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BPSC Mains General Studies – Science & Technology

General Studies Paper-II

Section III: Science & Technology

Topic: India's Space Programme and Space Governance

Structured Notes for **BPSC Mains Examination**

Prepared for serious aspirants focusing on **concept clarity, cultural understanding and answer writing preparation**.

These notes cover important topics of **India's Space Programme and Space Governance** relevant for **BPSC Mains GS Paper-II**.

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LESSON 1: INDIA'S SPACE PROGRAMME AND SPACE GOVERNANCE

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1. Foundations and launch systems

1.1 Indian Space Programme

1. Introduction

India's Space Programme is one of the world's most successful and cost-effective space programmes, aimed at harnessing space technology for national development, scientific advancement, and strategic self-reliance. Unlike many space-faring nations that initially pursued space exploration primarily for military or geopolitical competition, India adopted a development-oriented approach, using space technology to address the socio-economic needs of its people.

The programme is administered by the **Department of Space (DoS)** under the Government of India and is primarily implemented by the **Indian Space Research Organisation (ISRO)**, established on **15 August 1969**. Over the decades, ISRO has developed indigenous capabilities in satellite design, launch vehicle technology, remote sensing, satellite communication, navigation, planetary exploration, and human spaceflight.

The foundation of India's space vision was laid by **Dr. Vikram Sarabhai**, widely regarded as the *Father of the Indian Space Programme*. He believed that a developing country should utilize advanced technologies not merely for prestige but as powerful tools for improving the quality of life through better communication, education, weather forecasting, natural resource management, and disaster mitigation. This philosophy continues to guide India's space activities even today. India's space programme is based on four fundamental principles:

- **Peaceful use of outer space** for the benefit of humanity.
- **Development-oriented applications** to support socio-economic growth.
- **Self-reliance (Atmanirbharta)** through indigenous research and technological innovation.
- **Cost-effective and sustainable space missions** without compromising reliability and scientific excellence.

Today, India has emerged as a leading global space power with achievements such as the **Mars Orbiter Mission (Mangalyaan)**, **Chandrayaan missions**, **Aditya-L1**, and the ongoing **Gaganyaan Human Spaceflight Programme**. The opening of the space sector to private participation and the growing role of Indian space start-ups have further accelerated the country's ambition of becoming a major player in the global space economy.

In essence, India's Space Programme is not merely about exploring outer space; it is a strategic instrument for **national development, technological advancement, scientific research, economic growth, disaster resilience, and enhancing India's global stature as a responsible and innovative space-faring nation**.

2. Evolution of the Indian Space Programme

India's Space Programme has evolved gradually over the past six decades through continuous scientific innovation, institutional development, and technological self-reliance.

What began as a modest research initiative has transformed into one of the world's most successful and economical space programmes. The evolution of the programme can be understood in the following phases:

Foundation Phase (1960–1970): This phase marked the beginning of organized space research in India.

- In **1962**, the **Indian National Committee for Space Research (INCOSPAR)** was established under the leadership of **Dr. Vikram Sarabhai** with the support of the Department of Atomic Energy.
- The objective was to explore the peaceful applications of space technology for national development.
- In **1963**, India's first **sounding rocket** was launched from the **Thumba Equatorial Rocket Launching Station (TERLS)** in Kerala.
- During this period, India mainly relied on international cooperation while building indigenous scientific capabilities.

Institutional Development Phase (1969–1980): This phase witnessed the establishment of dedicated space institutions and the beginning of satellite development.

- On **15 August 1969**, the **Indian Space Research Organisation (ISRO)** was established, replacing INCOSPAR.
- In **1972**, the **Department of Space (DoS)** and the **Space Commission** were created to provide administrative and policy support.
- In **1975**, India launched its first satellite, **Aryabhata**, with assistance from the Soviet Union.
- Other early satellites, such as **Bhaskara-I** and **Bhaskara-II**, were launched for Earth observation and scientific research.
- In **1980**, India successfully launched the **Rohini Satellite (RS-1)** using the indigenously developed **SLV-3**, making India one of the few countries capable of launching its own satellites.

Expansion and Application Phase (1980–2005): During this phase, the focus shifted from experimentation to practical applications of space technology.

- Development of the **INSAT (Indian National Satellite System)** revolutionized communication, television broadcasting, meteorology, and telecommunication.
- The **Indian Remote Sensing (IRS)** satellite programme became one of the world's largest civilian remote sensing programmes.
- Development of the **Polar Satellite Launch Vehicle (PSLV)** significantly enhanced India's launch capability.
- Satellite technology began supporting agriculture, water resource management, fisheries, disaster management, education, and healthcare.
- India gradually achieved greater technological self-reliance in satellite manufacturing and launch services.

Global Recognition Phase (2005–2020): This period marked India's emergence as a globally respected space power.

- In **2008**, **Chandrayaan-1** became India's first lunar mission and confirmed the presence of water molecules on the Moon.
- The **Mars Orbiter Mission (Mangalyaan)**, launched in **2013** and successfully entering Mars orbit in **2014**, made India the **first country to reach Mars in its maiden attempt**.
- PSLV gained international recognition for its reliability by launching hundreds of foreign satellites.
- India successfully developed **cryogenic engine technology**, strengthening its heavy-lift launch capability through GSLV.
- Indigenous satellite navigation system **NavIC** was established.

New Space Era (2020–Present): The current phase is characterized by commercialization, private sector participation, human spaceflight, and advanced space exploration.

- The Government opened the space sector to **private companies and start-ups**.
- Institutions like **IN-SPACe** and **NewSpace India Limited (NSIL)** were established to promote commercial activities.
- **Chandrayaan-3 (2023)** successfully achieved a soft landing near the Moon's south pole, making India the **first country** to land in this region.
- **Aditya-L1 (2023)** became India's first dedicated solar observation mission.
- **SpaDeX (Space Docking Experiment)** demonstrated India's capability in autonomous satellite docking, an important technology for future space stations and human missions.
- The **Gaganyaan Mission** is preparing India for its first human spaceflight.
- India is also working towards establishing the **Bharatiya Antariksh Station** and undertaking future lunar and planetary exploration missions.

Timeline of Major Milestones

Year	Milestone
1962	Establishment of INCOSPAR
1963	First sounding rocket launched from Thumba
1969	Establishment of ISRO
1972	Creation of Department of Space and Space Commission
1975	Launch of Aryabhata, India's first satellite
1980	Rohini satellite launched using SLV-3
1994	First successful PSLV mission
2008	Chandrayaan-1 launched
2014	Mars Orbiter Mission successfully entered Mars orbit
2016	NavIC declared operational
2020	Space sector opened to private participation
2023	Chandrayaan-3 soft landing near Moon's south pole
2023	Launch of Aditya-L1

Year	Milestone
2024	SpaDeX mission demonstrated autonomous space docking capability

India's space programme reflects a remarkable journey from launching sounding rockets with international assistance to independently executing complex planetary missions and preparing for human spaceflight. Its evolution highlights the country's commitment to scientific excellence, self-reliance, and the peaceful use of space for national development.

3. Vision and Guiding Principles of India's Space Programme

India's Space Programme is guided by the vision of using space technology for national development while promoting scientific excellence, self-reliance, and the peaceful exploration of outer space.

Vision of India's Space Programme

The vision of the Indian Space Programme, as envisaged by **Dr. Vikram Sarabhai**, is to harness space technology for the socio-economic development of the country rather than treating space exploration merely as a symbol of national prestige. The programme aims to improve governance, communication, resource management, disaster preparedness, scientific research, and enhance India's strategic capabilities.

Guiding Principles

The Indian Space Programme is based on the following guiding principles:

- **Peaceful use of outer space** for the benefit of humanity.
- **Development-oriented approach**, focusing on communication, agriculture, weather forecasting, disaster management, and education.
- **Self-reliance (Atmanirbhar Bharat)** through indigenous development of satellites, launch vehicles, and space technologies.
- **Cost-effective innovation**, delivering world-class missions at comparatively lower costs.
- **International cooperation** while safeguarding national interests.
- **Sustainable and responsible use of outer space**, in accordance with international space laws and best practices.

These guiding principles have enabled India to emerge as a globally respected space power while ensuring that space technology directly contributes to national development and public welfare.

4. Institutional Framework of India's Space Programme

India's space programme is governed through a well-defined institutional framework comprising government bodies, research organizations, public sector enterprises, and private entities.

Department of Space (DoS)

- Established in **1972** under the **Prime Minister's Office (PMO)**.
- Formulates policies and oversees India's space activities.
- Provides administrative and financial support to ISRO and other space institutions.
- Coordinates national space programmes and international cooperation.

Indian Space Research Organisation (ISRO)

- Established on **15 August 1969**.
- Nodal agency responsible for implementing India's space programme.
- Develops satellites, launch vehicles, space applications, and scientific missions.
- Executes major missions such as **Chandrayaan, Mangalyaan, Aditya-L1, and Gaganyaan**.

Space Commission

- Constituted in **1972**.
- Apex policy-making body for India's space programme.
- Advises the Government on space policy, long-term planning, and resource allocation.
- Provides strategic direction for national space activities.

NewSpace India Limited (NSIL)

- Incorporated in **2019** as a Government of India enterprise.
- Commercial arm of the Department of Space.
- Markets ISRO's technologies, satellites, and launch services.
- Promotes commercialization of India's space capabilities.

Indian National Space Promotion and Authorization Centre (IN-SPACe)

- Established in **2020**.
- Autonomous agency under the Department of Space.
- Facilitates and regulates the participation of private companies in the space sector.
- Ensures fair access to ISRO's infrastructure and expertise.

Antrix Corporation Limited

- Established in **1992**.
- Former commercial arm of ISRO.
- Promoted international marketing of ISRO's products and services.
- Many of its commercial functions are now handled by **NSIL**.

Private Sector and Space Start-ups

- Participation increased after the **2020 space sector reforms**.
- Develop launch vehicles, satellites, propulsion systems, and space applications.

- Supported through policy reforms, IN-SPACe, and government initiatives.
- Contribute to innovation, employment, and the growth of India's space economy.

Together, these institutions ensure policy formulation, research, regulation, commercialization, and private sector participation, making India's space programme efficient, self-reliant, and globally competitive.

5. Major Space Infrastructure of India

India has developed a robust space infrastructure that supports satellite development, launch operations, mission control, tracking, and space research.

Launch Centres

- **Satish Dhawan Space Centre (SDSC), Sriharikota (Andhra Pradesh)** – India's primary spaceport for launching satellites and launch vehicles such as PSLV, GSLV, and LVM3.
- **Kulasekarapattinam Spaceport (Tamil Nadu)** *(under development)* – Being developed mainly for launching Small Satellite Launch Vehicles (SSLVs) into polar orbits.

Mission Control and Tracking Facilities

- **ISTRAC (ISRO Telemetry, Tracking and Command Network), Bengaluru** – Tracks and controls satellites and deep space missions.
- **Master Control Facility (MCF), Hassan and Bhopal** – Manages geostationary communication and navigation satellites.

Satellite Design and Research Centres

- **U. R. Rao Satellite Centre (URSC), Bengaluru** – Designs and develops satellites.
- **Space Applications Centre (SAC), Ahmedabad** – Develops satellite payloads and space applications for communication and remote sensing.
- **Physical Research Laboratory (PRL), Ahmedabad** – Conducts research in space science, astronomy, and planetary sciences.

Launch Vehicle and Propulsion Centres

- **Vikram Sarabhai Space Centre (VSSC), Thiruvananthapuram** – Lead centre for launch vehicle design and development.
- **Liquid Propulsion Systems Centre (LPSC)** – Develops liquid and cryogenic propulsion systems.
- **ISRO Propulsion Complex (IPRC), Mahendragiri** – Tests rocket engines and propulsion systems.

National Data and Application Centres

- **National Remote Sensing Centre (NRSC), Hyderabad** – Receives, processes, and disseminates satellite data for agriculture, disaster management, urban planning, and natural resource management.
- Supports various government departments through satellite-based geospatial services.

India's extensive space infrastructure provides end-to-end capabilities—from designing satellites and launch vehicles to launching, tracking, and utilizing space assets for national development.

6. Satellite Systems of India

India has developed a diverse range of satellite systems to support communication, navigation, weather forecasting, Earth observation, scientific research, and national security. These satellites play a crucial role in socio-economic development and strategic applications.

Communication Satellites (INSAT & GSAT Series): INSAT (Indian National Satellite System) was launched in **1983** and is one of the largest domestic communication satellite systems in the Asia-Pacific region. **GSAT** satellites are the newer generation of communication satellites. Placed mainly in **Geostationary Orbit (GEO)**.

Major Applications

- Television broadcasting
- DTH services
- Mobile and broadband communication
- Telemedicine and tele-education
- Disaster warning services
- Secure communication for strategic agencies

Remote Sensing Satellites (IRS & EOS Series): IRS (Indian Remote Sensing Satellite) programme began in **1988** with **IRS-1A**. India operates one of the **largest civilian remote sensing satellite constellations** in the world. New satellites are designated as **EOS (Earth Observation Satellites)**.

Major Applications

- Agriculture and crop monitoring
- Water resource management
- Forest and biodiversity conservation
- Urban and regional planning
- Disaster management
- Mineral exploration
- Environmental monitoring

Navigation Satellites (NavIC): NavIC (Navigation with Indian Constellation) is India's indigenous regional navigation system. Earlier known as **IRNSS (Indian Regional Navigation Satellite System)**. Provides accurate positioning over **India and up to 1,500 km beyond its borders**. Offers **Standard Positioning Service (SPS)** and **Restricted Service (RS)**.

Major Applications

- Road, rail, air, and maritime navigation
- Fleet management
- Disaster warning
- Fisheries
- Defence and strategic operations

Meteorological Satellites: Mainly include **INSAT**, **Kalpana**, and **INSAT-3D/3DR** series. Continuously monitor weather systems over the Indian region.

Major Applications

- Weather forecasting
- Cyclone tracking
- Monsoon monitoring
- Rainfall estimation
- Climate studies
- Early warning of extreme weather events

Scientific and Space Exploration Satellites: Developed for scientific research, astronomy, planetary exploration, and solar studies. Strengthen India's capabilities in space science and deep-space exploration.

Major Missions

- **AstroSat** – India's first dedicated space observatory.
- **Chandrayaan-1** – Confirmed the presence of water molecules on the Moon.
- **Aditya-L1** – India's first solar observation mission.
- **XPoSat** – India's first X-ray Polarimetry satellite for studying black holes and neutron stars.

Defence and Strategic Satellites: Developed to enhance national security and defence preparedness. Operated in coordination with defence agencies.

Major Satellites

- **GSAT-7 (Rukmini)** – Indian Navy.
- **GSAT-7A** – Indian Air Force.
- **EMISAT** – Electronic Intelligence (ELINT) satellite.
- **RISAT Series** – Radar Imaging Satellites capable of day-and-night, all-weather surveillance.

Major Applications

- Border surveillance
- Maritime security
- Intelligence gathering
- Secure military communication
- Disaster response

7. Launch Vehicle Programme

India's launch vehicle programme is the backbone of its space missions. Launch vehicles are rockets designed to carry satellites and spacecraft into different orbits. Over the years, ISRO has developed a series of indigenous launch vehicles with increasing payload capacity and technological sophistication.

Satellite Launch Vehicle (SLV)

The **Satellite Launch Vehicle (SLV-3)** was India's first experimental satellite launch vehicle. It successfully launched the **Rohini Satellite (RS-1)** into Low Earth Orbit in **1980**, making India the sixth country capable of launching satellites using an indigenously developed rocket. Though it had a limited payload capacity of about **40 kg**, SLV laid the foundation for India's future launch vehicle programme.

Augmented Satellite Launch Vehicle (ASLV)

The **Augmented Satellite Launch Vehicle (ASLV)** was developed to improve the payload capacity of SLV. It could place satellites weighing around **150 kg** into Low Earth Orbit. Although the programme experienced several failures, it helped ISRO master critical technologies such as stage separation, guidance, and control systems, which later proved essential for the success of PSLV.

Polar Satellite Launch Vehicle (PSLV)

The **Polar Satellite Launch Vehicle (PSLV)** is regarded as the **'Workhorse of ISRO'** due to its exceptional reliability and versatility. First successfully launched in **1994**, PSLV is capable of placing satellites into **Polar Sun-Synchronous Orbit (SSO)** as well as Low Earth Orbit. It has launched numerous Indian and foreign satellites and successfully carried out prestigious missions such as **Chandrayaan-1**, **Mars Orbiter Mission (Mangalyaan)**, **AstroSat**, and **Aditya-L1**. It is also known for launching **104 satellites in a single mission (2017)**, a world record at the time.

Geosynchronous Satellite Launch Vehicle (GSLV)

The **Geosynchronous Satellite Launch Vehicle (GSLV)** was developed to launch heavier communication satellites into **Geostationary Transfer Orbit (GTO)**. A major achievement of the programme was the successful development of an **indigenous cryogenic engine**, enabling India to reduce dependence on foreign technology. GSLV significantly enhanced India's capability to launch high-capacity communication and meteorological satellites.

Launch Vehicle Mark-3 (LVM3)

Earlier known as **GSLV Mk III**, **LVM3** is India's most powerful operational launch vehicle. It can carry heavy payloads to Low Earth Orbit and Geostationary Transfer Orbit. LVM3 successfully launched **Chandrayaan-2**, **Chandrayaan-3**, and is the designated launch vehicle for the **Gaganyaan Human Spaceflight Mission**. It is also being increasingly used for commercial satellite launches.

Small Satellite Launch Vehicle (SSLV)

The **Small Satellite Launch Vehicle (SSLV)** is India's latest launch vehicle, designed to launch **small satellites** into Low Earth Orbit. It is characterized by low cost, shorter preparation time, and quick turnaround, making it suitable for the rapidly growing commercial small satellite market. SSLV aims to strengthen India's competitiveness in the global NewSpace economy.

Reusable Launch Vehicle (RLV)

The **Reusable Launch Vehicle (RLV)** is an experimental programme aimed at developing reusable space transportation systems. By recovering and reusing major components of the launch vehicle, ISRO seeks to significantly reduce the cost of satellite launches. The successful **RLV-LEX (Landing Experiment)** has demonstrated India's progress towards reusable launch technology.

India's launch vehicle programme has evolved from small experimental rockets to advanced heavy-lift launch systems capable of supporting commercial launches, planetary exploration, and future human spaceflight missions, reflecting the country's growing technological self-reliance.

8. Major Space Missions of India

India's space missions reflect the country's growing capabilities in satellite technology, planetary exploration, astronomy, solar studies, and human spaceflight. These missions have enhanced India's scientific knowledge, technological expertise, and global standing in space exploration.

Aryabhata (1975)

Aryabhata was India's first satellite, launched on **19 April 1975** with Soviet assistance. Named after the ancient Indian mathematician and astronomer, the mission marked India's entry into the space age. It provided valuable experience in satellite design and space technology, laying the foundation for future indigenous satellite programmes.

Chandrayaan Programme

The **Chandrayaan Programme** represents India's lunar exploration efforts. **Chandrayaan-1 (2008)** discovered evidence of water molecules on the Moon, a landmark scientific achievement. **Chandrayaan-2 (2019)** successfully placed an orbiter around the Moon, although the lander did not achieve a soft landing. **Chandrayaan-3 (2023)** successfully landed near the Moon's south pole, making India the **first country** to achieve a soft landing in this region and the **fourth country** to successfully soft-land on the Moon.

Mars Orbiter Mission (Mangalyaan)

Launched in **2013**, the **Mars Orbiter Mission (Mangalyaan)** entered Mars orbit in **2014**, making India the **first country in the world to reach Mars in its maiden attempt** and the **first Asian nation** to successfully reach Mars orbit. The mission demonstrated India's capability to undertake complex interplanetary missions at a remarkably low cost and earned global recognition for its cost-effectiveness.

AstroSat

Launched in **2015**, **AstroSat** is India's first dedicated multi-wavelength space observatory. It studies celestial objects such as black holes, neutron stars, galaxies, and distant stars across multiple wavelengths, including ultraviolet and X-rays. AstroSat has significantly contributed to India's capabilities in space astronomy.

NavIC Mission

NavIC (Navigation with Indian Constellation) is India's indigenous regional navigation satellite system. It provides accurate positioning and timing services over India and surrounding regions. NavIC supports transportation, disaster management, fisheries, defence, and various civilian applications, reducing India's dependence on foreign navigation systems like GPS.

Aditya-L1 Mission

Launched in **2023**, **Aditya-L1** is India's first dedicated solar observation mission. Positioned at the **Lagrange Point (L1)**, approximately **1.5 million km** from Earth, it studies the Sun's corona, solar wind, solar flares, and space weather. The mission is expected to improve understanding of solar activities and their impact on Earth's communication and navigation systems.

XPoSat Mission

Launched in **2024**, **XPoSat (X-ray Polarimeter Satellite)** is India's first mission dedicated to studying the polarization of X-rays emitted by celestial sources such as black holes and neutron stars. It strengthens India's capabilities in high-energy astrophysics and complements observations made by AstroSat.

SpaDeX Mission

The **Space Docking Experiment (SpaDeX)** is a technology demonstration mission aimed at achieving autonomous docking and undocking of two spacecraft in orbit. This capability is essential for future human spaceflight, space stations, satellite servicing, and deep-space exploration missions. The successful demonstration marked a major technological milestone for India.

Gaganyaan Mission

The **Gaganyaan Mission** is India's first human spaceflight programme. It aims to send Indian astronauts (**Gagannauts**) into Low Earth Orbit aboard an indigenously developed spacecraft using the **LVM3** launch vehicle. The mission will make India one of the few countries with independent human spaceflight capability and is a significant step towards establishing an Indian space station.

Future Missions

India's future space roadmap includes the **NISAR Mission** (jointly with NASA) for Earth observation, **Shukrayaan-1** for the exploration of Venus, **Chandrayaan-4** for lunar sample return technologies, **Mangalyaan-2** for advanced Mars exploration, and the proposed **Bharatiya Antariksh Station** by **2035**. These missions reflect India's ambition to become a leading global space power through scientific research, technological innovation, and international collaboration.

India's space missions demonstrate a balanced approach that combines scientific discovery, technological advancement, commercial opportunities, and national development, establishing the country as one of the world's leading space-faring nations.

9. Applications of Space Technology in India

Space technology has become an integral part of India's socio-economic development. Satellites and space-based services support governance, economic growth, disaster resilience, environmental conservation, and national security. The applications of space technology extend across almost every sector of the economy.

Communication: Satellite communication has revolutionized India's communication infrastructure by providing reliable connectivity across the country, including remote and inaccessible regions. Communication satellites of the **INSAT** and **GSAT** series support television broadcasting, Direct-to-Home (DTH) services, internet connectivity, mobile communication, telecommunication networks, and satellite-based communication during emergencies. They also facilitate telemedicine, tele-education, and e-Governance services, thereby promoting inclusive development.

Agriculture: Remote sensing satellites play a crucial role in modern agriculture. Satellite imagery is used for crop acreage estimation, crop health monitoring, soil moisture assessment, irrigation planning, drought assessment, and yield forecasting. Programmes such as **FASAL (Forecasting Agricultural Output using Space, Agro-meteorology and Land-based Observations)** utilize satellite data for agricultural planning. Space technology also assists in identifying suitable areas for horticulture, watershed development, and precision farming.

Water Resources Management: Satellite data helps in mapping rivers, lakes, reservoirs, groundwater potential zones, and watersheds. It supports planning for irrigation projects, rainwater harvesting, floodplain mapping, and sustainable water resource management.

Remote sensing is extensively used under programmes like the **National Hydrology Project** for efficient water management.

Disaster Management: Space technology is an indispensable tool for disaster risk reduction and emergency response. Satellites provide early warning of cyclones, floods, droughts, forest fires, landslides, and tsunamis. During disasters, satellite images help in damage assessment, rescue operations, relief planning, and rehabilitation. The Decision Support Centre (DSC) and National Remote Sensing Centre (NRSC) provide near real-time satellite data to disaster management agencies.

Weather Forecasting and Climate Studies: Meteorological satellites continuously monitor cloud movement, rainfall patterns, cyclones, monsoon systems, and atmospheric conditions. Satellites such as **INSAT-3D** and **INSAT-3DR** have significantly improved the accuracy of weather forecasting and early warning systems. These services are particularly important for agriculture, aviation, shipping, fisheries, and disaster preparedness.

Navigation and Transportation: India's indigenous navigation system **NavIC** provides accurate positioning, navigation, and timing services. It supports road transport, railways, aviation, maritime navigation, fleet management, logistics, disaster alerts, and emergency services. NavIC is also used by fishermen for navigation and safety in coastal waters and has strategic applications in defence.

Fisheries: Satellite-based ocean observation helps identify **Potential Fishing Zones (PFZs)** by analyzing sea surface temperature and chlorophyll concentration. These advisories enable fishermen to locate fish-rich areas, reducing fuel consumption, increasing income, and improving marine resource management. Satellite communication also provides weather alerts to enhance fishermen's safety.

Urban and Regional Planning: Remote sensing and Geographic Information Systems (GIS) are widely used for urban planning, land-use mapping, infrastructure development, smart city planning, transportation network design, and monitoring unauthorized constructions. Satellite data supports sustainable urban development and efficient utilization of land resources.

Environmental Monitoring: Space technology enables continuous monitoring of forests, biodiversity, wetlands, glaciers, coastal ecosystems, desertification, air pollution, and climate change. Satellite observations help assess deforestation, monitor wildlife habitats, detect forest fires, and evaluate environmental degradation. Such information supports evidence-based environmental policymaking and conservation efforts.

Education: Satellite communication has expanded access to quality education, particularly in remote and rural areas. Educational programmes delivered through satellites support distance learning, digital classrooms, teacher training, and higher education. Initiatives such as **EDUSAT** have strengthened educational outreach across the country.

Healthcare: Satellite technology facilitates **telemedicine**, enabling specialist doctors in urban hospitals to provide medical consultation to patients in remote and inaccessible regions. It also supports healthcare management during disasters and public health emergencies by ensuring uninterrupted communication and coordination among medical institutions.

Defence and National Security: Space technology has become an important component of India's defence infrastructure. Satellites provide secure communication, surveillance, border monitoring, maritime domain awareness, reconnaissance, intelligence gathering, and navigation support for the armed forces. Satellites such as **GSAT-7**, **GSAT-7A**, **EMISAT**, and **RISAT** enhance India's strategic preparedness and national security.

Governance and Public Administration: Satellite-based applications improve governance by supporting land records management, rural development, infrastructure monitoring, mineral exploration, census activities, and implementation of government schemes. Geospatial technologies are increasingly used for evidence-based policy formulation and efficient public service delivery.

Scientific Research and Space Exploration: Scientific satellites such as **AstroSat**, **Aditya-L1**, and planetary missions like **Chandrayaan** and **Mangalyaan** have significantly enhanced India's capabilities in astronomy, planetary science, solar physics, and space research. These missions contribute to global scientific knowledge while promoting indigenous technological innovation.

Commercial and Economic Development: India's space programme has emerged as an important contributor to the economy through commercial satellite launches, satellite manufacturing, geospatial services, and the growing space start-up ecosystem. With policy reforms and increased private sector participation, the Indian space sector is expected to become a major contributor to the global space economy.

The applications of space technology in India extend far beyond space exploration. From improving agricultural productivity and disaster preparedness to strengthening national security and digital connectivity, space technology has become a powerful instrument for inclusive development and sustainable growth. Its expanding role in governance, commerce, scientific research, and strategic affairs highlights its importance in achieving India's vision of becoming a technologically advanced and self-reliant nation.

10. Major Achievements of India's Space Programme

India's Space Programme has achieved remarkable milestones in satellite technology, launch vehicles, planetary exploration, and commercial space services. These achievements have established India as one of the leading space-faring nations while demonstrating its capability to undertake complex missions in a cost-effective manner.

Development of Indigenous Space Technology

One of the greatest achievements of India's space programme is the development of indigenous capabilities in designing and manufacturing satellites, launch vehicles, cryogenic engines, navigation systems, and space applications. Despite international technology restrictions, India has achieved a high degree of self-reliance in critical space technologies.

Successful Launch Vehicle Programme

ISRO has developed a series of reliable launch vehicles, including **PSLV**, **GSLV**, **LVM3**, and **SSLV**. The **PSLV**, popularly known as the **'Workhorse of ISRO'**, has earned a global reputation for its reliability by successfully launching hundreds of Indian and foreign satellites. The successful development of the indigenous cryogenic engine further strengthened India's heavy-lift launch capability.

Advancement in Satellite Technology

India has established one of the world's largest civilian satellite programmes. Communication satellites (INSAT/GSAT), Earth observation satellites (IRS/EOS), navigation satellites (NavIC), meteorological satellites, and scientific satellites have significantly contributed to communication, agriculture, disaster management, weather forecasting, resource mapping, and national security.

Landmark Planetary Missions

India has successfully carried out several prestigious deep-space missions. **Chandrayaan-1** confirmed the presence of water molecules on the Moon, while **Chandrayaan-3** achieved a historic soft landing near the Moon's south pole in 2023, making India the first country to reach this region. The **Mars Orbiter Mission (Mangalyaan)** made India the first country to reach Mars orbit in its maiden attempt and the first Asian nation to successfully accomplish the feat.

Development of Indigenous Navigation System

The successful deployment of **NavIC (Navigation with Indian Constellation)** marked a significant achievement in navigation technology. It provides accurate positioning services over India and neighbouring regions, reducing dependence on foreign navigation systems such as GPS and enhancing both civilian and strategic capabilities.

Advancement in Space Science

Scientific missions such as **AstroSat**, **Aditya-L1**, and **XPoSat** have expanded India's capabilities in astronomy, solar physics, and high-energy astrophysics. These missions have enabled Indian scientists to contribute significantly to global space research.

Commercial Success in the Global Space Market

India has emerged as a trusted provider of affordable satellite launch services. Through **Antrix Corporation** and later **NewSpace India Limited (NSIL)**, ISRO has launched hundreds of foreign satellites for numerous countries. The opening of the space sector to private participation has further strengthened India's position in the global commercial space industry.

Record-Breaking Achievements

ISRO has achieved several world-class records, including launching **104 satellites in a single mission** using PSLV in **2017**, which was a world record at that time. India has also consistently demonstrated its ability to execute highly complex missions at a fraction of the cost incurred by many other space agencies.

Strengthening National Development

Perhaps the most significant achievement of India's space programme is its contribution to national development. Space technology has transformed communication, weather forecasting, disaster management, agriculture, fisheries, education, healthcare, navigation, and governance, directly improving the lives of millions of people across the country.

11. Commercialisation of India's Space Sector

The commercialisation of India's space sector aims to transform the country from a government-led space programme to a globally competitive space economy. Traditionally, ISRO focused on research and national development, while commercial activities were handled by **Antrix Corporation** and are now primarily managed by **NewSpace India Limited (NSIL)**, established in **2019**. The space sector was opened to private participation in **2020**, leading to the establishment of **IN-SPACe (Indian National Space Promotion and Authorization Centre)** to facilitate, regulate, and promote the activities of non-government entities. These reforms have encouraged private companies and start-ups to participate in satellite manufacturing, launch vehicle development, satellite-based services, and space technology innovation.

India's commercial space ecosystem is expanding rapidly with the emergence of start-ups such as **Skyroot Aerospace**, **Agnikul Cosmos**, **Pixxel**, and **Dhruva Space**. The sector offers opportunities in satellite launches, Earth observation, communication services, navigation, geospatial applications, and space tourism. India's cost-effective launch capability, particularly through **PSLV** and **LVM3**, has strengthened its position in the global launch services market. According to the **Indian Space Policy, 2023**, greater private participation, increased foreign investment, and public-private partnerships are expected to significantly enhance India's share in the global space economy, generate high-skilled employment, and support the vision of **Atmanirbhar Bharat**.

12. Space Reforms in India

India has introduced major reforms in the space sector to promote private participation, commercialisation, innovation, and global competitiveness. The landmark **Space Sector Reforms (2020)** ended ISRO's monopoly in several space activities and allowed private companies to build satellites, develop launch vehicles, establish launch facilities, and offer space-based services. The establishment of **IN-SPACe** as an independent regulator and **NSIL** as the commercial arm of the Department of Space has created an enabling ecosystem for non-government entities.

The **Indian Space Policy, 2023** further clarified the roles of ISRO, NSIL, IN-SPACe, and the private sector. While ISRO will focus on research, advanced technology, and strategic missions, private industries are encouraged to undertake manufacturing, launch services, satellite operations, and downstream applications. These reforms aim to attract investment, strengthen the space start-up ecosystem, enhance India's share in the global space economy, and support the vision of **Atmanirbhar Bharat**.

13. Emerging Technologies and Future Missions

Emerging Technologies

- **Reusable Launch Vehicle (RLV):** Aims to reduce the cost of space missions through reusable rocket technology.
- **Small Satellite Launch Vehicle (SSLV):** Designed for quick, low-cost launches of small satellites.
- **Space Docking Technology (SpaDeX):** Enables autonomous docking of spacecraft, essential for future space stations and deep-space missions.
- **Artificial Intelligence (AI) and Robotics:** Increasingly used in satellite operations, mission planning, autonomous navigation, and data analysis.
- **Advanced Propulsion Systems:** Development of semi-cryogenic and reusable propulsion technologies for next-generation launch vehicles.

Future Missions

- **Gaganyaan Mission:** India's first human spaceflight programme aimed at sending Indian astronauts into Low Earth Orbit.
- **Bharatiya Antariksh Station:** Proposed indigenous space station to be established by **2035**.
- **Chandrayaan-4:** Planned mission to demonstrate lunar sample return technologies.
- **Shukrayaan-1:** India's proposed mission to explore Venus and study its atmosphere and surface.
- **Mangalyaan-2:** Proposed advanced Mars mission with enhanced scientific objectives.
- **NISAR Mission:** Joint Earth observation mission of **ISRO and NASA** for monitoring Earth's ecosystems, glaciers, and natural hazards.

Challenges Before India's Space Programme

Despite remarkable achievements, India's Space Programme faces several technological, financial, and strategic challenges that need to be addressed to sustain its global competitiveness.

Limited Financial Resources

Although ISRO has consistently delivered cost-effective missions, its budget remains significantly lower than that of major space agencies such as **NASA (USA)** and **CNSA (China)**. Limited financial resources constrain investments in advanced technologies, deep-space exploration, and human spaceflight programmes.

Technological Challenges

India has achieved self-reliance in many areas, yet advanced technologies such as reusable launch systems, heavy-lift launch vehicles, deep-space communication, and next-generation propulsion systems require continuous research and development. Rapid technological advancements demand sustained innovation and skilled human resources.

Growing Global Competition

The global space sector has become highly competitive with countries like the **United States, China, Russia, and members of the European Space Agency (ESA)** making rapid progress. In addition, private companies such as **SpaceX** and **Blue Origin** have transformed the commercial launch market, increasing competition for cost-effective launch services.

Space Debris and Space Sustainability

The increasing number of inactive satellites, rocket stages, and orbital debris poses a serious threat to operational satellites and future space missions. Ensuring safe and sustainable use of outer space through debris mitigation and space traffic management has become an important challenge for India and the global community.

Regulatory and Commercial Challenges

With the opening of the space sector, India needs a robust regulatory framework to balance innovation, national security, commercial interests, and international obligations. Strengthening the private space ecosystem, attracting investment, and improving ease of doing business remain key priorities.

15. Conclusion

India's Space Programme is a remarkable example of how science and technology can be harnessed for national development and global leadership. From the launch of **Aryabhata** in 1975 to the successful **Chandrayaan-3**, **Aditya-L1**, and the upcoming **Gaganyaan Mission**, India has demonstrated excellence in satellite technology, launch vehicles, planetary exploration, and space applications. Guided by the vision of **Dr. Vikram Sarabhai**, the programme has consistently focused on the peaceful use of outer space, self-reliance, and inclusive socio-economic development.

With recent reforms, greater private sector participation, and an ambitious roadmap for future missions, India is emerging as a major player in the global space economy. However, sustaining this growth requires continued investment in research, advanced technologies, human resources, and sustainable space practices. As India moves towards becoming a developed nation, its space programme will remain a critical pillar of scientific innovation, strategic capability, economic growth, and national development.

LESSON 2: DEFENCE TECHNOLOGY AND INTERNAL SECURITY

Topics Covered under this Lesson

1. Defence programmes and missile systems

1.1 Integrated Guided Missile Development Programme (IGMDP)
1.2 Anti-ballistic missile development programme

2. Modern defence technologies

2.1 Application of drone technology
2.2 Swarm drones
2.3 AI in defence

3. Border management and defence production

3.1 Use of technology in border management
3.2 Science and technology in defence equipment production
3.3 Cyber warfare
3.4 Electronic warfare
3.5 Atmanirbhar Bharat in defence
3.6 Defence corridors

1. Defence programmes and missile systems

1.1 Integrated Guided Missile Development Programme (IGMDP)

1. Introduction

The **Integrated Guided Missile Development Programme (IGMDP)** was a landmark missile development programme launched by the **Government of India in 1983** under the **Defence Research and Development Organisation (DRDO)** to achieve **self-reliance in guided missile technology**. The programme aimed to develop a family of indigenous missiles capable of meeting the operational requirements of the **Indian Army, Navy, and Air Force**, thereby reducing dependence on foreign suppliers.

The programme was led by **Dr. A. P. J. Abdul Kalam**, who served as its **Chief Executive**, earning him the title **"Missile Man of India."** IGMDP laid the foundation for India's modern missile programme and significantly strengthened the country's strategic and defence capabilities.

Key Facts

- **Launched: 1983**
- **Implementing Agency: DRDO**
- **Programme Director: Dr. A. P. J. Abdul Kalam**
- **Officially Concluded: 2008**
- **Missiles Developed: Prithvi, Agni, Akash, Trishul, and Nag**

2. Objectives of IGMDP

- **Achieve Self-Reliance in Missile Technology:** Develop indigenous guided missile systems and reduce dependence on foreign countries for critical defence technologies.
- **Strengthen National Defence:** Equip the **Army, Navy, and Air Force** with a wide range of missiles for tactical, strategic, air defence, and anti-tank operations.
- **Develop Indigenous Technologies:** Build capabilities in **propulsion, guidance, navigation, control systems, seekers, and warhead technologies**, creating a strong domestic defence R&D base.
- **Enhance Strategic Deterrence:** Strengthen India's conventional and strategic deterrence capability to safeguard national security and maintain regional stability.
- **Promote Indigenous Defence Manufacturing:** Encourage collaboration among **DRDO, public sector undertakings, private industries, and academia** to establish a robust defence industrial ecosystem.

3. Missiles Developed under IGMDP

Prithvi Missile

- **Type:** Surface-to-Surface Short-Range Ballistic Missile (SRBM).
- **Variants: Prithvi-I (Army), Prithvi-II (Air Force), and Dhanush (Naval version).**
- **Range:** Approximately **150–350 km**, depending on the variant.

- **Significance:** India's **first indigenously developed ballistic missile**, capable of carrying both conventional and nuclear warheads.

Agni Missile

- **Type:** Surface-to-Surface Ballistic Missile (Strategic Missile).
- **Variants: Agni-I, Agni-II, Agni-III, Agni-IV, and Agni-V** with ranges from **700 km to over 5,000 km**.
- **Latest Development:** In **March 2024**, India successfully conducted **Mission Divyastra**, demonstrating **MIRV (Multiple Independently Targetable Re-entry Vehicle)** technology on **Agni-V**.
- **Significance:** Forms the backbone of India's **credible minimum nuclear deterrence** under the **Nuclear Command Authority**.

Akash Missile

- **Type:** Medium-Range Surface-to-Air Missile (SAM).
- **Range:** Around **25–45 km** (depending on the variant).
- **Role:** Designed to intercept **fighter aircraft, helicopters, drones, and cruise missiles**.
- **Significance:** Inducted into both the **Indian Army and Indian Air Force** and exported to friendly countries, showcasing India's growing defence manufacturing capability.

Nag Missile

- **Type:** Third-generation Anti-Tank Guided Missile (ATGM).
- **Features: Fire-and-Forget** missile equipped with an **Imaging Infrared (IIR) Seeker**.
- **Launch Platforms:** Ground-based **NAMICA** and helicopter-launched variant **HELINA (Dhruvastra)**.
- **Significance:** Enhances India's indigenous anti-armour warfare capability.

Trishul Missile

- **Type:** Short-Range Surface-to-Air Missile (SAM).
- **Role:** Developed to engage **low-flying aircraft, helicopters, and sea-skimming missiles**.
- **Status:** The project was **closed as a technology demonstrator** due to operational limitations.
- **Significance:** Technologies developed under Trishul contributed to several later missile programmes.

4. Achievements and Significance of IGMDP

- **Established Self-Reliance in Missile Technology:** IGMDP transformed India from a technology importer into a nation capable of designing, developing, and producing indigenous guided missiles.

- **Strengthened Strategic Deterrence:** The successful development of the **Prithvi** and **Agni** missile series significantly enhanced India's conventional and nuclear deterrence capabilities, contributing to national security.
- **Created a Strong Defence Industrial Ecosystem:** The programme promoted collaboration among DRDO, DPSUs, private industries, and academic institutions, laying the foundation for indigenous defence manufacturing.
- **Technological Advancements:** IGMDP led to the development of critical technologies such as solid and liquid propulsion, guidance and navigation systems, seekers, composite materials, and re-entry vehicle technology, which are now used in several advanced missile systems.
- **Foundation for Modern Missile Programmes:** The experience gained through IGMDP paved the way for advanced indigenous systems such as **Astra**, **Ballistic Missile Defence (BMD)**, **Quick Reaction Surface-to-Air Missile (QRSAM)**, **Rudram**, **Pralay**, and the MIRV-enabled Agni-V (Mission Divyastra).

5. Challenges and Legacy of IGMDP

- **Major Challenges:** The programme faced **technology denial regimes** (such as restrictions under the Missile Technology Control Regime before India joined it in 2016), technical complexities, project delays, and cost overruns. The **Trishul** missile could not meet all operational requirements and was eventually discontinued as an operational system.
- **Official Conclusion:** The **IGMDP was formally concluded in 2008**, after achieving most of its primary objectives. Thereafter, missile development continued through separate DRDO programmes based on technologies developed under IGMDP.
- **Enduring Legacy:** IGMDP laid the technological foundation for India's modern missile arsenal and established DRDO as a leading missile development organisation. It also strengthened indigenous capabilities in propulsion, guidance, navigation, seekers, and composite materials.
- **Recent Developments:** Building upon the IGMDP legacy, India has successfully developed advanced missile systems such as **BrahMos**, **Astra**, **QRSAM**, **MRSAM**, **Rudram**, **Pralay**, and demonstrated **MIRV technology through Mission Divyastra (2024)**, reinforcing India's position as a major missile power.

6. Conclusion

The **Integrated Guided Missile Development Programme (IGMDP)** marked a turning point in India's defence history by establishing a strong indigenous missile development ecosystem. It transformed India into a **self-reliant missile power**, significantly enhanced national security, and laid the foundation for advanced missile programmes such as **Agni-V, BrahMos, Astra, and Ballistic Missile Defence (BMD)**. The programme continues to inspire India's pursuit of **Atmanirbhar Bharat** in defence technology and its emergence as a leading global defence and aerospace power.

LESSON 3: ENVIRONMENT, CLIMATE CHANGE AND ENERGY RESOURCES

Topics Covered under this Lesson

1. Environmental issues and pollution

1.1 Environmental pollution (special focus on air pollution)
1.2 Waste management
1.3 Plastic pollution
1.4 Illegal mining and its environmental impact
1.5 Air quality index (AQI) and health impact
1.6 Net Zero target of India (2070)

2. Climate change and biodiversity

2.1 Causes and effects of climate change on human
2.2 Global warming
2.3 Biodiversity

3. Energy resources and sustainability

3.1 Renewable energy resources in context of India
3.2 Solar energy
3.3 Nuclear energy in India
3.4 Energy generation from urban waste
3.5 Electric mobility in India
3.6 Energy security vs sustainability debate
3.7 National Green Hydrogen Mission
3.8 Biofuels policy (ethanol blending programme)
3.9 National Action Plan on Climate Change (NAPCC)

1. Environmental issues and pollution

1.1 Environmental pollution (special focus on air pollution)

1. Environmental Pollution: Meaning and Types

Environmental pollution refers to the undesirable change in the physical, chemical, or biological characteristics of the environment due to the introduction of harmful substances or energy into air, water, or land. It disturbs the natural balance of ecosystems, adversely affects human health, reduces **biodiversity**, and hinders **sustainable development**.

Pollution has emerged as one of the most serious environmental challenges of the 21st century due to rapid industrialization, urbanization, population growth, and unsustainable patterns of production and consumption. According to the **World Health Organization** (WHO), pollution is responsible for millions of premature deaths every year, making it a major public health concern.

Major Types of Environmental Pollution

- **Air Pollution:** Contamination of the atmosphere by harmful gases, particulate matter, and toxic substances. It has become the most widespread environmental problem in India due to vehicular emissions, industries, thermal power plants, construction activities, and biomass burning.
- **Water Pollution:** Contamination of rivers, lakes, groundwater, and oceans by sewage, industrial effluents, agricultural chemicals, and plastic waste, making water unsafe for human use and aquatic life.
- **Soil Pollution:** Degradation of soil quality caused by excessive use of fertilizers and pesticides, industrial waste, mining activities, and improper disposal of solid waste, reducing agricultural productivity.
- **Noise Pollution:** Excessive and unwanted sound generated from traffic, industries, construction activities, loudspeakers, and urban settlements, adversely affecting physical and mental health.
- **Radioactive Pollution:** Release of radioactive substances from nuclear accidents, mining, medical applications, or improper disposal of radioactive waste, posing long-term risks to human health and the environment.

Why is Air Pollution the Most Critical Environmental Challenge?

Among all forms of pollution, **air pollution is considered the most serious environmental challenge** because it affects every individual irrespective of location or socio-economic status. Polluted air can travel across cities, states, and even national boundaries, making it a transboundary problem. Fine particulate matter ($PM_{2.5}$) and toxic gases not only cause respiratory and cardiovascular diseases but also reduce agricultural productivity, damage ecosystems, contribute to climate change, and impose a significant economic burden. Therefore, improving air quality is essential for achieving the goals of **sustainable development, public health, and inclusive economic growth**.

Types of Air Pollution

1. Outdoor (Ambient) Air Pollution

Outdoor air pollution occurs in the open atmosphere due to emissions from vehicles, industries, thermal power plants, construction activities, road dust, crop residue burning, and natural events such as dust storms and forest fires.

It is the primary cause of poor air quality in urban and industrial regions and affects millions of people simultaneously.

2. Indoor Air Pollution

Indoor air pollution occurs inside homes, offices, schools, and other enclosed spaces. In India, it is mainly caused by the use of biomass fuels (firewood, cow dung, crop residue), kerosene stoves, tobacco smoke, poor ventilation, and household chemicals.

Although urban air pollution receives greater attention, indoor air pollution remains a major health challenge, particularly among rural households and women.

Major Air Pollutants

(i) Particulate Matter ($PM_{2.5}$ and PM_{10}): Particulate Matter (PM) consists of tiny solid particles and liquid droplets suspended in the air.

- **$PM_{2.5}$** (diameter less than 2.5 micrometres) can penetrate deep into the lungs and even enter the bloodstream, making it the most dangerous air pollutant. $PM_{2.5}$ is regarded as the most critical air pollutant because its microscopic size allows it to enter the bloodstream, increasing the risk of cardiovascular diseases, stroke, and premature deaths.
- **PM_{10}** (diameter less than 10 micrometres) mainly affects the respiratory system.

Major sources: Vehicle emissions, industries, thermal power plants, road dust, construction activities, biomass burning, and stubble burning.

Effects: Asthma, chronic obstructive pulmonary disease (COPD), heart diseases, stroke, and reduced life expectancy.

(ii) Sulphur Dioxide (SO_2): Sulphur dioxide is mainly released from the burning of coal and petroleum products in thermal power plants and industries.

Effects: Irritates the eyes and respiratory tract. Causes acid rain, damaging forests, crops, buildings, and water bodies.

(iii) Nitrogen Oxides (NO_x): Nitrogen oxides are produced primarily from motor vehicles, thermal power plants, and industrial combustion.

Effects: Contribute to the formation of smog and ground-level ozone. Aggravate asthma and other respiratory diseases. Cause acid rain and reduce visibility.

(iv) Carbon Monoxide (CO): Carbon monoxide is a colourless, odourless, and poisonous gas formed due to incomplete combustion of fossil fuels.

Major sources: Motor vehicles, diesel generators, and household cooking fuels.

Effects: Reduces the oxygen-carrying capacity of blood. Causes headaches, dizziness, unconsciousness, and, at high concentrations, can be fatal.

(v) Ground-level Ozone (O_3): Unlike the protective ozone layer in the stratosphere, ground-level ozone is a harmful secondary pollutant formed by the reaction of nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight.

Effects: Irritates the lungs. Reduces crop productivity. Damages vegetation and forests.

(vi) Volatile Organic Compounds (VOCs): VOCs are carbon-based chemicals released from fuels, paints, solvents, petrochemical industries, and vehicle emissions.

Effects: Participate in the formation of smog and ozone. Some VOCs, such as benzene, are carcinogenic (cancer-causing).

(vii) Lead (Pb): Lead pollution mainly arises from battery manufacturing, metal processing industries, and improper disposal of electronic waste.

Effects: Damages the nervous system. Impairs brain development in children. Affects kidney function and cardiovascular health.

Air Quality Index (AQI)

The **Air Quality Index (AQI)** is a tool developed by the **Central Pollution Control Board (CPCB)** to communicate the quality of ambient air in a simple and understandable manner. It is calculated based on the concentration of major pollutants such as $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, O_3, NH_3, and Pb.

AQI Range	Category	Health Implication
0–50	Good	Minimal impact
51–100	Satisfactory	Minor discomfort to sensitive individuals
101–200	Moderate	Breathing discomfort for vulnerable groups
201–300	Poor	Discomfort during prolonged exposure

AQI Range	Category	Health Implication
301–400	Very Poor	Respiratory illness on prolonged exposure
401–500	Severe	Serious health impacts even on healthy individuals

3. Status of Air Pollution in India

Air pollution has emerged as one of India's most serious environmental and public health challenges. According to the **World Air Quality Report (IQAir)**, India continues to rank among the **most polluted countries in the world**, with several Indian cities consistently featuring among the global hotspots for $PM_{2.5}$ pollution. The **Indo-Gangetic Plain (IGP)**—covering Delhi, Punjab, Haryana, Uttar Pradesh, Bihar, and West Bengal—remains the most severely affected region due to high population density, industrial activities, vehicular emissions, crop residue burning, and adverse winter meteorological conditions. However, deteriorating air quality is no longer confined to North India, as several **coastal and southern cities** have also witnessed increasing pollution levels due to rapid urbanization and industrialization.

Air quality monitoring by the **Central Pollution Control Board (CPCB)** indicates that **$PM_{2.5}$ and PM_{10}** are the dominant pollutants in most Indian cities. According to the **State of Global Air Report 2024**, air pollution contributed to **over 2 million deaths in India in 2021**, making it one of the leading environmental risk factors for mortality. The **Energy Policy Institute at the University of Chicago (EPIC)** estimates that if particulate pollution is reduced to the **WHO guideline level (5 µg/m³ annual $PM_{2.5}$)**, the average Indian's life expectancy could increase by **more than 5 years**. Bihar is among the states facing persistently high particulate pollution, especially during the winter months.

Despite initiatives such as the **National Clean Air Programme (NCAP)** and the adoption of **BS-VI emission norms**, many cities continue to record AQI levels in the **'Poor', 'Very Poor', or 'Severe'** categories during winter. This highlights that while policy interventions have strengthened air quality management, effective implementation, inter-state coordination, and public participation remain critical for achieving sustained improvements.

4. Major Sources/Causes of Air Pollution in India

Vehicular Emissions

- Rapid growth in the number of private vehicles has made the transport sector one of the largest contributors to urban air pollution.
- Emissions from **cars, buses, trucks, two-wheelers, and diesel vehicles** release **$PM_{2.5}$, NO_x, CO, and hydrocarbons** into the atmosphere.
- Traffic congestion, idling vehicles, and poor traffic management further increase fuel consumption and emissions.
- Metropolitan cities such as **Delhi, Mumbai, Bengaluru, and Patna** experience high vehicular pollution, especially during peak hours.

- **Example:** Implementation of **BS-VI fuel standards** and promotion of **electric vehicles (EVs)** aim to reduce transport-related emissions.

Industrial and Thermal Power Plant Emissions

- Industries such as **cement, steel, refineries, brick kilns, and chemical plants** emit sulphur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter, and toxic gases.
- Coal-based thermal power plants remain one of the largest sources of SO_2 emissions in India.
- Small-scale industries often operate with inadequate pollution-control equipment.
- Industrial clusters around **Singrauli, Korba, Angul, and Delhi-NCR** have recorded poor air quality due to industrial emissions.
- **Example:** Installation of **Flue Gas Desulphurization (FGD)** systems is being promoted to reduce SO_2 emissions from thermal power plants.

Construction Activities and Road Dust

- Large-scale construction projects generate enormous quantities of dust (PM_{10} and $PM_{2.5}$).
- Uncovered construction materials, demolition activities, and excavation increase suspended particulate matter.
- Poorly maintained roads and movement of heavy vehicles resuspend dust into the atmosphere.
- Construction and road dust account for a significant share of particulate pollution in major cities.
- **Example:** The **Graded Response Action Plan (GRAP)** temporarily restricts construction activities during periods of severe air pollution in Delhi-NCR.

Agricultural Residue (Parali) Burning

- Farmers burn crop residue after harvesting to quickly prepare fields for the next crop.
- Paddy straw burning in **Punjab, Haryana, and western Uttar Pradesh** significantly worsens winter smog over North India.
- The smoke contains $PM_{2.5}$, carbon monoxide, methane, and other harmful pollutants.
- Although seasonal, stubble burning intensifies pollution when combined with low wind speed and temperature inversion.
- **Example:** The government promotes **Happy Seeder**, **PUSA Decomposer**, and crop residue management schemes as sustainable alternatives.

Household Biomass Burning and Waste Burning

- Millions of rural households still use **firewood, dung cakes, charcoal, and crop residues** for cooking and heating.
- Open burning of municipal solid waste and plastic releases toxic gases such as **dioxins and furans**.

- Indoor air pollution particularly affects women, children, and elderly people.
- In urban areas, burning of leaves and garbage contributes to localized air pollution.
- **Example:** The **Pradhan Mantri Ujjwala Yojana (PMUY)** promotes the use of clean LPG fuel to reduce household air pollution.

Natural Sources

- Natural events also contribute to air pollution, although their impact is generally temporary.
- **Dust storms** from the Thar Desert increase particulate matter in northern India.
- **Forest fires** release smoke, carbon monoxide, and particulate matter into the atmosphere.
- Seasonal meteorological conditions such as **temperature inversion** and low wind speed trap pollutants near the ground, especially during winter.
- **Example:** Dust storms during the summer months often cause a sudden deterioration in air quality across North India.

5. Impacts of Air Pollution

Health Impacts

- Air pollution is one of the leading environmental causes of premature deaths in India. According to the **State of Global Air Report 2024**, **over 2 million deaths** in India in **2021** were linked to air pollution.
- Fine particulate matter (**$PM_{2.5}$**) penetrates deep into the lungs and bloodstream, increasing the risk of **asthma, chronic obstructive pulmonary disease (COPD), lung cancer, stroke, and cardiovascular diseases**.
- Children, pregnant women, the elderly, and people with pre-existing illnesses are the most vulnerable sections of society.
- According to the **Energy Policy Institute at the University of Chicago (EPIC)**, current $PM_{2.5}$ pollution levels reduce the **average life expectancy of Indians by more than 5 years** compared to the WHO air quality guideline.
- Rising cases of respiratory illnesses during winter in cities like **Delhi, Patna, Lucknow, and Kanpur** highlight the growing public health burden.

Economic Impacts

- Air pollution causes substantial economic losses through increased healthcare expenditure, reduced labour productivity, absenteeism, and premature deaths.
- According to **Dalberg Advisors**, India could have gained nearly **USD 95 billion (around 3% of GDP)** in **2019** if safe air quality levels had been achieved.
- Pollution-related economic losses were estimated at **USD 36.8 billion (about 1.36% of GDP)** in 2019.
- States with higher pollution levels, including **Uttar Pradesh and Bihar**, suffer greater productivity losses due to disease burden and reduced workforce efficiency.

- Poor air quality also discourages tourism, affects investment, and increases the cost of urban healthcare infrastructure.

Environmental Impacts

- Air pollutants contribute to **acid rain**, which damages forests, agricultural fields, freshwater ecosystems, and historical monuments.
- Ground-level ozone reduces crop productivity by affecting plant growth and photosynthesis.
- Black carbon and other aerosols accelerate the melting of **Himalayan glaciers**, threatening long-term water security in northern India.
- Air pollution also reduces biodiversity by affecting birds, insects, and other wildlife.
- The **Taj Mahal** has experienced discoloration due to atmospheric pollutants, leading to the implementation of the **Taj Trapezium Zone (TTZ)** for pollution control.

Social Impacts

- Air pollution disproportionately affects **poor and marginalized communities**, who often live near industrial areas, highways, landfills, and waste disposal sites.
- Low-income households continue to rely on biomass fuels for cooking, increasing exposure to harmful indoor air pollution.
- Poor air quality results in school closures, reduced outdoor activities, and lower quality of life in urban centres.
- Frequent episodes of severe smog disrupt transportation, aviation, and daily economic activities.
- The unequal exposure to pollution makes air quality not only an environmental issue but also a **social justice and public health concern**.

Impact on Agriculture and Climate

- Air pollutants such as **ground-level ozone** reduce agricultural yields of crops like **wheat, rice, soybean, and cotton**, affecting food security.
- Deposition of pollutants degrades soil quality and alters ecosystem functions over time.
- Short-lived climate pollutants such as **black carbon** and **methane** contribute to global warming while simultaneously worsening local air quality.
- Crop residue burning creates a vicious cycle by increasing both particulate pollution and greenhouse gas emissions.
- Thus, controlling air pollution simultaneously supports **climate change mitigation, sustainable agriculture, and achievement of the Sustainable Development Goals (SDGs).**

6. Government Initiatives to Control Air Pollution

National Clean Air Programme (NCAP), 2019

- Launched by the **Ministry of Environment, Forest and Climate Change (MoEFCC)** as India's first comprehensive national strategy to improve air quality.
- Covers **130+ non-attainment cities** (cities consistently failing to meet National Ambient Air Quality Standards).
- Targets **up to 40% reduction in PM_{10} and $PM_{2.5}$ levels by 2025–26** (with 2017 as the base year).
- Focuses on city-specific action plans, expansion of air quality monitoring stations, source apportionment studies, and public participation.
- **Significance:** Has shifted India's approach from reactive pollution control to long-term air quality management.

Commission for Air Quality Management (CAQM), 2021

- Established through an Act of Parliament to coordinate air pollution control in **Delhi-NCR and adjoining states (Punjab, Haryana, Rajasthan, and Uttar Pradesh)**.
- Has powers to issue binding directions to state governments, industries, and pollution control authorities.
- Coordinates action on stubble burning, industrial emissions, construction dust, and vehicular pollution.
- Promotes inter-state coordination, which was previously a major challenge in pollution control.
- **Significance:** Provides a single institutional mechanism to address regional air pollution rather than city-wise interventions.

Graded Response Action Plan (GRAP) – Revised Framework

- GRAP prescribes **stage-wise emergency measures** based on the Air Quality Index (AQI), from **Stage I (Poor)** to **Stage IV (Severe+)**.
- Includes restrictions on construction activities, diesel generators, polluting industries, truck entry, and school operations during severe pollution episodes.
- The framework has been revised to ensure **earlier intervention** before pollution reaches emergency levels.
- Implemented by **CAQM** across Delhi-NCR.
- **Significance:** Enables timely action to reduce pollution peaks during winter.

Promotion of Cleaner Transport and BS-VI Emission Standards

- India implemented **Bharat Stage-VI (BS-VI)** emission norms nationwide in **2020**, significantly reducing emissions from new vehicles.

- The government is promoting **electric mobility** through schemes such as **PM E-Drive Scheme (2024)**, replacing the earlier FAME programme, to accelerate EV adoption and charging infrastructure.
- Expansion of metro rail, electric buses, ethanol-blended fuels, and CNG networks further supports cleaner transport.
- **Significance:** Addresses one of the largest contributors to urban air pollution—vehicular emissions.

Crop Residue Management and Biomass Utilisation

- The government promotes alternatives to stubble burning through the **Crop Residue Management (CRM) Scheme**.
- Financial assistance is provided for machinery such as the **Happy Seeder**, **Super Straw Management System (SMS)**, and **baling equipment**.
- Technologies like the **PUSA Decomposer** help convert crop residue into manure instead of burning it.
- Biomass is increasingly being used for **Compressed Biogas (CBG)** production under the **SATAT Initiative**, creating economic value from agricultural waste.
- **Significance:** Simultaneously reduces air pollution, improves soil health, and supports the circular economy.

Strengthening Air Quality Monitoring and Public Awareness

- The **Central Pollution Control Board (CPCB)** has expanded the network of **Continuous Ambient Air Quality Monitoring Stations (CAAQMS)** across the country.
- The **National Air Quality Index (AQI)** provides real-time information on air quality, enabling citizens to take preventive measures.
- Cities are increasingly using **remote sensing, satellite data, drones, and real-time emission monitoring systems** for pollution surveillance.
- Public campaigns such as **Swachh Bharat Mission**, **Mission LiFE (Lifestyle for Environment)**, and awareness drives encourage behavioural changes to reduce pollution.
- **Significance:** Better monitoring and informed public participation improve the effectiveness of pollution-control measures.

7. Challenges in Controlling Air Pollution

- **Weak Enforcement of Environmental Laws:** Although India has comprehensive laws and standards, inadequate monitoring, shortage of manpower, and poor compliance by industries and local authorities limit their effectiveness.
- **Rapid Urbanization and Motorization:** Unplanned urban growth, increasing private vehicle ownership, and rising energy demand continue to outpace pollution-control measures, especially in metropolitan and Tier-II cities.

- **Inter-State and Multi-sectoral Nature of Pollution:** Air pollutants travel across state boundaries, making coordination among states difficult. For example, stubble burning in Punjab and Haryana significantly affects air quality in Delhi-NCR.
- **Dependence on Fossil Fuels and Biomass:** Coal-based power generation, industrial fuel consumption, and biomass-based cooking in rural areas remain major sources of emissions despite the promotion of cleaner alternatives.
- **Limited Public Awareness and Behavioural Change:** Practices such as open waste burning, excessive use of private vehicles, and poor waste management continue due to inadequate public participation and awareness.
- **Climate and Meteorological Factors:** Temperature inversion, low wind speed, and dust storms, particularly during winter in the Indo-Gangetic Plain, trap pollutants near the surface, worsening air quality even when emissions remain constant.

9. Conclusion

Air pollution has emerged as one of the most pressing environmental and public health challenges in India, affecting human health, economic productivity, biodiversity, and climate resilience. While initiatives such as the **National Clean Air Programme (NCAP), CAQM, GRAP, and BS-VI emission norms** have strengthened the country's response, sustained improvements require effective implementation, scientific urban planning, clean energy transition, and active public participation.

Achieving the vision of **'Viksit Bharat 2047'** and the **Sustainable Development Goals (SDGs)** will require balancing economic growth with environmental sustainability. As the Supreme Court of India has observed, **"The right to live in a pollution-free environment is a part of the fundamental right to life under Article 21 of the Constitution."** Therefore, ensuring clean air is not merely an environmental obligation but a constitutional and developmental imperative for securing a healthier and more sustainable future.

LESSON 4: AGRICULTURE, BIOTECHNOLOGY AND HEALTH TECHNOLOGIES

Topics Covered under this Lesson

1. Agricultural technologies and practices

1.1 Organic farming
1.2 Use of technology in Indian agriculture

2. Genetic and biotechnology applications

2.1 GM crops
2.2 Application of biotechnology

3. Health, nutrition and ethical issues

3.1 Food fortification technology
3.2 DNA profiling (issue of conflicts)
3.3 Antimicrobial resistance (AMR)

1. Agricultural technologies and practices

1.1 Organic farming

1. Introduction

Organic farming is a sustainable agricultural system that maintains the health of soil, ecosystems, plants, animals, and humans by relying on natural biological processes instead of synthetic chemical fertilizers and pesticides. According to **IFOAM (International Federation of Organic Agriculture Movements)**, organic agriculture is a production system that sustains the health of soils, ecosystems, and people through ecological processes, biodiversity, and natural cycles.

Organic farming emphasizes the use of **compost, farmyard manure (FYM), vermicompost, green manure, biofertilizers, crop rotation, biological pest control, and integrated nutrient management** while prohibiting genetically modified organisms (GMOs) and most synthetic agrochemicals. In India, organic farming is rooted in traditional agricultural practices and has gained renewed importance due to concerns over soil degradation, declining soil fertility, groundwater pollution, climate change, and increasing demand for safe and chemical-free food.

Organic farming supports **sustainable agriculture**, conserves biodiversity, improves soil health, reduces environmental pollution, and contributes to achieving the **Sustainable Development Goals (SDGs)**, particularly **SDG 2 (Zero Hunger),** SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).

2. Need for Organic Farming

The intensive use of **chemical fertilizers, pesticides, and monocropping** since the Green Revolution has significantly increased agricultural production but has also resulted in declining **soil fertility, depletion of soil organic carbon, groundwater contamination, biodiversity loss, and increasing greenhouse gas emissions**. Organic farming addresses these challenges by improving soil health, enhancing microbial activity, conserving biodiversity, reducing environmental pollution, and increasing the resilience of agriculture to climate change through sustainable management of natural resources.

Organic farming also promotes food safety by producing chemical residue-free crops, reduces farmers' dependence on costly chemical inputs through the use of **locally available organic resources**, and generates additional rural employment in compost production, certification, processing, and value addition. Growing domestic and global demand for organic products provides better income opportunities for farmers, while the adoption of organic farming supports India's commitments under the National Mission for Sustainable Agriculture (NMSA), the Paris Agreement, and the Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on Land).

3. Principles of Organic Farming

- **Principle of Health:** Organic farming sustains the health of soil, plants, animals, humans, and the environment as one interconnected system.
- **Principle of Ecology:** It is based on natural ecological cycles, biodiversity, nutrient recycling, and sustainable use of natural resources.

- **Principle of Fairness:** It promotes fair relationships among farmers, consumers, workers, and future generations while ensuring animal welfare.
- **Principle of Care:** It follows the precautionary approach by avoiding technologies and practices that may harm human health or the environment.

4. Key Features and Components of Organic Farming

Soil Health Management

- Improves soil fertility through compost, farmyard manure (FYM), vermicompost, green manure, and biofertilizers.
- Enhances soil organic carbon, microbial activity, and water-holding capacity.

Crop Management

- Promotes crop rotation, mixed cropping, intercropping, cover crops, and mulching.
- Maintains soil fertility and reduces pest and disease incidence.

Nutrient Management

- Relies on natural nutrient sources and biological nitrogen fixation instead of synthetic fertilizers.
- Encourages recycling of crop residues and livestock waste.

Pest and Disease Management

- Uses biological control agents, neem-based pesticides, pheromone traps, and Integrated Pest Management (IPM).
- Minimizes chemical pesticide use while protecting beneficial organisms.

Weed Management

- Controls weeds through manual weeding, mulching, crop rotation, cover crops, and mechanical methods.
- Reduces dependence on chemical herbicides.

Livestock Integration

- Integrates livestock with crop farming to recycle nutrients through dung and urine.
- Ensures animal welfare by avoiding growth hormones, routine antibiotics, and GM feed.

5. Organic Farming Certification System in India

India has established a robust certification system to ensure the authenticity and quality of organic products. The **National Programme for Organic Production (NPOP)**, launched in **2001** and implemented by **APEDA**, provides third-party certification primarily for export-oriented organic products. For domestic markets, the **Participatory Guarantee System (PGS-India)**, introduced in **2011**, offers a low-cost, community-based certification mechanism for small and marginal farmers. Additionally, the **Jaivik Bharat Logo**, launched by **FSSAI** in **2017**, enables consumers to easily identify certified organic food products.

Together, these certification systems ensure that organic products comply with prescribed standards from production and processing to packaging and marketing.

6. Organic Farming in India

- India has one of the **largest numbers of organic farmers** in the world and is among the leading producers of organic agricultural products.
- According to **FiBL & IFOAM (World of Organic Agriculture 2025)**, India has **over 2.3 million organic producers**, the highest globally.
- As per **APEDA**, India had around **10.17 million hectares** under organic certification (cultivable land and wild harvest combined) in **2023–24**.
- Major organically cultivated crops include oilseeds, cereals, pulses, cotton, spices, tea, coffee, fruits, medicinal plants, and vegetables.
- Leading organic farming states include Madhya Pradesh, Maharashtra, Rajasthan, Gujarat, Karnataka, Odisha, and Sikkim.
- **Sikkim** became **India's first fully organic state in 2016**, while several North-Eastern states are expanding organic cultivation under government support.
- India exports organic products such as **soybean, oilseeds, cereals, tea, coffee, spices, processed foods, medicinal** plants, fruits, and vegetables to markets including the USA, European Union, Canada, Switzerland, Australia, and Japan.
- The organic sector is witnessing steady growth due to increasing domestic demand, export opportunities, and government initiatives promoting sustainable agriculture.

7. Government Initiatives for Organic Farming

- **Paramparagat Krishi Vikas Yojana (PKVY):** Launched in **2015** and now implemented under **PM-Rashtriya Krishi Vikas Yojana (PM-RKVY)**, it promotes cluster-based organic farming through financial assistance for organic inputs, certification, training, branding, and marketing. Farmers receive **₹31,500 per hectare for 3 years**, including **₹15,000 through DBT** for organic inputs.
- **Mission Organic Value Chain Development for North Eastern Region (MOVCD-NER):** Launched in **2015**, it promotes certified organic farming across the eight North-Eastern states through a value-chain approach covering production, processing, certification, and marketing. Farmers receive **₹46,500 per hectare for 3 years**.
- **National Programme for Organic Production (NPOP):** Implemented by **APEDA**, it provides third-party certification, quality standards, and facilitates exports of Indian organic products to international markets.
- **Participatory Guarantee System (PGS-India):** A low-cost, community-based certification system for domestic organic markets, particularly benefiting small and marginal farmers.
- **Jaivik Bharat Logo:** Introduced by **FSSAI** in **2017**, it enables consumers to identify certified organic food products sold in India.
- **Jaivik Kheti Portal:** A dedicated digital platform for registration of organic farmers, certification agencies, buyers, FPOs, and marketing of organic produce, improving market linkages.
- **Bharatiya Prakritik Krishi Paddhati (BPKP):** Promotes chemical-free farming based on indigenous practices such as Jeevamrit, Beejamrit, mulching, and biomass recycling. Certification is provided through the **PGS-India** framework.

8. Advantages of Organic Farming

Improves Soil Health and Fertility

Organic farming enhances soil fertility by increasing **soil organic carbon (SOC)**, improving soil structure, and promoting the growth of beneficial microorganisms such as bacteria, fungi, and earthworms. The continuous application of compost, green manure, crop residues, and biofertilizers improves nutrient cycling and water-holding capacity, ensuring sustainable productivity over the long term. According to the **Indian Council of Agricultural Research (ICAR)**, soils rich in organic matter exhibit better nutrient availability and resilience against degradation.

Conserves Biodiversity

Organic farming avoids synthetic pesticides and herbicides, thereby protecting pollinators, birds, earthworms, and beneficial insects. Crop rotation, mixed cropping, and agroforestry create diverse habitats that enhance ecological balance. According to the **Food and Agriculture Organization (FAO)**, organic farms generally support higher levels of biodiversity than conventional farms, contributing to ecosystem stability and natural pest control.

Reduces Environmental Pollution

The elimination of synthetic fertilizers and pesticides significantly reduces contamination of soil, groundwater, rivers, and lakes. Organic farming also minimizes nitrate leaching and chemical residues in food, helping preserve ecosystems and public health. This makes it an environmentally sustainable alternative to intensive chemical-based agriculture.

Enhances Climate Change Mitigation and Resilience

Organic farming contributes to **carbon sequestration** by increasing soil organic carbon and reducing greenhouse gas emissions associated with the manufacture and application of synthetic fertilizers. Healthy soils also retain more moisture, enabling crops to better withstand droughts and extreme weather events. Consequently, organic farming is increasingly recognized as an important component of **climate-smart agriculture**.

Produces Safe and Nutritious Food

Organic food is produced without synthetic pesticide residues, genetically modified organisms (GMOs), or unnecessary antibiotics and growth hormones. Growing consumer awareness regarding food safety has increased the demand for certified organic products in both domestic and international markets, making organic farming an important contributor to healthy diets.

Increases Farmers' Income through Premium Pricing

Certified organic products generally command **20–50% higher market prices** than conventionally produced crops due to increasing consumer demand. Government support through certification, branding, Farmer Producer Organizations (FPOs), and export promotion further improves farmers' income and market access, particularly for small and marginal farmers.

Reduces Dependence on External Inputs

Organic farming relies on locally available resources such as farmyard manure, compost, crop residues, green manure, and biofertilizers. This reduces farmers' dependence on costly chemical fertilizers and pesticides, lowers cultivation costs over time, and enhances self-reliance in agricultural production.

Promotes Sustainable Rural Development

Organic farming is relatively labour-intensive, creating employment opportunities in compost preparation, vermicomposting, organic input production, certification, processing, packaging, and value addition. It also encourages community participation through cluster-based farming models such as **Paramparagat Krishi Vikas Yojana (PKVY)**, strengthening rural livelihoods.

Boosts Organic Exports

India exports a wide range of organic products, including cereals, oilseeds, tea, coffee, spices, medicinal plants, fruits, vegetables, and processed foods to countries such as the **USA, European Union, Canada, Australia, and Japan**. Under the **National Programme for Organic Production (NPOP)**, India has established internationally recognized certification standards, enhancing its competitiveness in the global organic market.

9. Challenges in Organic Farming

Lower Productivity during the Transition Period

Organic farming often experiences a decline in crop yields during the initial **2–3 years** as the soil gradually restores its biological fertility after discontinuing chemical inputs. This transition period discourages many farmers from adopting organic practices.

High Certification Cost and Complex Procedures

Obtaining organic certification involves inspections, documentation, and compliance with prescribed standards, making the process costly and time-consuming for small and marginal farmers. Although **PGS-India** has reduced this burden for domestic markets, export certification remains expensive.

Limited Availability of Organic Inputs

The availability of quality compost, vermicompost, biofertilizers, biopesticides, and other organic inputs remains inadequate in many regions. Large-scale organic farming requires a consistent supply of these inputs, which is often lacking.

Marketing and Supply Chain Constraints

Organic farmers face challenges in storage, transportation, branding, certification, and market linkages. The absence of dedicated organic markets in many states reduces their ability to obtain premium prices.

Higher Labour Requirement

Practices such as manual weeding, compost preparation, mulching, and biological pest management require more labour than conventional farming, increasing production costs, especially where agricultural labour is scarce.

Lack of Awareness and Technical Knowledge

Many farmers are unfamiliar with scientific organic farming practices, certification procedures, and market opportunities. Limited extension services and inadequate training slow the adoption of organic agriculture.

Limited Research and Technology Support

Compared to conventional agriculture, research on high-yielding organic crop varieties, organic nutrient management, and biological pest control is relatively limited, affecting productivity and scalability.

Limited Domestic Market and Consumer Awareness

Despite growing demand, organic products constitute only a small share of India's food market due to higher prices, limited availability, and low consumer awareness about certified organic products.

Difficulty in Meeting India's Food Security Requirements

With a population exceeding **1.4 billion**, complete replacement of conventional farming by organic farming is currently impractical. Lower yields in certain crops may affect national food security, making a balanced approach necessary.

Risk of Fraud and Mislabeling

The increasing demand for organic products has led to instances of false labeling and counterfeit certification, reducing consumer confidence and affecting genuine organic producers.

10. Organic Farming vs Natural Farming vs Conventional Farming

Basis	Organic Farming	Natural Farming	Conventional Farming
Concept	Relies on natural inputs and certified organic practices.	Mimics natural ecosystems with minimal external inputs.	Depends on chemical fertilizers, pesticides, and modern agricultural technologies.
External Inputs	Organic manures, biofertilizers, and biopesticides are permitted.	Almost no external inputs; emphasizes on-farm preparations such as Jeevamrit and Beejamrit.	High dependence on synthetic fertilizers, pesticides, and herbicides.
Certification	Mandatory for marketing as "organic" under	No separate national certification system; generally promoted	No certification required.

Basis	Organic Farming	Natural Farming	Conventional Farming
	NPOP or **PGS-India**.	through government programmes.	
Productivity	Moderate; may decline during the transition period.	Generally lower in the initial years.	High productivity due to intensive input use.
Environmental Impact	Conserves soil, water, and biodiversity with low pollution.	Offers maximum ecological conservation and improves soil health.	Associated with soil degradation, water pollution, and biodiversity loss due to excessive chemical use.
Cost of Cultivation	Moderate after the transition period.	Lowest due to minimal external inputs.	Higher because of increasing costs of chemical inputs.
Government Support	PKVY, MOVCD-NER, NPOP, PGS-India.	National Mission on Natural Farming (NMNF) and BPKP.	Supported through fertilizer subsidy, irrigation, mechanization, MSP, etc.

11. Way Forward

- **Strengthen financial support:** Expand the coverage of **Paramparagat Krishi Vikas Yojana (PKVY)** and provide higher incentives during the 2–3 years transition period to offset initial yield losses.
- **Simplify certification:** Make **PGS-India** and **NPOP** certification more affordable, transparent, and digital to encourage greater participation by small and marginal farmers.
- **Promote research and innovation:** Increase investment in research on biofertilizers, biopesticides, climate-resilient organic crop varieties, and precision organic farming through **ICAR** and agricultural universities.
- **Develop robust value chains:** Strengthen Farmer Producer Organizations (FPOs), cold storage, processing, branding, e-commerce, and export infrastructure to improve market access and farmers' incomes.
- **Enhance farmer awareness:** Expand training, extension services, and digital advisory platforms to promote scientific organic farming practices and certification procedures.
- **Adopt a region-specific approach:** Encourage organic farming in rainfed, tribal, hilly, and North-Eastern regions where chemical input use is already low and the transition is easier.
- **Integrate with climate-smart agriculture:** Promote organic farming alongside natural farming, agroforestry, and sustainable water management to achieve India's climate commitments and Sustainable Development Goals (SDGs).

12. Conclusion

Organic farming is a sustainable and environmentally friendly agricultural system that improves **soil health, conserves biodiversity, reduces pollution, and produces safe food**. With continued government support, scientific research, improved certification, and stronger market linkages, organic farming can play a vital role in enhancing farmers' income, ensuring food security, promoting climate-resilient agriculture, and achieving sustainable agricultural development in India.

LESSON 5: DIGITAL TECHNOLOGY, COMMUNICATION AND CYBER SECURITY

Topics Covered under this Lesson

1. Digital ecosystem and communication technologies

1.1 5G Technology
1.2 Internet of Things (IoT)

2. Data governance and internet regulation

2.1 Net neutrality
2.2 Blockchain technology
2.3 Cryptocurrency

3. Cyber space and social impact

3.1 Cyber security in India
3.2 Social media (positive and negative aspects)
3.3 Digital divide (urban vs rural access gap)
3.4 Deepfake technology

1. Digital ecosystem and communication technologies

1.1 5G Technology

1. Introduction and Evolution of Mobile Communication

Definition of 5G Technology

5G (Fifth Generation) is the latest generation of mobile communication technology and the successor to 4G networks. It is a global wireless communication standard designed to provide ultra-high internet speed, extremely low latency (response time), greater network capacity, and seamless connectivity among billions of devices. Unlike previous generations that primarily focused on connecting people through voice and mobile internet, 5G aims to connect **people, machines, sensors, vehicles, industries, and public infrastructure**, making it the backbone of the **Digital Economy** and the **Fourth Industrial Revolution (Industry 4.0)**.

The International Telecommunication Union (ITU) has set ambitious performance targets for 5G, including **peak data speeds of up to 20 Gbps**, user-experienced speeds of around **100 Mbps**, latency as low as **1 millisecond**, and the ability to support **up to one million connected devices per square kilometre**. In comparison, 4G networks generally provide peak speeds of around **1 Gbps** under ideal conditions. These improvements enable applications that require real-time communication, such as autonomous vehicles, remote surgery, smart factories, and intelligent transport systems.

Evolution of Mobile Communication

Mobile communication technology has evolved continuously over the past four decades to meet growing communication and data needs.

Generation	Period	Key Features
1G	1980s	Analog technology supporting only voice calls with limited quality and security.
2G	1990s	Introduced digital communication, SMS, and basic internet services with data speeds up to about 64 Kbps.
3G	2000s	Enabled mobile internet, video calling, multimedia services, and speeds ranging from 1–2 Mbps.
4G	Around 2009	Offered broadband internet, HD video streaming, online gaming, cloud computing, and peak speeds up to about 1 Gbps.
5G	Commercial rollout since 2019 globally; launched in India in 2022	Provides ultra-fast broadband, ultra-low latency, massive machine connectivity, and supports advanced technologies such as Artificial Intelligence (AI), Internet of Things (IoT), cloud computing, augmented reality (AR), and virtual reality (VR).

Key Features of 5G Technology

5G represents a major technological leap because it offers several improvements over previous generations:

- **Ultra-high Speed:** It can theoretically achieve data speeds of up to **20 Gbps**, allowing ultra-high-definition video streaming, rapid downloading, and seamless cloud-based services.
- **Ultra-low Latency:** With response times as low as **1 millisecond**, 5G enables real-time applications such as robotic surgery, autonomous vehicles, industrial automation, and remote-control systems.
- **Massive Connectivity:** It can support nearly **one million connected devices per square kilometre**, making it suitable for smart cities, smart homes, precision agriculture, and industrial IoT.
- **Higher Network Capacity:** It can efficiently handle a much larger number of users and connected devices simultaneously without significant reduction in network performance.
- **Improved Energy Efficiency:** Modern 5G networks are designed to reduce energy consumption per unit of transmitted data, improving the battery life of connected IoT devices and supporting sustainable digital infrastructure.

Spectrum Bands Used in 5G

To achieve different levels of speed and coverage, 5G operates across three frequency bands.

- **Low Band Spectrum (Below 1 GHz):** It offers the widest geographical coverage and good signal penetration inside buildings but provides relatively lower internet speeds, generally up to about **100 Mbps**. It is particularly suitable for extending broadband services to rural and remote areas.
- **Mid Band Spectrum (1–6 GHz):** It provides a balanced combination of speed, coverage, and capacity. Consequently, it is considered the most practical spectrum for large-scale commercial deployment and industrial applications.
- **High Band Spectrum (Millimetre Wave/mmWave):** It offers extremely high speeds, reaching several gigabits per second, and very low latency. However, its coverage area is limited, and signals are easily blocked by buildings, trees, and other obstacles. Therefore, it requires a dense network of small cellular towers and is mainly suitable for smart factories, airports, stadiums, and other high-density urban locations.

India officially launched **5G services on 1 October 2022** under the **National Digital Communications Policy (NDCP), 2018**, which recognizes 5G as a key enabler of Digital India, Industry 4.0, Artificial Intelligence (AI), Internet of Things (IoT), cloud computing, and data-driven economic growth.

2. Applications of 5G Technology

Digital Governance and Public Service Delivery

5G technology has the potential to significantly strengthen **e-Governance** by enabling faster, more reliable, and real-time digital public services. Its ultra-low latency and high-speed connectivity facilitate instant communication between government departments, reducing delays in service delivery and improving administrative efficiency. It can support **AI-based citizen service platforms**, real-time monitoring of public infrastructure, intelligent traffic management, digital land record management, and integrated command and control centres in Smart Cities. In policing, 5G-enabled CCTV cameras, facial recognition systems, drones, and connected surveillance networks can improve crime prevention and emergency response.

The technology also enhances the delivery of digital services such as **DigiLocker, e-Hospital, UMANG, e-Courts, and Aadhaar-enabled services**, particularly in remote areas with reliable connectivity. Under the **National Digital Communications Policy (NDCP), 2018**, 5G has been recognised as a key enabler of Digital India. As India moves towards **Viksit Bharat 2047**, 5G is expected to make governance more transparent, efficient, and citizen-centric.

Agriculture and Precision Farming

5G can transform Indian agriculture by promoting **precision farming**, where farm operations are guided by real-time data rather than traditional practices. Through the **Internet of Things (IoT)**, farmers can monitor soil moisture, nutrient levels, weather conditions, crop health, and irrigation requirements using smart sensors connected over 5G networks. High-speed connectivity also enables the effective use of **drones** for crop monitoring, pesticide spraying, fertilizer application, and yield estimation, thereby reducing input costs and improving productivity. Artificial Intelligence integrated with 5G can provide farmers with timely advisories on pest attacks, irrigation scheduling, and market prices.

The technology also supports livestock monitoring through smart wearable devices and improves agricultural supply chains by enabling real-time tracking of produce. These applications complement initiatives such as the **Digital Agriculture Mission (2021–2025)** and the **Sub-Mission on Agricultural Mechanization (SMAM)**. By increasing productivity while reducing resource use, 5G can contribute to sustainable agriculture and higher farm incomes.

Healthcare and Telemedicine

5G technology has the potential to revolutionise healthcare by enabling **high-speed, reliable, and real-time medical services**, especially in underserved and rural areas. Its ultra-low latency supports **telemedicine**, allowing doctors to conduct high-quality video consultations, remotely diagnose patients, and monitor chronic diseases through wearable health devices. In advanced healthcare, 5G can facilitate **robot-assisted remote surgeries**, where specialists can perform procedures from distant locations with minimal delay. Connected ambulances equipped with 5G can transmit patients' vital signs, ECG, and medical history to hospitals before arrival, enabling faster emergency treatment.

The technology also strengthens **Artificial Intelligence (AI)-based diagnostics**, digital health records, and remote patient monitoring. In India, these applications complement the **Ayushman Bharat Digital Mission (ABDM)**, which aims to create an integrated digital health ecosystem through digital health IDs and electronic health records. Thus, 5G can improve healthcare accessibility, quality, and emergency response while reducing the rural-urban healthcare gap.

Education and Skill Development

5G can significantly enhance the quality and accessibility of education by enabling **interactive, immersive, and personalised learning experiences**. High-speed internet and low latency allow seamless access to online classes, high-definition educational content, and cloud-based learning platforms without interruption. Technologies such as **Augmented Reality (AR)** and **Virtual Reality (VR)** can create virtual laboratories, simulations, and practical training environments, particularly beneficial for science, engineering, and medical education. Educational institutions can also use AI-powered learning platforms to provide personalised instruction and real-time assessments.

For skill development, 5G enables advanced vocational training through virtual simulations in sectors such as manufacturing, healthcare, and defence. It also supports government initiatives like **PM eVIDYA, SWAYAM, DIKSHA, and the National Digital Education Architecture (NDEAR)** by improving digital connectivity and expanding access to quality education in rural and remote regions. Overall, 5G can bridge the digital divide and contribute to building a skilled workforce for the digital economy.

Industry 4.0 and Manufacturing

5G is a key enabler of **Industry 4.0**, which refers to the integration of digital technologies such as **Artificial Intelligence (AI), Internet of Things (IoT), robotics, cloud computing, and big data** into manufacturing processes. Its high-speed connectivity and ultra-low latency allow machines, sensors, and robots to communicate in real time, resulting in **smart factories** with minimal human intervention.

Industries can use 5G for predictive maintenance, automated quality inspection, remote operation of machinery, inventory management, and supply chain optimisation, thereby reducing production costs and increasing efficiency. The technology also supports the development of **private captive networks** for factories, ensuring secure and uninterrupted industrial communication. In India, 5G is expected to strengthen initiatives such as **Make in India, Production Linked Incentive (PLI) Scheme, Digital India, and Atmanirbhar Bharat** by improving industrial competitiveness, encouraging advanced manufacturing, and attracting investment in high-technology sectors.

Smart Cities, Transport and Urban Infrastructure

5G can play a transformative role in developing **smart cities** by enabling real-time communication between urban infrastructure, public services, and citizens. It supports **intelligent traffic management systems**, AI-enabled surveillance cameras, smart parking, adaptive street lighting, waste management, and efficient water and electricity distribution through connected sensors. In the transport sector, 5G enables **Vehicle-to-Vehicle (V2V)** and **Vehicle-to-Infrastructure (V2I)** communication, improving road safety, reducing traffic congestion, and supporting the future deployment of autonomous vehicles.

Public transport systems can also benefit from real-time tracking, predictive maintenance, and seamless digital ticketing. Under India's **Smart Cities Mission**, Integrated Command and Control Centres (ICCCs) are increasingly using advanced communication technologies for urban governance, disaster response, and public safety. Thus, 5G can improve the efficiency, sustainability, and quality of urban life while supporting the vision of smart and resilient cities.

Disaster Management and Public Safety

5G technology can significantly improve **disaster preparedness, emergency response, and public safety** by enabling the rapid transmission of real-time data. During natural disasters such as floods, cyclones, earthquakes, and landslides, 5G networks can support **early warning systems**, high-definition drone surveillance, satellite communication, and real-time sharing of information among disaster management agencies. Emergency responders can use connected drones and robots to locate survivors in hazardous areas where human access is difficult. High-speed connectivity also enables uninterrupted communication between police, fire services, hospitals, and disaster response forces, ensuring faster rescue and relief operations.

In India, agencies such as the **National Disaster Management Authority (NDMA)** and **India Meteorological Department (IMD)** can leverage 5G to strengthen disaster forecasting, risk assessment, and emergency coordination. Thus, 5G can help reduce loss of life and property by enabling faster and more effective disaster management.

Defence and Internal Security

5G has emerged as a strategic technology for strengthening **national security, defence preparedness, and internal security**. Its high-speed, secure, and low-latency communication enables real-time coordination among defence forces during military operations. The technology supports advanced applications such as AI-enabled surveillance systems, unmanned aerial vehicles (drones), autonomous military vehicles, smart border monitoring, and network-centric warfare.

Security agencies can use 5G-enabled CCTV cameras, facial recognition systems, and intelligent surveillance networks for crime prevention, counter-terrorism, and crowd management. Along India's international borders, 5G can improve the effectiveness of smart fencing, sensor networks, and drone-based monitoring to detect infiltration and illegal activities. However, the growing dependence on digital networks also increases the importance of **cybersecurity**, requiring robust encryption, indigenous telecom infrastructure, and secure communication systems to protect critical national assets.

Emerging Technologies Enabled by 5G

5G serves as the foundation for several **next-generation digital technologies** by providing ultra-fast data transfer, ultra-low latency, and the ability to connect millions of devices simultaneously. It enables the large-scale deployment of the **Internet of Things (IoT)**, where smart sensors continuously exchange data in homes, industries, agriculture, and cities. **Artificial Intelligence (AI)** and **Big Data Analytics** become more effective as 5G facilitates real-time collection and processing of massive volumes of data. The technology also strengthens **Edge Computing**, allowing data to be processed closer to the user, thereby reducing delays in applications such as autonomous vehicles and industrial automation.

Similarly, **Cloud Computing** benefits from faster and more reliable access to computing resources. 5G further supports immersive technologies such as **Augmented Reality (AR)** and **Virtual Reality (VR)** in education, healthcare, entertainment, and training. These technologies collectively drive **Industry 4.0**, digital innovation, and the growth of the digital economy. According to the **National Digital Communications Policy (NDCP), 2018**, the convergence of 5G with AI, IoT, cloud computing, and data analytics is expected to accelerate India's digital transformation and create new opportunities for economic growth and employment.

3. Status of 5G in India

Launch and Rollout of 5G

- India officially launched **5G services on 1 October 2022** at the **India Mobile Congress** in New Delhi.
- Commercial rollout began in major metropolitan cities and has been rapidly expanded across the country.
- As of **2026**, 5G services are available in almost all districts, making India one of the fastest countries in terms of 5G deployment.
- Major telecom operators providing 5G services include **Reliance Jio**, **Bharti Airtel**, and **BSNL** (through phased indigenous 4G/5G rollout).

Government Policy Support

- The **National Digital Communications Policy (NDCP), 2018** identified 5G as a key technology for India's digital transformation.
- The policy aims to provide universal broadband connectivity, promote digital infrastructure, and encourage innovation in emerging technologies.
- The government has also simplified procedures for telecom infrastructure deployment through the **Telecommunication Act, 2023** and revised **Right of Way (RoW)** rules.

Spectrum Auction

- India conducted its first **5G spectrum auction in 2022**, allocating spectrum across **Low Band (700 MHz), Mid Band (3300 MHz), and High Band (26 GHz/mmWave)**.
- The auction generated over **₹1.5 lakh crore** in revenue, making it one of the country's largest spectrum auctions.
- Adequate spectrum allocation has enabled telecom companies to expand high-speed 5G services across India.

Indigenous 5G Development

- India has developed an **indigenous 4G/5G technology stack** under the leadership of **C-DOT (Centre for Development of Telematics)**.
- The government is promoting domestic manufacturing of telecom equipment under **Atmanirbhar Bharat**, **Make in India**, and the **Production Linked Incentive (PLI) Scheme**.
- Indigenous development aims to reduce dependence on imported telecom equipment and strengthen national cybersecurity.

Research and Innovation

- The **Bharat 6G Vision**, launched in **2023**, aims to position India among the global leaders in next-generation communication technologies by **2030**.
- The **100 5G Use Case Labs** initiative has been launched in higher educational institutions to promote innovation in sectors such as agriculture, healthcare, smart cities, education, and logistics.
- Collaboration among government, academia, startups, and industry is accelerating the development of indigenous telecom technologies.

4. Challenges in 5G Deployment

High Infrastructure Cost

- 5G requires a much denser network of telecom towers, small cells, optical fibre, and advanced equipment than previous generations.
- Telecom operators need to make substantial investments in upgrading existing infrastructure, increasing the financial burden on the sector.
- The high capital expenditure may slow down expansion, particularly in economically less-developed regions.

Low Optical Fibre Connectivity

- Optical fibre forms the backbone of a high-speed 5G network, but **only about one-third of India's telecom towers are fibre-connected**.
- Experts estimate that fibre connectivity needs to exceed **60–70%** for efficient nationwide 5G services.
- Inadequate fibre infrastructure affects network speed, reliability, and service quality, especially in rural areas.

Rural-Urban Digital Divide

- The initial rollout of 5G has largely been concentrated in metropolitan and urban areas due to higher commercial viability.
- Rural and remote regions continue to face challenges such as inadequate telecom infrastructure, unreliable electricity supply, and limited digital literacy.
- Unless addressed, 5G may widen the existing digital divide between urban and rural populations.

High Spectrum Pricing

- Spectrum acquisition involves significant financial investment by telecom companies.
- High spectrum costs reduce the financial capacity of telecom operators to invest in network expansion and technological innovation.
- Affordable spectrum pricing is essential for faster and wider 5G deployment.

Cybersecurity and Data Privacy Risks

- As billions of devices become interconnected through 5G, the risk of cyberattacks, data theft, ransomware, and network vulnerabilities increase significantly.
- Critical sectors such as defence, healthcare, banking, and power infrastructure require robust cybersecurity mechanisms and strong data protection frameworks.
- Strengthening indigenous telecom technologies and cyber resilience has become a national priority.

Dependence on Imported Telecom Equipment

- India continues to rely on imports for several advanced telecom components and semiconductor technologies.
- Excessive dependence on foreign equipment may create supply chain vulnerabilities and strategic security concerns.
- Promoting domestic manufacturing and indigenous research is crucial for achieving technological self-reliance.

Way Forward

- **Strengthen Digital Infrastructure:** Expand optical fibre connectivity, telecom towers, and small-cell networks to ensure seamless nationwide 5G coverage.
- **Promote Domestic Manufacturing:** Encourage indigenous production of telecom equipment through **Make in India**, **Atmanirbhar Bharat**, and the **PLI Scheme**.
- **Rationalise Spectrum Pricing:** Adopt affordable and investor-friendly spectrum pricing to accelerate network expansion.
- **Bridge the Rural-Urban Divide:** Extend 5G connectivity to rural and remote areas through targeted government support and public-private partnerships.
- **Enhance Cybersecurity:** Develop strong cybersecurity frameworks, indigenous telecom technologies, and robust data protection mechanisms to secure critical infrastructure.
- **Invest in Research and Innovation:** Strengthen collaboration among academia, industry, startups, and research institutions to develop future communication technologies, including **6G**.
- **Promote Digital Skills:** Improve digital literacy and create a skilled workforce capable of leveraging 5G-enabled technologies across sectors.

6. Conclusion

5G is not merely a faster mobile network but a **foundational technology** for India's digital transformation. By enabling advanced applications in governance, agriculture, healthcare, education, manufacturing, and smart cities, it has the potential to accelerate economic growth, improve public service delivery, and enhance citizens' quality of life.

However, realizing its full benefits will require robust digital infrastructure, affordable spectrum, strong cybersecurity, and inclusive rural connectivity. With sustained policy support and indigenous innovation, 5G can play a pivotal role in achieving the goals of **Digital India**, **Atmanirbhar Bharat**, and **Viksit Bharat 2047**.

LESSON 6: EMERGING TECHNOLOGIES AND ADVANCED SCIENCE

Topics Covered under this Lesson

1. Advanced digital and intelligent technologies

1.1 Artificial Intelligence (AI)
1.2 ChatGPT technology
1.3 Use of Robot technology (pros and cons)

2. Industrial and frontier technologies

2.1 3D Printing
2.2 Application of Nano technology
2.3 National Quantum Mission (NQM)
2.4 India Semiconductor Mission (ISM)

3. Core scientific developments and applications

3.1 Rare Earth Metals
3.2 Super conductivity
3.3 Gravitational Waves
3.4 Super Computers in India
3.5 Cloud seeding

1. Advanced digital and intelligent technologies

1.1 Artificial Intelligence (AI)

1. Introduction

Artificial Intelligence (AI) is a branch of computer science that enables machines or computer systems to perform tasks that normally require **human intelligence**, such as learning, reasoning, problem-solving, decision-making, language understanding and pattern recognition. AI systems analyse large volumes of data, identify patterns and continuously improve their performance through experience. Unlike traditional computer programs that follow fixed instructions, AI can make predictions and support decision-making based on available data.

AI is not intended to replace human intelligence completely. Rather, it acts as an **intelligent assistant** by improving efficiency, reducing human effort and enabling faster and more accurate decisions in various sectors. **Machine Learning (ML)** and **Deep Learning (DL)** are important subsets of AI that enable computers to learn from data and solve increasingly complex problems. Recent advances in **Generative AI** (such as ChatGPT and Gemini) have further expanded AI's capabilities by enabling machines to generate text, images, audio and computer code.

Why is AI Important Today?

- AI is driving the **Fourth Industrial Revolution (Industry 4.0)** by transforming industries through automation, intelligent decision-making and data-driven innovation.
- It is becoming an essential technology for improving **healthcare, agriculture, education, governance, defence, manufacturing, finance and scientific research**.
- Governments across the world, including India, are investing heavily in AI to promote economic growth, improve public service delivery and enhance global competitiveness.
- India's vision of **"AI for All"**, promoted by **NITI Aayog** and strengthened through the **IndiaAI Mission**, aims to ensure that AI benefits every section of society while promoting responsible and ethical use.
- AI is often called the **"new electricity"** because, like electricity transformed every industry in the 20th century, AI is expected to transform almost every sector of the economy in the 21st century.

2. Evolution of Artificial Intelligence (AI)

- **1956:** The term **"Artificial Intelligence"** was coined by **John McCarthy** at the Dartmouth Conference, marking the birth of AI as a scientific discipline.
- **1980s–1990s:** Development of **Machine Learning (ML)** enabled computers to learn from data instead of relying only on fixed programming.
- **2010s:** Advances in **Deep Learning (DL)**, cloud computing and big data significantly improved AI's ability in image recognition, speech processing and language understanding.

- **2022 onwards:** The emergence of **Generative AI** (e.g., ChatGPT, Gemini, Claude) revolutionized AI by enabling machines to generate human-like text, images, audio and computer code.
- **Present:** AI has become a strategic technology driving innovation in sectors such as healthcare, agriculture, education, governance, defence and scientific research.

3. Difference between AI, Machine Learning (ML), Deep Learning (DL) and Generative AI

Aspect	Artificial Intelligence (AI)	Machine Learning (ML)	Deep Learning (DL)	Generative AI
Meaning	Broad field that enables machines to mimic human intelligence	Subset of AI that learns from data	Subset of ML using multi-layered neural networks	AI that creates new content such as text, images, audio and videos
How it Works	Uses rules, logic and learning techniques	Learns patterns from data	Learns complex patterns from large datasets	Generates new content based on learned patterns
Data Requirement	Low to High	Moderate	Very High	Very High
Examples	Virtual assistants, expert systems	Spam filters, recommendation systems	Face recognition, speech recognition	ChatGPT, Gemini, DALL·E, Midjourney

4. Applications of Artificial Intelligence (AI)

AI in Agriculture

Artificial Intelligence is making agriculture **more productive, efficient and climate-resilient** by enabling data-driven farming practices.

- **Precision Farming:** AI analyses soil health, weather conditions and satellite images to recommend the optimum time for sowing, irrigation and fertilizer application, thereby increasing productivity while reducing input costs.
- **Crop Disease Detection:** AI-powered applications can identify crop diseases and pest attacks at an early stage by analysing images of affected crops, enabling timely treatment and reducing crop losses. **Example:** *Plantix* helps farmers diagnose crop diseases through smartphone images.
- **Yield Prediction:** AI uses historical data, weather forecasts and crop conditions to estimate agricultural output, helping farmers and governments plan procurement and food distribution efficiently. **Example:** The **Microsoft–ICRISAT AI Project** in Andhra Pradesh increased groundnut yield by nearly **30%** through AI-based sowing advisories.
- **Farmer Advisory Services:** AI-powered chatbots and digital platforms provide farmers with real-time information on government schemes, weather forecasts and best farming practices. **Example:** The Government of India's **Kisan e-Mitra** chatbot under PM-KISAN offers instant assistance to farmers.

AI in Healthcare

Artificial Intelligence is transforming healthcare by improving **diagnosis, treatment, medical research and healthcare delivery**.

- **Early Disease Diagnosis:** AI analyses X-rays, CT scans and MRI images with high accuracy, enabling doctors to detect diseases such as tuberculosis, cancer and pneumonia at an early stage. **Example:** Indian startup **Qure.ai** uses AI for rapid detection of TB from chest X-rays.
- **Cancer Screening and Personalized Treatment:** AI helps identify diseases in their early stages and assists doctors in designing personalized treatment plans based on patient data. **Example:** Bengaluru-based **Niramai** uses AI-based thermal imaging for early breast cancer screening without radiation.
- **Drug Discovery and Medical Research:** AI significantly reduces the time and cost of developing new medicines by analysing vast biomedical datasets. **Example:** AI accelerated vaccine and drug research during the **COVID-19 pandemic**.
- **Telemedicine and Healthcare Access:** AI-powered virtual assistants and remote monitoring systems improve healthcare access in rural and underserved areas. **Example:** The **Indian Council of Medical Research (ICMR)** has issued ethical guidelines for the responsible use of AI in healthcare.

AI in Education

Artificial Intelligence is making education **more personalized, accessible and effective** by catering to the diverse learning needs of students.

- **Personalized Learning:** AI analyses students' learning patterns, strengths and weaknesses to provide customized study materials, quizzes and learning paths, thereby improving learning outcomes.
- **Smart Teaching and Assessment:** AI automates routine tasks such as evaluation, attendance, question generation and performance analysis, allowing teachers to focus more on interactive teaching.
- **24×7 Learning Support:** AI-powered virtual tutors and chatbots provide instant explanations, doubt resolution and multilingual learning support, making quality education accessible anytime and anywhere. **Example:** Platforms such as **ChatGPT** and **Google Gemini** are increasingly being used as learning assistants.
- **Government Initiatives:** AI is being integrated into digital education platforms to improve learning outcomes. **Example:** The **DIKSHA** platform uses AI-based recommendations to provide personalized digital learning resources, while **PM eVIDYA** expands access to online education across the country.

AI in Governance and Public Services

Artificial Intelligence is improving governance by making **public service delivery faster, transparent and citizen-centric**.

- **Efficient Public Service Delivery:** AI-powered chatbots and virtual assistants provide citizens with instant information on government schemes, certificates and grievance redressal, reducing delays and improving accessibility. **Example: Kisan e-Mitra** assists farmers under the PM-KISAN scheme.

- **Better Decision-Making:** AI analyses large volumes of administrative data to support evidence-based policymaking, resource allocation and implementation of welfare schemes.
- **Smart Governance and Urban Management:** AI helps monitor traffic, manage public utilities, detect tax evasion and improve municipal services through real-time data analysis. **Example:** AI-enabled **Integrated Command and Control Centres (ICCCs)** under the **Smart Cities Mission** help manage traffic, surveillance and emergency response.
- **Language Inclusion and Digital Governance:** AI is breaking language barriers by enabling real-time translation and voice-based access to government services. **Example:** The **BHASHINI** initiative promotes AI-driven translation and speech technologies to deliver digital services in Indian languages.

AI in Banking and Financial Services

Artificial Intelligence is transforming the banking and financial sector by improving **efficiency, security and customer experience**.

- **Fraud Detection and Cybersecurity:** AI analyses millions of financial transactions in real time to detect suspicious activities, helping banks prevent fraud, phishing and cyberattacks before major losses occur.
- **Digital Banking and Customer Support:** AI-powered chatbots and virtual assistants provide 24×7 customer support, resolve queries instantly and reduce waiting time. **Example: SIA** (State Bank of India) and **EVA** (HDFC Bank) assist customers with banking services and information.
- **Credit Assessment and Loan Approval:** AI evaluates customers' financial history, spending behaviour and repayment capacity to assess creditworthiness, enabling faster and more accurate loan approvals while reducing the risk of bad loans.
- **Investment and Financial Planning:** AI-based robo-advisors analyse market trends and investor preferences to provide personalised investment advice and portfolio management, making financial services more accessible.

AI in Defence and National Security

Artificial Intelligence is strengthening national security by enhancing **surveillance, intelligence gathering, border management and modern warfare capabilities**.

- **Intelligence, Surveillance and Reconnaissance (ISR):** AI analyses satellite imagery, drone feeds and sensor data to identify suspicious activities, enabling faster and more accurate intelligence for security agencies.
- **Autonomous Defence Systems:** AI enables drones, unmanned ground vehicles and robotic systems to carry out surveillance, reconnaissance and logistics operations in high-risk areas with minimal human intervention. **Example: DRDO's Alpha-S** swarm drone system can coordinate multiple drones simultaneously for surveillance and combat missions.
- **Border Management:** AI-powered cameras, sensors and facial recognition systems help monitor borders, detect illegal infiltration and improve real-time situational

awareness. **Example:** AI-enabled surveillance systems are being deployed along India's international borders to strengthen border security.

- **Cyber Defence and Threat Detection:** AI continuously monitors digital networks to detect cyberattacks, malware and unusual activities, enabling rapid response to emerging security threats.

AI in Industry and Manufacturing

Artificial Intelligence is driving **Industry 4.0** by making manufacturing smarter, faster and more cost-effective.

- **Smart Manufacturing:** AI automates production processes, monitors machinery in real time and optimizes manufacturing operations, leading to higher productivity and lower operational costs.
- **Predictive Maintenance:** AI analyses machine performance and sensor data to predict equipment failures before they occur, reducing downtime and maintenance costs. **Example: Tata Steel** uses AI-based predictive maintenance to improve operational efficiency in its manufacturing plants.
- **Quality Control:** AI-powered computer vision systems inspect products with high precision, detect defects and ensure consistent product quality. **Example: Maruti Suzuki** uses AI-enabled vision systems for quality inspection during automobile manufacturing.
- **Supply Chain Optimization:** AI forecasts demand, manages inventory and optimizes logistics, enabling industries to reduce waste and improve delivery efficiency.

AI in Transport and Smart Mobility

Artificial Intelligence is making transportation **safer, faster and more efficient** by improving traffic management, logistics and public transport systems.

- **Intelligent Traffic Management:** AI analyses real-time traffic data to optimize traffic signals, reduce congestion and improve road safety. **Example:** AI-based **Adaptive Traffic Management Systems (ATMS)** have been implemented in cities such as **Bengaluru and Delhi** to reduce travel time.
- **Road Safety and Accident Prevention:** AI-enabled cameras detect traffic violations such as overspeeding, wrong-side driving and red-light jumping, helping authorities enforce traffic rules more effectively.
- **Railway Safety and Operations:** AI monitors railway tracks, signalling systems and locomotives to predict faults and prevent accidents, thereby improving operational efficiency. **Example:** Indian Railways is increasingly using AI-based predictive maintenance for locomotives and critical railway infrastructure.
- **Smart Logistics and Route Optimization:** AI identifies the shortest and most fuel-efficient routes for passenger and freight transport, reducing transportation costs and carbon emissions.

AI in Disaster Management

Artificial Intelligence is enhancing disaster management by enabling **early warning, rapid response and effective damage assessment**, thereby reducing the loss of life and property.

- **Early Warning Systems:** AI analyses weather, satellite and historical disaster data to accurately predict floods, cyclones, heatwaves and other natural disasters, allowing authorities to issue timely warnings.
- **Disaster Monitoring and Damage Assessment:** AI processes satellite images and drone data to identify affected areas, assess the extent of damage and support faster relief and rehabilitation operations.
- **Search and Rescue Operations:** AI-powered drones and robots help locate survivors, monitor inaccessible areas and assist rescue teams during earthquakes, floods and landslides.
- **Disaster Risk Planning:** AI helps governments identify disaster-prone regions and prepare mitigation strategies through predictive modelling. **Example: Google Flood Hub** uses AI to provide flood forecasts in India, while the **India Meteorological Department (IMD)** is increasingly using AI for improving weather prediction.

AI in Environment and Climate Change

Artificial Intelligence is supporting environmental conservation by enabling **efficient monitoring, sustainable resource management and climate action**.

- **Air and Water Quality Monitoring:** AI analyses real-time environmental data to predict pollution levels, identify pollution hotspots and support timely policy interventions. **Example:** AI-based models are being used to improve **Air Quality Index (AQI)** forecasting in major Indian cities.
- **Wildlife and Forest Conservation:** AI-powered camera traps, drones and image recognition systems help monitor wildlife populations, detect poaching activities and protect biodiversity. **Example:** AI-enabled camera traps are being used for **tiger monitoring** in several Indian tiger reserves.
- **Forest Fire Detection and Climate Monitoring:** AI analyses satellite imagery to detect forest fires at an early stage and supports climate modelling by analysing large volumes of environmental data.
- **Sustainable Resource Management:** AI optimizes the use of water, energy and natural resources, helping reduce wastage and supporting sustainable development.

AI in Space Research

Artificial Intelligence is revolutionizing space research by improving **mission planning, satellite operations and analysis of vast amounts of space data**.

- **Satellite Data Analysis:** AI rapidly analyses images received from Earth observation satellites to monitor agriculture, urbanization, natural disasters and climate change, enabling faster and more accurate decision-making.

- **Space Mission Planning:** AI assists scientists in mission planning, spacecraft navigation and autonomous decision-making, reducing human intervention and improving mission efficiency.
- **Space Debris Monitoring:** AI tracks thousands of space objects, predicts possible collisions and helps protect operational satellites from damage, ensuring safer space operations.
- **Planetary Exploration:** AI enables robotic spacecraft and planetary rovers to navigate unfamiliar terrain, identify scientific targets and perform autonomous operations. **Example:** ISRO is increasingly integrating AI into satellite data processing and future missions such as **Gaganyaan** and **Chandrayaan** to improve mission efficiency.

AI in Cyber Security

Artificial Intelligence is strengthening cybersecurity by enabling **real-time threat detection, faster response and proactive defence** against cyber threats.

- **Threat Detection and Prevention:** AI continuously monitors network activity, identifies unusual behaviour and detects cyber threats such as malware, ransomware and phishing attacks before they cause significant damage.
- **Fraud Detection:** AI analyses millions of digital transactions in real time to identify suspicious activities, helping banks, e-commerce platforms and payment systems prevent financial fraud.
- **Automated Incident Response:** AI automatically isolates infected systems, blocks malicious traffic and assists cybersecurity teams in responding quickly to cyber incidents, thereby minimizing damage.
- **Protection of Critical Infrastructure:** AI safeguards critical sectors such as banking, power grids, defence and telecommunications by continuously monitoring digital networks and identifying vulnerabilities. **Example: CERT-In** is increasingly leveraging AI and advanced analytics to strengthen India's cyber resilience against evolving cyber threats.

5. Advantages / Significance of Artificial Intelligence (AI)

- **Economic Growth and Productivity:** AI automates repetitive tasks, improves operational efficiency and reduces costs, thereby enhancing productivity across agriculture, manufacturing, healthcare and services. It is expected to become a major driver of India's digital economy.
- **Improved Public Service Delivery:** AI enables faster, transparent and citizen-centric governance through smart administration, digital service delivery, grievance redressal and evidence-based policymaking.
- **Better Healthcare and Quality of Life:** AI supports early disease diagnosis, personalized treatment, drug discovery and telemedicine, making quality healthcare more accessible, especially in rural and remote areas.
- **Scientific Innovation and Research:** AI accelerates research by analysing large datasets, supporting discoveries in fields such as biotechnology, pharmaceuticals, climate science and space exploration.

- **National Security and Disaster Resilience:** AI strengthens border surveillance, cybersecurity, disaster prediction and emergency response, thereby enhancing India's internal security and disaster preparedness.
- **Inclusive and Sustainable Development:** AI promotes financial inclusion, smart agriculture, environmental conservation and efficient resource management, contributing to the achievement of the **Sustainable Development Goals (SDGs)** and **Viksit Bharat 2047**.

6. Challenges and Concerns of Artificial Intelligence (AI)

- **Job Displacement and Skill Gap:** AI-driven automation may replace routine and repetitive jobs, particularly in manufacturing, customer support and data entry, increasing the need for reskilling and upskilling of the workforce.
- **Bias and Ethical Concerns:** AI systems learn from existing data, which may contain biases based on gender, caste or race. As a result, AI-based decisions may be unfair or discriminatory if not properly monitored.
- **Privacy and Data Security:** AI requires vast amounts of personal data for training and decision-making. Inadequate protection of such data may lead to privacy violations, identity theft and misuse of sensitive information.
- **Deepfakes and Misinformation:** AI-generated fake images, videos and audio (deepfakes) can spread misinformation, influence elections, damage reputations and pose serious challenges to national security.
- **Cybersecurity Risks:** While AI strengthens cyber defence, it can also be misused by cybercriminals to develop sophisticated malware, automate hacking attempts and launch large-scale cyberattacks.
- **Lack of Transparency and Accountability:** Many AI systems function as **'black boxes'**, making it difficult to understand how decisions are made or who should be held accountable when AI causes errors or harm.
- **Legal and Regulatory Challenges:** The rapid growth of AI has outpaced existing laws, creating challenges related to liability, copyright, intellectual property and ethical governance.
- **Digital Divide and High Cost:** Unequal access to digital infrastructure, skilled manpower and computing resources may widen the technology gap between developed and developing regions, including between urban and rural India.

7. AI Governance and Regulation in India

India follows a **pro-innovation and risk-based approach** to AI governance, aiming to promote innovation while ensuring that AI remains **safe, transparent, ethical and accountable**.

- **National Strategy for AI (2018):** Released by **NITI Aayog** with the vision of **"AI for All"**, focusing on inclusive growth and the use of AI in sectors such as healthcare, agriculture, education, smart mobility and smart cities.
- **Responsible AI Framework:** NITI Aayog's **Responsible AI for All** guidelines promote principles such as **fairness, transparency, accountability, privacy and safety** in the development and deployment of AI.

- **Digital Personal Data Protection (DPDP) Act, 2023:** Provides a legal framework for the protection and lawful processing of personal data, which is crucial for AI systems relying on large datasets.
- **Global Cooperation:** India actively participates in global AI governance discussions through platforms such as the **G20**, **Global Partnership on AI (GPAI)** and the **Bletchley Declaration** on AI safety.

8. Government Initiatives Promoting Artificial Intelligence (AI)

- **IndiaAI Mission (2024):** Flagship mission with an outlay of **₹10,371.92 crore** to strengthen AI computing infrastructure, indigenous AI models, startups, skill development and responsible AI innovation.
- **National Strategy for AI – AI for All:** Launched by **NITI Aayog (2018)** to promote the use of AI in priority sectors such as healthcare, agriculture, education, smart mobility and smart cities.
- **IndiaAI Compute Portal:** Provides access to high-performance **Graphics Processing Units (GPUs)**, enabling startups, researchers and academic institutions to develop AI applications at affordable costs.
- **BHASHINI (National Language Translation Mission):** Uses AI to provide real-time translation and speech technologies in Indian languages, making digital services more inclusive and accessible.
- **Centres of Excellence (CoEs) in AI:** The Government has established AI Centres of Excellence in sectors such as **healthcare, agriculture and sustainable cities** to promote research, innovation and industry collaboration.
- **AI Skilling and Innovation:** Initiatives such as **FutureSkills PRIME**, Digital India and AI-focused programmes in **IITs, IIITs and NITs** are strengthening India's AI talent pool and innovation ecosystem.

9. Conclusion

Artificial Intelligence has emerged as a transformative technology with the potential to revolutionize sectors such as **healthcare, agriculture, education, governance, manufacturing and national security**. For India, AI offers a unique opportunity to accelerate economic growth, improve public service delivery and achieve the vision of **Viksit Bharat 2047**.

However, the rapid adoption of AI must be accompanied by **ethical governance, data privacy, transparency and skill development** to address challenges such as job displacement, bias and cybersecurity risks. A **human-centric and responsible AI ecosystem**, guided by the principle of **"AI for All"**, will ensure that technological progress benefits every section of society.