R.C.REDDY
IAS STUDY CIRCLE

# APPSC GROUP-1 STRATEGIC REVISION FOR MAINS

# TEST SERIES - 2026

## SECTIONAL TEST-7_PAPER-1

## SCIENCE & TECHNOLOGY - II

## MODEL ANSWERS

**Q 1 (A) India's pursuit of energy security must balance affordability, sustainability and strategic autonomy. Examine the challenges in India's energy transition and evaluate the role of government policies in achieving a low-carbon economy.**

**Demand of the Question:**

- Examine the **key challenges** in India's energy transition.
- Evaluate the **role of government policies** in achieving a **low-carbon economy** while ensuring **energy security**.

The **Economic Survey 2025–26** highlights that India's energy transition is guided by the four pillars of **energy security, affordability, accessibility and sustainability**. As the world's third-largest energy consumer with rapidly growing energy demand, India faces the complex task of reducing carbon emissions without compromising economic growth or strategic autonomy.

**Challenges in India's Energy Transition**

- **High Fossil Fuel Dependence:** Coal continues to be the backbone of India's power sector, contributing nearly **55% of installed power generation**. This makes rapid decarbonisation difficult while ensuring reliable electricity supply.
- **Rising Energy Demand:** Rapid urbanisation, industrialisation, economic growth and increasing electrification are driving a steady rise in energy demand, necessitating a balance between expanding access and reducing emissions.
- **Import Dependence:** India imports nearly **85% of its crude oil** and around **50% of its natural gas**, making the economy vulnerable to geopolitical tensions, supply disruptions and global price volatility.
- **Renewable Energy Integration:** The intermittent nature of solar and wind power requires significant investments in **energy storage systems, pumped hydro projects, smart grids and transmission infrastructure** to maintain grid stability.
- **Critical Mineral Security:** The transition to clean energy depends on minerals such as **lithium, cobalt, nickel and rare earth elements**, where India has limited domestic reserves and remains dependent on imports.
- **Financing Constraints:** Achieving a low-carbon transition requires substantial long-term investments in renewable energy, transmission networks, battery storage and green technologies.
- **Ensuring a Just Transition:** Phasing down fossil fuels affects coal-dependent regions and workers. A successful transition requires **reskilling, alternative livelihoods and regional economic diversification**.
- **Technology and Manufacturing Gaps:** Emerging technologies such as **green hydrogen, carbon capture and storage (CCUS), advanced batteries and grid-scale storage** require greater domestic innovation, manufacturing capacity and cost competitiveness.

**Government Policies for promoting a Low-Carbon Economy:**

| Policy/Initiative | Contribution |
|---|---|
| **National Green Hydrogen Mission** | Promotes green hydrogen for decarbonising hard-to-abate sectors such as steel, fertilisers and refineries. |
| **PM Surya Ghar: Muft Bijli Yojana** | Expands rooftop solar, reduces household electricity costs and promotes distributed renewable energy. |
| **National Solar Mission & Wind Energy Programme** | Accelerate renewable energy capacity and diversify India's energy mix. |
| **PM-KUSUM Scheme** | Solarises agricultural pumps, reducing diesel consumption and improving farmers' energy security. |
| **National Bioenergy Programme & SATAT Initiative** | Promote compressed biogas and waste-to-energy, supporting a circular economy. |
| **PM E-Drive & National Electric Mobility Mission** | Encourage electric mobility and reduce dependence on imported petroleum fuels. |
| **PAT Scheme & UJALA Programme** | Improve energy efficiency and reduce energy intensity across industries and households. |
| **Mission LiFE** | Encourages sustainable lifestyles and behavioural changes to complement technological interventions. |

**Evaluation -**

Government policies have accelerated renewable energy deployment, energy efficiency and clean technology adoption, making India one of the fastest-growing renewable energy markets. Simultaneously, initiatives such as **domestic solar manufacturing, Green Hydrogen Mission and critical mineral partnerships** strengthen India's strategic autonomy in the clean energy sector. However, challenges relating to storage technologies, grid modernisation, climate finance, domestic manufacturing capabilities and a just transition continue to constrain the pace of decarbonisation.

India's energy transition should therefore follow an **orderly, inclusive and technology-driven pathway** that combines renewable energy expansion, energy efficiency, clean manufacturing, critical mineral security and international cooperation. Such a balanced approach will enable India to achieve a **low-carbon economy** while safeguarding **energy security, affordability and sustainable development**, in line with the vision of **Viksit Bharat @2047**.

**Q 1 (B). The future of India's energy sector lies in diversification rather than dependence on a single source. Discuss the prospects and limitations of conventional and non-conventional energy resources in ensuring long-term energy security.**

**Demand of the Question:**

- Discuss the **prospects and limitations** of both conventional and non-conventional energy resources.
- Examine how a **diversified energy mix** can ensure India's **long-term energy security**.

India's commitment to achieve **Net Zero emissions by 2070** and derive nearly **50% of its installed electric capacity from non-fossil fuel sources** requires a diversified energy mix that balances **reliability, affordability and environmental sustainability**. Given India's rapidly growing energy demand and import dependence, no single energy source can independently ensure long-term energy security.

**Prospects and Limitations of Conventional Energy Resources:**

- **Coal:** Coal remains the backbone of India's power sector, contributing nearly **55% of installed power generation**. It provides reliable and affordable base-load power, supporting industrial growth and energy access. However, it is carbon-intensive, contributes to air pollution and poses challenges to India's decarbonisation goals.
- **Petroleum:** Petroleum is indispensable for transport, petrochemicals and industrial activities. However, India imports nearly **85% of its crude oil**, making the economy vulnerable to geopolitical conflicts, supply disruptions and volatile international prices.
- **Natural Gas:** Natural gas is a relatively cleaner fossil fuel and serves as a transition fuel for industries, power generation and city gas distribution. Nevertheless, limited domestic production and dependence on LNG imports constrain its long-term contribution.
- **Hydropower:** Hydropower provides renewable base-load power, supports grid stability and enables pumped storage. However, large projects involve high capital costs, ecological impacts, rehabilitation issues and increasing climate-related risks.

**Prospects and Limitations of Non-Conventional Energy Resources:**

- **Solar Energy:** India has immense solar potential and has emerged as one of the world's leading solar energy producers. Solar energy is clean, abundant and increasingly cost-effective. However, its intermittent nature necessitates investments in battery storage and modern transmission infrastructure.
- **Wind Energy:** Wind energy complements solar generation and offers significant potential, especially in coastal and offshore regions. Its expansion is constrained by location-specific availability and grid connectivity.
- **Green Hydrogen:** The **National Green Hydrogen Mission** positions India to decarbonise sectors such as steel, fertilisers and refineries while reducing fossil fuel dependence. High production costs and evolving technologies remain major challenges.
- **Bioenergy:** Ethanol blending, compressed biogas and biomass-based power promote waste utilisation, rural incomes and energy diversification. However, feedstock availability and supply-chain constraints affect scalability.

- **Nuclear Energy:** Nuclear power provides reliable, low-carbon base-load electricity with a high-capacity factor. However, high capital costs, long gestation periods, safety concerns and waste management issues limit rapid expansion.

**Government Initiatives Supporting Energy Diversification:**

| Initiative | Contribution |
|---|---|
| **National Solar Mission** | Expands solar capacity and reduces dependence on fossil fuels. |
| **National Green Hydrogen Mission** | Promotes clean hydrogen and strengthens energy independence. |
| **PM Surya Ghar: Muft Bijli Yojana** | Encourages rooftop solar and decentralised clean energy generation. |
| **PM-KUSUM Scheme** | Solarises agriculture and reduces diesel consumption. |
| **SATAT Initiative & National Bioenergy Programme** | Promote compressed biogas and waste-to-energy solutions. |
| **Nuclear Energy Expansion (PHWR Programme)** | Enhances reliable low-carbon base-load electricity generation. |

India's long-term energy security lies not in replacing one source with another but in **building a resilient and diversified energy ecosystem**. An optimal mix of conventional fuels for reliability and renewable energy for sustainability, supported by energy storage, smart grids, domestic manufacturing and technological innovation, will enable India to achieve **energy security, strategic autonomy and sustainable economic growth**, while advancing its vision of **Viksit Bharat @2047**.

**Value Addition:**

- **National Energy Goal:** India aims to achieve **500 GW of non-fossil fuel installed electricity capacity by 2030**, strengthening clean energy security.
- **Energy Efficiency:** India's **Energy Intensity of GDP** has declined by over **one-third since 2005**, reflecting improvements in energy efficiency through measures such as the **PAT Scheme** and **UJALA**.
- **Global Leadership:** India co-founded the **International Solar Alliance (ISA)** and the **Global Biofuels Alliance**, reinforcing its leadership in clean energy cooperation.
- **Emerging Focus:** The **Critical Minerals Mission (Union Budget 2025–26)** seeks to secure supply chains for lithium, cobalt, nickel and rare earth elements essential for the clean energy transition.

**Q.2 (A). Explain the salient features of Nuclear Energy. How does nuclear energy contribute to India's energy mix?**

**Demand of the Question:**

- Explain the **salient features** of nuclear energy.
- Discuss its contribution towards **India's energy mix, energy security and clean energy transition**.

India is the **third-largest producer and consumer of electricity** globally, and its energy demand is projected to more than double by 2047. Achieving **energy security** while meeting the commitment of **Net Zero emissions by 2070** necessitates a diversified energy mix. In this context, nuclear energy serves as a reliable, low-carbon and strategically important source of electricity.

**Salient Features of Nuclear Energy:**

- **Low Carbon Energy Source:** Nuclear power generates electricity with negligible greenhouse gas emissions, supporting India's climate commitments.
- **Reliable Base-load Power:** Unlike solar and wind, nuclear plants operate continuously with a **high-capacity factor**, ensuring uninterrupted electricity supply.
- **High Energy Density:** A small quantity of uranium produces enormous energy, requiring comparatively less fuel and land than fossil fuel-based power plants.
- **Energy Security:** Reduces dependence on imported fossil fuels and diversifies India's energy basket.
- **Supports Renewable Energy:** Provides stable base-load electricity, balancing the intermittency of renewable sources and enhancing grid stability.
- **Long Operational Life:** Nuclear power plants have long service lives (40–60 years or more), making them suitable for long-term infrastructure planning.
- **Strategic Importance:** Indigenous reactor technologies and India's thorium programme strengthen technological self-reliance and strategic autonomy.

**Contribution to India's Energy Mix**

- **Clean Energy Transition:** Nuclear power reduces the carbon intensity of electricity generation while complementing renewable energy.
- **Reliable Power Supply:** Ensures round-the-clock electricity for industries, urban centres and critical infrastructure.
- **Diversification of Energy Sources:** Reduces excessive dependence on coal and imported crude oil, improving energy resilience.
- **Industrial Competitiveness:** Stable electricity supply supports manufacturing, transport electrification and digital infrastructure.
- **Climate Change Mitigation:** Contributes to achieving India's Nationally Determined Contributions (NDCs) and Net Zero target.

- **Long-term Energy Independence:** India's thorium-based programme offers a sustainable pathway for future energy security.

**India's Nuclear Energy Policy Framework:**

| Policy / Programme | Significance |
|---|---|
| **Atomic Energy Act, 1962** | Governs the development, control and peaceful use of atomic energy in India. |
| **Three-Stage Nuclear Power Programme** | Designed by **Dr. Homi J. Bhabha** to utilise India's limited uranium and vast thorium reserves for long-term energy security. |
| **Civil Nuclear Cooperation (2008)** | Opened access to international uranium supplies, advanced reactor technology and global nuclear commerce. |
| **Civil Liability for Nuclear Damage Act, 2010** | Provides a legal framework for compensation and liability in case of nuclear accidents. |
| **Indigenous PHWR & Fast Breeder Reactor Programme** | Promotes self-reliance in reactor technology and supports future thorium utilisation. |

Nuclear energy is not a substitute for renewable energy but a **strategic complement** that enhances reliability, energy security and decarbonisation. By expanding indigenous nuclear capacity, strengthening safety standards and leveraging its unique thorium advantage, India can build a **diversified, resilient and sustainable energy system**, advancing its vision of **Viksit Bharat@2047**.

**Value Addition:**

**Installed Capacity:** India has an installed nuclear power capacity of **about 8 GW**, with multiple reactors under construction to expand clean electricity generation.

**Thorium Advantage:** India possesses nearly **25% of the world's thorium reserves**, forming the foundation of its long-term nuclear strategy.

**Institutional Framework:**

- **Department of Atomic Energy (DAE)** – Policy and programme implementation
- **NPCIL** – Construction and operation of commercial nuclear power plants
- **AERB** – Nuclear and radiation safety regulation

**Global Perspective:** The **IPCC** recognises nuclear energy as a key low-carbon technology capable of providing reliable base-load electricity alongside renewable energy.

**Q.2 (B). "Development and environmental conservation are complementary rather than contradictory." Discuss this statement in the light of Environmental Impact Assessment (EIA), natural resource conservation and climate-resilient development.**

**Demand of the Question**

- Explain how **development and environmental conservation can be mutually reinforcing**.
- Discuss the role of **Environmental Impact Assessment (EIA), natural resource conservation and climate-resilient development** in achieving sustainable development.

As the **Brundtland Commission (1987)** observed, *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* In an era of climate change and ecological degradation, economic growth and environmental protection are no longer competing objectives but **two pillars of sustainable development**.

**Development and Environmental Conservation: Complementary Goals**

Economic development depends on healthy ecosystems that provide water, forests, fertile soils, biodiversity and climate regulation. Conversely, environmental degradation increases disaster risks, reduces agricultural productivity and imposes significant economic costs. Thus, conservation strengthens long-term development.

**Role of Environmental Impact Assessment (EIA)**

- **Scientific Decision-Making:** Assesses environmental consequences before project approval, enabling informed policy decisions.
- **Mitigation of Adverse Impacts:** Suggests pollution control, afforestation, biodiversity conservation and rehabilitation measures.
- **Promotes Sustainable Infrastructure:** Encourages environmentally compatible project design and resource-efficient technologies.
- **Public Participation:** Ensures transparency and incorporates concerns of local communities through public consultations.
- **Legal Compliance:** Facilitates adherence to environmental laws and constitutional obligations under **Articles 48A and 51A(g)**.

**Natural Resource Conservation as a Foundation for Development:**

- **Forest Conservation** safeguards biodiversity, ecosystem services and livelihoods while acting as a major carbon sink.
- **Water Conservation** through watershed development, rainwater harvesting and efficient irrigation enhances agricultural sustainability.
- **Soil Conservation** improves productivity and prevents land degradation.
- **Biodiversity Conservation** supports food security, pharmaceuticals, pollination and ecological resilience.

- **Sustainable Mineral Management** promotes scientific mining, land reclamation and circular economy practices.

**Climate-Resilient Development:**

- **Climate-resilient infrastructure** reduces losses from floods, cyclones and heatwaves.
- **Renewable energy expansion** promotes economic growth while lowering greenhouse gas emissions.
- **Nature-based Solutions** such as mangrove restoration and urban forests enhance resilience against climate extremes.
- **Climate-smart agriculture** improves productivity through drought-resistant crops, precision farming and efficient water use.
- **Disaster Risk Reduction** aligned with the **Sendai Framework** minimises economic and human losses.

**Government Initiatives:**

| Initiative | Contribution |
|---|---|
| **Environmental Impact Assessment (EIA) Notification, 2006** | Mandates prior environmental clearance for specified developmental projects. |
| **National Action Plan on Climate Change (NAPCC)** | Integrates climate mitigation and adaptation into development planning through eight national missions. |
| **Green India Mission** | Enhances forest cover, carbon sequestration and ecosystem restoration. |
| **CAMPA** | Supports afforestation and ecological restoration to compensate for forest diversion. |
| **Mission LiFE** | Promotes sustainable lifestyles and responsible resource consumption. |
| **National Mission for Sustainable Agriculture (NMSA)** | Enhances climate resilience and sustainable agricultural practices. |

Development and environmental conservation are **mutually reinforcing rather than mutually exclusive**. By strengthening Environmental Impact Assessment, conserving natural resources and mainstreaming climate resilience into planning, India can achieve **inclusive, environmentally sustainable and economically resilient development**, consistent with the vision of **Viksit Bharat@2047**.

**Value Addition:**

**Constitutional Backing: Article 48A** directs the State to protect and improve the environment, while **Article 51A(g)** makes environmental protection a Fundamental Duty of every citizen.

**SDG Linkage:** Directly advances **SDG 13 (Climate Action), SDG 15 (Life on Land), SDG 6 (Clean Water)** and **SDG 12 (Responsible Consumption and Production).**

**Economic Perspective:** The **Economic Survey** highlights **Green Growth** as one of the key pillars of sustainable development, emphasising low-carbon and resource-efficient economic expansion.
**Supreme Court Principle:** The Court has consistently upheld the principles of **Sustainable Development**, **Precautionary Principle** and **Polluter Pays Principle** as integral to environmental governance.

**Q.3 (A). Climate change is no longer merely an environmental issue but a developmental and social justice challenge. Examine India's climate action in the context of climate justice, international environmental agreements and sustainable development.**

**Demand of the Question**

- Explain why climate change has become a **developmental and social justice issue**.
- Examine **India's climate action** with reference to **climate justice, international environmental agreements and sustainable development**.

The **Paris Agreement (2015)** recognises that climate change poses an urgent and potentially irreversible threat to human societies and ecosystems. For a developing country like India, climate change extends beyond environmental degradation—it affects **food security, livelihoods, public health, poverty alleviation and inter-generational equity**. Consequently, India's climate strategy seeks to balance **economic growth with environmental sustainability**, guided by the principle of **Climate Justice**.

**Climate Change as a Developmental and Social Justice Challenge:**

- **Agriculture & Food Security:** Erratic monsoons, droughts and floods reduce agricultural productivity, affecting small and marginal farmers.
- **Livelihoods:** Climate-sensitive sectors such as agriculture, fisheries and forestry face income losses, increasing rural distress.
- **Public Health:** Rising temperatures, heatwaves and vector-borne diseases disproportionately affect vulnerable populations.
- **Disaster Risks:** Frequent cyclones, floods and extreme weather events damage infrastructure and slow economic development.
- **Social Inequality:** Poor households, women, tribal communities and coastal populations bear the greatest climate burden despite contributing the least to emissions.

**India's Climate Action through Climate Justice**

India advocates **"Climate Justice"**, recognising that while climate change is a global challenge, **historical responsibility and developmental needs must be fairly considered.**

- Follows the principle of **Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC)**.
- Pursues **low-carbon development** without compromising poverty eradication and inclusive growth.
- Expands renewable energy while ensuring **energy access and affordability**.
- Promotes sustainable lifestyles through **Mission LiFE (Lifestyle for Environment)**.
- Strengthens adaptation measures to protect vulnerable communities from climate risks.

**India and International Environmental Agreements:**

| Agreement | India's Contribution |
|---|---|
| **UNFCCC (1992)** | Advocates equity, CBDR-RC and climate justice in global negotiations. |
| **Kyoto Protocol (1997)** | Participated under differentiated obligations for developing countries. |
| **Paris Agreement (2015)** | Updated NDCs; committed to reducing emissions intensity and achieving **Net Zero by 2070**. |
| **Montreal Protocol & Kigali Amendment** | Phasing out ozone-depleting substances and reducing HFC emissions. |
| **Convention on Biological Diversity (CBD)** | Conserves biodiversity while promoting sustainable resource use. |

**Climate Action for Sustainable Development:**

- **Renewable Energy Expansion** through solar, wind, hydro and green hydrogen reduces fossil fuel dependence.
- **National Action Plan on Climate Change (NAPCC)** integrates climate action through eight national missions.
- **National Green Hydrogen Mission** promotes clean industrial growth and energy security.
- **Green India Mission** enhances carbon sinks through afforestation and ecosystem restoration.
- **PM-KUSUM and Climate-Smart Agriculture** improve farmer resilience and sustainable resource use.
- **Disaster-resilient infrastructure** and early warning systems strengthen adaptation to climate extremes.

**Government Initiatives:**

| Initiative | Contribution |
|---|---|
| **National Action Plan on Climate Change (NAPCC)** | Framework for climate mitigation and adaptation through eight national missions. |
| **Mission LiFE** | Encourages sustainable consumption and behavioural change. |
| **National Green Hydrogen Mission** | Accelerates decarbonisation of hard-to-abate sectors. |
| **Green India Mission** | Enhances forest cover and carbon sequestration. |
| **National Adaptation Fund for Climate Change (NAFCC)** | Supports adaptation projects in vulnerable sectors and regions. |
| **Coalition for Disaster Resilient Infrastructure (CDRI)** | Promotes climate-resilient infrastructure globally. |

India's climate strategy reflects the principle that **environmental sustainability, economic development and social justice are mutually reinforcing**. By combining climate justice, international cooperation and sustainable development, India is striving to build a **resilient, inclusive and low-carbon economy**, contributing responsibly to global climate action while safeguarding the developmental aspirations of its people.

**Value Addition:**

**Panchamrit Commitments (COP26):**

- **500 GW** non-fossil electricity capacity by 2030.
- **50%** of installed electricity capacity from non-fossil fuel sources by 2030.
- **Net Zero emissions by 2070.**

**Global Leadership:** India co-founded the **International Solar Alliance (ISA)** and the **Coalition for Disaster Resilient Infrastructure (CDRI)**, demonstrating leadership in global climate governance.

**Constitutional Basis: Article 48A** and **Article 51A(g)** provide constitutional support for environmental protection and sustainable development.

**SDG Linkage:** Advances **SDG 7 (Clean Energy), SDG 13 (Climate Action), SDG 15 (Life on Land)** and **SDG 17 (Partnerships for the Goals).**

**Q.3 (B). International environmental conventions have significantly influenced India's environmental governance. Discuss the contribution of major global environmental agreements in shaping India's environmental policies.**

**Demand of the Question**

- Discuss the role of **major international environmental conventions**.
- Examine how these agreements have shaped **India's environmental governance and policy framework**.

Environmental challenges such as **climate change, biodiversity loss and pollution transcend national boundaries**, necessitating global cooperation. As a responsible global stakeholder, India has aligned its domestic environmental policies with international commitments while balancing the principles of **sustainable development, climate justice and national development priorities**.

**Contribution of Major International Environmental Agreements:**

| Convention / Agreement | Influence on India's Environmental Governance |
|---|---|
| **Stockholm Conference (1972)** | Marked the beginning of modern environmental governance in India; led to the **42nd Constitutional Amendment (1976)** introducing **Articles 48A & 51A(g)** and strengthened environmental legislation. |
| **Convention on Biological Diversity (CBD), 1992** | Led to the **Biological Diversity Act, 2002**, Biodiversity Rules (2004), National Biodiversity Authority (NBA) and People's Biodiversity Registers. |
| **UNFCCC (1992)** | Guided India's climate governance through the **National Action Plan on Climate Change (NAPCC)**, State Action Plans on Climate Change (SAPCCs) and climate adaptation policies. |
| **Kyoto Protocol (1997)** | Encouraged participation in the **Clean Development Mechanism (CDM)**, promoting renewable energy and energy-efficient projects. |
| **Paris Agreement (2015)** | Influenced India's updated **Nationally Determined Contributions (NDCs)**, Net Zero by 2070 target, renewable energy expansion and Green Hydrogen Mission. |
| **Montreal Protocol (1987) & Kigali Amendment** | Led to the phase-out of ozone-depleting substances through the **Ozone Depleting Substances (Regulation and Control) Rules, 2000** and phased reduction of HFCs. |
| **Ramsar Convention (1971)** | Strengthened wetland conservation through the **Wetlands (Conservation and Management) Rules, 2017** and expansion of Ramsar sites. |
| **UN Convention to Combat Desertification (UNCCD)** | Promoted watershed development, land restoration and India's commitment to achieve **Land Degradation Neutrality (LDN)** by 2030. |
| **CITES (1973)** | Strengthened wildlife protection, regulation of wildlife trade and implementation of the **Wild Life (Protection) Act, 1972**. |

**Impact on India's Environmental Policies:**

- **Strengthened Legal Framework** through laws governing forests, biodiversity, wildlife, pollution control and environmental protection.
- **Mainstreamed Sustainable Development** into planning, infrastructure and resource management.
- **Accelerated Renewable Energy Transition** to reduce emissions and enhance energy security.
- **Improved Biodiversity Conservation** through protected areas, conservation reserves and community participation.
- **Enhanced Climate Adaptation** through disaster resilience, climate-smart agriculture and ecosystem restoration.
- **Promoted International Cooperation** in technology transfer, climate finance and environmental governance.

**Major Government Initiatives Inspired by Global Commitments:**

| Initiative | Linked Global Commitment |
|---|---|
| **National Action Plan on Climate Change (NAPCC)** | UNFCCC & Paris Agreement |
| **National Green Hydrogen Mission** | Paris Agreement |
| **Green India Mission** | Paris Agreement & CBD |
| **Biological Diversity Act, 2002** | Convention on Biological Diversity |
| **Wetlands Rules, 2017** | Ramsar Convention |
| **Mission LiFE** | Paris Agreement and sustainable consumption goals |

International environmental conventions have transformed India's environmental governance from a **regulatory approach to a sustainability-oriented framework**. By harmonising global commitments with domestic priorities through legislation, institutions and policy reforms, India has strengthened environmental protection while pursuing **inclusive growth, climate resilience and sustainable development**, reflecting its vision of **"Vasudhaiva Kutumbakam"** and **Viksit Bharat@2047**.

**Value Addition:**

**Constitutional Influence:** The **42nd Constitutional Amendment (1976)** inserted **Article 48A** (Directive Principle) and **Article 51A(g)** (Fundamental Duty), reflecting the spirit of the Stockholm Conference.
**Climate Justice:** India consistently advocates **Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC)** in international climate negotiations.

**Global Leadership:** India co-founded the **International Solar Alliance (ISA)** and the **Coalition for Disaster Resilient Infrastructure (CDRI)**, demonstrating leadership beyond treaty obligations.

**SDG Linkage:** These conventions collectively advance **SDGs 6, 7, 12, 13, 14 and 15**, integrating environmental protection with sustainable development.

**Q.4 (A). Disaster management has shifted from post-disaster relief to disaster risk reduction. Discuss the role of science, technology and early warning systems in building disaster-resilient communities.**

The **Sendai Framework for Disaster Risk Reduction (2015–2030)** advocates a paradigm shift from **"managing disasters" to "managing disaster risks."** Recognising that disasters cannot always be prevented but their impacts can be minimised, India has increasingly integrated **science, technology and early warning systems** into disaster governance to save lives, protect livelihoods and strengthen resilience.

**Shift from Relief-Centric to Disaster Risk Reduction (DRR):**

- Focuses on **prevention, preparedness, mitigation and resilience** rather than merely post-disaster response.
- Emphasises **risk-informed development planning** and resilient infrastructure.
- Encourages community participation, capacity building and multi-hazard preparedness.
- Integrates disaster risk reduction into national and state development policies.

**Role of Science and Technology in Disaster Risk Reduction:**

- **Risk Assessment & Hazard Mapping:** GIS, Remote Sensing and satellite imagery identify hazard-prone areas and support scientific land-use planning.
- **Weather & Climate Forecasting:** Advanced numerical weather prediction models improve forecasting of cyclones, heavy rainfall, heatwaves and droughts.
- **Artificial Intelligence & Big Data:** AI analyses large datasets to predict disaster patterns, optimise evacuation planning and improve emergency response.
- **Drone Technology:** Facilitates rapid damage assessment, search and rescue operations, delivery of relief materials and monitoring of inaccessible areas.
- **Space Technology:** ISRO satellites provide real-time monitoring of floods, cyclones, forest fires and landslides.
- **Resilient Infrastructure:** Scientific standards improve the design of earthquake-resistant buildings, cyclone shelters and flood-resilient infrastructure.

**Role of Early Warning Systems:**

- **Cyclone Early Warning:** Accurate forecasting by IMD enables timely evacuation, substantially reducing disaster-related mortality.
- **Flood Forecasting:** Central Water Commission (CWC) and satellite-based monitoring provide advance flood warnings.

- **Tsunami Warning:** The **Indian Tsunami Early Warning Centre (ITEWC), INCOIS** issues rapid alerts for coastal regions across the Indian Ocean.
- **Heatwave & Lightning Alerts:** IMD disseminates location-specific advisories through mobile applications, SMS and media platforms.
- **Last-Mile Connectivity:** Common Alerting Protocol (CAP), mobile messaging, sirens and community volunteers ensure warnings reach vulnerable populations.

**Government Initiatives:**

| Initiative | Contribution |
|---|---|
| **Disaster Management Act, 2005** | Established institutional framework for disaster risk reduction through NDMA, SDMAs and DDMAs. |
| **National Disaster Management Plan (NDMP), 2019** | Aligns India's disaster strategy with the Sendai Framework and SDGs. |
| **Mission Mausam** | Modernises weather forecasting through Doppler Weather Radars, high-performance computing and AI-based prediction models. |
| **National Cyclone Risk Mitigation Project (NCRMP)** | Develops cyclone-resilient infrastructure and strengthens early warning dissemination. |
| **Coalition for Disaster Resilient Infrastructure (CDRI)** | Promotes resilient infrastructure and global cooperation in disaster risk reduction. |
| **CAP-based Integrated Alert System** | Delivers multi-hazard warnings through mobile networks and digital communication platforms. |

Science, technology and early warning systems have transformed disaster management from a **reactive relief-based approach to a proactive resilience-based strategy**. By combining technological innovation with community participation and risk-informed governance, India is strengthening **disaster-resilient communities** capable of withstanding future climate and disaster risks while advancing the vision of **Viksit Bharat@2047**.

**Value Addition:**

**Global Framework:** The **Sendai Framework (2015–2030)** identifies **"Understanding Disaster Risk"** as its first priority for action, emphasising science and evidence-based policymaking.

**India's Strength:** India has developed one of the world's most effective **Cyclone Early Warning Systems**, reducing cyclone-related mortality dramatically over the past two decades.

**Technology Ecosystem: ISRO, IMD, INCOIS, CWC and NRSC** together provide an integrated scientific framework for multi-hazard forecasting and disaster management.

**SDG Linkage:** Disaster Risk Reduction directly supports **SDG 11 (Sustainable Cities), SDG 13 (Climate Action)** and the **Sendai Framework**.

**Q.4 (B). Climate change has increased the frequency of natural disasters. Examine India's preparedness for disaster management.**

**Demand of the Question**

- Explain how **climate change has intensified natural disasters**.
- Examine **India's preparedness** for effective disaster management.

According to the **IPCC Sixth Assessment Report (AR6)**, climate change is increasing the **frequency and intensity of extreme weather events**, including heatwaves, floods, cyclones and droughts. As one of the world's most climate-vulnerable countries, India has shifted from a **relief-centric approach** to a **preparedness and resilience-based disaster management framework**, integrating scientific forecasting, institutional capacity and community participation.

**Climate Change and Increasing Disaster Risks:**

- **Frequent Heatwaves:** Rising temperatures have increased the occurrence of prolonged and intense heatwaves across India.
- **Extreme Rainfall & Floods:** Warmer oceans and atmosphere have intensified cloudbursts and urban flooding.
- **Severe Cyclones:** Higher sea surface temperatures have increased the intensity of cyclones in the Arabian Sea and Bay of Bengal.
- **Droughts & Water Stress:** Erratic monsoons and changing rainfall patterns have aggravated drought conditions.
- **Landslides & Glacial Hazards:** Retreating glaciers and extreme rainfall have increased landslides and Glacial Lake Outburst Floods (GLOFs) in the Himalayas.

**India's Preparedness for Disaster Management:**

**1. Strong Institutional Framework**

- **Disaster Management Act, 2005** established **NDMA, SDMAs, DDMAs and NDRF**.
- **National Disaster Management Plan (NDMP), 2019** aligns with the **Sendai Framework** and SDGs.
- Regular mock drills and capacity-building programmes strengthen preparedness.

**2. Advanced Early Warning Systems**

- **India Meteorological Department (IMD)** provides timely forecasts for cyclones, heatwaves and heavy rainfall.
- **INCOIS** operates the **Indian Tsunami Early Warning Centre (ITEWC)** for the Indian Ocean region.
- **Central Water Commission (CWC)** issues flood forecasts using real-time hydrological monitoring.
- Mobile alerts, CAP-based warning systems and social media improve last-mile communication.

**3. Science and Technology Integration**

- **ISRO satellites**, GIS, Remote Sensing and drones support hazard mapping, disaster monitoring and damage assessment.

- AI and Big Data improve forecasting, evacuation planning and emergency response.
- Doppler Weather Radars and high-performance computing enhance weather prediction accuracy.

**4. Disaster-Resilient Infrastructure**

- Cyclone shelters, embankments and resilient public infrastructure reduce disaster impacts.
- Climate-resilient urban planning and updated building codes improve disaster resistance.
- The **Coalition for Disaster Resilient Infrastructure (CDRI)** promotes resilient infrastructure nationally and globally.

**5. Community-Based Disaster Preparedness**

- Community volunteers, local institutions and Self-Help Groups participate in disaster awareness and evacuation.
- School safety programmes and disaster preparedness campaigns strengthen grassroots resilience.

**Major Government Initiatives:**

| Initiative | Contribution |
|---|---|
| **Disaster Management Act, 2005** | Provides the statutory framework for disaster prevention, preparedness, response and recovery. |
| **National Disaster Management Plan (NDMP)** | Integrates disaster risk reduction into development planning in line with the Sendai Framework. |
| **Mission Mausam** | Modernises weather forecasting through AI, Doppler Weather Radars and high-performance computing. |
| **National Cyclone Risk Mitigation Project (NCRMP)** | Strengthens cyclone forecasting, evacuation infrastructure and coastal resilience. |
| **Coalition for Disaster Resilient Infrastructure (CDRI)** | Promotes resilient infrastructure against climate-induced disasters. |
| **National Disaster Response Force (NDRF)** | Specialised force for disaster response, search and rescue operations. |

**Challenges**

- Increasing frequency and complexity of **multi-hazard disasters** due to climate change.
- Rapid **urbanisation and unplanned development** in hazard-prone areas.
- Limited disaster preparedness capacity at the **local government level**.
- Financing gaps for **climate adaptation and resilient infrastructure**.
- Need for stronger **inter-agency coordination** and improved last-mile connectivity.

India has made significant progress in disaster preparedness through robust institutions, scientific forecasting, resilient infrastructure and community participation. However, as climate risks continue to intensify, sustained investments in **risk-informed development, climate adaptation and technology-driven disaster management** will be essential to build a **disaster-resilient and climate-resilient India**.

**Value Addition:**

**Global Framework:** The **Sendai Framework for Disaster Risk Reduction (2015–2030)** emphasises preparedness, resilience and "Build Back Better" in recovery and reconstruction.

**Climate Perspective:** The **IPCC AR6** concludes that human-induced climate change has increased the frequency and intensity of many weather and climate extremes.

**India's Success Story:** Improved forecasting and timely evacuations have reduced cyclone mortality dramatically compared to previous decades, making India's cyclone management a globally recognised best practice.

**SDG Linkage:** Strengthens **SDG 11 (Sustainable Cities), SDG 13 (Climate Action)** and **SDG 9 (Resilient Infrastructure).**

**Q.5 (A). Environmental pollution has emerged as one of the greatest public health challenges of the 21st Century. Analyse the major sources of pollution and evaluate the effectiveness of pollution control measures in India.**

**Demand of the Question**

- Analyse the **major sources of environmental pollution**.
- Evaluate the **effectiveness of pollution control measures** adopted by India.

According to the **World Health Organization (WHO)**, environmental pollution is among the **leading global risk factors for premature mortality and disease burden**. Rapid urbanisation, industrialisation and unsustainable consumption have intensified **air, water, soil and noise pollution**, making pollution not merely an environmental concern but also a **public health and developmental challenge**.

**Major Sources of Environmental Pollution**

**1. Air Pollution**

- Vehicular emissions due to rapid motorisation.
- Industrial emissions and thermal power plants.
- Crop residue burning and biomass combustion.
- Construction activities and road dust.
- Household use of solid fuels for cooking and heating.

**2. Water Pollution**

- Discharge of untreated municipal sewage.
- Industrial effluents containing toxic chemicals.
- Agricultural runoff carrying fertilisers and pesticides.
- Plastic waste and biomedical waste entering water bodies.

**3. Soil Pollution**

- Excessive use of chemical fertilisers and pesticides.
- Improper disposal of hazardous and electronic waste.
- Mining activities and industrial contamination.
- Open dumping of municipal solid waste.

**4. Noise Pollution**

- Traffic congestion and vehicular horns.
- Industrial machinery.
- Construction activities.
- Loudspeakers and firecrackers.

**Pollution Control Measures in India**

| Measure | Contribution |
|---|---|
| **Air (Prevention and Control of Pollution) Act, 1981** | Regulates industrial emissions and empowers Pollution Control Boards. |
| **Water (Prevention and Control of Pollution) Act, 1974** | Controls water pollution and mandates treatment of wastewater. |
| **Environment (Protection) Act, 1986** | Umbrella legislation empowering the Central Government to protect and improve the environment. |
| **National Clean Air Programme (NCAP)** | Targets reduction of particulate pollution in non-attainment cities through city-specific action plans. |
| **Swachh Bharat Mission (Urban & Gramin)** | Improves sanitation and scientific solid waste management. |
| **Namami Gange Programme** | Focuses on sewage treatment, river rejuvenation and pollution abatement. |

**Evaluation of Pollution Control Measures**

**Achievements**

- **Strengthened Legal Framework** through comprehensive environmental legislation and regulatory institutions.
- **Improved Air Quality Monitoring** with expansion of Continuous Ambient Air Quality Monitoring Stations (CAAQMS).
- **Cleaner Fuels** through the nationwide adoption of **BS-VI emission norms** and expansion of cleaner public transport.

- **Better Sanitation Coverage** under Swachh Bharat has reduced open defecation and improved waste management.
- **River Rejuvenation** projects have expanded sewage treatment capacity in major river basins.
- Growing adoption of **renewable energy** has contributed to reducing dependence on fossil fuels.

**Limitations**

- Weak enforcement and inadequate compliance with environmental regulations.
- Large quantities of **untreated sewage** continue to pollute rivers and lakes.
- Persistent **stubble burning**, construction dust and vehicular emissions affect urban air quality.
- Poor segregation and scientific disposal of solid, plastic and e-waste.
- Limited financial and technical capacity of Urban Local Bodies and Pollution Control Boards.
- Rising pollution due to rapid urbanisation and industrial expansion.

**Way Forward**

- Strengthen **real-time monitoring** and strict enforcement of pollution standards.
- Promote **circular economy** and Extended Producer Responsibility (EPR).
- Accelerate transition to **clean energy and electric mobility**.
- Improve **sewage treatment and scientific waste management**.
- Encourage public participation through **Mission LiFE** and environmental awareness.
- Integrate pollution control into urban planning and climate-resilient development.

Pollution poses a serious threat to **public health, environmental sustainability and economic productivity**. While India has established a robust legal and institutional framework, its effectiveness depends on **strong enforcement, technological innovation, behavioural change and cooperative governance**. A preventive and integrated approach will be essential to achieve **cleaner ecosystems and a healthier Viksit Bharat@2047**.

**Value Addition:**

**Constitutional Basis: Article 48A** directs the State to protect and improve the environment, while **Article 51A(g)** makes environmental protection a Fundamental Duty of every citizen.
**Judicial Principles:** The Supreme Court has evolved the **Polluter Pays Principle**, **Precautionary Principle** and **Public Trust Doctrine** as cornerstones of environmental jurisprudence.

**Institutional Framework: CPCB** coordinates national pollution control efforts, while **SPCBs/PCCs** monitor compliance and enforce environmental standards at the State level.

**SDG Linkage:** Pollution control advances **SDG 3 (Good Health), SDG 6 (Clean Water), SDG 11 (Sustainable Cities), SDG 12 (Responsible Consumption)** and **SDG 13 (Climate Action).**

**Q.5 (B). Solid waste management is no longer merely a sanitation issue but a resource management challenge. Discuss the principles of circular economy and evaluate India's initiatives towards sustainable waste management.**

**Demand of the Question:**

- Explain why **solid waste management (SWM)** has evolved from a sanitation concern to a **resource management challenge**.
- Discuss the **principles of Circular Economy** and evaluate **India's initiatives** for sustainable waste management.

According to the **UNEP**, a **Circular Economy** aims to keep materials and products in use for as long as possible by minimizing waste and maximizing resource efficiency. For India, generating over **1.7 lakh tonnes of municipal solid waste daily**, waste management is no longer about disposal alone but about **recovering resources, creating green jobs and promoting sustainable development**.

**Solid Waste Management: From Sanitation to Resource Management**

- Rapid urbanisation and consumption have increased **municipal solid waste generation**.
- Unscientific dumping causes **air, water and soil pollution**, besides methane emissions.
- Waste contains valuable **metals, plastics, paper, glass and organic matter**, which can be recovered and reused.
- Scientific waste management supports **resource conservation, energy recovery and economic growth**.

**Principles of Circular Economy:**

- **Reduce** – Minimise resource use and waste generation through sustainable production and consumption.
- **Reuse** – Extend the life of products through repair, refurbishment and repeated use.
- **Recycle** – Recover materials for manufacturing new products.
- **Recover** – Convert non-recyclable waste into energy, compost or bio-CNG.
- **Resource Efficiency** – Maximise value from every unit of material and energy.
- **Extended Producer Responsibility (EPR)** – Producers are responsible for collection, recycling and environmentally sound disposal of post-consumer waste.

**India's Initiatives Towards Sustainable Waste Management:**

| Initiative | Contribution |
|---|---|
| **Solid Waste Management Rules, 2016** | Mandate source segregation, door-to-door collection and scientific processing of waste. |
| **Swachh Bharat Mission (Urban & Gramin)** | Improved sanitation, waste collection and public awareness. |

| Initiative | Contribution |
|---|---|
| **Plastic Waste Management Rules, 2016** | Introduced **EPR** and phased out identified single-use plastics. |
| **E-Waste (Management) Rules, 2022** | Strengthened formal recycling through producer responsibility. |
| **GOBARdhan Scheme** | Converts biodegradable waste into biogas, bio-CNG and organic manure. |
| **Waste-to-Energy Programme** | Encourages energy generation from non-recyclable municipal waste. |

**Evaluation of India's Initiatives:**

**Achievements -**

- Improved **door-to-door waste collection** in urban areas.
- Increased emphasis on **source segregation** and decentralized waste processing.
- Expansion of **composting, bio-methanation and waste-to-energy** facilities.
- Strengthened recycling ecosystem through **EPR** for plastics and e-waste.
- Greater public awareness through **Swachh Bharat Mission** and **Mission LiFE**.

**Challenges -**

- Low levels of **source segregation** in many cities.
- Heavy dependence on **landfills and open dumping**.
- Limited recycling and scientific processing capacity.
- Weak enforcement of waste management rules and EPR obligations.
- Poor integration of the **informal waste sector** into formal systems.
- Financial and technical constraints of Urban Local Bodies (ULBs).

**Way Forward-**

- Ensure **100% segregation at source** and decentralized waste processing.
- Strengthen **Material Recovery Facilities (MRFs)** and recycling infrastructure.
- Integrate informal waste pickers into formal waste management systems.
- Promote **circular economy practices** across industries through fiscal incentives.
- Expand waste-to-wealth technologies, including **bio-CNG, composting and waste-to-energy**.
- Encourage behavioural change through **Mission LiFE** and citizen participation.

The future of solid waste management lies not in **managing waste**, but in **managing resources**. By embracing the principles of the **Circular Economy**, strengthening scientific waste processing and fostering responsible production and consumption, India can transform **"waste into wealth"**, ensuring both **environmental sustainability and resource security** for future generations.

**Value Addition:**

**Waste Hierarchy: Refuse → Reduce → Reuse → Recycle → Recover → Dispose** is the globally accepted hierarchy for sustainable waste management.
**NITI Aayog's Circular Economy Roadmap** identifies priority sectors such as **municipal solid waste, plastics, batteries, e-waste, construction & demolition waste, automobiles, textiles and agriculture** for accelerating circularity.

**Economic Survey Insight:** Circular Economy enhances **resource productivity, reduces import dependence, lowers carbon emissions and generates green employment**.

**SDG Linkage:** Advances **SDG 11 (Sustainable Cities), SDG 12 (Responsible Consumption & Production), SDG 13 (Climate Action)** and **SDG 15 (Life on Land).**

**Q.6 (A). Biotechnology is transforming agriculture, healthcare and industry, but it also raises ethical and biosafety concerns. Critically examine the opportunities and challenges of biotechnology in India.**

**Demand of the Question**

- Examine the **opportunities offered by biotechnology** in agriculture, healthcare and industry.
- Critically analyse the **ethical, biosafety and regulatory challenges** associated with biotechnology in India.

Biotechnology harnesses **living organisms, cells and biomolecular processes** to develop products and technologies that improve human well-being. Recognised as a **Sunrise Sector** under India's **BioE3 Policy (2024)**, biotechnology has emerged as a key driver of **food security, healthcare innovation, industrial sustainability and economic growth**. However, its rapid expansion also raises important concerns relating to **biosafety, ethics and environmental sustainability**.

**Opportunities of Biotechnology:**

**1. Agriculture-**

- Development of **high-yielding, pest-resistant and climate-resilient crop varieties**.
- Reduced dependence on chemical pesticides through **Bt technology**.
- Biofertilizers and biopesticides promote **sustainable agriculture**.
- Tissue culture enables rapid multiplication of disease-free planting material.
- Supports food and nutritional security through biofortification.

**2. Healthcare-**

- Development of **vaccines, recombinant drugs and monoclonal antibodies**.
- Precision medicine and **gene therapy** improve treatment of genetic disorders.
- Rapid disease diagnosis through molecular diagnostic technologies.
- Stem cell research offers promising therapies for regenerative medicine.

- India's biotechnology ecosystem demonstrated its strength during the **COVID-19 pandemic**.

**3. Industry & Environment-**

- Production of **biofuels, bioplastics and bio-based chemicals**.
- Industrial enzymes improve efficiency while reducing pollution.
- Bioremediation helps clean oil spills, heavy metals and contaminated soils.
- Supports the **bioeconomy**, creating high-skilled employment and exports.

**Challenges and Concerns:**

**Ethical Challenges -**

- Ethical concerns over **gene editing and human germline modification**.
- Privacy and misuse of **genetic data**.
- Patent-related issues affecting affordability and equitable access.
- Moral concerns regarding cloning and embryonic stem cell research.

**Biosafety Concerns-**

- Potential ecological risks from **Genetically Modified (GM) organisms**.
- Gene flow from GM crops to wild relatives, affecting biodiversity.
- Emergence of pest resistance and ecological imbalance.
- Need for rigorous risk assessment before commercial release.

**Regulatory & Socio-economic Challenges -**

- Lengthy regulatory approval processes.
- Low public awareness and misconceptions regarding biotechnology.
- Limited investment in research and commercialization.
- Need for skilled human resources and advanced research infrastructure.
- Balancing innovation with precautionary regulation.

**Government Initiatives:**

| Initiative | Contribution |
|---|---|
| **BioE3 Policy (2024)** | Promotes biotechnology for Economy, Employment and Environment through high-performance biomanufacturing. |
| **Department of Biotechnology (DBT)** | Supports biotechnology research, innovation and capacity building. |
| **Biotechnology Industry Research Assistance Council (BIRAC)** | Promotes biotech startups and industry-academia collaboration. |
| **National Biotechnology Development Strategy** | Strengthens research, innovation and commercialisation. |

| Initiative | Contribution |
|---|---|
| **National Guidelines for Biosafety** | Regulate research, testing and environmental release of GM organisms through GEAC and related authorities. |
| **National Biopharma Mission** | Accelerates indigenous vaccine and biopharmaceutical development. |

**Critical Evaluation:**

**Strengths -**

- Expanding biotech startup ecosystem and growing bioeconomy.
- Strong capabilities in vaccine manufacturing and biopharmaceuticals.
- Increasing application in agriculture, healthcare and environmental management.
- Policy support through **BioE3** and Atmanirbhar Bharat initiatives.

**Limitations -**

- Biosafety and ethical concerns require robust regulatory oversight.
- Commercialisation of research remains limited.
- Inadequate public awareness regarding GM technologies.
- Need for stronger academia-industry collaboration and greater R&D investment.

Biotechnology has the potential to address some of India's most pressing challenges in **food security, healthcare, energy and environmental sustainability**. However, its long-term success depends on a **science-based regulatory framework, strong biosafety standards and ethical governance** that fosters innovation while safeguarding human health, biodiversity and public trust.

**Value Addition**

**BioE3 Policy (2024):** Focuses on **High-Performance Biomanufacturing** across six thematic areas, promoting **Economy, Employment and Environment**.

**India's Bioeconomy:** India's bioeconomy has grown rapidly over the past decade, making biotechnology one of the country's fastest-growing knowledge sectors.

**Regulatory Framework: GEAC (Genetic Engineering Appraisal Committee)** under the Environment (Protection) Act, 1986, is the apex body for environmental approval of GM organisms.

**SDG Linkage:** Biotechnology contributes to **SDG 2 (Zero Hunger), SDG 3 (Good Health), SDG 9 (Industry & Innovation), SDG 12 (Responsible Consumption)** and **SDG 13 (Climate Action).**

**Q.6 (B). Genetic engineering has revolutionised modern science but generated significant public debate. Discuss its applications in agriculture and medicine, highlighting the ethical, legal and environmental concerns.**

**Demand of the Question:**

- Discuss the **applications of genetic engineering** in **agriculture and medicine**.
- Highlight the **ethical, legal and environmental concerns** associated with its use.

The advent of **recombinant DNA technology** and advanced gene-editing tools such as **CRISPR-Cas9** has transformed genetic engineering into one of the most significant scientific breakthroughs of the 21st century. While it offers immense potential for enhancing **food security, healthcare and economic development**, its widespread application has also generated concerns relating to **biosafety, ethics and regulation**.

**Applications of Genetic Engineering:**

**1. Agriculture**

- **Genetically Modified (GM) Crops:** Development of insect-resistant crops such as **Bt Cotton**, reducing pesticide use and improving productivity.
- **Climate-resilient Crops:** Development of drought-, salinity- and heat-tolerant crop varieties to address climate change.
- **Biofortification:** Enhances nutritional content by increasing vitamins and micronutrients (e.g., Vitamin A, iron and zinc).
- **Disease-resistant Crops:** Reduces crop losses and improves food security.
- **Improved Shelf Life:** Minimises post-harvest losses and food wastage.

**2. Medicine**

- **Recombinant Therapeutics:** Production of insulin, growth hormones, vaccines and clotting factors.
- **Gene Therapy:** Corrects defective genes for treating inherited genetic disorders.
- **Precision Medicine:** Enables personalised treatment based on an individual's genetic profile.
- **Monoclonal Antibodies:** Used in the treatment of cancer, autoimmune and infectious diseases.
- **Rapid Vaccine Development:** Facilitates development of recombinant and mRNA vaccines against emerging diseases.

**Ethical, Legal and Environmental Concerns:**

**A. Ethical Concerns**

- Human **germline editing** raises concerns about designer babies and alteration of future generations.
- Equity and affordability of advanced genetic therapies.
- Ethical issues surrounding embryonic stem cell research and cloning.

- Privacy and misuse of genetic information.

**B. Legal & Regulatory Concerns**

- Need for rigorous biosafety regulations governing research and commercial release.
- Intellectual Property Rights (IPRs) and patent issues affecting access to technology.
- Labelling and consumer choice regarding GM food products.
- Need for transparent, science-based regulatory approvals.

**C. Environmental Concerns**

- Gene flow from GM crops to wild relatives, affecting biodiversity.
- Evolution of pest resistance and herbicide-resistant weeds.
- Potential impacts on non-target organisms and beneficial insects.
- Reduction in genetic diversity due to large-scale monoculture cultivation.

**India's Regulatory Framework:**

| Framework / Institution | Role |
|---|---|
| **Environment (Protection) Act, 1986** | Provides the legal basis for regulating genetically engineered organisms. |
| **Rules, 1989** | Regulate research, field trials and environmental release of GM organisms. |
| **Genetic Engineering Appraisal Committee (GEAC)** | Apex body for environmental approval of GM crops and organisms. |
| **Department of Biotechnology (DBT)** | Promotes biotechnology research and issues biosafety guidelines. |
| **Food Safety and Standards Authority of India (FSSAI)** | Regulates food safety aspects relating to GM food products. |

**Critical Evaluation:**

**Opportunities**

- Enhances agricultural productivity and nutritional security.
- Accelerates development of affordable medicines and vaccines.
- Promotes innovation and strengthens India's bioeconomy.
- Supports climate-resilient agriculture and sustainable development.

**Challenges**

- Public concerns regarding long-term health and environmental impacts.

- Regulatory delays and policy uncertainty.
- Balancing innovation with biosafety and ethical safeguards.
- Need for greater public awareness and scientific communication.

Genetic engineering holds immense promise for addressing challenges in **food security and healthcare**, but its long-term acceptance depends on maintaining a **careful balance between scientific innovation and robust ethical, legal and environmental safeguards**. Responsible regulation and evidence-based policymaking are therefore essential to ensure that technological progress benefits society without compromising ecological integrity.

**Value Addition:**

**Bt Cotton** remains the **only GM crop approved for commercial cultivation in India**, reflecting India's cautious approach to agricultural biotechnology.

**CRISPR-Cas9** enables precise and efficient gene editing and earned its developers the **2020 Nobel Prize in Chemistry**.

**Cartagena Protocol on Biosafety (2000):** India is a Party to the Protocol, which regulates the safe transboundary movement and handling of **Living Modified Organisms (LMOs).**

**SDG Linkage:** Genetic engineering contributes to **SDG 2 (Zero Hunger), SDG 3 (Good Health), SDG 9 (Industry, Innovation & Infrastructure)** while necessitating safeguards consistent with **SDG 15 (Life on Land).**

**Q.7 (A). Advances in biomedical science have considerably improved disease prevention and healthcare outcomes. Discuss the role of vaccines, immunisation programmes and biotechnology in strengthening India's public health system.**

**Demand of the Question:**

- Discuss the role of **vaccines, immunisation programmes and biotechnology** in improving public health.
- Explain how these advances have strengthened **India's healthcare system**.

The **World Health Organization (WHO)** considers **immunisation one of the most cost-effective public health interventions**, preventing millions of deaths annually. In India, advances in **vaccines, biotechnology and digital health** have significantly strengthened disease prevention, reduced mortality and enhanced the resilience of the public health system.

**Role of Vaccines in Public Health:**

- **Prevent Communicable Diseases** such as polio, measles, diphtheria, hepatitis and cervical cancer.
- **Reduce Mortality and Morbidity**, especially among infants, children and pregnant women.
- **Herd Immunity** protects vulnerable populations by reducing disease transmission.
- **Cost-effective Intervention**, reducing long-term healthcare expenditure.
- **Pandemic Preparedness**, enabling rapid response to emerging infectious diseases.

**Role of Immunisation Programmes**

- **Universal Immunisation Programme (UIP)** provides free vaccination against major vaccine-preventable diseases.
- **Mission Indradhanush** and **Intensified Mission Indradhanush (IMI)** improve coverage among underserved and high-risk populations.
- **Pulse Polio Programme** enabled India to achieve **Polio-Free Certification (2014)**.
- Introduction of **Rotavirus, Pneumococcal Conjugate Vaccine (PCV), MR Vaccine and HPV Vaccine** has expanded protection against childhood diseases.
- **Digital platforms like U-WIN** strengthen beneficiary tracking, vaccine logistics and monitoring.

**Role of Biotechnology in Strengthening Public Health**

- **Indigenous Vaccine Development** (e.g., COVID-19 vaccines) enhanced India's health security.
- **Recombinant DNA Technology** enables production of vaccines, insulin and other biopharmaceuticals.
- **Molecular Diagnostics** facilitate early detection of infectious and genetic diseases.
- **Genomics and Precision Medicine** support personalised healthcare and disease surveillance.
- **Biopharmaceutical Research** accelerates innovation in therapeutics, diagnostics and regenerative medicine.

**Government Initiatives:**

| Initiative | Contribution |
|---|---|
| **Universal Immunisation Programme (UIP)** | Provides free vaccination against major vaccine-preventable diseases. |
| **Mission Indradhanush & Intensified Mission Indradhanush** | Improves immunisation coverage among children and pregnant women. |
| **U-WIN Platform** | Digital platform for vaccination records, beneficiary tracking and vaccine management. |
| **National Biopharma Mission** | Strengthens indigenous vaccine and biopharmaceutical research. |
| **BioE3 Policy (2024)** | Promotes biotechnology-led innovation for Economy, Employment and Environment. |
| **Ayushman Bharat** | Expands access to affordable healthcare, complementing preventive health initiatives. |

**Critical Evaluation:**

**Achievements-**

- Elimination of **Wild Polio** and **Maternal & Neonatal Tetanus**.

- Significant reduction in child mortality through expanded immunisation.
- Strong indigenous vaccine manufacturing capacity, making India a leading global vaccine producer.
- Improved digital health governance through **CoWIN** and **U-WIN** platforms.
- Enhanced pandemic preparedness and disease surveillance.

**Challenges**

- Vaccine hesitancy and misinformation in some communities.
- Gaps in immunisation coverage in remote and tribal areas.
- Cold-chain and last-mile delivery challenges.
- Need for higher investment in biomedical research and innovation.
- Emerging infectious diseases require continuous surveillance and vaccine development.

Advances in vaccines, immunisation and biotechnology have shifted India's public health strategy from **treatment-centric to prevention-oriented healthcare**. Sustained investments in **research, digital health, universal immunisation and indigenous biotechnology** will be crucial for building an **equitable, resilient and future-ready public health system** capable of addressing both existing and emerging health challenges.

**Value Addition:**

**Universal Immunisation Programme (1985)** is one of the **largest public immunisation programmes in the world**, covering millions of children and pregnant women annually.

**India's Vaccine Leadership:** India is often called the **"Vaccine Pharmacy of the World"**, supplying affordable vaccines to numerous countries.

**National One Health Mission** promotes integrated surveillance of **human, animal and environmental health** to combat emerging diseases.

**SDG Linkage:** Advances **SDG 3 (Good Health and Well-being), SDG 9 (Industry, Innovation & Infrastructure)** and **SDG 10 (Reduced Inequalities).**

**Q.7 (B). Emerging and re-emerging infectious diseases continue to threaten global health security. Examine the causes of disease outbreaks and evaluate India's preparedness to prevent and manage infectious diseases.**

**Demand of the Question:**

- Examine the **causes of emerging and re-emerging infectious diseases**.
- Evaluate **India's preparedness** to prevent, detect and manage infectious disease outbreaks.

The **World Health Organization (WHO)** has identified emerging and re-emerging infectious diseases as one of the greatest threats to global health security. Factors such as **climate change, rapid urbanisation, antimicrobial resistance and increased human-animal interactions** have accelerated the emergence of diseases like COVID-19, Nipah, Zika and Avian Influenza. Consequently, India has strengthened its public health system through **surveillance, vaccination and the One Health approach**.

**Causes of Disease Outbreaks:**

**1. Environmental & Ecological Factors**

- Climate change expands the geographical spread of **vector-borne diseases** such as dengue and malaria.
- Deforestation and habitat destruction increase **human-wildlife interactions**, facilitating zoonotic diseases.
- Rapid urbanisation and poor sanitation favour disease transmission.

**2. Globalisation & Mobility**

- International travel and trade accelerate cross-border spread of infectious diseases.
- High population density facilitates rapid community transmission.

**3. Microbial Evolution**

- Mutation of viruses leads to new variants with higher transmissibility.
- **Antimicrobial Resistance (AMR)** reduces the effectiveness of existing drugs.

**4. Weak Public Health Determinants**

- Low immunisation coverage in vulnerable populations.
- Inadequate disease surveillance in remote areas.
- Poor hygiene, unsafe water and malnutrition increase susceptibility.

**India's Preparedness for Infectious Disease Management:**

**1. Disease Surveillance -**

- **Integrated Disease Surveillance Programme (IDSP)** enables early detection and reporting of outbreaks.
- Expansion of genomic surveillance through the **INSACOG** network helps track emerging variants.
- AI-enabled digital surveillance strengthens real-time monitoring.

**2. Immunisation & Preventive Healthcare**

- **Universal Immunisation Programme (UIP)** protects against major vaccine-preventable diseases.
- **Mission Indradhanush** improves vaccination coverage in underserved areas.
- Indigenous vaccine development enhances national health security.

**3. Strengthening Healthcare Infrastructure**

- **Ayushman Bharat** strengthens primary healthcare through Health & Wellness Centres.
- Expansion of laboratory networks, ICU facilities and emergency response capacity.
- Improved stockpiling of essential medicines and medical equipment.

**4. One Health Approach**

- Integrates **human, animal and environmental health** for surveillance of zoonotic diseases.
- Strengthens coordination among health, veterinary and environmental agencies.

**5. Research & Biotechnology**

- Indigenous vaccine development and genomic research.
- Strengthening diagnostic capacity through biotechnology and molecular testing.

**Government Initiatives:**

| Initiative | Contribution |
|---|---|
| **Integrated Disease Surveillance Programme (IDSP)** | Early detection and reporting of disease outbreaks. |
| **National Centre for Disease Control (NCDC)** | Surveillance, epidemiological investigations and outbreak response. |
| **INSACOG** | Genomic surveillance of emerging pathogens and variants. |
| **Universal Immunisation Programme (UIP)** | Prevents major vaccine-preventable diseases through universal vaccination. |
| **National One Health Mission** | Integrated surveillance of human, animal and environmental health. |
| **Ayushman Bharat** | Strengthens primary healthcare and public health infrastructure. |

**Evaluation:**

**Strengths**

- Robust nationwide disease surveillance network.
- Strong vaccine manufacturing and immunisation capacity.
- Improved laboratory and genomic surveillance.
- Increasing adoption of digital health platforms and real-time reporting.
- Growing emphasis on the One Health approach.

**Challenges**

- Emerging threat of **Antimicrobial Resistance (AMR)**.
- Inadequate healthcare infrastructure in some rural and remote regions.
- Shortage of trained epidemiologists and public health professionals.
- Vaccine hesitancy and misinformation.
- Need for greater investment in public health research and pandemic preparedness.

In an increasingly interconnected world, preventing infectious diseases requires **proactive surveillance, resilient healthcare systems and coordinated global action**. By strengthening the **One Health approach, scientific research, universal immunisation and public health preparedness**, India can effectively safeguard both **national and global health security** against future disease outbreaks.

**Value Addition:**

**One Health Approach:** Recognises that **human, animal and environmental health are interconnected**, making multisectoral collaboration essential for preventing zoonotic diseases.

**Global Health Framework:** The **International Health Regulations (IHR), 2005** provide the global framework for surveillance, reporting and response to public health emergencies.

**AMR Challenge:** The **WHO** considers **Antimicrobial Resistance (AMR)** among the top global public health threats, requiring rational use of antibiotics and strengthened surveillance.

**SDG Linkage:** Supports **SDG 3 (Good Health & Well-being), SDG 6 (Clean Water & Sanitation)** and **SDG 17 (Global Partnerships).**

**Q.8 (A). Scientific innovation requires both encouragement and regulation. Discuss the importance of Intellectual Property Rights (IPR) in promoting scientific research and technological innovation while ensuring public interest.**

**Demand of the Question**

- Discuss the role of **Intellectual Property Rights (IPR)** in promoting **scientific research and technological innovation**.
- Explain how IPR should be balanced with **public interest and social welfare**.

The **World Intellectual Property Organization (WIPO)** defines Intellectual Property Rights (IPRs) as legal rights that protect creations of the mind, encouraging innovation by granting inventors exclusive rights for a limited period. For a knowledge-driven economy like India, an effective IPR regime is essential to foster **research, investment and technology transfer**, while ensuring that innovation remains **accessible, affordable and socially beneficial**.

**Importance of IPR in Scientific Research & Technological Innovation:**

**1. Promotes Innovation and Creativity**

- Provides legal protection and incentives for inventors and researchers.
- Encourages investment in high-risk research and development (R&D).
- Rewards creativity through exclusive commercial rights.

**2. Encourages Research & Development**

- Enables innovators to recover research investments.
- Attracts private sector participation in science and technology.
- Supports innovation in pharmaceuticals, biotechnology, AI and clean energy.

**3. Facilitates Technology Transfer**

- Encourages licensing and commercialization of new technologies.
- Promotes industry-academia collaboration.
- Enhances foreign investment and global technology partnerships.

**4. Economic Growth and Competitiveness**

- Strengthens the **knowledge economy** and startup ecosystem.
- Generates employment through innovation-driven industries.
- Improves global competitiveness and export potential.

**Need to Safeguard Public Interest**

**1. Affordable Access to Medicines**

- Prevent monopolistic pricing through **compulsory licensing** under the Patents Act, 1970.
- Ensure access to life-saving drugs during public health emergencies.

**2. Balance Innovation with Social Welfare**

- Encourage innovation without compromising public health and food security.
- Prevent misuse of patent rights and anti-competitive practices.

**3. Protect Traditional Knowledge**

- Prevent **biopiracy** through the **Traditional Knowledge Digital Library (TKDL)**.
- Recognise and protect indigenous knowledge systems.

**4. Promote Equitable Technology Access**

- Encourage affordable access to green technologies, agricultural innovations and educational resources.
- Ensure that publicly funded research benefits society at large.

**Government Initiatives:**

| Initiative | Contribution |
|---|---|
| **National IPR Policy, 2016** | Promotes innovation, awareness, commercialization and enforcement of IPRs. |
| **Patents Act, 1970 (as amended)** | Balances patent protection with public interest through provisions such as compulsory licensing. |
| **Start-up India** | Facilitates patent filing support, fast-track examination and reduced fees for startups. |
| **Traditional Knowledge Digital Library (TKDL)** | Protects India's traditional medicinal knowledge from biopiracy. |
| **Patent (Amendment) Rules** | Simplify and expedite patent examination procedures. |
| **Atal Innovation Mission (AIM)** | Promotes innovation, entrepreneurship and technology development. |

**Critical Evaluation:**

**Benefits**

- Encourages scientific research and technological advancement.
- Strengthens India's innovation ecosystem and startup culture.
- Promotes commercialization of research and technology transfer.
- Enhances global competitiveness and attracts investment.

**Concerns**

- High cost of patented medicines and technologies.
- Patent evergreening and anti-competitive practices.
- Limited awareness of IPR among researchers, MSMEs and startups.
- Need to balance innovation incentives with public welfare.

An effective IPR regime should strike a **careful balance between rewarding innovation and protecting public interest**. By encouraging scientific research while ensuring affordable access to essential technologies, India can foster an innovation ecosystem that is **competitive, inclusive and socially responsible**.

**Value Addition:**

**India's IPR Regime** is **TRIPS-compliant**, while retaining safeguards such as **compulsory licensing** and **Section 3(d)** of the Patents Act to prevent evergreening of pharmaceutical patents.

**Traditional Knowledge Digital Library (TKDL)** has successfully prevented **biopiracy** by documenting India's traditional medicinal knowledge and making it accessible to patent offices worldwide.

**Global Framework:** The **WTO's TRIPS Agreement** establishes minimum international standards for the protection and enforcement of Intellectual Property Rights.

**SDG Linkage:** IPR supports **SDG 9 (Industry, Innovation & Infrastructure), SDG 3 (Good Health & Well-being)** and **SDG 8 (Decent Work & Economic Growth).**

**Q.8 (B). Scientific temper, innovation and technology have become essential drivers of national development. Evaluate the initiatives taken by India and Andhra Pradesh to promote science, research and innovation.**

**Demand of the Question:**

- Explain the importance of **scientific temper, innovation and technology** in national development.
- Evaluate the initiatives taken by **India and Andhra Pradesh** to promote **science, research and innovation**.

**Article 51A(h)** of the Constitution makes it a **Fundamental Duty** of every citizen to develop the **scientific temper, humanism and the spirit of inquiry and reform**. In the knowledge-driven economy of the 21st century, scientific innovation has become a key determinant of **economic growth, technological self-reliance and global competitiveness**.

**Importance of Scientific Temper, Innovation & Technology**

- Drives **economic growth** through productivity and value addition.
- Promotes **self-reliance** in strategic sectors such as defence, space, biotechnology and semiconductors.
- Improves governance through **Digital Public Infrastructure (DPI)** and e-Governance.
- Addresses societal challenges in **healthcare, agriculture, energy and climate resilience**.
- Creates **high-skilled employment** and strengthens the startup ecosystem.

**Government of India Initiatives:**

| Initiative | Contribution |
|---|---|
| **National Education Policy (NEP), 2020** | Promotes research, critical thinking, innovation and multidisciplinary education. |
| **Anusandhan National Research Foundation (ANRF)** | Strengthens research funding and academia-industry collaboration. |
| **Atal Innovation Mission (AIM)** | Establishes Atal Tinkering Labs and Atal Incubation Centres to nurture innovation. |
| **BioE3 Policy (2024)** | Promotes biotechnology-led innovation for Economy, Employment and Environment. |
| **National Quantum Mission** | Develops indigenous capabilities in quantum computing, communication and sensing. |
| **IndiaAI Mission** | Promotes AI infrastructure, innovation and skill development. |
| **Startup India** | Encourages technology-based entrepreneurship and innovation. |

**Initiatives by Andhra Pradesh:**

| Initiative | Contribution |
|---|---|
| **AP Information Technology Policy (2024–29)** | Promotes investments in AI, electronics, cloud computing and emerging technologies. |
| **AP Drone Policy 4.0 (2024–29)** | Positions Andhra Pradesh as a national hub for drone manufacturing, R&D and skill development. |
| **AI University at Amaravati (Proposed)** | Develops advanced research and skilled human resources in Artificial Intelligence. |
| **Google–AP Collaboration** | Supports AI-enabled governance, digital skilling and innovation ecosystems. |
| **Meta–AP Partnership** | Expands citizen-centric digital public services through WhatsApp-based governance. |
| **Innovation & Startup Ecosystem** | Encourages incubation, entrepreneurship and industry-academia collaboration through universities and innovation centres. |

**Evaluation:**

**Achievements -**

- Rapid growth of India's **startup and innovation ecosystem**.
- Global leadership in **Digital Public Infrastructure** such as Aadhaar and UPI.
- Significant progress in **space technology, biotechnology, AI and digital governance**.
- Andhra Pradesh emerging as a destination for **AI, drones and electronics manufacturing**.
- Greater collaboration between academia, industry and government.

**Challenges**

- India's **R&D expenditure remains below 1% of GDP**, lower than many innovation-driven economies.
- Limited private sector investment in research.
- Brain drain of highly skilled researchers.
- Regional disparities in innovation infrastructure.
- Need for stronger industry-academia collaboration and commercialization of research.

Scientific temper and innovation are the **foundation of a knowledge-based society**. By nurturing research, encouraging entrepreneurship and investing in emerging technologies, India and Andhra Pradesh can build an **innovation-driven economy** capable of delivering sustainable growth, technological self-reliance and improved quality of life for their citizens.

**Value Addition:**

**Constitutional Basis: Article 51A(h)** makes the development of **scientific temper, humanism and the spirit of inquiry** a Fundamental Duty.

**Innovation Ecosystem:** India ranks among the **top 40 countries in the Global Innovation Index**, reflecting steady progress in innovation capacity.

**National Vision: Anusandhan National Research Foundation (ANRF)** seeks to strengthen India's research ecosystem by fostering collaboration between universities, research institutions and industry.

**SDG Linkage:** Promotes **SDG 4 (Quality Education), SDG 8 (Decent Work), SDG 9 (Industry, Innovation & Infrastructure)** and **SDG 17 (Partnerships for the Goals).**