean water: BOD $<$1 mg/L
- pH of drinking water: 6.5–8.5
- Turbidity unit: NTU ($<$1 NTU drinking water)
- TSS: solids on filter; TS = TDS + TSS
- DO $>$6 mg/L for healthy aquatic life

Wastewater Treatment

- Primary: physical; 30–40% BOD, 50–65% TSS
- Secondary: biological; 85–95% BOD
- Tertiary: advanced; $>$99% BOD + pathogens
- Activated sludge = most common secondary process
- Trickling filter = biofilm on media
- ZLD = Zero Liquid Discharge (tertiary required)

➥ Point source = identifiable location (pipe); Non-point = diffuse (agricultural field)

Flash Revision 3 — Solid Waste, Noise, E-Waste

(Quick Recall)

Solid Waste & MSW

- India: 62 MT/year MSW; only 22–28% treated
- SWM Rules 2016: green/blue/red bins
- Composting: aerobic, 4–8 weeks, ideal for India (50% organic)
- Sanitary landfill: clay/HDPE liner + leachate collection
- Incineration: 850–1100°C; volume $\downarrow$90%
- Hazardous waste: ICRT characteristics
- Hierarchy: Reduce $>$ Reuse $>$ Recycle $>$ Recover $>$ Dispose

Noise, Plastic, E-Waste

- Threshold for hearing damage: $>$85 dB (8 h/day)
- India Noise Rules 2000: Industrial 75 dB
- Noise pollution: NIHL, tinnitus, hypertension
- Microplastics: $<$5 mm; found in human blood
- Plastic banned (single-use): India 2022
- E-waste: India 3rd largest generator
- Lead (Pb): CRT; brain/kidney damage
- Mercury: lamps; Minamata disease
- E-Waste Rules 2016: EPR by producers

1. (Su'25) The most damaging gas emitted from factories, power plants, and population is:
(A) O_3 (B) SO_2 (C) NO_x **(D) CO_2**

2. (Su'25) BOD test is carried out at:
(A) 25°C, 5 days **(B) 20°C, 5 days** (C) 37°C, 2 days

3. (W'25) Which equipment is most efficient for removing very fine particles?
(A) Cyclone (B) Gravity settling **(C) ESP** (D) Scrubber

4. COD measures:
(A) Only biodegradable matter **(B) All organic matter**
(C) Only dissolved solids (D) Suspended solids

5. Noise pollution rule in India sets industrial limit at:
(A) 55 dB (B) 65 dB **(C) 75 dB** (D) 85 dB

PYQ Worked — APCE Comparison (W'25 — 7M)

Q: Compare air pollution control equipment (7M)

Equipment	Principle	Size Removed	Eff.	Cost	Removes gas?
Gravity Settling	Gravity	$>75\ \mu m$	50–70%	Low	No
Cyclone	Centrifugal	5–50 μm	70–90%	Low	No
Fabric Filter	Filtration	$<1\ \mu m$	$>99\%$	Med	No
ESP	Electrostatic	0.01–10 μm	99.9%	High	No
Wet Scrubber	Impaction + absorption	All + gases	70–99%	Med	**Yes**

Key exam points: ESP = highest efficiency. Wet scrubber = ONLY one removing gases. Gravity settling = simplest/cheapest. ESP used in thermal power stations; cyclone in cement, grain storage.

Important Definitions Recap — Unit 2 (Exam Guide)

Term	Definition
Pollution	Presence of harmful substances in environment above natural levels
Pollutant	Substance causing harmful change in environment
BOD	O_2 needed by microbes to decompose organic matter ($20^\circ C \times 5$ days) in mg/L
COD	O_2 needed to chemically oxidise all organic matter using $K_2Cr_2O_7$ in mg/L
TSS	Total Suspended Solids = solids retained on filter (mg/L)
Turbidity	Cloudiness of water due to suspended particles; measured in NTU
Mist	Liquid droplets (40–500 μm) suspended in atmosphere
Aerosol	Solid/liquid particles (0.01–10 μm) stably suspended in gas
Dust	Solid particles (>1 μm) from mechanical action
MSW	Solid waste from households, commercial and street sources in urban area
E-waste	Discarded electrical and electronic equipment
EPR	Extended Producer Responsibility (producers take back used products)

Unit 2 — Summary (25% Weightage)

Air & Water Pollution

- Primary vs Secondary pollutants
- Air control equipment: ESP, Cyclone, Scrubber
- Acid rain: pH < 5.6, $SO_2 + NO_x + H_2O$
- Photochemical smog: NO_x + HC + UV
- BOD (5 days, 20°C) vs COD (2–3 hrs, $K_2Cr_2O_7$)
- COD $\geq$ BOD always
- Wastewater: Primary (physical) $\rightarrow$ Secondary (biological) $\rightarrow$ Tertiary (advanced)

Solid Waste, Noise, E-Waste

- MSW: green/blue/red bins (SWM Rules 2016)
- Disposal: sanitary landfill, composting, incineration
- Hazardous waste: ICRT; secured landfill; HT incineration
- Noise: >85 dB causes NIHL; industrial limit 75 dB
- Plastic: microplastics in human blood; single-use banned (2022)
- E-waste: Lead (brain), Mercury (Minamata), Cadmium (kidney)
- E-Waste Rules 2016: EPR; authorised recyclers only

Weightage: 25% | Hours: 7 | Highest weightage unit in ES — Prepare thoroughly!

Unit 3: Renewable Energy Technologies

Environmental Sustainability — DI02000051

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Unit 3 — Syllabus Coverage

Topics (Weightage: 25% | Hours: 7)

- **3.1** Introduction: Renewable vs Non-renewable, advantages, India status
- **3.2** Solar energy: photovoltaic (solar cell), solar thermal, water heater, cooker
- **3.3** Wind energy: turbine types, working, HAWT vs VAWT
- **3.4** Biomass energy: biogas (fixed dome, floating drum), biofuels
- **3.5** Hydropower, tidal, wave, OTEC
- **3.6** Geothermal energy, hydrogen energy, fuel cells
- **3.7** Energy conservation, efficiency, BEE, green buildings

GTU PYQ: Su'25, W'25 — Solar cell, biogas plant, wind turbine (25% weightage)

3.1 Introduction to Renewable Energy

Classification · Advantages · India Status

Energy — Classification (Exam Guide — 3M)

Type	Characteristic	Examples
Conventional (Non-renewable)	Finite, exhaustible Formed over millions of years	Coal, oil, natural gas, nuclear Form 80% of global energy supp
Renewable	Naturally replenished Inexhaustible; low pollution	Solar, wind, hydropower Biomass, tidal, geothermal
Non-conventional	Newer renewable sources Alternative to fossil fuels	Solar PV, wind, ocean energy Hydrogen, fuel cells

India's energy: 58% from fossil fuels; but renewable capacity growing rapidly (target: 500 GW by 2030). India = 4th largest renewable energy producer globally (2023).

Advantages & Limitations of Renewable Energy (Exam — 4M)

Advantages

- ➥ Inexhaustible / perpetually available
- ➥ Zero / low direct GHG emissions
- ➥ Reduces dependence on fossil fuel imports
- ➥ Decentralised — rural electrification
- ➥ Low operating cost (free fuel: sun, wind)
- ➥ Creates local employment
- ➥ Reduces air pollution and health costs
- ➥ Energy security for nations

Limitations

- ➥ Intermittent (sun/wind not always available)
- ➥ High initial capital cost
- ➥ Low energy density
- ➥ Requires large land area
- ➥ Storage challenge (batteries costly)
- ➥ Geographic dependent (solar in tropics, wind in coastal areas)
- ➥ Grid integration challenges

India — Renewable Energy Status (Exam Guide — 3M)

India's Installed Capacity (2023–24)

Source	Capacity (GW)	Notes
Solar	≈73 GW	World's 4th largest; Rajasthan, Gujarat, Ta
Wind	≈44 GW	World's 4th; Tamil Nadu, Gujarat, Rajastha
Hydropower (large)	≈47 GW	Sikkim, HP, Uttarakhand, Karnataka
Biomass / bioenergy	≈10 GW	Sugarcane states; NE India
Total Renewable	≈180 GW	Target: 500 GW by 2030

Key policies: National Solar Mission (2010); National Wind Policy; PM-KUSUM (solar for farmers); MNRE = Ministry of New and Renewable Energy. India pledged Net Zero by **2070** at COP26.

3.2 Solar Energy

Photovoltaic · Solar Thermal · Water Heater · Cooker

Solar Radiation — Basics (Exam Guide — 3M)

Key Terms

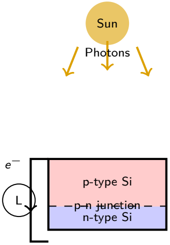
Solar constant: 1361 W/m^2 (energy from sun at top of atmosphere)

Insolation: Solar radiation received per unit area on Earth's surface. India receives: 4–7 kWh/m^2/day

Peak Sun Hours (PSH): Hours/day when average irradiance = 1 kW/m^2

India Solar Resource

- 300+ sunny days/year (most of India)
- Best regions: Rajasthan, Gujarat, Punjab
- Thar Desert = best solar irradiation
- India's total solar potential estimated at **750 GW**
- Jawaharlal Nehru National Solar Mission: target 100 GW (2022) → achieved!



Working

1. **Photons** from sunlight strike the solar cell
2. Silicon (p-n junction): photons knock out electrons (photoelectric effect)
3. **Electric field** at junction drives electrons → current flows through external circuit
4. **DC electricity** produced

Efficiency: 15–22% (commercial)

Cell → **Module** → **Array** → **System**

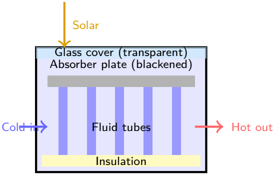
Photovoltaic — Types & Applications (Exam Guide — 3M)

PV Cell Types

Monocrystalline Si: Efficiency 18–22%; long life; costly
Polycrystalline Si: Efficiency 15–18%; cheaper; common
Thin Film (a-Si, CdTe): Efficiency 10–12%; flexible; light; low cost
Perovskite: $>$25% lab efficiency; next-generation
Bifacial: Absorbs light from both sides

Applications

- ➥ Rooftop solar (homes, factories)
- ➥ Solar street lights
- ➥ Solar water pumps (PM-KUSUM)
- ➥ Grid-scale solar farms
- ➥ Off-grid rural electrification
- ➥ Satellites and spacecraft
- ➥ Solar EV charging
- ➥ Solar lanterns (BIS standard)



Working

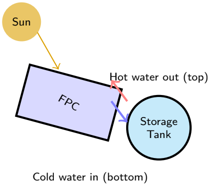
Glass cover: Allows solar radiation in; traps infrared (greenhouse effect)

Absorber plate: Black-painted to absorb max solar heat

Fluid tubes: Water/fluid heated as it flows through

Insulation: Prevents heat loss from back and sides

Temperature achieved: 60–90°C
Used for: domestic water heating



Key Details

Working: Cold water enters FPC from bottom; heated by solar energy; hot water rises by natural convection (thermosiphon) to storage tank at top.

Temperature: 60–80°C
Saves: 1500–2000 units electricity/year for 100 LPD system

Types: Thermosiphon (no pump) / Forced circulation (pump)
India: BIS IS 12933; subsidised by MNRE

Box-type Solar Cooker

Components:
➥ Outer box + inner black tray
➥ Double glass lid (traps heat)
➥ Plane mirror reflector (boosts heat)

Working: Sunlight reflected + directly enters; inner box heats to **150°C**; suitable for boiling, baking, steaming.

Advantages:
No fuel cost; no smoke/pollution; nutritional value retained; simple.

Limitations:
Not for frying/fast cooking; needs direct sunlight; slow.

Other Solar Thermal Devices

Solar dryer: Dries fish, fruits, crops using solar heat

Solar still: Distils brackish/salty water using solar evaporation

Concentrated Solar Power (CSP):
Parabolic trough / Tower concentrates sunlight to generate steam → turbine → electricity. Temperatures: 200–1000°C.

Scheffler Reflector: Fixed-focus community cooker used in India

Solar Energy — Summary & India Status (Exam Guide — 3M)

Advantages

- ➥ Abundant; India gets avg 5–6 kWh/m^2/day
- ➥ Zero fuel cost after installation
- ➥ Zero GHG during operation
- ➥ Modular — from 1W to GW scale
- ➥ Low maintenance; 25-year panel life
- ➥ Dual use — agrivoltaics

Limitations

- ➥ Intermittent (night, cloud) $\Rightarrow$ needs storage
- ➥ Land intensive: 1 GW $\approx$ 3000–5000 acres
- ➥ Panel manufacturing has some carbon footprint
- ➥ Panel waste by 2050 (10 million tonnes)
- ➥ High upfront cost (though falling fast: 2/unit)

Ladakh's Hanle has India's first Dark Sky Reserve. **World's largest solar park:** Bhadla, Rajasthan (2.7 GW). **Kochi Metro:** First metro powered 100% by solar.

Wind Energy Basics

Wind energy converts kinetic energy of wind into electrical energy using wind turbines. Wind is solar energy in another form (sun heating causes pressure differences → wind).

Wind Power Formula

$$P = \frac{1}{2}\rho A v^3$$

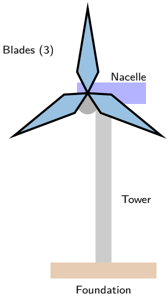
Where: ρ = air density, A = swept area, v = wind speed.

Power $\propto v^3$ — small increase in wind speed gives large power gain!

India Wind Resource

- ➥ Potential: ≈800 GW (at 100 m hub height)
- ➥ Best states: Tamil Nadu, Gujarat, Rajasthan, Karnataka
- ➥ Coastal and inland plains best
- ➥ Offshore: Gujarat, Tamil Nadu coasts
- ➥ Min useful wind speed: 3–4 m/s

Wind Turbine — Components (Exam Guide — 4M)



Key Components

Rotor blades: Capture wind kinetic energy; aerofoil shape
Hub: Connects blades; transfers rotation to shaft
Nacelle: Houses gearbox, generator, brake system
Gearbox: Steps up RPM (slow blade to fast generator)
Generator: Converts mechanical to electrical energy
Tower: Raises rotor to height with stronger winds
Foundation: Anchors turbine to ground

HAWT vs VAWT (Exam Guide — 4M)

Feature	HAWT (Horizontal Axis)	VAWT (Vertical Axis)
Orientation	Axis horizontal; faces wind	Axis vertical; omnidirectional
Efficiency	Higher (35–45%)	Lower (25–35%)
Wind direction	Must face wind (yaw mechanism)	Accepts wind from all direction
Installation	Tall tower needed	Low to ground; easy access
Noise	More	Less
Maintenance	Difficult (nacelle at height)	Easier (equipment at ground)
Examples	Most commercial turbines	Darrieus, Savonius types
Applications	Grid-scale, offshore	Urban, small scale, rooftop

➥ **Most commercial wind turbines are HAWT** with 3 blades, hub height 80–120 m, rated power 1–5 MW.

Step-by-step working

Step 1: Wind strikes aerofoil-shaped rotor blades; lift force causes rotation (like aircraft wing)

Step 2: Blades rotate the main shaft (low RPM: 10–25 RPM)

Step 3: Gearbox increases shaft speed to 1000–1800 RPM for generator

Step 4: Generator converts rotational energy to AC electricity

Step 5: Yaw mechanism rotates nacelle to face wind (HAWT only)

Step 6: Pitch control adjusts blade angle (feathers blades if wind too strong)

Step 7: Transformer steps up voltage; connected to grid

➥ **Cut-in speed:** $\approx$3 m/s (starts generating). **Rated speed:** $\approx$12 m/s (full power). **Cut-out speed:** $\approx$25 m/s (turbine shut down for safety).

Wind Energy — Advantages & Challenges (Exam — 3M)

Advantages

- ➥ Renewable; zero fuel cost; zero GHG (operation)
- ➥ Land dual-use: farming + wind turbines
- ➥ Low water usage (unlike thermal)
- ➥ Fast installation
- ➥ Offshore wind = high speed, consistent
- ➥ Lowest cost electricity in many regions
- ➥ India's wind cost: 2.5–3/unit

Challenges

- ➥ Intermittent (no wind = no power)
- ➥ Bird and bat mortality
- ➥ Noise pollution near residential areas
- ➥ Visual impact (aesthetic objections)
- ➥ Land required for wind farms
- ➥ Best areas often far from demand centres
- ➥ Gearbox maintenance complex

3.4 Biomass Energy

Biogas · Biofuels · Biomass Power

Biomass Energy — Types (Exam Guide — 3M)

Biomass

Biomass = organic material from plants and animals used as fuel. It stores solar energy through photosynthesis.

Types of Biomass

- ➥ **Wood:** Firewood, charcoal, pellets
- ➥ **Agricultural residue:** Paddy straw, bagasse, cotton stalks
- ➥ **Animal dung:** Cow dung for biogas
- ➥ **Municipal solid waste:** Organic fraction
- ➥ **Energy crops:** Jatropha, switchgrass, sugarcane
- ➥ **Aquatic biomass:** Algae

Conversion Pathways

Thermochemical: Combustion, gasification, pyrolysis

Biochemical: Anaerobic digestion (biogas), fermentation (ethanol)

Chemical: Transesterification (biodiesel from vegetable oil)

➥ India's biomass potential: **500 million tonnes/year**

Biogas — Composition & Benefits (Exam Guide — 4M)

Biogas

Biogas is produced by **anaerobic digestion** of organic matter by methanogenic bacteria. Also called **gobar gas** in rural India.

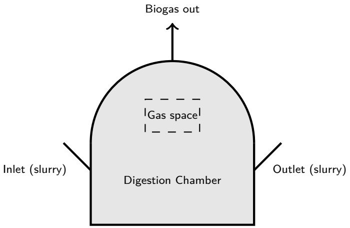
Composition

Gas	% by volume
Methane (CH_4)	55–65%
Carbon dioxide (CO_2)	30–40%
Hydrogen (H_2)	1–5%
Nitrogen, H_2S	traces

Benefits

- Cooking + electricity from cow dung
- Slurry = excellent organic fertiliser
- Reduces indoor air pollution (vs wood fire)
- Reduces GHG (captures CH_4 from dung)
- Decentralised energy for rural homes
- Carbon-neutral energy cycle

Fixed Dome Biogas Plant (PYQ — 4M)



Fixed Dome

Also called: Deenbandhu model (India); Janta model; Chinese model

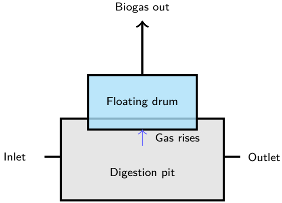
Construction: Permanent brick/concrete fixed dome underground

Gas storage: Gas stored in fixed gas space above slurry; creates gas pressure

Slurry: Displaced to expansion chamber when gas pressure builds

Advantage: Low cost; long life; no rust
Disadvantage: Gas pressure variable; cracks possible

Floating Drum Biogas Plant (PYQ — 4M)



Floating Drum (KVIC)

Also called: KVIC model (Khadi & Village Industries Commission)

Construction: Steel drum floats on slurry; rises as gas accumulates; provides constant pressure

Advantage: Constant gas pressure; visible gas production (drum rises); easy to operate

Disadvantage: Steel drum rusts; higher cost; maintenance needed

Biogas Plants — Comparison (PYQ — 4M)

Feature	Fixed Dome (Deenbandhu)	Floating Drum (KVIC)
Structure	Permanent brick/concrete dome	Steel drum floating on slurry
Gas pressure	Variable (changes with gas volume)	**Constant** pressure
Gas indicator	Not visible	Drum rises — visible
Cost	**Lower**	Higher (steel drum)
Life	**Longer** (20–30 years, no rusting)	Shorter (steel rusts: 10–15 yr)
Maintenance	Lower	Drum needs regular anti-rust t
Leakage	Possible (if cracks form)	Less common
Popularity	Most common in India	Older design; less common now

➥ Both use cattle dung + water (1:1 ratio); daily feed; 4–8 weeks retention time.

Types of Biofuels

1st Generation: From food crops
➥ **Bioethanol:** Sugarcane, corn fermentation
➥ **Biodiesel:** Transesterification of vegetable oil (Jatropha, soybean)

2nd Generation: From agricultural/forestry waste
➥ Cellulosic ethanol from straw, grass

3rd Generation: From algae
➥ Very high yield per hectare; not commercially viable yet

India Biofuel Policy

National Biofuel Policy (2018):
➥ Target E20 (20% ethanol in petrol) by 2025
➥ Blending reduces oil import bill
➥ Jatropha plantation on wasteland
➥ GOBAR-Dhan scheme (biogas from waste)

E20 reduces CO_2 by ≈10%, CO by ≈50% vs pure petrol.

Improved Biomass Cook Stove (Exam Guide — 3M)

Problem with Traditional Chulhas

Traditional 3-stone cook stoves: efficiency 5–10%; produces thick smoke (CO, $PM_{2.5}$) ⇒ **indoor air pollution** causes 4 million deaths/year globally (WHO).

Improved Cook Stove

- ➥ Efficiency: 25–40%
- ➥ Insulated combustion chamber
- ➥ Better air-fuel mixing
- ➥ Reduces fuel use 50–60%
- ➥ Less smoke and CO
- ➥ India: Pradhan Mantri Ujjwala Yojana (PMUY) — LPG connections

Gasifier Stove (Advanced)

- ➥ Biomass partly combusted; producer gas (CO, H_2) generated
- ➥ Burns cleanly; efficiency >50%
- ➥ Biochar by-product is soil amendment
- ➥ Used in institutions, small industries
- ➥ India: several CSIR models available

Working Principle

Potential energy of stored water (behind dam) is converted to kinetic energy as water flows through penstocks, which drives turbines to generate electricity. **PE → KE → Electrical Energy.**

Types

Run-of-river: No large reservoir; uses natural flow
Reservoir: Dam stores water; steady generation
Pumped Storage: Off-peak electricity pumps water up; peak demand releases it
Micro-hydro: <100 kW; remote areas
Mini-hydro: 100 kW – 5 MW

Issues

- ➥ Large dams: displacement of communities
- ➥ Forest/biodiversity submergence
- ➥ Methane from reservoir organic decay
- ➥ Seismic risk

Example: Bhakra-Nangal, Tehri, Sardar Sarovar Dam (India)

Tidal, Wave & OTEC Energy (Exam Guide — 3M)

Type	Source	Working
Tidal	Moon's gravity causes tides	Tidal barrage; turbines in tidal flo
Wave	Wind-driven surface waves	Oscillating water column (OWC)
OTEC	Temp difference: surface vs deep ocean	Warm water evaporates working f

OTEC needs: $\Delta T \geq 20^\circ$C between surface and 1000 m depth. Tropical coasts (Tamil Nadu, Lakshadweep) suitable.
Tidal potential India: 8000 MW (Gulf of Khambhat highest).

Geothermal Energy

Source: Earth's internal heat (radioactive decay)

Types:
- Dry steam (direct use)
- Flash steam (85% plants)
- Binary cycle (low-temp)

Uses: Electricity, space heating, direct heat
India: **Manikaran** (Parvati Valley), Tattapani (MP)
World: Iceland (30% energy); Geysers, USA; New Zealand

Hydrogen Energy

Source: Green hydrogen = electrolysis using renewable electricity

Fuel cell: $H_2 + O_2 \rightarrow H_2O$ + electricity; zero emission

Advantages:
- Highest energy density
- Zero GHG at point of use
- Long-duration storage

India: National Green Hydrogen Mission (2023); target 5 MT/year by 2030

3.7 Energy Conservation & Efficiency

BEE Ratings · Energy Audit · Green Buildings

Energy Conservation — Principles (Exam Guide — 3M)

Definition

Energy conservation = reducing energy consumption by using less energy services OR improving efficiency (doing the same work with less energy).

4-R Approach

Reduce: Use less energy; turn off lights
Replace: Use energy-efficient alternatives (LED vs incandescent)
Recover: Waste heat recovery systems
Renew: Switch to renewable sources

Energy efficiency formula: $\eta = \frac{\text{Useful output}}{\text{Energy input}} \times 100\%$

Methods

- **Lighting:** LED (80% less energy than incandescent)
- **HVAC:** 5-star AC; proper insulation
- **Industry:** VFD motors, co-generation
- **Transport:** EVs, public transport
- **Buildings:** Passive design, green roofs

BEE Star Ratings (Exam Guide — 3M)

Bureau of Energy Efficiency (BEE)

BEE (under Ministry of Power, India, est. 2002) promotes energy efficiency through star labelling of appliances.

Appliance	1-Star	3-Star	5-Star	Key Metric
AC	High energy use	Medium	**Most efficient**	ISEER (kWh/kW
Refrigerator	High	Medium	**Low energy**	kWh/year
Fan	Low RPM	Medium	**High efficiency**	W per RPM
LED Bulb	–	–	Better than all CFL	lm/W

5-star AC saves Rs 6,000–12,000/year vs 1-star. India's UJALA scheme: 360+ million LED bulbs replaced; saves 38 billion units/year.

Energy Audit (Exam Guide — 3M)

Definition

Energy audit is a systematic examination of an organisation's energy flows to identify where energy is used and find opportunities for energy savings.

Types

Preliminary (Walk-through): Quick overview; identifies obvious waste

Detailed Audit: Comprehensive measurement; identifies all savings; recommended improvements with payback periods

Steps

1. Collect historical energy bills
2. Site walkthrough; identify major consumers
3. Measure energy use of each system
4. Calculate energy intensity
5. Identify savings opportunities
6. Cost-benefit analysis
7. Report & implement recommendations

Green Buildings (Exam Guide — 4M)

Green Building

A **green building** is designed, constructed and operated to minimise environmental impact: efficient use of energy, water and materials; healthy indoor environment.

Rating Systems

GRIHA (Green Rating for Integrated Habitat Assessment): Indian system; from Ministry of New & RE

LEED (Leadership in Energy & Env. Design): US; used in India for commercial buildings

IGBC: Indian Green Building Council

Key Features

- Passive solar design (orientation, shading)
- Energy-efficient HVAC and lighting
- Rainwater harvesting
- Waste management on-site
- Green roofs and walls
- Solar panels on rooftop
- Use of locally-sourced, recycled materials

Smart Grid & Demand Response (Exam Guide — 3M)

Smart Grid

A smart grid uses digital communication technology to detect and react to local changes in energy use:

➥ 2-way communication between utility and consumer
➥ Real-time monitoring of generation and consumption
➥ Automatic fault detection
➥ Integrates renewable energy and EVs
➥ Smart meters for consumers

Energy Storage

Problem: Solar/wind are intermittent

Storage solutions:
➥ **Li-ion batteries:** Most common; EVs, grid
➥ **Pumped hydro:** 94% of global storage
➥ **Compressed air (CAES):** Underground
➥ **Hydrogen (LDES):** Long-duration storage
➥ **Flywheels:** Short-duration grid stability

India Energy Policy & Targets (Exam Guide — 3M)

Policy / Programme	Target	Year
Jawaharlal Nehru National Solar Mission	100 GW solar	Achieved 2
National Wind Energy Mission	140 GW wind	2030
UJALA Scheme	LED lighting (360M bulbs)	Ongoing
PM-KUSUM	10 GW (solar pumps)	2022
National Hydrogen Mission	5 MT green H_2	2030
GOBAR-Dhan Scheme	10,000 biogas plants	Ongoing
Perform, Achieve, Trade (PAT)	Industrial energy saving	Ongoing
Overall RE target	**500 GW**	**2030**
Net Zero	50% energy from renewables	**2070**

Comparison of Renewable Energy Sources (Exam Guide — 7M)

Source	Working	Efficiency	Advantages	Limitations
Solar PV	Photoelectric effect	15–22%	Abundant; modular	Intermittent; area
Solar Thermal	Heat collection	60–80% (FPC)	Simple; low cost	Cloudy days
Wind	Aerodynamic lift	35–45%	Low cost/unit	Variable; bird kills
Biomass	Combustion/AD	25–40%	Carbon-neutral; firm	Land; water; smoke
Biogas	Anaerobic digestion	50–65%	Rural; fertiliser by-product	Feedstock needed
Hydro	Potential energy	85–90%	Reliable; long life	Displacement; methane
Tidal	Tidal flow	25–40%	Predictable	High capital; few sites
Geothermal	Earth heat	10–23%	24/7 reliable; small area	Location-specific

Sector	Technology	Energy Saving
Lighting	LED vs incandescent	80% saving
Appliances	5-star rated	30–50% saving
HVAC	Inverter AC, VRF system	30–60% saving
Motors (industry)	Variable Frequency Drive (VFD)	20–50% saving
Buildings	Insulation, double glazing	30–40% saving
Transport	Electric vehicles	60–70% vs IC engine
Industry	Waste heat recovery, cogeneration	20–40% saving

Negawatt: 1 unit saved = 1 unit NOT generated ⇒ no pollution, no cost. Cheapest power = *power you don't use*.

Biogas — Anaerobic Digestion Process (Exam — 4M)

4-Stage Process

Stage 1 — Hydrolysis:
Complex organic molecules (fats, proteins, carbohydrates) broken into simpler molecules (sugars, fatty acids, amino acids) by hydrolytic bacteria.

Stage 2 — Acidogenesis:
Simple molecules converted to volatile fatty acids (acetic acid, propionic acid), CO_2, H_2 by acidogenic bacteria.

Stage 3 — Acetogenesis:
Fatty acids converted to acetic acid, H_2, CO_2 by acetogenic bacteria.

Stage 4 — Methanogenesis:
Methanogenic archaea (bacteria) convert acetic acid + CO_2 + H_2 $\rightarrow$ CH_4 (methane) + H_2O.

Conditions needed: Anaerobic; temperature 35–37°C; pH 7–8; no toxic substances.

Feature	Solar Cell (PV)	Solar Thermal Collector
Output	Electrical energy (DC)	Heat energy (hot water/s
Working	Photovoltaic (photoelectric) effect	Absorption and heat tran
Efficiency	15–22%	60–80% (FPC)
Main material	Silicon semiconductor	Blackened copper/alumin
Application	Power generation, charging	Water heating, cooking,
Temperature output	Not applicable	60–200°C (FPC to evacu
Storage	Battery (costly)	Insulated tank (cheap)

SDG 7: Affordable Clean Energy

Targets:

➥ Universal access to affordable, reliable, modern energy by 2030

➥ Increase share of renewable energy globally

➥ Double the rate of energy efficiency improvement

1 billion people lack electricity; 3 billion cook on solid biomass (SDG 7.1)

Cross-cutting SDG Links

SDG 13: Climate action (renewables reduce GHG)

SDG 11: Sustainable cities (solar rooftop, EV)

SDG 3: Good health (clean cooking fuel reduces IAP)

SDG 8: Decent work (green jobs in RE sector)

SDG 9: Industry innovation (clean industry tech)

Q1: Solar panel output

A solar panel of area 2 m^2 receives solar radiation of 800 W/m^2. Efficiency = 18%. Find the electrical output.

Solution: Input power = $800 \times 2 = 1600$ W
Output = $1600 \times 0.18 =$ **288 W**

Q2: Wind power

Wind turbine: swept area = 50 m^2, wind speed = 8 m/s, air density = 1.25 kg/m^3, efficiency = 35%. Find output power.

Solution: $P_{wind} = \frac{1}{2}\rho A v^3 = \frac{1}{2} \times 1.25 \times 50 \times 8^3 = 16000$ W
Output = $16000 \times 0.35 =$ **5600 W = 5.6 kW**

Biomass Energy — Advantages & Challenges (Exam Guide — 3M)

Advantages

- ➥ **Carbon neutral:** CO_2 released was absorbed during growth
- ➥ **Firm power:** Available 24/7 (unlike solar/wind)
- ➥ **Rural employment:** Farmers supply biomass
- ➥ **Waste management:** Utilises agricultural waste
- ➥ **Biogas:** By-product fertiliser improves crops
- ➥ **Reduces firewood demand:** Protects forests

Challenges

- ➥ Land needed for energy crops (food vs fuel)
- ➥ Water-intensive: irrigation for energy crops
- ➥ Combustion still releases particulates
- ➥ Seasonal availability of feedstock
- ➥ Collection and transport logistics
- ➥ 1st-gen biofuels affect food prices

India's Energy Mix — Present & Future (Exam Guide — 3M)

India's Energy Mix (2024)

Source	**Installed Capacity (GW)**	**Share**
Coal (thermal)	≈215	≈50%
Renewables (total)	≈180	≈42%
– Solar	≈73	
– Wind	≈44	
– Hydro (large)	≈47	
Gas	≈25	6%
Nuclear	≈7	2%
Total	**≈430**	

India's COP26 commitments: (1) 500 GW RE by 2030; (2) 50% energy from renewables by 2030; (3) Reduce carbon intensity 45% vs 2005; (4) Net zero by 2070.

Q: Explain the working of a solar cell with diagram (4M)

Principle: Photovoltaic (photoelectric) effect — when photons of sufficient energy strike a semiconductor (silicon p-n junction), electron-hole pairs are created.

Working:
1. Photons from sunlight strike the silicon solar cell
2. At the p-n junction, built-in electric field separates electron-hole pairs
3. Free electrons flow through external circuit → **DC current generated**
4. Multiple cells connected in series/parallel form a **module**; modules form an **array**

Efficiency: Monocrystalline 18–22%; Polycrystalline 15–18%; Thin film 10–12%

Applications: Rooftop power, solar street lights, space satellites, water pumps.

Advantages: No moving parts; long life (25 yr); zero fossil fuel; modular.

Q: Explain fixed dome biogas plant with diagram (4M)

Also called: Deenbandhu / Janta model (India)

Construction: Underground fixed-dome structure made of brick/concrete. Inlet pipe for slurry (cattle dung + water 1:1). Outlet chamber for slurry displacement. Gas outlet pipe at top.

Working:
1. Fresh slurry (cattle dung + water) fed through inlet daily
2. Anaerobic bacteria digest organic matter in digester
3. Biogas (55–65% CH_4) accumulates in fixed gas space (dome top)
4. Gas pressure displaces slurry to expansion chamber (outlet side)
5. Biogas tapped for cooking or electricity via gas pipe
6. Spent slurry from outlet used as fertiliser (biofertiliser)

Retention time: 40–60 days **Temperature:** 30–40°C optimal

Q: Explain working of wind turbine (4M)

Principle: Kinetic energy of wind → mechanical rotation → electrical energy.

Main components: 3 aerofoil-shaped rotor blades; hub; gearbox; generator; tower; yaw and pitch control.

Working:
1. Wind strikes the 3 rotor blades; aerodynamic lift causes rotation
2. Blades rotate main shaft (low speed: 10–25 RPM)
3. **Gearbox** steps up shaft speed to 1000–1800 RPM
4. **Generator** converts rotational energy to AC electricity
5. **Yaw system** (HAWT) always orients nacelle to face wind direction
6. **Pitch control** adjusts blade angle to control power output
7. Transformer steps up voltage and power fed to grid

Wind speeds: Cut-in 3 m/s | Rated 12 m/s | Cut-out 25 m/s

PYQ Worked — Fixed Dome vs Floating Drum (Exam — 4M)

Q: Compare fixed dome and floating drum biogas plants (4M)

Feature	Fixed Dome (Deenbandhu)	Floating Drum (KVIC)
Structure	Permanent brick/concrete dome (underground)	Steel drum floating on slurry in pit
Gas pressure	Variable	**Constant** (drum weight = constant p
Gas storage indicator	Not visible	**Drum position** shows gas volume
Initial cost	**Lower**	Higher (steel drum)
Life span	20–30 years (no rust)	10–15 years (steel rusts)
Maintenance	**Less**	More (drum painting, rust prevention
Reliability	Cracks may cause gas leakage	Less leakage
Use in India	**Most popular**	Older model; less common now

➥ Both: dung:water = 1:1; 40–60 day retention; produce 55–65% CH_4 in biogas; slurry = biofertiliser.

PYQ Worked — Non-Conventional Energy Sources

(Exam — 4M)

Q: Enumerate non-conventional energy sources with advantages (4M)

1. Solar energy: Sun's radiation; PV cells (electricity) + flat plate collector (heat). Advantage: abundant, zero GHG.

2. Wind energy: Kinetic energy of wind; HAWT/VAWT turbines. Advantage: zero fuel, low operating cost.

3. Biomass energy: Organic matter; biogas, biofuels. Advantage: carbon-neutral, rural benefit.

4. Tidal energy: Sea tides; tidal barrage/stream. Advantage: predictable, coastal.

5. Wave energy: Ocean waves; OWC turbines. Advantage: consistent on coastlines.

6. Geothermal energy: Earth's internal heat; steam turbines. Advantage: 24/7 reliable, small footprint.

7. Ocean Thermal Energy (OTEC): Temp difference; Rankine cycle. Advantage: tropical countries.

8. Hydrogen fuel cell: Green $H_2 + O_2 \rightarrow H_2O$ + electricity. Zero GHG at

PYQ Worked — Energy Conservation Methods (Exam — 4M)

Q: Describe 5 methods of energy conservation (4M)

1. Replace incandescent with LED:
LED uses 80% less electricity; same luminous output. India's UJALA: 360M LEDs replaced.

2. Switch off unused appliances:
Standby mode still consumes 5–15% of rated power; switch off and unplug.

3. Use energy-efficient appliances (BEE 5-star):
5-star AC saves Rs 6,000/year vs 1-star.

4. Proper insulation of buildings:
Double-glazed windows; wall insulation; reduces heating/cooling energy 30–40%.

5. Use public transport / EVs:
EVs: 3–4$\times$ more efficient than IC engines; bus/metro reduces per-capita energy 5–10$\times$.

6. Renewable energy adoption:
Rooftop solar, solar water heaters avoid fossil fuel consumption entirely.

1. The working principle of a solar cell is:
(A) Thermoelectric effect **(B) Photovoltaic effect**
(C) Piezoelectric effect (D) Magnetoelectric effect

2. In a fixed dome biogas plant, the gas pressure is:
(A) Variable (B) Constant (C) Zero at start (D) Regulated by valve

3. HAWT stands for:
(A) High-Altitude Wind Technology **(B) Horizontal Axis Wind Turbine**

4. Biogas contains primarily:
(A) CO_2 and H_2 **(B) CH_4 and CO_2** (C) H_2 and N_2

5. BEE stands for:
(A) Bureau of Environmental Efficiency **(B) Bureau of Energy Efficiency**

6. KVIC model biogas plant = ?
(A) Fixed dome **(B) Floating drum** (C) Tubular (D) Plug flow

Common Mistakes in Unit 3 (Exam Warning)

Wrong	Correct
Solar cell works on thermoelectric effect	**Photovoltaic (photoelectric) effect**
Fixed dome has constant pressure	**Floating drum has constant pressure**; fixed dome has variable
Floating drum is more popular in India	**Fixed dome (Deenbandhu) more popular** (cheaper, longer life)
Biogas = 100% methane	Biogas = 55–65% CH_4 + 30–40% CO_2
VAWT is more efficient than HAWT	**HAWT more efficient** (35–45% vs 25–35%)
Hydropower efficiency is low	Hydro is **most efficient** RE (85–90%)
Solar panel is same as solar cell	Cell → Module → Array → System (different scales)

Solar Energy

- Solar constant: 1361 W/m^2
- India: 4–7 kWh/m^2/day (300+ sunny days)
- PV = photovoltaic; p-n junction silicon
- Efficiency: Mono 18–22%; Poly 15–18%
- Solar water heater: 60–80°C; thermosiphon
- Box solar cooker: 150°C
- India solar capacity: ≈73 GW (2024)
- World's largest solar park: Bhadla, Rajasthan (2.7 GW)
- Cost: Rs 2/unit (solar now cheapest energy in India)

Wind Energy

- Power $\propto v^3$ (wind speed cubed)
- HAWT: horizontal axis; most efficient (35–45%)
- VAWT: vertical; all wind directions; less efficient
- Cut-in: 3 m/s; Rated: 12 m/s; Cut-out: 25 m/s
- India wind capacity: ≈44 GW
- Best states: TN, Gujarat, Rajasthan
- 3 rotor blades; hub; nacelle (gearbox + generator); tower
- Yaw system: orients nacelle to face wind
- Pitch control: adjusts blade angle

Flash Revision 2 — Biomass, Hydro, Geothermal

(Quick Recall)

Biomass & Biogas

- Biogas: 55–65% CH_4, 30–40% CO_2
- Anaerobic digestion: 4 stages (hydrolysis, acidogenesis, acetogenesis, methanogenesis)
- Fixed dome (Deenbandhu): variable pressure; low cost; no rust
- Floating drum (KVIC): constant pressure; steel rusts
- Dung:Water = 1:1; retention 40–60 days
- Biofuel: 1st gen = food crops; 2nd gen = agricultural waste
- E20 petrol: 20% ethanol; target 2025

Hydro, Geo, Tidal

- Hydropower: most efficient RE (85–90%)
- Pumped storage = energy battery (pump up off-peak; release peak)
- Tidal: moon's gravity; Gulf of Khambhat 8000 MW potential
- OTEC: needs $\Delta T \geq 20^{\circ}C$ (surface vs deep ocean)
- Geothermal: Earth heat; flash steam most common
- India geothermal: Manikaran (HP), Tattapani (MP)
- Hydrogen fuel cell: $H_2 + O_2 \rightarrow H_2O$ + electricity; zero GHG

Flash Revision 3 — Policy & Conservation (Quick Recall)

India RE Policy

- MNRE = Ministry of New and Renewable Energy
- Target: 500 GW RE by 2030
- Net Zero: 2070 (COP26 pledge)
- JNNSM: 100 GW solar mission (achieved!)
- PM-KUSUM: solar pumps for farmers
- GOBAR-Dhan: biogas from waste
- National Green Hydrogen Mission: 5 MT H_2 by 2030
- UJALA: 360 million LED bulbs; saves 38 BU/year

Energy Conservation

- BEE (Bureau of Energy Efficiency): est. 2002
- 5-star rating = most efficient
- LED: 80% less energy than incandescent
- ISEER (Indian Seasonal Energy Efficiency Ratio) for ACs
- Energy audit: identify + fix energy waste
- Green building: GRIHA (India); LEED (US/India)
- Negawatt = 1 unit saved = 1 unit not generated
- 4-R: Reduce, Replace, Recover, Renew

Important Definitions Recap — Unit 3 (Exam Guide)

Term	Definition
Renewable energy	Energy from naturally replenished sources (sun, wind, biomass, water)
Solar cell	Semiconductor device converting solar radiation to DC electricity via photovoltaic effect
Insolation	Solar radiation received per unit area at Earth's surface ($kWh/m^2/day$)
Biogas	Combustible gas (55–65% CH_4) produced by anaerobic digestion of organic matter
Anaerobic digestion	Microbial breakdown of organic matter in absence of oxygen, producing biogas
Biofuel	Liquid fuel (ethanol, biodiesel) derived from biological sources (sugarcane, Jatropha)
Energy audit	Systematic examination of energy flows to identify conservation opportunities
Green building	Building designed for minimal energy/water/material use; rated by GRIHA/LEED
HAWT	Horizontal Axis Wind Turbine; rotor shaft horizontal and parallel to wind direction
BEE	Bureau of Energy Efficiency (India, Ministry of Power); administers star labelling

India's Renewable Energy Champions (GK for MCQ)

Achievement	Detail
World's largest solar park	Bhadla, Rajasthan (2.7 GW)
World's largest wind farm	Muppandal Wind Farm, Tamil Nadu
India's 1st solar city	Anandpur Sahib, Punjab
India's 1st solar-powered metro	Kochi Metro
Best solar state	Rajasthan (highest solar irradiation)
Best wind state	Tamil Nadu (oldest wind installations)
Geothermal: best sites	Manikaran (HP), Tattapani (MP)
India RE position globally	4th largest RE producer (2023)
Countries ahead in RE	China, USA, Germany
MNRE HQ	New Delhi (Ministry of New and Renewable Energy

Q. Write a short note on Solar Water Heater. (4M)
Ans: Flat plate collector tilted at latitude angle. Glass cover traps solar heat. Black absorber plate absorbs >95% radiation. Water heated to 60–80°C by thermosiphon (no pump). Insulated storage tank at top. Saves 1500–2000 units electricity/year per 100 LPD system.

Q. Write a short note on Wind farm. (4M)
Ans: A wind farm is a cluster of 10–200+ wind turbines at a windy site. HAWT turbines of 1–5 MW each. Located on ridges, plains or offshore. Grid-connected. India's largest wind states: Tamil Nadu, Gujarat. Challenges: bird mortality, noise, visual impact. India target: 140 GW by 2030.

Q. What is cogeneration? (3M)
Ans: Simultaneous generation of electricity and useful heat from same fuel source (e.g., steam turbine exhaust used for heating). Efficiency reaches 80% vs 35% for electricity alone. Used in industries, hospitals, hotels.

Unit 3 — Summary (25% Weightage)

Solar & Wind

- PV cell: photovoltaic effect; Si p-n junction
- FPC: absorber plate → hot water 60–80°C
- HAWT > VAWT efficiency; yaw + pitch control
- Wind power $\propto v^3$; cut-in 3 m/s, rated 12 m/s
- India: 73 GW solar, 44 GW wind (2024)

Biomass & Others

- Biogas: 55–65% CH_4 by anaerobic digestion
- Fixed dome (Deenbandhu): cheaper, variable pressure
- Floating drum (KVIC): constant pressure, rusts
- Biofuel: E20 petrol by 2025 (India)
- Hydro most efficient RE: 85–90%

Conservation & Policy

- BEE star ratings; 5-star = most efficient
- LED: 80% energy saving vs incandescent
- Energy audit: preliminary and detailed types
- Green building: GRIHA (India), LEED (US)
- India RE target: 500 GW by 2030; Net Zero 2070
- UJALA: 360 million LEDs; saves 38 BU/year

Key PYQs: Solar cell working, Biogas fixed dome, Wind turbine, Fixed dome vs floating drum, Non-conventional energy types, Conservation methods

Weightage: 25% | Hours: 7 | Equal to

Unit 4: Climate Change and Global Warming

Environmental Sustainability — DI02000051

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April 2, 2026

Unit 4 Syllabus Overview (20% Weightage, 6 Hours)

Unit 4 Topics

4.1 Greenhouse Effect and Greenhouse Gases
4.2 Global Warming — Causes, Evidence, Consequences
4.3 Climate Change Impacts (sea level, extreme weather, biodiversity)
4.4 Carbon Footprint, Carbon Credits and Carbon Trading
4.5 Mitigation Strategies (renewables, carbon capture, afforestation)
4.6 Adaptation Strategies (disaster management, resilient agriculture)
4.7 International Climate Agreements (Kyoto, Paris, COP)

20% marks | 6 lecture hours | PYQ topics: GHG, Paris Agreement, Carbon footprint, Mitigation vs Adaptation

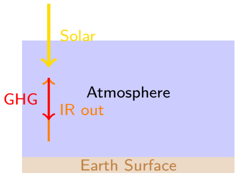
Section 4.1

Greenhouse Effect and Greenhouse Gases

Solar radiation budget:

- Sun emits shortwave radiation (UV + visible)
- Earth absorbs ≈70%; reflects 30% (albedo)
- Earth emits longwave (infrared) radiation to space
- **Without greenhouse effect:** Earth's avg temp $= -18^\circ$C
- **With natural GHE:** actual avg temp $= +15^\circ$C
- GHE raises temperature by **33°C** — essential for life!

Problem: Industrial era has **enhanced** the greenhouse effect, causing **global warming**.



Greenhouse Gases (GHGs) (4.1)

GHG	Formula	GWP (100yr)	Main Sources
Carbon dioxide	CO_2	**1** (reference)	Fossil fuels, deforestation
Methane	CH_4	**25**	Livestock, rice fields, landfills, natural gas
Nitrous oxide	N_2O	**298**	Fertilisers, sewage, combustion
CFC-12	CCl_2F_2	**10,900**	Refrigerants, aerosols (banned – Montreal)
HFC-134a	CH_2FCF_3	**1,430**	AC refrigerants (replacing CFCs)
SF_6	SF_6	**22,800**	Electrical switchgear equipment
Water vapour	H_2O	–	Natural; feedback amplifier

GWP = Global Warming Potential relative to CO_2 over 100 years.
Current CO_2 level: ≈421 ppm (2024) vs pre-industrial 280 ppm (+50%!)

Global GHG share by sector:

Sector	Share
Energy (electricity, heat)	25%
Agriculture, forestry, land use	24%
Industry (cement, steel)	21%
Transport	14%
Buildings	6%
Others	10%

India GHG Profile

- India: 3rd largest emitter (after China, USA)
- India emits ≈3.3 Gt CO_2eq / year
- Per capita: 2.4 t/yr (world avg: 7 t/yr)
- India contributes ≈7% to global GHG
- India energy sector = 75% of India GHG
- India's NDC: reduce emission intensity 45% by 2030 (vs 2005)

Section 4.2

Global Warming — Causes, Evidence, Consequences

Anthropogenic Causes

1. **Burning fossil fuels:** coal, oil, gas $\rightarrow$ CO_2, N_2O
2. **Deforestation:** releases stored C; reduces C sink
3. **Agriculture:** livestock CH_4; rice fields; N fertilisers
4. **Industry:** cement ($CaCO_3 \rightarrow CO_2$); steel, chemicals
5. **Waste:** landfills emit CH_4; sewage emits N_2O
6. **Refrigerants/CFCs:** high GWP; HFCs replacing CFCs

Natural Causes

1. **Volcanic eruptions:** CO_2, SO_2 (short-term cooling)
2. **Solar variability:** sunspot cycles ($\pm 0.1\%$ irradiance)
3. **Milankovitch cycles:** orbital changes (very slow, 10,000–100,000 yr)
4. **Ocean circulation:** ENSO, thermohaline circulation

Note: Natural causes **cannot explain** the rapid warming since 1950 — IPCC: **human activities are the dominant cause**.

Evidence of Global Warming (Observed Data)

Indicator	Observed Change	Period
Global mean temperature	$+1.1^\circ$C	Since pre-industrial (
Sea level rise	+20 cm	Since 1900; rate acc
Arctic sea ice extent	-40% in summer	Since 1980s
Greenland ice loss	280 Gt/year	Last decade
Ocean heat content	Increased at all depths	Measured since 1955
Glacier retreat	90%+ glaciers retreating	Global (NASA data)
Coral bleaching	Great Barrier Reef; 4 mass events	Since 1998
CO_2 concentration	421 ppm (2024) vs 280 ppm	Pre-industrial baselin
Extreme weather	Frequency + intensity increased	IPCC AR6 2021

Physical Consequences

- Sea level rise (thermal expansion + ice melt)
- More frequent extreme heat waves
- Intense hurricanes, cyclones, floods
- Droughts and desertification
- Permafrost thawing → CH_4 feedback loop
- Glacier retreat → freshwater crisis

Human/Eco Consequences

- Crop failure: food insecurity for billions
- Coral bleaching → fishery collapse
- Species extinction (6th mass extinction)
- Climate refugees (coastal, small islands)
- Spread of vector-borne diseases (malaria, dengue)
- Economic losses: trillions/year by 2100

IPCC AR6 (2021): +1.5°C is the "safe" limit; currently on track for +2.5–3.0°C by 2100 unless drastic action.

Section 4.3

Climate Change Impacts

Two causes of sea level rise:

1. Thermal expansion (steric):
Water expands as it warms. Oceans absorb >90% of excess heat. Contributes ≈50% of observed SLR.

2. Ice melt (eustatic):
Greenland ice sheet, Antarctic ice sheets, mountain glaciers. Contributes other ≈50%.

Observed: +3.6 mm/year (recent decade)
Projected: 0.28–1.01 m by 2100 (IPCC AR6)

Impacts:
- Flooding of coastal cities (Mumbai, Kolkata)
- Loss of small island nations (Maldives, Tuvalu)
- Salinisation of freshwater aquifers
- Displacement of 1 billion coastal people

Vulnerable Countries

- Bangladesh: 17% of land below 1m
- Maldives: avg elevation 1.5 m
- Netherlands: 27% below sea level
- Egypt: Nile delta at risk
- India: Mumbai, Kolkata, Chennai
- USA: Miami, New Orleans, NYC

How does warming intensify extreme weather?

Every 1°C rise → atmosphere holds 7% more water vapour (Clausius-Clapeyron). This fuels:

Event	**Change with Warming**	**Recent Example**
Heat waves	More frequent, longer, hotter	Europe 2022 (48°C); India 2024
Cyclones/Hurricanes	More intense (Cat 4–5); more rapid intensification	Cyclone Biparjoy, 2023
Heavy rainfall/floods	More intense precipitation	Pakistan floods 2022 (33M displac
Droughts	Longer, more severe	Horn of Africa 2022; SW USA 202
Wildfires	Longer fire season, larger area	Australia 2019-20; Canada 2023
Cold spells	Paradoxically, polar vortex disruption	Texas freeze 2021

Impacts on Species & Ecosystems

Range shifts:
Species moving poleward or to higher altitudes ($\approx$6 km/decade). Alpine species face "extinction on mountain tops".

Phenological mismatch:
Flowers bloom earlier; pollinators not yet active $\rightarrow$ reproduction failure.

Coral bleaching:
Corals expel zooxanthellae when ocean temp rises $>1^{\circ}$C. 14% of global corals lost in 2009–2018 (GCRMN 2020).

Mass extinctions:
Current extinction rate 100–1000$\times$ background rate. 1 million species threatened (IPBES 2019).

Ocean acidification:
$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow$ lowers ocean pH. Dissolves shells of molluscs, echinoderms.

Climate Change Impacts on India (National Context)

Physical Impacts

- **Monsoon changes:** erratic timing; dry spells + floods
- **Himalayan glaciers:** Gangotri retreating 22 m/year
- **Sea level:** Mumbai, Kolkata at risk
- More intense cyclones (Bay of Bengal warmer)
- Heat waves: Delhi 2024 (52.9°C, all-time record)
- Extreme rainfall: Kerala 2018, Uttarakhand 2021

Socio-Economic Impacts

- Agriculture: wheat yield −6% per 1°C rise
- 600M people depend on monsoon for water
- Fisheries: warming ocean disrupts patterns
- Health: dengue, malaria spreading north
- Labour productivity loss in outdoor work
- GDP loss: 2.8% by 2050 (World Bank est.)

Section 4.4

Carbon Footprint, Carbon Credits
and Carbon Trading

Definition

Total greenhouse gas emissions (expressed as CO_2 equivalent — CO_2eq) caused directly and indirectly by an individual, organisation, event, or product over its lifecycle.

Types

Direct (Scope 1): Own fuel combustion (furnace, fleet)

Indirect (Scope 2): Purchased electricity/heat

Value chain (Scope 3): Supply chain, product use, disposal

Per Capita Comparison

USA: $\approx$15 t CO_2eq/year
EU average: $\approx$8 t
China: $\approx$8 t
India: $\approx$2.4 t (much lower!)
World average: $\approx$7 t
Sustainable target: $<$2 t by 2050

How to reduce? Switch to RE, use EVs, eat less meat, fly less, plant trees, buy local.

Definition

A **carbon credit** is a tradeable permit that represents the right to emit **1 tonne of CO_2eq**. Organisations that reduce emissions earn credits; those that exceed their limit must buy credits.

Clean Development Mechanism (CDM) — Kyoto Protocol:
Developed countries can fund emission-reduction projects in developing countries and earn **Certified Emission Reductions (CERs)** = carbon credits.

Example: A cement plant in India installs waste heat recovery → earns CERs → sells to EU company that is over its quota.

Voluntary carbon market: Companies voluntarily offset emissions (e.g., airline lets you offset your flight).

Types of carbon offset projects: Renewable energy, reforestation, methane capture, cookstove programs

Carbon Trading & Cap-and-Trade (4.4)

How Cap-and-Trade Works

Step 1: Government sets a **CAP** (total allowed emissions) for a sector.
Step 2: Companies get **allowances** (permits) for their share.
Step 3: Companies that emit less than their allowance can **sell surplus**.
Step 4: Companies over limit must **buy allowances** or face penalty.
Step 5: Cap reduced over time → total emissions fall.

System	**Feature**
EU ETS (Emissions Trading Scheme)	World's largest, 11,000 installations c
California Cap-and-Trade	Links with Quebec (Canada)
China ETS (since 2021)	World's largest by volume
India Carbon Credit Trading Scheme (CCTS)	Launched 2023 (India's first)

Carbon neutral: CO_2 emitted = CO_2 removed/offset (net zero CO_2 only).

Net zero: All GHG emissions reduced to near-zero; remaining offset by carbon sinks (forests, DACCS).

Carbon negative/Climate positive: Removes more CO_2 than it emits (e.g., Bhutan is carbon negative!).

DACCS: Direct Air Carbon Capture and Storage — machines pull CO_2 from air; expensive but promising.

BECCS: Bioenergy with Carbon Capture and Storage — burn biomass (carbon-neutral) + capture emissions = **negative emissions**.

India's target: Net zero by **2070** (announced at COP26, Glasgow).

Section 4.5

Mitigation Strategies

Mitigation vs Adaptation (Critical Distinction)

Mitigation (Reduce the Cause)

Actions that reduce or prevent GHG emission or enhance carbon sinks.
Goal: Stop further climate change from happening.
Examples: Switch to renewable energy; improve fuel efficiency; plant forests; carbon capture.

Adaptation (Live with the Effect)

Actions that help humans and ecosystems cope with the impacts of climate change that cannot be avoided.
Goal: Reduce vulnerability to existing and future changes.
Examples: Build sea walls; drought-resistant crops; early warning systems; disease surveillance.

We need BOTH — mitigation reduces long-term risk; adaptation handles locked-in changes.

Energy Sector Mitigation (4.5)

1. Transition to renewable energy:
Solar, wind, hydro, geothermal replace coal/oil. Eliminates Scope 1 and 2 emissions from power sector.

2. Energy efficiency:
LED lighting; 5-star appliances; EV/hybrid vehicles; building insulation. Reduces demand.

3. Carbon capture & storage (CCS):
Capture CO_2 at source (power plant or cement factory), compress, and inject into deep geological formations. Cost: $50–100/tonne.

4. Nuclear power:
Low lifecycle GHG (12 g CO_2eq/kWh vs coal 820 g). IPCC includes nuclear as mitigation option. Controversial (waste, safety).

5. Green hydrogen:
Electrolysis of water using RE. Zero-emission fuel for heavy industry and transport.

Land Use, Forests & Blue Carbon (Natural Mitigation)

Forests

- Forests store ≈660 Gt C (2× atmosphere)
- **Afforestation:** plant trees on previously treeless land
- **Reforestation:** replant already-cleared forest
- India planted 1.5 billion trees (2016–2020)
- REDD+: UN program pays developing countries to **not** deforest
- Agroforestry: trees + crops together

Blue Carbon

- Mangroves, seagrasses, salt marshes store carbon at 5–10× rate of tropical forests
- Called "blue carbon" ecosystems
- Degradation → fast CO_2 release
- India: 4,992 km^2 mangroves (4th largest worldwide)
- Protection = low-cost mitigation

Sustainable Agriculture as Mitigation (4.5)

Agriculture causes ≈10–12% of global GHG emissions. Mitigation options:

Source	**Emission**	**Mitigation**
Livestock	CH_4 (ruminant digestion)	Feed additives (3-NOP), fewer ca
Paddy fields	CH_4 (anaerobic flooding)	Alternate wetting and drying; SR
Nitrogen fertiliser	N_2O	Precision fertilisation, nitrificatio
Crop residue burning	CO_2, black carbon	Mechanised incorporation, biocha
Land clearing	CO_2	Forest protection, agroforestry

Biochar: Charred crop residue buried in soil → stable carbon for 1000+ years.

Section 4.6

Adaptation Strategies

Adaptation Strategies (4.6)

Infrastructure-based adaptation:
- Sea walls, surge barriers, levees for coastal flooding
- Elevated roads and buildings in flood-prone areas
- Green roofs and urban heat island mitigation

Agricultural adaptation:
- Drought-resistant/heat-tolerant crop varieties (GM crops, traditional varieties)
- Crop diversification; change cropping calendar
- Rainwater harvesting, drip irrigation

Health adaptation:
- Early warning systems for heat waves
- Vector-borne disease surveillance (dengue, malaria)
- Cool shelters and emergency response plans

Ecosystem-based adaptation (EbA):
- Restore mangroves (protect coasts naturally)
- Watershed protection; wetland restoration

Disaster Management and Climate Resilience (4.6)

Disaster Risk Reduction (DRR)

Sendai Framework 2015–2030: Global disaster risk reduction plan (UNDRR)
Priority Actions:
1. Understand disaster risk (hazard mapping, exposure data)
2. Strengthen disaster risk governance (NDMA, SDMA)
3. Invest in resilience (early warning, infrastructure)
4. Enhance preparedness (response, recovery)

India's Institutions

- **NDMA:** National Disaster Management Authority (Disaster Management Act 2005)
- **NDRF:** National Disaster Response Force (16 battalions)
- **IMD:** Indian Meteorological Department (weather forecasting)
- **INCCA:** India Network for Climate Change Assessment

Resilient Agriculture (4.6)

Climate-Smart Agriculture (CSA): FAO concept; 3 pillars: Productivity + Adaptation + Mitigation

Key practices:

1. **Drought-resistant varieties:** millet, sorghum over rice/wheat in dry areas
2. **Traditional crops:** native landraces often more resilient than modern HYVs
3. **Water-efficient irrigation:** drip irrigates 40–60% less water
4. **Weather-based crop insurance:** Pradhan Mantri Fasal Bima Yojana (PMFBY)
5. **Agroforestry:** trees provide buffer against temperature extremes
6. **Integrated pest management (IPM):** climate change shifts pest ranges
7. **Crop diversification:** reduces risk of complete crop failure

India's initiative: NICRA (National Innovations in Climate Resilient Agriculture)

Urban Climate Adaptation (Smart City Planning)

Urban Heat Island

Cities are 2–5°C warmer than surrounding rural areas.

Solutions:

- Green roofs and vertical gardens
- Cool/white/reflective roofs
- Urban tree canopy (>25% cover)
- Permeable pavement (reduce runoff)
- Water bodies (lakes, ponds)

Flood Resilience

- Sponge city concept (China): urban design that absorbs water
- Early flood warning systems (24–48 hr alert)
- Flood plains left free of construction
- Wetland restoration in urban fringe
- Elevated evacuation corridors

Section 4.7

International Climate Agreements

UNFCCC — Foundation of Climate Diplomacy (4.7)

UNFCCC: United Nations Framework Convention on Climate Change
Adopted: Rio Earth Summit, 1992
In force: March 21, 1994
Signatories: 197 parties (near-universal)

Objective: "Stabilize GHG concentrations at a level that would prevent dangerous human interference with the climate system."

Principles:
• **Common but Differentiated Responsibilities (CBDR):** Developed countries must act first (historical emitters)
• Precautionary principle (act even with scientific uncertainty)
• Technology transfer and financial support to developing nations

COP: Conference of Parties — annual meeting. COP1 (Berlin 1995) → COP28 (Dubai 2023).

Kyoto Protocol (1997) (4.7)

Adopted: Kyoto, Japan, 1997 **In force:** Feb 2005

First binding treaty to reduce GHG emissions.
Target: Annex I (developed) countries reduce emissions by 5.2% below 1990 levels (2008–2012).

Three flexible mechanisms:
1. **Emissions Trading (ET):** countries trade unused quota
2. **Joint Implementation (JI):** Annex I invests in emission reduction in other Annex I countries
3. **Clean Development Mechanism (CDM):** Annex I funds projects in developing countries $\rightarrow$ earns CER credits

Limitation: USA never ratified; China, India (developing) had no binding targets.
Doha Amendment (2012): Extended to 2020 with new targets (most countries committed).

Paris Agreement (2015) — COP21 (PYQ — Most Important)

Key Features of Paris Agreement

Adopted: COP21, Paris, December 12, 2015
Parties: 196 (nearly all nations including USA, China, India)

Goal: Keep global warming **well below 2°C** above pre-industrial (aim for 1.5°C).

Mechanism: NDCs (Nationally Determined Contributions) — each country sets own target, reviewed every 5 years.

Key provisions:
- \$100 billion/year green climate fund (developed $\rightarrow$ developing)
- Transparency and accountability (global stocktake)
- Loss and damage mechanism for vulnerable nations

India's NDC: 45% emission intensity reduction by 2030; 500 GW RE capacity; Net Zero by 2070.

USA: withdrew 2017 (Trump); rejoined 2021 (Biden); withdrew again 2025 (Trump).

Notable COPs and Milestones (Quick Reference)

COP	Location/Year	Key Outcome
COP1	Berlin, 1995	Berlin Mandate: developed countries to take lead
COP3	Kyoto, 1997	**Kyoto Protocol** — first binding emission targets
COP13	Bali, 2007	Bali Roadmap; developing countries included
COP15	Copenhagen, 2009	Copenhagen Accord (non-binding; major disappointment)
COP17	Durban, 2011	Durban Platform; agreed to new universal agreement
COP21	Paris, 2015	**Paris Agreement** — NDCs; 2°C / 1.5°C goal
COP26	Glasgow, 2021	"Coal phase-down"; India Net Zero 2070; $100B fund
COP27	Sharm el-Sheikh, 2022	Loss and Damage Fund agreed for first time
COP28	Dubai, 2023	First global stocktake; fossil fuel transition language

Kyoto vs Paris: Comparison (PYQ — 4–6M)

Feature	Kyoto Protocol (1997)	Paris Agreement (2015)
Approach	Top-down: targets set by treaty	Bottom-up: self-determined NDCs
Binding targets	Yes for Annex I (developed) only	No binding emission targets
Developing countries	Exempt from targets	All must contribute (CBDR preserved)
USA	Never ratified	Signed, withdrew, rejoined
Mechanism	CDM, JI, ET	Green Climate Fund, NDCs
Goal	5.2% below 1990	Well below 2°C / 1.5°C
Review cycle	Fixed commitment periods	NDCs reviewed every 5 years
Status	Succeeded by Paris 2020	In force; current framework

IPCC and India's Climate Commitments (4.7)

IPCC

IPCC: Intergovernmental Panel on Climate Change
Est: 1988 (WMO + UNEP)
Role: Assess scientific literature on climate change (NOT a research body).
Reports: Assessment Reports every 5–7 years.
AR6 (2021): "Human influence warmed the climate at unprecedented rate."
Nobel Peace Prize 2007 (shared with Al Gore)

India's NDC (Updated 2022)

- Reduce emission intensity of GDP by 45% by 2030 (vs 2005)
- Achieve 50% cumulative electric power from non-fossil sources by 2030
- Create carbon sink of 2.5–3 Gt CO_2eq through forests by 2030
- Net Zero by 2070
- 500 GW renewable energy by 2030

Other Key Environmental Agreements (Quick Reference)

Agreement	Year	Focus
Vienna Convention	1985	Framework for ozone layer protection
Montreal Protocol	1987	Phase-out of ozone-depleting substances (CFCs); r
Brundtland Commission	1987	Defined sustainable development
Rio Earth Summit (UNCED)	1992	UNFCCC + Convention on Biodiversity + Agenda
Kyoto Protocol	1997	Binding GHG emission targets (Annex I)
Doha Development Agenda	2001	Trade and environment linkages (WTO)
Paris Agreement	2015	NDCs; 1.5°C goal
Glasgow Climate Pact	2021 (COP26)	Coal phase-down; 1.5°C reaffirmed
Kigali Amendment	2016	Phase-down of HFCs (high GWP refrigerants)
Kunming-Montreal (COP15 biodiversity)	2022	30×30 goal: protect 30% land/sea by 2030

1. Post-combustion CCS:
Capture CO_2 from flue gas using amine scrubbing; compress; inject underground. Proven but expensive ($60–100/t). Best for cement, steel.

2. Pre-combustion (IGCC):
Convert fuel to syngas ($CO+H_2$); separate CO_2 before burning. Used in Integrated Gasification Combined Cycle power plants.

3. Oxy-fuel combustion:
Burn fuel in pure oxygen $\rightarrow$ flue gas is nearly pure CO_2 (easy capture). High energy penalty.

4. Direct Air Capture (DAC):
Pull CO_2 directly from atmosphere using chemical sorbents. Cost: $300–600/t (falling). Climeworks (Iceland) operational.

5. Enhanced weathering:
Spread crushed silicate rock on croplands $\rightarrow$ rock weathers, absorbs CO_2. Also fertilises soil.

Linking RE to Climate Mitigation (Integration)

Energy Source	GHG (g CO_2eq/kWh)	vs Coal (820)	Role in Mitigation
Solar PV	20–50	−97%	Rooftop + utility scale replacement
Wind	7–15	−98%	Grid-scale electricity; no fuel
Nuclear	12	−98%	Baseload; no GHG at operation
Hydro	4–30	−97%	Peaking power + storage
Natural gas (CCGT)	490	−40%	Transition fuel (still emits!)
Coal with CCS	100–200	−75%	Bridge if CCS scales up
Coal	820	(reference)	Highest emitter — phase out

Key message: Replacing coal with solar + wind alone can eliminate ≈35% of global GHG. Fastest, cheapest mitigation.

Forests as Carbon Sinks (LULUCF)

Global forests store 660 Gt of C — 2× what's in the atmosphere.

Deforestation emits 4–6 Gt CO_2/year — equivalent to all of EU and India combined!

Why forests matter for climate:
- Absorb ≈30% of human CO_2 emissions every year (2.6 Gt C/yr)
- Regulate water cycle — forests drive local + regional rainfall
- Cooling effect via evapotranspiration (not just carbon storage)

India's forest cover: 21.7% of land (target: 33% under Forest Policy 1988)
Programs: Green India Mission; CAMPA fund; Van Dhan Vikas Kendra

REDD+: Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN program under UNFCCC)

Circular Economy as Climate Mitigation (Systems Thinking)

Linear economy: Take → Make → Dispose (high GHG)
Circular economy: Reduce → Reuse → Recycle → Recover

Why it helps climate?
• Recycling aluminium: 95% less energy vs making new
• Recycled steel: 72% less energy; recycled paper: 60% less
• Extending product life → fewer factories running → fewer emissions
• Organic waste composting avoids landfill CH_4

Examples:
• Rent-not-buy models (cars, tools, clothes)
• Industrial symbiosis (Kalundborg, Denmark): waste from one factory = input for another
• EPR (Extended Producer Responsibility): producer responsible for product end-of-life

Why climate finance matters:
Climate change is a market failure — fossil fuels don't pay for environmental damages. Public finance must bridge the gap.

Key funds:
- **Green Climate Fund (GCF):** largest dedicated climate fund; $100B/yr pledge (Paris); channels money to developing countries
- **Adaptation Fund:** focus on adaptation in most vulnerable developing countries (COP13, Bali 2007)
- **Global Environment Facility (GEF):** 1991; funds projects in environment/climate

India's access:
- India approved for GCF projects (solar, metro rail, wetland)
- ISA: International Solar Alliance (India-France initiative, 120 countries)

Paris Agreement — Deeper Look (Exam Favourite)

What makes Paris different from Kyoto?

- **Universal:** all 196 parties (rich + poor) have targets
- **Flexible:** NDCs are self-determined (not top-down)
- **Ratchet mechanism:** Every 5 years, NDCs must be revised upward (no back-sliding)
- **Long-term goal:** Net zero emissions in second half of 21st century
- **Transparency:** all countries report progress; global stocktake every 5 years

Key Articles:

Art 2: Temperature goal (2°C / 1.5°C)
Art 4: NDCs every 5 years; CBDR
Art 6: Carbon market mechanisms
Art 9: Finance ($100B/yr; from 2025: $300B/yr – COP29 2024)
Art 12: Climate education and public awareness

Weakness: NDCs currently track for +2.5°C — insufficient!

Individual Actions

- Switch to LED (saves 80% electricity)
- Use EV or public transport
- Eat less red meat (cow = 70 kg CO_2/kg beef)
- Fly less; or offset flights
- Reduce AC use; better insulation
- Plant trees, protect local forests
- Compost food waste (no landfill CH_4)
- Buy energy-efficient (5-star BEE) appliances

Corporate Actions

- Science-based targets (SBTi)
- 100% renewable energy (RE100 initiative)
- Carbon disclosure (CDP reporting)
- Scope 3 supply chain sustainability
- ESG reporting; green bonds
- Circular design of products
- CSR in afforestation, community RE

Worked PYQs

Unit 4 — Climate Change
Past Year Question Practice

Q: Explain greenhouse effect and list main greenhouse gases (4M)

Greenhouse Effect:
Shortwave solar radiation passes through Earth's atmosphere and warms the surface. The warmed Earth emits longwave (infrared) radiation. Greenhouse gases (GHGs) in the atmosphere absorb this infrared and re-radiate it in all directions — including back to Earth. This traps heat, raising surface temperature.

Natural GHE: raises Earth temp from -18°C to $+15^\circ$C — essential for life.
Enhanced GHE: excess GHGs from human activity $\rightarrow$ global warming.

Main GHGs (with GWP):
1. CO_2 (GWP=1) — fossil fuels, deforestation
2. CH_4 (GWP=25) — livestock, landfills
3. N_2O (GWP=298) — fertilisers, combustion
4. CFCs/HFCs (GWP up to 10,000+) — refrigerants
5. Water vapour — amplifies other GHGs

Q: Describe the Paris Agreement and India's commitments (4M)

Paris Agreement (COP21, 2015):
- Adopted Dec 12, 2015; in force Nov 2016
- Goal: Limit warming to **well below 2°C** above pre-industrial; pursue 1.5°C
- Each country submits NDC (Nationally Determined Contribution) – revised every 5 years
- $100 billion/year climate finance from developed to developing countries
- Transparency and global stocktake mechanism
- Loss and damage provisions for vulnerable nations

India's NDC commitments:
- Reduce GDP emission intensity by 45% below 2005 levels by 2030
- 50% of electricity from non-fossil fuel sources by 2030
- Create additional carbon sink of 2.5–3 Gt CO_2eq via forests by 2030
- Net zero emissions by **2070**

Q: Define carbon footprint. How can it be reduced? (4M)

Definition:
Carbon footprint = total GHG emissions (expressed as CO_2 equivalent) caused directly and indirectly by an individual/organisation/product/event.

Categories:
- **Direct:** personal combustion (car, gas stove)
- **Indirect:** electricity consumed, flights, food production

How to reduce:
1. Use renewable energy (solar, wind) for electricity
2. Use EVs or public transport (reduce transport GHG 14%)
3. Eat plant-based diet (less meat = less CH_4 from livestock)
4. Improve building insulation (reduce heating/cooling energy)
5. Buy energy-efficient (BEE 5-star) appliances (LED, AC, fridge)
6. Reduce, reuse, recycle (less industrial production needed)
7. Plant trees (forest = carbon sink)

PYQ — Mitigation vs Adaptation (4M)

Q: Differentiate between mitigation and adaptation to climate change (4M)

Aspect	Mitigation	Adaptation
Definition	Reduce/prevent GHG emission or enhance carbon sinks	Adjust to cope with actual/expect mate change impacts
Focus	Addressing the **cause** of climate change	Addressing the **effects** of climate ch
Goal	Slow down climate change; reduce future risks	Reduce current/future vulnerability
Timeframe	Long-term impact	Short + long-term benefit
Examples	Switch to solar; plant forests; EVs; CCS	Sea walls; drought-resistant crops; early warning
Who benefits	Everyone globally (public good)	Local communities (private+public b

India needs both: mitigation (via RE targets) and adaptation (via NICRA, NDMA, sea walls, climate-resilient crops).

PYQ — Kyoto Protocol (Exam — 4M)

Q: Write notes on Kyoto Protocol (4M)

Kyoto Protocol (1997):
- Adopted at COP3, Kyoto, Japan (Dec 1997); in force Feb 2005
- First legally **binding international treaty** on GHG reduction
- Operated under UNFCCC framework

Key features:
- **Annex I (developed) countries** must reduce emissions 5.2% below 1990 levels in 2008–2012
- Developing countries (India, China) had **no binding** targets (CBDR)
- USA didn't ratify (world's largest emitter at that time)

Three mechanisms:
1. Emissions Trading: trade surplus allowances
2. Joint Implementation: Annex I countries earn credits via projects in other Annex I
3. CDM: fund emission-reduction projects in developing countries, earn CERs

Significance: Established carbon market; paved way for Paris Agreement.

1. The Paris Agreement aims to limit warming to:
(A) 1°C **(B) 1.5–2°C** (C) 3°C (D) 0.5°C

2. GWP of methane (CH_4) over 100 years is:
(A) 1 **(B) 25** (C) 298 (D) 100

3. India's net zero target year under Paris Agreement is:
(A) 2050 (B) 2030 **(C) 2070** (D) 2060

4. CDM stands for:
(A) Carbon Dioxide Management **(B) Clean Development Mechanism**

5. IPCC stands for:
(A) Intergovernmental Panel on Climate Change (B) International Protocol on Climate Control

6. Pre-industrial CO_2 level was:
(A) 315 ppm (B) 350 ppm **(C) 280 ppm** (D) 180 ppm

Common Mistakes in Unit 4 (Exam Warning)

Wrong	Correct
Greenhouse effect is harmful	**Natural GHE is essential** for life; enhanced GHE is harmful
Paris Agreement was in 1997	1997 = **Kyoto Protocol**; Paris = **2015**
Kyoto Protocol binds all countries	Only **Annex I** (developed) countries had binding targets
COP is a law-making body	COP is a **negotiating conference**; it agrees on treaties
Mitigation = living with climate change	Mitigation = **reducing causes**; Adaptation = living with effects
Global warming = same as climate change	GW = rising avg temp; CC = broader pattern changes
India has no climate targets	India's NDC: 45% intensity cut, 500 GW RE, Net Zero 2070

Flash Revision 1 — GHE & Global Warming (Quick Recall)

Greenhouse Effect

- Solar input = shortwave radiation (UV + visible)
- Earth emits longwave (IR) radiation
- GHGs absorb and re-radiate IR $\rightarrow$ warming
- Natural GHE: -18°C $\rightarrow$ $+15^\circ$C (33°C warming)
- CO_2: GWP 1 | CH_4: 25 | N_2O: 298 | CFCs: up to 10,900
- CO_2 now: 421 ppm (vs 280 pre-industrial)
- Evidence: 1.1°C warming; SLR 20 cm; ice melt

Global Warming Impacts

- SLR: 20 cm since 1900; +3.6 mm/yr now
- 0.28–1.01 m rise by 2100 (IPCC AR6)
- More intense cyclones, floods, droughts
- Coral bleaching (temp $>1^\circ$C above normal)
- 1 million species threatened (IPBES 2019)
- India: glacier retreat, erratic monsoon, heat waves
- Heat wave record: Delhi 52.9°C (2024)

Flash Revision 2 — Carbon Markets & Mitigation

(Quick Recall)

Carbon Markets

- 1 carbon credit = right to emit 1 t CO_2eq
- Cap-and-trade: government sets cap; companies buy/sell
- CDM: fund RE/efficiency projects in developing countries → earn CERs
- EU ETS: world's largest; 11,000 installations
- India CCTS: launched 2023
- Voluntary offset: airlines, companies
- Net zero ≠ carbon neutral (net zero = all GHGs)

Mitigation Actions

- Renewable energy replaces fossil fuels
- Energy efficiency (LED = 80% less energy)
- CCS: capture CO_2 at source; store underground
- DAC: pull CO_2 from air ($300–600/t)
- Afforestation + REDD+
- Circular economy: recycled Al = 95% less energy
- EV: 3–4× more efficient than IC engine

Flash Revision 3 — International Agreements (Quick Recall)

Key Treaties

- UNFCCC 1992 (Rio): foundation treaty; 197 parties
- Kyoto Protocol 1997: binding targets for Annex I; CDM/JI/ET
- Paris Agreement 2015 (COP21): NDCs; 2°C/1.5°C goal; all countries
- Glasgow Pact 2021 (COP26): coal phase-down; India Net Zero 2070
- Montreal Protocol 1987: CFC phase-out; most successful
- Kigali 2016: phase-down HFCs

Adaptation

- Adaptation = living with effects (vs mitigation = reduce cause)
- Sea walls, drought-resistant crops, early warning
- NDMA: National Disaster Management Authority (India)
- Sendai Framework 2015: global DRR
- CSA: Climate-Smart Agriculture (FAO)
- NICRA: India's climate-resilient agriculture program
- EbA: Ecosystem-based Adaptation (mangroves, wetlands)

Important Definitions Recap — Unit 4 (Exam Guide)

Term	Definition
Greenhouse gas	Gas that absorbs and re-emits infrared radiation, trapping heat in atmosphere
GWP	Global Warming Potential — warming effect of 1 kg GHG relative to 1 kg CO_2 over 100 years
Carbon footprint	Total GHG emissions (CO_2eq) of an individual, org, product or event
Carbon credit	Permit to emit 1 tonne CO_2eq; tradeable in carbon markets
CDM	Clean Development Mechanism: Annex I countries earn credits funding RE projects in developing nations
NDC	Nationally Determined Contribution: each country's Paris Agreement climate action plan
Mitigation	Reducing GHG emissions or enhancing carbon sinks to limit climate change
Adaptation	Adjusting human/natural systems to cope with actual or expected climate impacts
Net zero	Reducing all GHG to near-zero; remaining offset by carbon sinks/CCS
IPCC	Intergovernmental Panel on Climate Change (1988); synthesizes climate science

Fact	Value
Current global warming (vs pre-industrial)	+1.1°C (IPCC AR6, 2021)
Paris target	Well below 2°C; pursue 1.5°C
Current CO_2 concentration	≈421 ppm (2024)
Pre-industrial CO_2	280 ppm
GWP of CH_4	25 (100-year)
GWP of N_2O	298 (100-year)
India net zero year	2070
India emission intensity reduction target	45% below 2005 by 2030
India RE target	500 GW by 2030
Sea level rise observed	+20 cm since 1900

Q. What is ocean acidification? (3M)
Ans: As CO_2 levels in atmosphere rise, more CO_2 dissolves in oceans. $CO_2 + H_2O \rightarrow H_2CO_3$ (carbonic acid), lowering ocean pH from 8.2 to 8.1 (30% more acidic on logarithmic scale). Threatens marine organisms with calcium carbonate shells (oysters, corals, plankton) and disrupts food chains.

Q. What is the Kyoto CDM? (3M)
Ans: Clean Development Mechanism under Kyoto Protocol. Allows Annex I (developed) countries to fund emission-reduction projects in non-Annex I (developing) countries and earn Certified Emission Reductions (CERs). Acts as carbon credit they can use to meet their own Kyoto targets. Win-win: developing countries get clean technology investment; developed countries get credits.

Q. What is permafrost thawing? (2M)
Ans: Frozen soil in Arctic regions thaws as Earth warms. Releases stored CH_4 (trapped organic matter decays)
creating a vicious positive feedback loop: more warming $\rightarrow$ more thaw $\rightarrow$ more CH_4 $\rightarrow$ more warming.

Unit 4 — Summary (20% Weightage)

GHE & Warming

- Natural GHE warms Earth by 33°C (essential!)
- Enhanced GHE → global warming (+1.1°C so far)
- Top GHGs: CO_2 (GWP 1), CH_4 (25), N_2O (298), CFCs
- Impacts: SLR, extreme weather, coral bleaching, extinction

International Agreements

- UNFCCC 1992: foundation framework
- Kyoto 1997: binding for Annex I; CDM/JI/ET
- Paris 2015: NDCs; 2°C/1.5°C; all countries
- India NDC: 45% intensity cut; 500 GW RE; Net Zero 2070

Carbon Markets

- 1 carbon credit = right to emit 1 t CO_2eq
- CDM: developed countries fund RE in developing
- Cap-and-trade: EU ETS (largest); India CCTS (2023)
- Net zero: reduce all GHG + offset remaining

Key Actions

- Mitigation: RE, EV, forests, CCS, circular economy
- Adaptation: sea walls, drought crops, early warning

Weightage: 20% | Hours: 6 | Top PYQs: GHE/GWP, Paris Agreement, Carbon foot-

Unit 5: Environmental Policy and Governance

Environmental Sustainability — DI02000051

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April 2, 2026

Unit 5 Syllabus Overview (20% Weightage, 6 Hours)

Unit 5 Topics

5.1 Environmental Laws in India (EPA 1986, WPA 1972, FCA 1980)
5.2 Pollution Control Rules (Air, Water, Noise, Plastic, E-Waste)
5.3 Environmental Impact Assessment (EIA)
5.4 Environmental Management System (EMS) — ISO 14001 / EMAS
5.5 Global Environmental Agreements (UNFCCC, CBD, CITES, Basel, Montreal, Stockholm)
5.6 Corporate Social Responsibility (CSR) in Environment
5.7 NGOs, Public Participation and Right to Information

20% marks | 6 lecture hours | PYQ topics: EPA 1986, EIA process, ISO 14001, International conventions

Section 5.1

Environmental Laws in India

Constitutional Basis for Environment (5.1)

Fundamental Rights (Part III):
• **Art 21:** Right to life includes right to live in a clean, pollution-free environment (SC interpretation)

Directive Principles (Part IV):
• **Art 48A** (added 1976): State shall protect and improve environment; safeguard forests and wildlife

Fundamental Duties (Part IVA):
• **Art 51A(g):** Every citizen's duty to protect and improve natural environment including forests, lakes, rivers and wildlife

Division of powers:
• Concurrent List – Entry 17A: forests; Entry 17B: protection of wild animals and birds
• State List – Entry 6: public health and sanitation
• Centre passes framework laws; States implement them

Environment Protection Act (EPA) 1986 (PYQ — 4M)

EPA 1986 — Umbrella Environment Law

Year: 1986 (after Bhopal Gas Tragedy, 1984)
Ministry: Ministry of Environment, Forest and Climate Change (MoEFCC)

Powers conferred:

- Set standards for emissions and discharges of environmental pollutants
- Regulate environmental impact assessment (EIA)
- Prevent, control and abate environmental pollution
- Inspect premises and take samples; seize equipment
- Notify Eco-Sensitive Areas (ESAs); coastal regulation zones (CRZ)

Key rules under EPA:

- Environment Impact Assessment (EIA) Notification 2006
- Hazardous Waste Management Rules
- E-Waste Management Rules
- Plastic Waste Management Rules

Penalty: Up to 5 years imprisonment; fine up to Rs 1 lakh per day of violation

Water (Prevention and Control of Pollution) Act 1974 (5.1)

Water Act 1974

Year: 1974 (India's first Environment Act!)
Amendment: 1988 (strengthened penalties)

Key provisions:
• Prohibits discharge of sewage/trade effluent into water bodies without consent
• Establishes **CPCB** (Central Pollution Control Board) — national regulatory body
• Establishes **SPCBs** (State Pollution Control Boards) — state-level enforcement
• Industries need **Consent to Establish (CTE)** and **Consent to Operate (CTO)** from SPCB
• Effluent standards set for industries

CPCB rolls:
• Sets national ambient water quality standards
• Issues directions to SPCBs
• Coordinates research, training, monitoring

Air (Prevention and Control of Pollution) Act 1981 (5.1)

Air Act 1981

Year: 1981 (ratifying 1972 Stockholm Conference commitment)
Amendment: 1987 (included noise as air pollutant!)

Key provisions:

- Declares all of India an **Air Pollution Control Area**
- Industries in sensitive areas need consent from SPCB to emit
- Sets emission standards for vehicles and industries
- CPCB monitors National Ambient Air Quality Standards (NAAQS)

NAAQS 2009 (24-hour limits):

$PM_{2.5}$	60 $\mu g/m^3$ (24hr)	40 $\mu g/m^3$ (annual)
PM_{10}	100 $\mu g/m^3$ (24hr)	60 $\mu g/m^3$ (annual)
NO_2	80 $\mu g/m^3$ (24hr)	40 $\mu g/m^3$ (annual)
SO_2	80 $\mu g/m^3$ (24hr)	50 $\mu g/m^3$ (annual)

WPA 1972 — Wildlife Law

Year: 1972 (before CITES 1973; India's first wildlife law)
Recent amendment: 2022 (Wildlife Protection Amendment Act)

Key provisions:
• Prohibits hunting/trapping of wild animals listed in Schedules (except with permission)
• **6 Schedules:** Schedule I = highest protection (tiger, elephant); Schedule VI = banned plants
• Protects **National Parks** (no human activity), **Wildlife Sanctuaries** (some buffers), **Tiger Reserves**
• Establishes **Wildlife Crime Control Bureau (WCCB)**
• Regulates trade in wildlife and plant product

Tiger Project: Project Tiger (1973) — 54 Tiger Reserves covering 2.97% of India's area
Elephant Project: Project Elephant (1992) — 33 elephant reserves
Amendment 2022: Implemented India's obligations under CITES

FCA 1980

Year: 1980 (to check rapid deforestation in 1970s)
Amendment: 1988; 2023 (Van Mitra: carbon credits for forests)

Key provisions:
• No state can deforest or use forest land for non-forest purposes without **Central Government approval**
• Power projects, mining, roads, etc. in forests need clearance from MoEFCC
• Forest diversion requires **compensatory afforestation** (equal area planted elsewhere)
• **CAMPA** (Compensatory Afforestation Fund Management and Planning Authority) manages compensatory planting funds

Why important?
India's forest cover: 21.7% (2021 State of Forest Report). Constitutional target: 33% (National Forest Policy 1988).
FCA saved millions of hectares from being diverted.

India’s Environmental Laws at a Glance (Quick Reference)

Act	Year	What It Protects	Key Body Created
Water (P&CP) Act	1974	Water bodies from pollution	CPCB / SPCB
Wildlife Protection Act	1972	Wild animals and plants	WCCB; Tiger Reserves
Forest Conservation Act	1980	Forests from diversion	MoEFCC clearances
Air (P&CP) Act	1981	Air quality; noise (1987)	CPCB / SPCB
Environment Protection Act	1986	Umbrella act; EIA; all media	MoEFCC
Biological Diversity Act	2002	Biodiversity; traditional knowledge	NBA, SBB
NGT Act	2010	Speedy env. justice	National Green Tribunal
E-Waste Rules	2022	E-waste management	MoEFCC / SPCBs
Plastic Waste Rules	2016/2022	Plastic pollution	SPCBs / ULBs

Section 5.2

Pollution Control Rules

Rules: Plastic Waste Management Rules 2016; amended 2021, 2022

Ban on single-use plastics (July 2022): thick list incl.:

- Polystyrene (thermocol) items
- Plastic ear buds; plastic flags
- Plastic sticks in balloons; candy sticks
- Plastic cutlery (plates, cups, straws, stirrers, forks, spoons)
- Plastic bags <75 microns (from 2022); <120 microns (from 2023)

Responsibility:

- **Producers/importers/brand owners (PIBOs):** Extended Producer Responsibility (EPR)
- Must register; set collection targets; report to CPCB

Penalty: Fine + up to 5 years imprisonment (under EPA 1986)

Latest Rules: E-Waste Management Rules 2022 (replaced 2016 rules)

Scope: All electrical and electronic equipment (EEE) — phones, computers, TVs, fridges, washing machines, batteries (except lead-acid batteries)

Extended Producer Responsibility (EPR):

- Producers must register with CPCB
- Annual collection targets (starting 60%, increasing to 70%+ by 2026)
- Must ensure channelling to registered dismantlers/recyclers

Refurbisher obligations: Register and report
Role of CPCB: Maintain national e-waste registry; audit; enforce

Prohibited: Disposal in landfills; burning; acid baths (illegal but common in informal sector)
India's e-waste generation: 3rd largest in world (≈3.2 Mt/year, 2022); only 15–22% formally recycled

Noise Pollution (Regulation and Control) Rules 2000 (5.2)

Rules: Noise Pollution (Regulation and Control) Rules 2000
Under: EPA 1986

Ambient noise standards (limits in dB(A)):

Zone	**Day (6am–10pm)**	**Night (10pm–6am)**
Industrial	75 dB(A)	70 dB(A)
Commercial	65 dB(A)	55 dB(A)
Residential	55 dB(A)	45 dB(A)
Silence Zone	50 dB(A)	40 dB(A)

Silence zones: Within 100m of school, hospital, court, religious place.
No loudspeaker between 10pm and 6am without permission.
Enforcement: Police + SPCB + District Magistrate

Rules: Hazardous and Other Wastes (Management and Transboundary Movement) Rules 2016
Under: EPA 1986

Definition: Waste with physical, chemical or biological characteristics that may:
- Cause significant harm to human health or environment
- Be toxic, flammable, corrosive, reactive, or infectious

Classification: Listed in Schedules I, II, III of the Rules (36 categories)

Obligations of Generator:
- Register with SPCB; maintain inventory
- Proper labelling, storage, handling
- Manifest system for movement (tracking document)
- Dispose only at TSDF (Treatment, Storage and Disposal Facility)

Transboundary: Import/export of hazardous waste regulated under Basel Convention (ratified by India, 1992).

Section 5.3

Environmental Impact Assessment (EIA)

EIA — Definition and Purpose (5.3)

Definition

EIA: Environmental Impact Assessment is a **systematic process** to predict and evaluate the likely impacts of a proposed project/activity on the **physical, biological and socio-economic environment** before the project is sanctioned.

Purpose of EIA

- Identify and predict adverse impacts of projects before construction begins
- Suggest mitigation measures to minimise or eliminate impacts
- Enable decision-makers to approve/reject projects with full information
- Involve affected public and communities in decisions
- Ensure sustainable development (not every project should proceed)
- Legal requirement under EPA 1986 (EIA Notification 2006)

Under EIA Notification 2006, projects are classified as:

Category	Scope	Approving Authority
Category A	Large projects (national impact): thermal power >500 MW; airports; large industries	**MoEFCC** (EAC: Expert Appraisal Committee)
Category B	Smaller projects (local impact): Category B1 and B2	**SEIAA** (State-level Expert Appraisal Authority)

32 project types need EIA: mining, industries, infrastructure (highways, ports), power plants, river valley projects, special economic zones, etc.
Below thresholds: de facto exemption from EIA (but not from other laws).

EIA Process — Steps (PYQ — 4–6M)

Standard EIA Process (8 steps):

1. Screening: Is EIA required? (Category A or B?)
2. Scoping: Identify significant issues / Terms of Reference (TOR)
3. Baseline Data Collection: Study existing environmental conditions (air, water, soil, ecology, socioeconomics) for 3 seasons
4. Impact Prediction: Predict magnitude and significance of impacts during construction + operation
5. Mitigation: Suggest measures to reduce significant impacts (Engineering, Management, or Compensation)
6. EIA Report (EIA/EMP): Compile into Final EIA + Environmental Management Plan
7. Public Hearing: Mandatory 30-day notice; public/NGOs raise concerns; recorded
8. Decision (Environmental Clearance): MoEFCC/SEIAA grant, reject, or ask for changes
Post-clearance: **monitoring** and **compliance** reporting (half-yearly)

EIA Report Components (5.3)

EIA Report Contains

1. Project Description: Location, layout, process, raw materials, water/energy needs.

2. Baseline Report: Existing air, water, noise, soil, ecology, socioeconomic conditions.

3. Impact Assessment: Predicted impacts on each environmental component.

4. Alternatives Analysis: Comparison of project site/technology alternatives.

5. Environmental Management Plan (EMP): Specific mitigation measures + monitoring plan.

6. Risk Analysis: Worst-case accident scenarios; emergency plan.

7. Public Hearing Summary: Grievances raised; project response.

8. Executive Summary: Non-technical summary (mandatory for public).

Section 5.4

Environmental Management System
ISO 14001 / EMAS

Definition

An **Environmental Management System (EMS)** is a set of processes and practices that enables an organisation to reduce its environmental impacts and increase its operating efficiency.

Why implement EMS?

- Ensure legal compliance with environmental laws
- Reduce pollution, waste, energy and water use
- Improve corporate image (customers, investors, regulators)
- Lower costs (energy, waste, fines)
- Access international markets (many buyers require ISO 14001)
- Document environmental performance for reporting (ESG, CSR)

Most widely adopted standard: ISO 14001:2015 (International Organization for Standardization)

>300,000 organisations certified globally (2022); India: >15,000 certificates

ISO 14001 — Plan-Do-Check-Act Cycle (5.4)

ISO 14001 is built on the **PDCA (Plan-Do-Check-Act)** continual improvement cycle:

PLAN:
- Environmental policy (set by top management)
- Identify significant aspects & impacts
- Legal and other requirements
- Set objectives and targets
- Environmental Management Programme

DO:
- Roles and responsibilities
- Training and awareness
- Document control
- Emergency preparedness

CHECK:
- Monitoring and measurement
- Evaluation of compliance
- Internal audit
- Management review

ACT:
- Nonconformity and corrective action
- Continual improvement
- Update objectives for next cycle

ISO 14001 — Key Elements (5.4)

Clause	Content
4 Context	Understand organisation and its environment; stakeholders; scope
5 Leadership	Top management commitment; environmental policy; roles
6 Planning	Risks and opportunities; environmental aspects/impacts; objectives
7 Support	Resources; competence; communication; documented information
8 Operation	Operational controls; emergency preparedness and response
9 Performance eval	Monitoring; internal audit; management review
10 Improvement	Nonconformity; corrective action; continual improvement

Certification process: Internal audit → Management review → Third-party audit by accredited CB → ISO 14001 Certificate (valid 3 years; annual surveillance audits).

Definition

LCA evaluates the environmental impact of a product or service through its **entire life cycle** — "cradle to grave" or "cradle to cradle".

4 Phases of LCA (ISO 14040/44):

1. **Goal and scope definition:** What product? What system boundary? What impact categories?
2. **Life Cycle Inventory (LCI):** Collect data on all inputs (energy, water, materials) and outputs (emissions, waste)
3. **Life Cycle Impact Assessment (LCIA):** Map inventory to impact categories (GWP, ozone depletion, eutrophication, toxicity)
4. **Interpretation:** Identify significant processes; sensitivity analysis; conclusions

Applications: Product eco-design; Environmental Product Declarations (EPD); carbon footprint labelling; green procurement
Example: LCA of EV vs petrol car shows EV is lower over full lifecycle (despite battery manufacturing impact)

Section 5.5

Global Environmental Agreements

Stockholm Conference 1972 (5.5)

Stockholm Conference — Foundation of International Environment Law

Full name: UN Conference on the Human Environment
Date/Place: June 5–16, 1972; Stockholm, Sweden
June 5 = World Environment Day (since 1974)

Key outcomes:

- Stockholm Declaration: 26 principles of environmental protection
- Action Plan: 109 recommendations
- Created **UNEP** (United Nations Environment Programme), Nairobi
- India's Environment (Protection) Act 1986 inspired by Stockholm
- Established concept of "Principle of Preventive Action"

India's contribution: India's PM Indira Gandhi gave keynote speech: "Poverty is the greatest polluter." (Famous quote)

Followed by **Rio Earth Summit 1992** (UNCED), **Johannesburg 2002** (WSSD), **Rio+20 2012**.

CBD and CITES (5.5)

CBD (1992)

Convention on Biological Diversity
Adopted: Rio 1992; in force 1993
Parties: 196

3 objectives:
1. Conservation of biodiversity
2. Sustainable use of components
3. Fair and equitable sharing of benefits from genetic resources

Nagoya Protocol (2010): Access and Benefit Sharing (ABS) for genetic resources.
India: Biological Diversity Act 2002; National Biodiversity Authority (NBA)

CITES (1973)

Convention on International Trade in Endangered Species of Wild Fauna and Flora
Adopted: 1973; in force 1975
Parties: 183

3 Appendices:
I: Threatened species (trade prohibited)
II: Species needing control (permit required)
III: Protected in at least one country

India ratified 1976. Tiger, elephant, rhino on Appendix I. Implemented via WPA 1972 (Amendment 2022).

Basel, Rotterdam, Stockholm Conventions (5.5)

Basel Convention (1989):
Control of transboundary movement of hazardous wastes. Prohibits exporting hazardous waste from OECD to non-OECD countries. India ratified 1992.

Rotterdam Convention (1998):
Prior Informed Consent (PIC) procedure for trade in hazardous chemicals and pesticides. Exporting country must get consent from importing country before shipment.

Stockholm Convention (2001):
Persistent Organic Pollutants (POPs). Targets the "dirty dozen": DDT, dioxins, furans, PCBs, etc. Prohibits/restricts manufacture and use. India ratified 2006.

Minamata Convention (2013):
Control mercury pollution (after Minamata disease in Japan from mercury-contaminated fish). Phase-out of mercury in products; regulate emissions from industry.

Montreal Protocol 1987 — The Success Story (5.5)

Montreal Protocol

Full name: Montreal Protocol on Substances That Deplete the Ozone Layer
Adopted: September 16, 1987; in force: 1989 (Sept 16 = World Ozone Day)
Parties: 198 (only treaty ratified by every UN member state!)

What it does:
• Phase-out of CFCs, halons, HCFCs, HBFCs, carbon tetrachloride, methyl bromide
• Developed countries completed CFC phaseout by 1996; developing by 2010
• **Kigali Amendment (2016):** Phase-down of HFCs (high GWP replacements for CFCs)

Result:
• Ozone layer over Antarctica is healing; full recovery expected by 2060–2066
• Called "the most successful international environmental treaty" (Kofi Annan)
• Also avoided $+0.5^{\circ}$C of warming (CFCs are also potent GHGs!)

Global Agreements Quick Reference (Exam Table)

Agreement	Year	Focus	India?
Stockholm Conference	1972	Foundation; UNEP created	Yes (Indira Gandhi keynote)
CITES	1973	Trade in endangered species	Yes (1976)
Vienna Convention	1985	Ozone: framework	Yes
Montreal Protocol	1987	CFCs/ozone-depleting substances	Yes (1992)
Basel Convention	1989	Hazardous waste trade	Yes (1992)
Rio Earth Summit / CBD	1992	Biodiversity; Agenda 21; UNFCCC	Yes
Kyoto Protocol	1997	Binding GHG targets (Annex I)	Yes (no binding target)
Rotterdam Convention	1998	Hazardous chemicals PIC	Yes (2005)
Stockholm Convention	2001	POPs (DDT, dioxins)	Yes (2006)
Nagoya Protocol	2010	Benefit sharing of genetic resources	Yes (2012)
Paris Agreement	2015	2°C / 1.5°C; NDCs	Yes
Kigali Amendment	2016	HFC phase-down	Yes

Section 5.6

Corporate Social Responsibility (CSR) in Environment

CSR in India — Companies Act 2013 (5.6)

CSR Mandate (Section 135, Companies Act 2013)

Applicability: Companies with:
- Net worth $\geq$ Rs 500 crore, OR
- Turnover $\geq$ Rs 1000 crore, OR
- Net profit $\geq$ Rs 5 crore

Obligation: Spend at least **2% of average net profit** (3 years) on CSR activities

CSR activities including environment (Schedule VII):
- Environmental sustainability
- Ecological balance
- Conservation of natural resources
- Maintaining quality of soil, air, water
- Afforestation

India = first country in world to mandate CSR spending by law

Beyond legal compliance — voluntary corporate actions:

1. ESG (Environmental, Social, Governance) reporting:
Voluntary disclosure on carbon footprint, water use, waste, biodiversity.

2. Green bonds:
Fixed income instruments where proceeds fund green projects (RE, green buildings, clean transport). Global green bond market: $500B (2023).

3. Science-Based Targets (SBTi):
Companies set GHG reduction targets aligned with 1.5°C; verified by third party. Over 7000 companies committed.

4. RE100 initiative:
Pledge to use 100% renewable electricity. Members: Apple, Google, Tata Motors, Infosys, etc.

5. Zero Waste to Landfill: Waste hierarchy; EPR; industrial symbiosis.

Section 5.7

NGOs, Public Participation
and Right to Information

NGOs and Public Participation (5.7)

Role of NGOs

NGOs (Non-Governmental Organisations) play crucial roles in environmental protection:

- **Advocacy:** Lobbying for stronger environmental laws and enforcement
- **Public awareness:** Campaigns, rallies, social media (e.g., Chipko Movement)
- **Monitoring:** Citizen science; reporting violations to SPCB or NGT
- **Litigation:** PIL (Public Interest Litigation) in courts; approach NGT
- **Grassroots action:** Community forestry, waste management, RE adoption

Famous Indian NGOs/Movements:
• **Chipko Movement (1973):** Uttarakhand; villagers hugged trees to prevent felling
• **Save Silent Valley:** Kerala; stopped hydropower project in rainforest 1973–1983
• **Narmada Bachao Andolan:** Medha Patkar; displaced communities from dam
• **TERI** (The Energy and Resources Institute): Research + advocacy

RTI Act 2005

Right to Information Act 2005: Citizens can request information from any public authority within 30 days.

How it helps environment:
• Obtain factory pollution data
• Get EIA reports (now public)
• Monitor government action on complaints
• Access CPCB/SPCB records

NGT Act 2010

National Green Tribunal: Established 2010 (National Green Tribunal Act)
Speedy resolution of environmental disputes; specialised technical judges.

• Handles civil cases related to environment

• Can impose fines, order restoration

• No court fee; accessible to citizens

• India: 1st country with dedicated env. tribunal with technical members

Principles of Environmental Governance (Policy Concepts)

1. Polluter Pays Principle (PPP):
Those who cause pollution must bear the cost of cleaning it up and compensating victims. Embedded in EPA 1986.

2. Precautionary Principle:
Where there is scientific uncertainty, action to prevent harm should NOT be delayed. Better safe than sorry.

3. Sustainable Development (Brundtland, 1987):
"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

4. Environmental Justice:
No community (especially poor/indigenous) should bear disproportionate environmental burden.

5. Common but Differentiated Responsibilities (CBDR):
All countries must act, but developed (historical emitters) must do more.

India's Key National Environmental Policies (Reference)

Policy	Year	Focus
National Forest Policy	1988	33% forest cover target; community forestry
National Conservation Strategy & Policy	1992	Biodiversity; integration of env in development
National Environment Policy (NEP)	2006	Guiding framework; sustainable development
National Action Plan on Climate Change (NAPCC)	2008	8 national missions (solar, water, Himalaya, etc.)
JNNSM (Solar Mission)	2010	100 GW solar (achieved 2023)
Swachh Bharat Mission	2014	Clean India; solid waste management; open defeca
National Air Quality Index (AQI)	2015	Real-time air quality reporting (6 pollutants)
Plastic Waste Ban	2022	Single-use plastics banned; EPR strengthened
National Green Hydrogen Mission	2023	5 MT H_2 by 2030

NAPCC — 8 National Missions (India's Climate Policy)

National Action Plan on Climate Change (2008)

Mission	Focus
1. Jawaharlal Nehru National Solar Mission	100 GW solar (achieved!)
2. National Mission for Enhanced Energy Efficiency	Star ratings; PAT Scheme for industries
3. National Mission on Sustainable Habitat	Green buildings; public transport
4. National Water Mission	20% water efficiency improvement
5. National Mission for Sustaining the Himalayan Ecosystem	Glacier monitoring; alpine ecology
6. National Mission for a Green India	10 Mha additional forest cover
7. National Mission for Sustainable Agriculture	NICRA; climate-resilient farming
8. National Mission for Strategic Knowledge for Climate Change	Research; capacity building

PAT Scheme: Perform, Achieve and Trade — market-based mechanism for energy efficiency in large industries (like cap-and-trade for energy).

Key Regulatory Bodies in India (Quick Reference)

Body	Established	Role
CPCB	1974	Central Pollution Control Board; standards; coordin
SPCB/PCCs	1974 onwards	State Pollution Control Boards; industry consents; r
MoEFCC	1985 (Ministry)	Policy; EIA clearances; international treaties; laws
Wildlife Crime Control Bureau	2007	Enforce WPA; combat poaching and illegal trade
WCCB	2007	Investigate wildlife crimes; national + international
National Biodiversity Authority (NBA)	2003	Implement Biological Diversity Act 2002
National Green Tribunal (NGT)	2010	Adjudicate environmental disputes speedily
Bureau of Energy Efficiency (BEE)	2002	Star labelling; energy audit; PAT scheme
MNRE	1992	Ministry of New and Renewable Energy; policy + pr
NDMA	2005	National Disaster Management Authority; DRR

Sustainable Development Goals (SDGs) & Environment (UN 2030 Agenda)

UN Agenda 2030: 17 SDGs (Sept 2015; replaced MDGs)

Environment-focused SDGs:

SDG 6	Clean water and sanitation
SDG 7	Affordable and clean energy
SDG 11	Sustainable cities and communities
SDG 12	Responsible consumption and production
SDG 13	Climate action
SDG 14	Life below water (ocean conservation)
SDG 15	Life on land (forests, biodiversity)

India's progress:

SDG 7: On track (500 GW RE target)
SDG 13: On track (Paris commitments + Net Zero 2070)
SDG 6: Jal Jeevan Mission; Swachh Bharat

Green Economy and Sustainable Development

(Integration)

Green Economy

UNEP definition: Economy that results in improved human well-being and social equity while significantly reducing environmental risks.

Sector transitions:

- **Energy:** Fossil fuel → Renewables + efficiency
- **Agriculture:** Conventional → Organic, agroforestry, no-till
- **Industry:** Linear → Circular; waste = resource
- **Transport:** ICE → EVs + public transit + walking/cycling
- **Buildings:** Conventional → Net-zero energy buildings

India green economy tools:

- Green bonds (SEBI guidelines 2023)
- Carbon Credit Trading Scheme (CCTS 2023)
- PAT Scheme (energy efficiency credits)
- FAME II (EV subsidies)

Air Quality Index (AQI) (Policy Tool)

India AQI launched 2015 by CPCB under "Swachh Vayu, Swasth Bharat"

Calculated for 6 pollutants: $PM_{2.5}$, PM_{10}, O_3, NO_2, SO_2, CO

AQI Range	Category	Health Impact
0–50	Good	Minimal
51–100	Satisfactory	Minor for sensitive group
101–200	Moderate	Breathing discomfort for some
201–300	Poor	Breathing discomfort for all on prolonged exposure
301–400	Very Poor	Respiratory illness on prolonged exposure
401–500	Severe	Affects healthy; serious for diseased persons

Delhi AQI: often 300–500 in winter (Oct–Feb) due to crop stubble burning + cold + low wind.

1. Carbon Border Adjustment Mechanism (CBAM — EU 2023):
EU charges import duty based on carbon content of product. Forces exporters (including India) to decarbonise. Starts with steel, cement, aluminium.

2. EPR (Extended Producer Responsibility):
Producers responsible for products at end of life. India: Plastic EPR (2022), E-Waste EPR (2022).

3. Green Hydrogen Policy (India 2022):
Waived banking charges; RE connectivity priority; production targets.

4. Just Transition:
Ensuring coal-dependent communities have alternative jobs as coal phases down. India: NTPC re-training programs.

5. Payment for Ecosystem Services (PES):
Compensate communities for maintaining forests/wetlands that provide clean water, carbon storage, biodiversity. CAMPA is India's version.

Worked PYQs

Unit 5 — Policy & Governance
Past Year Question Practice

Q: Explain significance and key provisions of EPA 1986 (4M)

Why enacted: After Bhopal Gas Tragedy (Dec 1984), India needed a comprehensive umbrella environment law. EPA 1986 was enacted on May 23, 1986.

Key provisions:

1. Government can set standards for discharge/emission of pollutants
2. Restrict areas and industrial activities near sensitive zones
3. Authority to inspect; take samples; seize offending equipment
4. Environmental Impact Assessment (EIA) mandatory for designated projects
5. Notify Eco-Sensitive Areas (ESAs); coastal regulation zones
6. Central Government can issue directions to any person/industrial unit

Significance:

- Umbrella law: all other environmental rules (hazardous waste, e-waste, plastic) made under EPA
- Created MoEFCC as central authority
- India's response to Stockholm Conference commitments

Penalty: 5 yrs imprisonment + Rs 1 lakh/day fine

PYQ — EIA Process (Su'25, W'24, 6M)

Q: Explain the EIA process with flowchart/steps (6M)

EIA Process (8 steps):

1. Screening: Determine if EIA is required (Category A or B under EIA Notification 2006)
2. Scoping: Identify key issues; prepare Terms of Reference (TOR); consult stakeholders
3. Baseline data: 3-season study of air, water, soil, ecology, noise, socioeconomy
4. Impact prediction: Predict impacts of project during construction and operation
5. Mitigation: Design measures to minimise adverse impacts; prepare EMP
6. EIA Report: Compile all findings in EIA Report + Environmental Management Plan (EMP)
7. Public Hearing: 30-day mandatory notice; public meeting; record concerns
8. Decision: MoEFCC (Cat A) or SEIAA (Cat B) grants Environmental Clearance (EC)

Post-clearance: Half-yearly compliance monitoring report submitted to MoEFCC.

PYQ — ISO 14001 (4M)

Q: Explain ISO 14001 (EMS) with its benefits (4M)

ISO 14001: International standard for Environmental Management System (EMS); current version 2015.

Basis: Plan-Do-Check-Act (PDCA) continual improvement framework.

Key elements:
- Environmental policy (top management commitment)
- Identify significant environmental aspects and impacts
- Set measurable environmental objectives and targets
- Operational controls; training; emergency plan
- Monitoring; internal audit; management review; corrective action

Benefits:
1. Legal compliance (know your obligations; avoid fines)
2. Reduce environmental impacts (water, energy, waste)
3. Lower costs (efficiency gains)
4. Improve brand image; customer trust
5. Market access (international buyers require ISO 14001)
6. ESG reporting framework

PYQ — Montreal Protocol (4M)

Q: Write a note on Montreal Protocol and its importance (4M)

Montreal Protocol (1987):
- International treaty to phase out ozone-depleting substances (ODS)
- Adopted Sept 16, 1987; in force Jan 1989
- Ratified by 198 parties (every UN member state — only such treaty!)

ODS targeted: CFCs, halons, HCFCs, carbon tetrachloride, methyl bromide, HBFCs

Key achievement:
- Developed countries phased out CFCs by 1996; developing by 2010
- Ozone hole over Antarctica is healing; full recovery by 2060–2066
- Avoided $+0.5^\circ$C of warming (CFCs = potent GHGs)

Kigali Amendment (2016): Phase-down of HFCs (replacements that turned out to have high GWP)

Why it succeeded: Universal; specific targets; technology/financial support to developing countries; industry cooperation (DuPont developed HFC alternatives).

1. EPA 1986 was enacted primarily in response to:
(A) Chernobyl accident **(B) Bhopal Gas Tragedy** (C) Stockholm Conference (D) Gulf War

2. EIA Notification in India is under which act?
(A) Water Act (B) Air Act **(C) EPA 1986** (D) Forest Act

3. CPCB was established by:
(A) Water Act 1974 (B) Air Act 1981 (C) EPA 1986 (D) WPA 1972

4. Montreal Protocol targets:
(A) CO_2 **(B) Ozone-depleting substances** (C) Mercury (D) POPs

5. 30$\times$30 target (protect 30% land/sea by 2030) comes from:
(A) Paris Agreement **(B) Kunming-Montreal (CBD COP15)** (C) CITES (D) Basel

Common Mistakes — Unit 5 (Exam Warning)

Wrong	**Correct**
EPA 1986 was enacted after Stockholm	Stockholm = 1972; EPA 1986 = after **Bhopal 1984**
CPCB was created by EPA 1986	CPCB created by **Water Act 1974**
Paris Agreement targets ozone	Paris = GHGs and climate; ozone = **Montreal Protocol**
EIA is done after construction	EIA is done **before** project starts
ISO 14001 is law	ISO 14001 is a **voluntary standard** (not law)
WPA was 1986	WPA (Wild Life Protection Act) = **1972**
Stockholm Convention = 1972 conference	Stockholm Conference = 1972; **Stockholm Convention (POPs) = 2001**

Flash Revision 1 — Indian Laws (Quick Recall)

Key Acts

- WPA 1972: wildlife; Schedule I = highest protection
- Water Act 1974: CPCB + SPCBs; Consent to Operate
- FCA 1980: forest diversion needs Central approval
- Air Act 1981: NAAQS; whole India = air pollution control area
- EPA 1986: umbrella law; all rules under it; EIA; ESAs
- BDA 2002: biodiversity; NBA; national register
- NGT 2010: speedy env justice; technical judges
- Companies Act 2013: 2% CSR mandatory for large companies

EIA Quick Facts

- EIA Notification 2006 (under EPA 1986)
- Cat A: national impact → MoEFCC approval
- Cat B: local impact → SEIAA approval
- 8 steps: Screening → Scoping → Baseline → Prediction → Mitigation → Report → Public Hearing → Decision
- Public hearing: 30-day notice, mandatory
- Post-clearance: half-yearly monitoring report

Flash Revision 2 — ISO 14001 and Global Treaties
(Quick Recall)

ISO 14001 EMS

- Voluntary international standard; current version 2015
- PDCA: Plan-Do-Check-Act continual improvement
- Identify significant aspects and impacts
- Set objectives + targets; EMP
- Internal audit; management review
- Benefits: legal compliance, cost savings, market access
- >300,000 certifications globally (2022)
- LCA: cradle to grave; ISO 14040/44

Global Treaties

- CITES 1973: trade in endangered species
- Montreal Protocol 1987: CFCs; most successful treaty; ozone healing
- Basel 1989: hazardous waste trade
- CBD 1992: biodiversity; ABS (Nagoya 2010)
- Rotterdam 1998: PIC for hazardous chemicals
- Stockholm Conv. 2001: POPs (DDT, dioxins)
- Minamata 2013: mercury control
- Paris 2015: climate; NDCs

Flash Revision 3 — Policy and Governance (Quick Recall)

India Policy

- NAPCC 2008: 8 missions (Solar, Water, Agriculture...)
- NEP 2006: guiding national environment policy
- CCTS 2023: India's carbon trading market
- Green Hydrogen Policy 2022
- Plastic ban 2022: SUPs banned; EPR mandatory
- E-Waste Rules 2022: EPR; 60% collection target
- Swachh Bharat 2014: solid waste + sanitation
- SDGs 2015: SDG 7 (energy), 13 (climate), 15 (land)

Institutions and Tools

- CPCB: Central Pollution Control Board (est. 1974)
- SPCB: State-level; Consent to Establish + Operate
- MoEFCC: Ministry; EIA clearances
- NGT: National Green Tribunal (2010)
- BEE: Bureau of Energy Efficiency (2002)
- NBA: National Biodiversity Authority (2003)
- Polluter Pays Principle
- Precautionary Principle

Important Definitions — Unit 5 (Exam Guide)

Term	Definition
EIA	Systematic process to predict and evaluate impacts of proposed project on environment before sanction
EMS	Environmental Management System: framework for an organisation to manage its environmental impacts
ISO 14001	International voluntary standard specifying requirements for an EMS; PDCA cycle
CPCB	Central Pollution Control Board: national body to set standards; coordinate state PCBs
SPCB	State Pollution Control Board: enforce pollution control; grant Consent to Establish/Operate
EPA 1986	Umbrella environment law; gives government power to regulate all environmental media
EIA Notification	2006 notification under EPA; 32 categories of projects must undergo EIA
CDM	Clean Development Mechanism (Kyoto): developed countries fund RE projects in developing countries
LCA	Life Cycle Assessment: cradle-to-grave evaluation of environmental impact of product/service
CSR	Corporate Social Responsibility: companies investing in social/environmental benefit (2% of profit mandatory in India)

PYQ — Convention on Biological Diversity (3–4M)

Q: Write a short note on CBD (4M)

CBD: Convention on Biological Diversity
Adopted: Rio Earth Summit, June 5, 1992; **In force:** Dec 1993
Parties: 196 countries (USA is a signatory but has not ratified)

Three main objectives:

1. Conservation of biological diversity
2. Sustainable use of its components (genetic resources, species, ecosystems)
3. Fair and equitable sharing of benefits from utilisation of genetic resources

Nagoya Protocol (2010): Access and Benefit Sharing (ABS) — indigenous communities must be compensated when their genetic resources / traditional knowledge is used commercially.

India's implementation:

- Biological Diversity Act 2002
- National Biodiversity Authority (NBA), Chennai
- State Biodiversity Boards (SBBs) in each state
- Biodiversity Management Committees (BMCs) at local level

Kunming-Montreal (COP15, 2022): 30×30 goal: protect 30% of land and 30% of oceans by 2030.

1. World Environment Day is observed on:
(A) April 22 **(B) June 5** (C) September 16 (D) October 2

2. Which cycle is called the "gaseous cycle"?
(A) Carbon/Nitrogen cycle (B) Phosphorus cycle (C) Sulfur cycle (D) Water cycle

3. BOD stands for:
(A) Biological Oxygen Demand (B) Bacteriological Oxygen Deficiency

4. Which is India's 1st comprehensive environment law?
(A) Air Act 1981 **(B) Water Act 1974** (C) EPA 1986 (D) WPA 1972

5. "Indira Gandhi" famously said at Stockholm: "Poverty is the greatest _____":
(A) polluter (B) enemy (C) problem (D) challenge

6. EMAS is the European Union equivalent of:
(A) ISO 9001 **(B) ISO 14001** (C) ISO 45001 (D) SA8000

Q. What is the Polluter Pays Principle? (3M)
Ans: A fundamental principle of environmental law and policy: entities that produce pollution must bear the cost of preventing damage to human health and the environment. In India, embedded in EPA 1986. If a factory discharges untreated effluent and contaminates a river, it must fund cleanup + compensate affected communities.

Q. What is the Precautionary Principle? (3M)
Ans: When there is scientific uncertainty about an activity's potential harm to the environment or health, precautionary action should be taken BEFORE evidence of harm is confirmed. Principle 15 of Rio Declaration 1992. Applied in India by Supreme Court (MC Mehta cases). Better to prevent harm than wait for proof.

Q. What is CAT A project in EIA? (2M)
Ans: Projects with significant national-level environmental impact; require Environmental Clearance from MoEFCC (Ministry of Environment). Examples: thermal power plants >500 MW, airports, large mining, river valley projects.

Unit 5 — Summary (20% Weightage)

Indian Laws & EIA

- WPA 1972, Water Act 1974, FCA 1980, Air Act 1981
- EPA 1986 (umbrella law; after Bhopal 1984)
- EIA Notification 2006: Cat A (MoEFCC), Cat B (SEIAA)
- 8-step EIA: Screening to Clearance; public hearing mandatory
- CPCB (national); SPCB (state); MoEFCC (central ministry)

ISO 14001

- Voluntary EMS standard; PDCA cycle
- Aspects and impacts; objectives; monitoring; audit
- LCA: cradle-to-grave product assessment

Global Agreements

- CITES 1973; Montreal 1987 (most successful = ozone heals)
- Basel 1989 (hazardous waste); CBD 1992 (biodiversity)
- Stockholm Conv. 2001 (POPs); Paris 2015 (climate)
- CBDR: all act, developed do more

CSR & Policy

- Companies Act 2013: 2% profit to CSR (India, mandatory)
- NAPCC: 8 missions; SDG 7, 13, 15
- Polluter Pays + Precautionary Principles
- NGT 2010; RTI 2005; Chipko, NBA

Weightage: 20% | Hours: 6 | Top PYQs: EPA 1986, EIA process, ISO 14001, Montreal Protocol, CBD