

GREEN FILES

Volume 53 (Jan to March 2025)

Volume 54 (April to June 2025)

**Emerging Technologies
in the field of
Environment Protection and Conservation**



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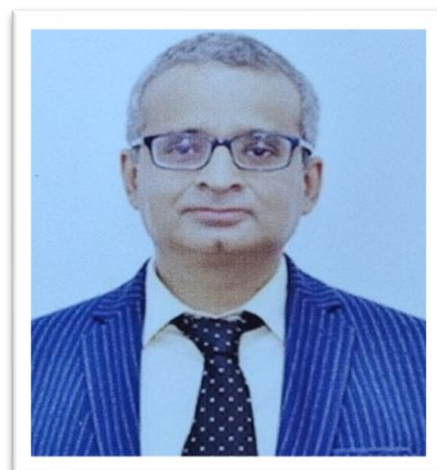
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Foreword

In this combined release of *The Green Files* — encompassing the 53rd Edition (January to March 2025) and the 54th Edition (April to June 2025) — we navigate through the dynamic landscape of **Emerging Technologies in the Field of Environment Protection and Conservation**.



As a Global Training Facility of the INTOSAI WGEA, iCED has remained at the forefront of this transformation by not only strengthening the capacity of Supreme Audit Institutions across the world but also building domestic expertise to respond to India's environmental challenges. Through national and international training programmes, workshops, and collaborations with institutions like IIT Madras, iCED has reinforced its role as a hub for **capacity building, knowledge exchange, and innovation in environmental auditing and sustainability**. This edition of *Green Files* reflects these commitments, while also providing readers with perspectives that connect global experiences with national priorities.

The first half of 2025 marked a period of significant progress in India's environmental governance, where emerging technologies, evolving policies, and strong institutional collaborations shaped the national discourse. Issues such as plastic pollution, air quality, biodiversity conservation, sustainable agriculture, and blue economy management continue to remain at the core of India's developmental priorities. At the same time, the rapid growth of tools such as Artificial Intelligence, Machine Learning, GIS, and IoT has opened up new pathways for monitoring, analysis, and decision-making in the environmental domain.

Further, on its path to support environment audits, iCED identified some themes based on environmental challenges posed by it and prepared a Compendium of Auditable areas on emerging environmental themes. In these lines, along with this combined edition of *Green Files Volume 53 & 54*

(January–June 2025), we are also publishing a **supplementary “Compendium on Audit Frameworks on Emerging Environmental Themes”** on ten critical environmental issues including agriculture and groundwater, air pollution, renewable energy, sanitation, wetlands, rivers, sustainable cities, rural development, EIA, and disaster management. Each framework integrates policy context, data points, judicial directives, and case studies, supported by practical checklists to guide auditors through planning, execution, and reporting.

We look forward to your suggestions to make Green Files as informative and user friendly as possible. Your contributions within the broad scope of this quarterly journal will be highly appreciated, including any feedback you may like to share on the featured articles.

(Dr. Abhishek Gupta)
Additional Dy. Comptroller and Auditor General
and Director General,
iCED, Jaipur

Message from the Director (Training & Research)

Dear Readers,



I am happy to present iCED's quarterly journal, "Green Files 53rd Edition (January to March 2025) and the 54th Edition (April to June 2025) for the period of January to June 2025. This issue is dedicated to a theme of paramount importance – **Emerging Technologies in the field of Environment Protection and conservation.** In this edition we are focusing on how emerging technologies are helping us in conservation and protection of the environment which sustains our lives.

This issue brings together a wide range of articles and features covering pressing themes such as plastic waste management, smart urban solutions, biodiversity conservation, renewable energy transitions, air pollution monitoring, smart agriculture, groundwater management, and disaster resilience. Each contribution reflects both the challenges and the opportunities that define India's environmental landscape today.

During this period, iCED conducted a series of national and international training programmes, workshops, and knowledge-sharing initiatives that reinforced its role as a Global Training Facility under INTOSAI WGEA. These programmes not only addressed traditional audit areas such as extractive industries, health, and water governance, but also ventured into forward-looking domains including the Blue Economy, ESG frameworks, and the application of Artificial Intelligence and Machine Learning in environmental audits. The learnings from these engagements are reflected in the content of this volume, making it both timely and relevant.

In addition to this edition, we are also releasing a **supplementary "Compendium on Audit Frameworks on Emerging Environmental Themes"** on ten critical environmental issues, which we believe will be of immense value to auditors and stakeholders. Together, these publications

serve as practical knowledge tools—combining policy context, data, judicial directives, and field-based experiences—to support evidence-based audits and informed decision-making. We hope this compendium serves as a catalyst for more impactful environmental audits, ones that not only assess performance but also help shape stronger policies, improve governance, and foster sustainability.

We hope this newsletter informs, inspires, and encourages action. The shift to clean energy is not just a necessity—it's an opportunity to build a greener, self-reliant India.

(Meena Bisht)
Director (Training & Research)
iCED, Jaipur

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iCED in its Role

iCED and IIT Madras MoU

iCED signed an MoU with IIT Madras to collaborate for capacity building and research in Environment Audit and Environmental, Social and Governance (ESG). This partnership will leverage Artificial Intelligence (AI), Machine Learning (ML) and other technological advancements for improving the effectiveness of these areas of auditing.



International Visits

A delegation of INTOSAI-WGEA from SAI Finland and SAI Maldives visited iCED, Jaipur from 2–4 June 2025 to discuss revamping environmental audit courses and strengthening global partnerships. Discussions were held to restructure International Training Programmes by reducing their duration, introducing pre-programme online sessions, customising content, and providing post-training handholding and e-learning support. iCED will also conduct a series of international webinars in 2025–26 on themes such as environmental accounting, biodiversity–climate nexus, green fiscal policy, and sustainability reporting. The meeting highlighted iCED's role in the Audit Clinic initiative, providing expert support on diverse environmental audit areas.

Discussions were also held on a proposed joint course on Disaster Risk and Resilience in collaboration with UNDRR.



Training Programmes at iCED: January – June 2025

The International Centre for Environment Audit and Sustainable Development (iCED), Jaipur, continued its endeavour of strengthening audit capabilities and promoting sustainability-focused knowledge sharing through a rich bouquet of training programmes and workshops during the first half of 2025. These programmes catered to officers from the Indian Audit and Accounts Department (IA&AD), other government organisations, and international participants from Supreme Audit Institutions (SAIs), reflecting iCED's global outreach and commitment to professional excellence.

Recognizing the rapid advancements in artificial intelligence and machine learning, and their growing importance in the field of audit, iCED entered into a partnership with IIT Madras to deliver specialized training on the **Use of Artificial Intelligence and Machine Learning in Audit of Emerging Environmental issues and ESG (Environmental, Social, and Governance)**. The inaugural session was held from 21–25 April 2025.

This programme introduced officers to cutting-edge AI/ML techniques relevant to audit, with a special emphasis on environmental challenges and ESG considerations. Conducted in collaboration with IIT Madras, it highlighted iCED's commitment to future-ready, tech-driven auditing practices. As a result, this initiative stood out as one of the most innovative and forward-thinking training programmes of 2025.



Further, on emphasis of the C&AG of India to strengthen the Auditor and Auditee relationship, iCED took the first step by engaging Indian Air Force to enhance their understanding of the audit processes.

Designed exclusively for IAF officers, it reinforced institutional synergy and capacity building in defence audit. This flagship programme reflected iCED's expanding role in sector-specific training and was one of the most impactful highlights of the period.



iCED conducted two trainings under this –

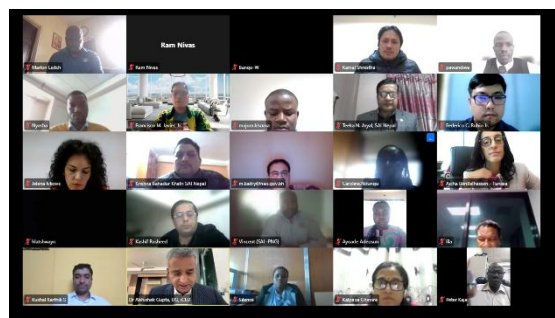
1. Training on conduct of Audit by CAG for officers of the Indian Air Force (17–21 March 2025)
2. Training Programme on Appreciation of CAG Audit for Indian Air Force officers (7–11 April 2025)

To support field offices in enhancing the quality of Audit, iCED conducted a two-day onsite Training Programme on Prevention, Control & Abatement of Air Pollution in Madhya Pradesh (10–11 June 2025) for assistance in Performance Audit on the same topic.



International Trainings

1. ITP on Audit of Extractive Industries (INTOSAI WGEI) (Online) (Part-I) (6–10 January 2025)
 - o Conducted online, this programme engaged officers from different SAIs in examining audit approaches to the governance and sustainability of extractive industries.



- Participants of SAIs from Bhutan, Brazil, India, Jamaica, Nigeria, Papua New Guinea, Poland, Republic of Kenya, South Sudan, Zambia, and Zimbabwe attended the training.
2. International Workshop on "Biodiversity with special reference to forest resources" (3–7 February 2025)
- Officers from SAIs participated in this workshop, which focused on biodiversity conservation with an emphasis on forest resources.
 - Participants of SAIs from Bhutan, ECA/France, Kenya, Maldives, Nigeria, Poland, and India participated in the training.



3. ITP on Audit of Extractive Industries (INTOSAI WGEI) (Onsite) (Part-II) (3–7 March 2025)
- The onsite component provided participants an opportunity to consolidate learning from the online



module with practical case studies and field exposure.

- Participants of SAIs from Bhutan, Brazil, India, Jamaica, Nigeria, Papua New Guinea, Poland, Republic of Kenya, South Sudan, Zambia, and Zimbabwe participated in the training.

National Trainings

Other trainings conducted by iCED are as follows -

1. NTP on "Climate Change with reference to Marine Ecosystem, Biodiversity Loss and Marine Pollution" (13–17 January 2025) focusing on climate change in the context of marine ecosystems, biodiversity loss, and marine pollution.
2. NTP on "Blue Economy with special focus on Marine Tourism and Audit of SDG 14 and related SDGs" (20–24 January 2025) explored opportunities and challenges in the blue economy, with emphasis on marine tourism and the audit of SDG 14 (Life Below Water) and related goals.
3. UN Audit Training for Audit Teams of WHO hosted entities (28–31 January 2025), was a specialised programme for audit teams of WHO-hosted entities
4. NTP on "Audit of Water Pollution and Sustainable use of Water" (17–21 February 2025) focusing on methodologies for auditing water pollution and ensuring sustainable water use.
5. National Workshop on "Audit of Health Sector and Higher Education with special reference to SDGs" (10–11 March 2025) examined audits in critical social sectors with reference to SDGs, bringing together

perspectives on public health and education governance.

6. NTP on "Blue Economy: Challenges and Opportunities for Marine and Coastal Ecosystem Conservation" (19–23 May 2025) examined challenges and opportunities for conserving marine and coastal ecosystems under the blue economy framework.
7. National Webinar on Estate Management (2 June 2025) a one-day online webinar addressed best practices in estate management.
8. NTP on "Audit of Sustainable Agriculture and Surface Irrigation schemes" (16–20 June 2025) focused on sustainable agriculture and the audit of surface irrigation schemes, both critical areas for food security and natural resource management.

The training programmes conducted by iCED during the first half of 2025 were supported by a rich pool of faculty drawn from **international audit institutions, Indian Audit and Accounts Department (IA&AD), academia, research organisations, and regulatory bodies**. Faculty from **SAIs of Uganda, Kenya, Indonesia, Finland, Maldives, and the USA** shared global experiences in auditing extractive industries, biodiversity, and climate-related governance challenges, while senior officers from CAG India contributed practical insights through audit methodologies and case studies in environment and defence sectors.

Renowned experts from leading institutions such as **IITs, JNU, TERI, MNIT Jaipur, Wildlife Institute of India, BITS Pilani,**

Annamalai University, and Pondicherry University, along with sectoral organisations like **NCCR, NCSCM, CMFRI, CIFT, IITM, RFRI, and Wetlands International South Asia,** brought subject expertise in areas including **climate change, marine ecosystems, biodiversity, water governance, air pollution, and sustainable agriculture**. Their sessions highlighted both scientific research and policy perspectives.

In its regular pursuit of enhancing the quality of trainings, iCED also conducts study trips on focused themes such as-



“Study trip to study water recycling and re-use at MNIT Jaipur” for the participants of National Training Programme on “Audit of Water Pollution and Sustainable use of Water”



“Field Visit to Danta Ramgarh village Jaipur for the participants of National Training Programme on “Audit of Sustainable Agriculture and Surface Irrigation schemes”

World Environment Day 2025 mobilizes commitment, action to end plastic pollution globally

By: Shri Manoj Kumar, SAO

The World Environment Day 2025 was celebrated in Jeju, Republic of Korea, on 5th June 2025, under the theme #BeatPlasticPollution. World Environment Day 2025 calls for collective action to tackle plastic pollution. It comes exactly two months before countries resume negotiations towards a global treaty to end plastic pollution.¹

The official ceremony for World Environment Day in Jeju, Republic of Korea, highlighted the urgency of ending plastic pollution, a global crisis that affects much life of life on Earth. More than 2,500 events marked World Environment Day in virtually every corner of the world, and millions of people engaged with the day's hashtags – #WorldEnvironmentDay and #BeatPlasticPollution – which were trending worldwide.

Photo- Getty images



Governments, businesses, educational institutions, civil society, and communities

worldwide joined in efforts to advocate for an end to plastic pollution and addressed plastic pollution in their spaces.

On 4 June, the Global Partnership on Plastic Pollution and Marine Litter (GPML)² – for which UNEP serves as the secretariat – launched the Global Plastics Hub³, a one-stop platform for data, knowledge, and collaboration to end plastic pollution.

“Plastic waste clogs rivers, pollutes the ocean, and endangers wildlife. And as it breaks-down into smaller parts, it infiltrates every corner of Earth: from the top of Mount Everest to the depths of the ocean; from human brains; to human breastmilk.”

UN Secretary-General António Guterres

As part of World Environment Day 2025, UNEP's initiative, the Tide Turners Plastic Challenge, held a summit in India showcasing inspiring stories and best practices from youth leaders across the country who have taken meaningful steps to reduce plastic waste in their communities.⁴

India's Commitment towards combating the Plastic Menace

- India backs global efforts via Basel Convention, G20 Osaka Vision and High Ambition Coalition.
- Plastic Waste Rules 2021 ban single-use items and regulate plastic carry bags.
- EPR Portal holds producers accountable; 103 lakh tonnes plastic waste processed till Dec. 2024.

¹ [UNEP: Plastic Pollution](#)

² [UNEP: Global Partnership on Plastic Pollution and Marine Litter \(GPML\)](#)

³ [Global Plastics Hub](#)

⁴ [UNEP: World Environment Day 2025](#)

- India Plastic Challenge and National Expo promote plastic alternatives.
- Plastic Parks and CSIR tech turn waste into fuel and recyclable products.
- Swachh Bharat Mission boosts rural and urban plastic waste management.
- Kamalpur and Trichy show success with compostable bags and cloth bag drives.
- India drives a plastic-free future through policy, innovation and public action.

[PIB: World Environment Day 2025](#)

UN Ocean Conference delivers unified call to action and strong commitments

The 2025 United Nations Ocean Conference was held during the period 9th to 13th June 2025, in Nice, France. The conference was attended by more than 170 countries adopting an inter-governmentally agreed declaration committing to urgent action to conserve and sustainably use the ocean. 55 Heads of State and Government, along with 15,000 participants from civil society, business, and science, participated in the UN Ocean Conference co-hosted by the Governments of France and Costa Rica, including more than 450 side events, to accelerate action and mobilize all actors to conserve and sustainably use the ocean. The

fourth UN Ocean Conference, in 2028, will be co-hosted by Chile and the Republic of Korea.

The political declaration⁵ titled ***Our ocean, our future: united for urgent action*** calls for concrete steps to expand marine protected areas, decarbonize maritime transport, combat marine pollution, and mobilize finance for vulnerable coastal and island nations, among others. The declaration – together with bold voluntary commitments by States and other entities – constitutes the **Nice Ocean Action Plan**.

The Marine Biodiversity Treaty (BBNJ Agreement)

The BBNJ Agreement, adopted in June 2023, is a crucial legal instrument to protect marine life and ecosystems in the two-thirds of the ocean that lie beyond any country's jurisdiction. In a big step towards entry into force of the Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction ([BBNJ Agreement](#)), 19 more States ratified the Agreement in the margins of the Conference, and 20 more signed it, bringing the total number of signatures to 136, and ratifications to 50 States plus the European Union.

⁵ [United Nations Ocean Conference 2025](#)

India's Smart Solutions for Waste Management

Driving Clean Cities Through Innovation & Technology

By: Shri Rohan Sharma, AAO

India is rapidly urbanizing, and with this urban growth comes the mounting challenge of managing waste efficiently and sustainably. To meet this challenge, the government has been deploying smart, tech-driven, and decentralized solutions under national missions such as the **Swachh Bharat Mission – Urban (SBM-U)**, **Smart Cities Mission**, and the **National Faecal Sludge and Septage Management (FSSM) Policy**. These innovations are not only transforming waste into wealth but also helping cities become cleaner, healthier, and more liveable.

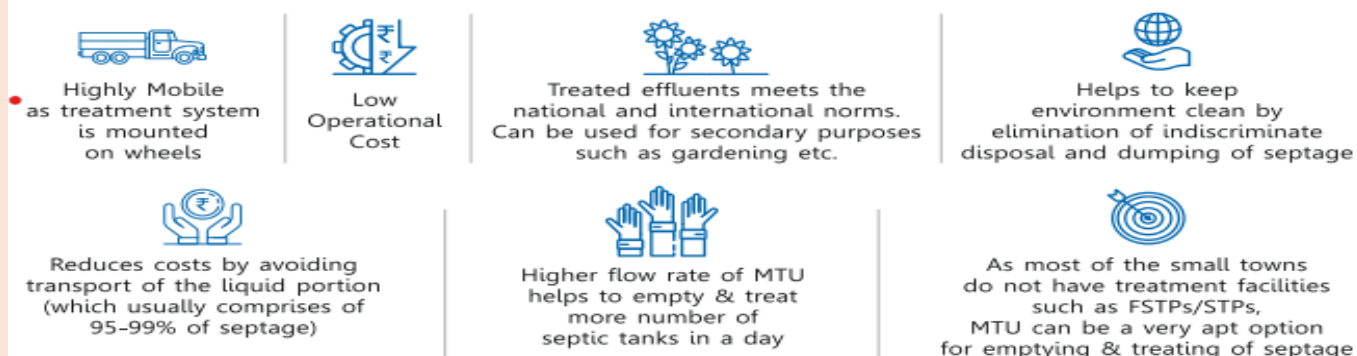
1. Mobile Sludge Treatment Units (MTUs)

In areas lacking permanent faecal sludge treatment plants (FSTPs), **Mobile Sludge Treatment Units** provide an innovative solution. These truck-mounted units treat sludge at the collection point or at temporary sites, making treatment faster and reducing the need for long-distance transport.

- MTUs help local bodies improve sanitation in smaller towns and peri-urban areas.

Major Advantages

Addresses several barriers to achieving safely managed septage waste

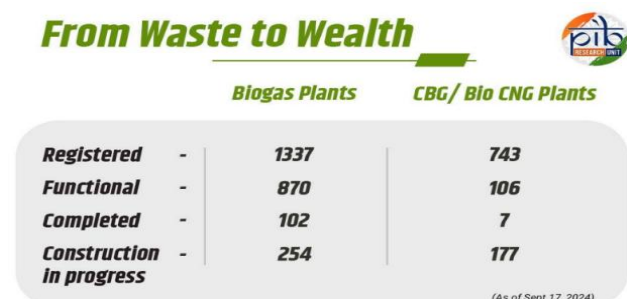


- Deployed under support from **MoHUA's FSSM policy**, states like Tamil Nadu and Maharashtra have adopted these units widely.¹



¹ [Mobile Septage treatment Unit \(MTU\)](#)

2. Turning Waste into Wealth: Indore's GOBARDhan Plant Sets a Green Benchmark



Indore, India's cleanest city, has taken a pioneering step in sustainable urban development with the establishment of Asia's largest Bio-CNG plant under the **GOBARDhan (Galvanizing Organic Bio-Agro Resources Dhan)** initiative. Inaugurated by Prime Minister Narendra Modi in 2022, the plant converts 550 tonnes of municipal solid waste daily into **17,000 kg of Bio-CNG** and over **100 tonnes of organic compost**.

This state-of-the-art facility is a shining example of how waste can be transformed into valuable resources. Operated by the Indore Municipal Corporation, the plant processes segregated organic waste through anaerobic digestion, reducing landfill burden and cutting **130,000 tonnes of CO₂ emissions** annually.

The project forms part of a larger national push for a **circular economy**, aligned with the Swachh Bharat Mission. It also supports farmers with high-quality manure, creates jobs in waste management, and contributes to India's renewable energy goals.

With **over 1,300 biogas plants registered** nationwide and continued government backing—including ₹10,000 crore earmarked for 500 new waste-to-wealth projects—the GOBARDhan scheme



Figure 1 Indore's GOBARDhan Plant

stands as a model of clean energy innovation and environmental responsibility.²

3. India's Zero-Landfill Cities: Turning Waste into Opportunity

In a major leap toward sustainable urban living, cities like **Ambikapur (Chhattisgarh)**, **Chandrapur (Maharashtra)**, and **Taliparamba (Kerala)** are redefining waste management through the **zero-landfill city model**. This approach emphasizes **maximum waste recovery, minimal dumping**, and complete integration of recycling and treatment at the source.

Ambikapur, once plagued by overflowing garbage and legacy waste, is now a national model. With the involvement of **women self-help groups** and the innovative **Garbage Clinic Model**, the city has

² [PIB: Waste into Wealth](#)

achieved **100% segregation and processing** of waste. Its old dumpsite has been transformed into a resource recovery centre. **Chandrapur**, formerly dependent on indiscriminate dumping, has reclaimed its old dumping ground through **biomining** and now processes **95% of its waste** scientifically. A new sanitary landfill handles only a **tiny fraction of rejects**, showing a remarkable turnaround.



Figure 2 Ambikapur Legacy waste treatment: Jute capping, after which the entire waste surface is covered with capping materials like leaf



Figure 3 Chandrapur: Sub-segregated waste at the material recovery facility

Taliparamba adopted **decentralized waste management** in 2012, distributing **bio-bins to 9,500 households** for home composting. Today, the city scientifically processes **99% of its waste**, and its former dumpsite now serves as a material recovery facility.

These cities prove that a **zero-landfill model**—rooted in **segregation at source, community participation**, and **resource recovery**—is not just an



Figure 4 Taliparamba: Remediation of the dumpsite

environmental ideal, but a practical and replicable solution for urban India.³

4. Plastic Waste Tracking and EPR

Processing Plastic Waste: Best Practices

Jamshedpur is setting a strong example in sustainable plastic waste management through innovative practices:

- **Plastic Roads:** The city has constructed over **20 km of roads** using non-recyclable plastic waste. Plastic collected from Dry Waste Collection Centres is shredded into fine particles (2–4 mm) and used to coat gravel. This coated gravel is then mixed with bitumen to build roads that are **stronger and cost-effective**, with no additional material cost.
- **Eco-Bricks:** To encourage responsible plastic disposal at the household level, **eco-bricks** are being made by stuffing **non-recyclable multilayered plastic (MLP)** into empty plastic bottles. These are used in schools and residential societies to build colorful walls, turning waste into utility and helping children see value in what was once garbage.

³[NITI Aayog: Waste-Wise Cities](#)

- **Waste-Free Crematorium:** A plasma-based waste disposer



PET bottles filled with multi-layered plastic waste by children, to be converted into eco-bricks

has been installed at the local crematorium. This system ionizes air through a magnetic field to burn waste without extra energy input. Smoke is filtered through bag filters that are automatically cleaned, making the crematorium entirely **waste-free**.⁴

Case Study: Canada's Path to Zero Plastic Waste – Progress, Challenges, and the Role of Smart Governance¹

Canada has committed to achieving **zero plastic waste by 2030**, as part of a joint federal, provincial, and territorial strategy. While progress has been made, several governance and data-related gaps continue to hinder effective implementation.

Plastic Waste Trends

Between **2012 and 2018**, Canada's plastic waste increased by **15%**, from **3.5 million tonnes to 4 million tonnes annually**. As of **2019**, Canada's **plastic treatment and recycling rates** were comparable to other OECD countries. However, unlike many OECD peers who rely more heavily on incineration, **Canada landfills a significantly higher share** of its plastic waste—highlighting a pressing need for waste diversion innovations.



Governance and Collaboration

The audit found that **Environment and Climate Change Canada (ECCC)** had set up a **clear governance structure** with well-defined roles and responsibilities. However, the success of the strategy hinges on **multi-level collaboration**—with the federal government depending on partnerships with **provinces, municipalities, and the private sector**.

Data Gaps Undermine Progress

A major challenge identified was **delayed data availability**: the most recent national data (as of March 2023) was from 2020, indicating a **3-year-and-3-month lag** in reporting by Statistics Canada. Additionally, **ECCC lacked a comprehensive data framework** to address critical knowledge gaps in plastic waste management.

Recommendations from the INTOSAI WGEA 2024 Report

Drawing on global audit practices, the report recommends:

⁴ [NITI Aayog: Waste-Wise Cities](#)

¹ [Independent Auditor's Report - Canada](#)

- **Developing real-time plastic waste monitoring systems**, using digital tracking and standardized reporting.
- **Enhancing data governance**, including clearer timelines and accountability for national reporting.
- **Boosting intergovernmental cooperation** through shared audit frameworks and joint capacity-building.
- **Engaging stakeholders**—particularly the private sector and citizens—to innovate in reuse, design, and circularity.

Conclusion

Canada's strategy to reach zero plastic waste by 2030 is commendable, but its success will depend on **better data systems, stronger partnerships, and faster implementation** of smart waste management tools. The audit underscores the need for a **whole-of-government and society approach**, informed by real-time, accurate data and transparent governance.²

Conclusion

India's urban sanitation and waste management strategies demonstrate scalable innovations with strong policy alignment and decentralization. The **Mobile Sludge Treatment Units (MTUs)** serve as critical interventions in underserved areas, offering immediate faecal sludge treatment and reducing transport needs—vital for audit indicators like efficiency and service equity. The **GOBARDhan Bio-CNG plant in Indore** showcases effective public investment and circular economy returns, converting municipal waste into green energy and organic compost, with measurable emissions reductions.

Zero-landfill models in cities like Ambikapur and Taliparamba prove that decentralized, community-driven waste processing can eliminate legacy waste while improving public health outcomes. **Jamshedpur's plastic reuse innovations**, from plastic roads to waste-free crematoria, highlight cost-effective,

locally adaptable solutions. These efforts are backed by robust policy tools like the **Plastic Waste Management Rules and EPR frameworks**, although audit attention is needed on enforcement consistency and data transparency.

Internationally, **Canada's path to zero plastic waste** underscores common challenges: delayed data, fragmented governance, and implementation lags. Comparative audit findings stress the need for **real-time tracking systems, multi-level coordination, and stakeholder-driven innovation**.

While India's waste management initiatives reflect commendable progress and innovation, audits should focus on evaluating long-term impact, inter-agency coordination, real-time data use, and community participation to ensure sustainability and replicability.

²[Zero Plastic Waste](#)

Reimagining Rivers: Technology for Rejuvenation and Resilience

By Shri Ajay Babu Meena, AAO

1. Introduction

Rivers, the lifeblood of ecosystems and human civilizations, face unprecedented challenges from pollution, climate change, and overexploitation, threatening their ecological and socio-economic roles. In India and globally, innovative technologies are redefining river conservation, offering solutions to rejuvenate degraded waterways and build resilience against environmental stressors. From Geographic Information Systems (GIS) and remote sensing to IoT-based sensors, drones, and bioremediation, these tools enable precise monitoring, efficient water management, and sustainable restoration. Programs like India's Namami Gange and Australia's Sustainable Rivers Audit exemplify technology's potential to map river health, treat pollution, and engage communities. By integrating data-driven insights with nature-based solutions, such as wetland restoration and smart irrigation, technology fosters a holistic approach to river rejuvenation.

2. Real-time Water-Quality Monitoring

Central Pollution Control Board (CPCB) in collaboration with State Pollution Control Boards (SPCBs) in the States and Pollution Control Committees (PCCs) in Union Territories has established a National Water Quality Monitoring Network (NWMP) in order to assess status of water quality of water resources and to facilitate for prevention and control of pollution in water bodies. Present water quality monitoring network under

NWMP comprises 4484 stations on surface and groundwater in 28 States and 8 Union Territories. Monitoring is carried out with a frequency on monthly, quarterly, half yearly and yearly basis.

The Central Pollution Control Board (CPCB) and Central Water Commission (CWC) have installed a total thirteen Real Time Water Quality Monitoring Stations (RTWQMS) on river Ganga, Yamuna and tributaries of Ganga (i.e. Ramganga and Gomti) for monitoring of in-situ river water quality parameters.¹

3. Advancements in Sewage & Wastewater Treatment

India has made significant strides in sewage and wastewater treatment to address water scarcity, pollution, and public health concerns, driven by rapid urbanization and industrialization. According to the Central Pollution Control Board (CPCB), urban India generates approximately 72,368 million liters per day (MLD) of sewage, against which a treatment capacity of 31841 mld is available. Further, Indian cities currently treat only 28 per cent of the 72,368 million litres of sewage they generate every day.

States like Andhra Pradesh, Telangana, Bihar, Maharashtra, and Haryana have upgraded sewage treatment plants (STPs) with modern technologies such as Sequencing Batch Reactors (SBRs) and Moving Bed Biofilm Reactors (MBBRs)², achieving 80-90% treatment efficiency compared to 65% for older methods like

¹[CPCB: National Water Quality Monitoring Programme \(NWMP\)](#)

²[Down-to-earth: Advanced sewage wastewater treatment](#)

activated sludge processes. Hyderabad upgraded an STP to release treated effluent into Durgam Cheruvu Lake using SBR technology.³

4. Bio-remediation Technology

Bio-remediation, an eco-friendly technology, utilizes microorganisms to degrade pollutants in soil, water, and wastewater, addressing India's environmental challenges. The Central Pollution Control Board (CPCB) promotes bio-remediation for industrial effluents, oil spills, and contaminated sites. The Ministry of Environment, Forest and Climate Change supports in-situ and ex-situ bio-remediation for hazardous waste sites.

Indian Institute of Technology Guwahati Researchers have carried out a study of coal mines on the 'bioremediation' of Acid Mine Drainage (AMD) (Acidic wastewater generated from coal mines) in Constructed Wetlands. This is the first study to demonstrate the bioremediation of AMD from the Northeastern Coalfields (NEC) using Constructed Wetlands. This research provides an efficient sustainable treatment approach to mitigate AMD pollution while addressing the long-term operational sustainability issues encountered in Constructed Wetlands receiving AMD.

5. Green-Bridge Technology: Green bridge technology is based on filtration, biodegradation and biosorption mechanisms by microbes and plants. It is a combination of Ecofert – which is an active microbial consortium, biomats, sand, gravels and plants. The stones/boulders act as a filtering material and prevent the solids from passing through the bridges. The green plants/flora grown at the banks of the water body also

contributes towards the treatment of the wastewater.⁴

6. Flood prediction through AI

The Google Flood Forecasting Initiative aims to use Google's infrastructure and machine learning expertise for providing accurate real-time flood forecasting information and alerts to those in affected regions. This is made possible through AI and physics-based modelling which create accurate and scalable inundation models in real-world settings. With reliable on-ground data obtained from governmental agencies, Google's river flood forecasting models can more accurately predict not only when and where a flood might occur, but the severity of the event as well.

First piloted in the Patna region of Bihar in 2018, Google's flood forecasting initiative was extended to the whole of India by 2020, covering 200 million people across more than 250,000 Sq. km.

Through an innovative approach for inundation modelling, the initiative aims to provides unprecedented lead time, accuracy and clarity in flood forecasting. Real-time river measurements and forecasts are obtained for this initiative through Google's collaboration with the Central Water Commission (CWC).⁵

7. Flood Watch India

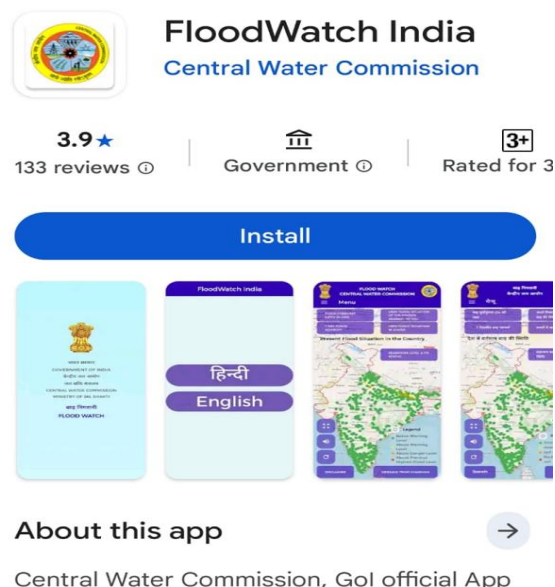
Flood Watch India', developed in-house by the Central Water Commission, utilizes advanced technologies such as satellite data analysis, mathematical modelling and real-time monitoring to deliver accurate and timely flood forecasts. It was first launched on 17th August 2023 with the aim of using mobile phones to disseminate information related to flood situation in the country and

³[PIB: Sewage Water Treatment](#)

⁴[Centre for Science and Environment: Green Bridge Technology](#)

⁵[India AI: Using AI to predict floods and save lives](#)

flood forecasts up to 7 days on a real-time basis to the public.



The newer version of the app provides current information at 592 flood monitoring stations, thus imparting users with an extensive and detailed overview of flood conditions across the country. Further, it also provides additional information regarding the storage positions of 150 major reservoirs in the country which shall help in better understanding of the possible flood situation in their downstream areas.⁶

8. River Interlinking and Water Management: National River Linking Project

The National River Linking Project (NRLP), overseen by the National Water Development Agency (NWDA) under the Ministry of Jal Shakti, is a transformative initiative to address water scarcity and support river conservation by transferring approximately 200 billion cubic meters of water annually across 30 river links (16 peninsular and 14 Himalayan). The project employs advanced technologies to optimize water distribution,

enhance irrigation, and mitigate floods while preserving river ecosystems.

It integrates some of the cutting-edge technologies for efficient water management.

Tunnelling and Canal Systems:

Advanced engineering facilitates the construction of canals and tunnels to transfer water across basins. The Ken-Betwa link, a flagship project, includes a 77-km canal and a 2-km tunnel to irrigate drought-prone Bundelkhand.

Solar-Powered Pumping: Solar energy powers water-lifting systems, reducing operational costs and environmental impact.⁷

Case Studies: Technology in National and International Audit Reports

9. Performance Audit of Rejuvenation of River Ganga (Namami Gange)-CAG Report 39 of 2017

The CAG audit report examined the Bhuvan Ganga Web Portal and Mobile App, developed by the National Remote Sensing Centre (NRSC) under a June 2015 MoU with the National Mission for Clean Ganga (NMCG). The initiative aimed to utilize Geospatial Information System (GIS) mapping to support pollution abatement in the River Ganga by facilitating planning, execution, and monitoring of projects, while also serving as a centralized data repository for Ganga-related information. The audit found that the MoU lacked specific timelines for NRSC's responsibilities, hindering timely implementation. Additionally, no regular joint meetings were held to monitor progress, with a 14-month gap before the first meeting post-MoU. The use of remote sensing and mobile applications, which could enable real-time tracking of pollution, project progress, and ecological changes, was minimal and ineffective. This limited adoption of data-

⁶[IndiaAI: AI to predict floods and save lives](#)

⁷[National Water Development Agency](#)

driven systems weakened monitoring and evaluation efforts. The report recommended stronger integration of GIS and remote sensing technologies to enhance planning, execution, and oversight of Ganga conservation projects for improved outcomes.⁸

10. Australia: Sustainable Rivers Audit (SRA) for Murray-Darling Basin

The Sustainable Rivers Audit (SRA), implemented in Australia's Murray-Darling Basin (MDB), provides a systematic framework for assessing river ecosystem health, with technology playing a critical role. Key findings from reports include:

Technological Tools: The SRA uses environmental metrics derived from field samples and modelling, combined with remote imagery to assess five themes: Hydrology, Fish, Macroinvertebrates, Vegetation, and Physical Form. Remote sensing is employed to monitor vegetation extent and vigor every six years, using aerial imagery and sampling plots.

Conceptual Models and Data Integration: The audit integrates data through expert-system rules to generate an Ecosystem Health Index, supported by conceptual models. Reference conditions, estimated using historical data, expert knowledge, and modelling, provide benchmarks for assessing human impacts.

Outcomes and Scalability: The SRA completed health assessments from 2004–2007 at valley and altitudinal zone scales, with plans for future trend assessments. Technologies like remote sensing and modelling enabled consistent, scalable monitoring across the basin, unlike traditional on-site methods.⁹

11. Conclusion

The integration of advanced technologies into river conservation marks a transformative era for rejuvenating and strengthening these vital ecosystems. Tools like GIS, IoT sensors, drones, and AI-driven analytics have demonstrated their ability to monitor water quality, manage resources, and mitigate ecological threats, as seen in initiatives like Namami Gange and global programs. By combining these with nature-based solutions, such as bioremediation and community-driven monitoring, governments and stakeholders can address pollution, habitat loss, and climate impacts effectively. Reimagining rivers requires not only technological innovation but also inclusive policies and community engagement to ensure sustainable outcomes. By embracing these advancements, we can restore rivers as resilient lifelines, safeguarding their ecological and cultural significance for generations to come.

⁸[C&AG of India: Report No. 3 of 2017](#)

⁹[Australian Government: 2008 Sustainable Rivers Audit](#)

Forests from Above: Drones and GIS in India's Conservation Efforts and use in Audit

Dr Mahesh Kumar Saini
(Research Associate, iCED, Jaipur)

Introduction

Forests support the livelihoods of a significant portion of the global human and livestock population and have been sustainably managed through community participation since ancient times. Due to effective planning and proactive government policies, India has shown a consistent increase in forest cover. According to the Global Forest Resource Assessment 2020 by Food and Agriculture Organization (FAO), India ranks among the top 10

of growing stock, supports livelihoods and contributes to carbon credit gains. A forest cover degradation analysis (2011–2021) identified 93,000 km² as potential areas for density improvement and carbon sequestration of 636 million tonnes, highlighting India's continued efforts in forest conservation and climate action (FSI, 2023¹).

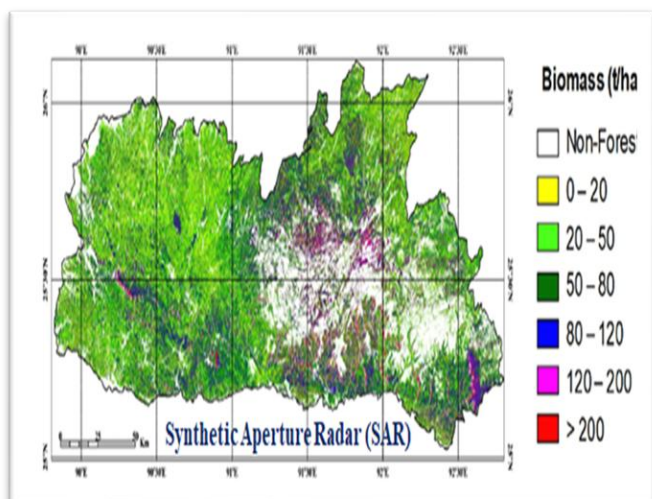
Monitoring of Forest

Technologies such as the Internet of Things (IoT), Wireless Sensor Networks (WSNs), the Internet of Trees, and Deep Learning are being leveraged to enhance forest ecosystem management. These innovations enable intelligent sensing, real-time monitoring, and advanced analysis for critical applications such as detecting forest fires, illegal logging, and wildlife poaching. Deploying real-time sensor networks and utilizing energy-harvesting technologies to power digital systems sustainably within forest environments. These approaches aim to create a more resilient, efficient, and inclusive forest management framework through the integration of smart technologies.

countries in forest area and is third in annual net gain in forest cover during 2010–2020. According to Forest Survey of India, forests act as a net carbon sink, reflecting the nation's commitment to climate change mitigation and adaptation. The Forest Fire Alert System by Forest Survey of India (FSI) has become crucial for fire control, with improved prediction accuracy using meteorological data. Burnt area mapping at the national level is a notable achievement. Agroforestry, covering 127,590 km² with 1,292 million m³

Advancements in technology have transformed forest monitoring worldwide, enabling more accurate, real-time, and large-scale assessments of forest health, degradation, and illegal activities. Remote sensing, satellite imagery, LiDAR (Light Detection and Ranging), drones, and AI-driven data analytics are increasingly used to monitor forests and combat deforestation.

Image Source: NESAC



¹ [India State of Forest Report 2023](#)

One notable global case is **Global Forest Watch (GFW)**, an initiative led by the World Resources Institute. GFW uses satellite data from NASA and ESA, combined with AI algorithms, to detect deforestation in near real-time. In countries like **Brazil**, GFW has been instrumental in monitoring illegal logging in the Amazon. Authorities have used its alerts to enforce environmental laws and protect indigenous territories.

Similarly, **Norway's International Climate and Forest Initiative** supports forest monitoring in tropical countries through high-resolution satellite data and public access platforms. In **Indonesia**, this has helped detect peatland degradation and forest fires, allowing rapid response and policy adjustments.

LiDAR technology is also being used in **Canada** and the **United States** to assess forest biomass and carbon stock with high precision. These innovations, supported by global partnerships and open data sharing, represent a shift toward transparent, data-driven forest governance and conservation at a global scale.

The Forest Survey of India (FSI) uses satellite-based remote sensing to publish biennial India State of Forest Reports, which offer detailed forest cover assessments. Additionally, drones are now being employed for aerial mapping and monitoring of inaccessible areas. A notable case study is the Uttarakhand Forest Department, which utilized drone surveillance combined with GIS mapping to monitor forest fires and illegal tree felling in high-altitude zones.

Another example is the Forest Fire Alert System 2.0 developed by FSI in collaboration with the Indian Space Research Organisation

(ISRO), which provides near real-time alerts and accurate fire prediction models using satellite imagery and meteorological data. Between November 2020 and June 2021, over 52,000 fires were detected using MODIS satellite sensors and over 3.45 lakh using SNPP-VIIRS sensors. Dry deciduous forests are most severely affected, while evergreen, semi-evergreen, and montane temperate forests are less affected. Over 36% of India's forest area is prone to frequent fires, with 4% classified as extremely fire-prone and 6% as very highly fire-prone. Despite these fires, 35.7% of forest areas remain mostly unaffected. Satellite-based remote sensing and GIS tools have improved the ability to prevent and manage forest fires through early warning system, real time monitoring, and mapping of burnt areas (FSI, 2025²).

Case Studies on use of Drones and GIS in Audit Report

Audit Report: Performance Audit Report of the Comptroller and Auditor General of India on Afforestation and Social Forestry Programme Government of Uttar Pradesh Report No. 2 of the year 2024

Observation: Forest Department failed to ensure the compliance of the guidelines by the user agency in construction of the dam without having final approval for diversion of reserved forest land falling in dam area.

Recommendation: The Forest Department should strictly follow the guidelines for compensatory afforestation and should levy and realise the compensatory afforestation charges, additional NPV and centage charges from the user agencies as per extant instructions.

²[Forest Survey of India: Forest Fire](#)

Conclusion:

India has made significant progress in forest conservation through sustainable practices, technological innovation, and proactive policies. Despite challenges like increasing forest fires and degradation, modern tools such as drones, satellite-based remote sensing, GIS, IoT, and AI have strengthened forest monitoring and management. Initiatives like the Forest Fire Alert System

and drone surveillance have improved early warning and response times. Global collaborations and real-time data sharing further support India's efforts. With over 36% of forest area fire-prone, continuous innovation and public participation are essential to protect biodiversity, enhance carbon sequestration, and ensure long-term forest health and ecosystem services.



Emerging Technologies in Renewable Energy Transition in India

By: Rohit Kirodiwal, AAO

India, with its burgeoning population and rapid economic growth, is at a critical juncture in its quest for sustainable energy solutions. As the nation intensifies its focus on renewable energy, emerging technologies are playing a pivotal role in shaping a cleaner and greener future. From advancements in solar energy to innovations in wind power and bioenergy, these technologies are revolutionizing the renewable energy landscape in India.

India's Renewable Energy Goals

India is committed to achieve ambitious renewable energy targets, including reaching 500 GW of non-fossil fuel energy capacity by 2030 and meeting 50% of its energy requirements from renewable sources. To fulfil these goals, the country has embraced cutting-edge technologies and fostered partnerships with global innovators¹.

Emerging Technologies in Solar Energy

While India has made significantly progress in solar energy installation with Monocrystalline Silicon Solar Cells, Polycrystalline Silicon Solar Cells with different efficiency levels.

Perovskite Solar Cells

Perovskite solar cells are hailed as the next generation of photovoltaic technology. With higher efficiency rates and lower production costs than traditional silicon-based cells, perovskite cells are transforming India's solar landscape.

Indian scientists at the International Advanced Research Centre (ARCI) have enhanced the performance and durability of perovskite solar cells by precisely tuning the length and porosity of Titanium Dioxide (TiO₂) nanorods used in the electrode. This innovation enables deeper perovskite infiltration and improved electron transport, resulting in higher efficiency and greater long-term stability. The breakthrough addresses key challenges in perovskite technology and represents a step toward more cost-effective, resilient solar solutions.²

Floating Solar Farms

Space constraints in urban and agricultural areas have led to the emergence of floating solar farms. These farms utilize water bodies such as reservoirs and lakes to host solar panels, reducing land usage while enhancing energy output.

India has implemented several successful floating solar projects, NTPC Ramagundam floating solar plant in Telangana³ being the



Image: Omkareshwar Floating Solar Park, Khandwa
Madhya Pradesh

¹ [PIB: India's Renewable Energy Capacity Hits New Milestone](#)

² [Department of Science and Technology, Government of India](#)

³ [PIB: NTPC Ramagundam Floating Solar Power Plant](#)

first and Omkareshwar floating solar park is being developed which will be Asia's largest floating solar park with capacity of 600 MW⁴.

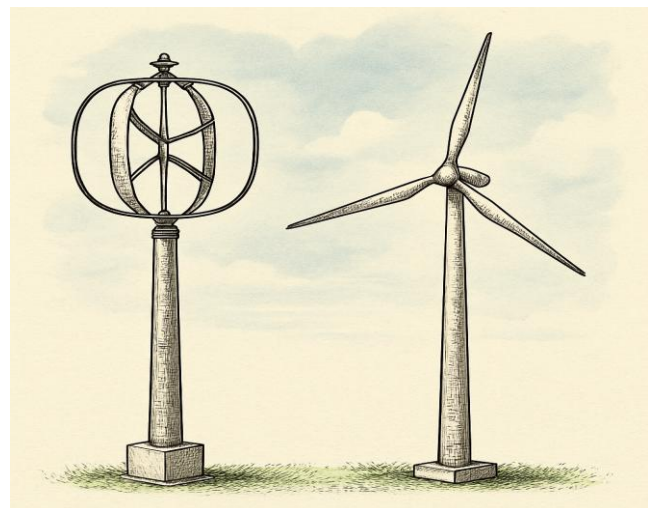
Solar Tracking Systems

Solar tracking systems enhance the efficiency of photovoltaic panels by keeping them aligned with the sun's trajectory throughout the day. By maximizing energy capture, these systems are particularly useful in regions with variable sunlight patterns. India's solar parks are increasingly incorporating this technology to optimize output.

Innovations in Wind Energy

Vertical Axis Wind Turbines

Vertical axis wind turbines (VAWT) are compact and efficient, making them suitable for both urban and rural settings. Unlike traditional horizontal axis turbines, VAWTs can generate power from wind coming from any direction. Their versatility is enabling India to expand wind energy projects into previously untapped locations.



High-Efficiency Blade Designs

Advanced blade designs, often inspired by biomimicry⁵, are improving the performance of wind turbines. These innovations reduce noise, increase durability, and enhance

energy generation, making wind power a more sustainable option for India.

Hybrid Systems

Hybrid systems that combine wind and solar energy are gaining traction in India. These systems leverage the complementary nature of wind and solar resources, ensuring a stable and reliable energy supply. To harness the capacities of both solar and wind energy, Government of India has launched National Solar Wind Policy under which 2874.50 MW capacity has been installed as on 31 March 2025⁶.

Bioenergy Technologies

Advanced Biogas Plants

Biogas plants are being upgraded with technologies that enhance methane capture and efficiency. Innovations such as anaerobic digesters are enabling India to convert agricultural and organic waste into clean energy while reducing greenhouse gas emissions.

Algae-Based Biofuels

Algae-based biofuels are emerging as a promising alternative to fossil fuels. These biofuels have high energy density and are produced sustainably, making them ideal for India's transportation and manufacturing sectors.

Waste-to-Energy Conversion

India is increasingly adopting waste-to-energy technologies that transform municipal and industrial waste into electricity and heat. These systems address waste management challenges while contributing to energy production.

India has been able to harness bioenergy through Biomass and Waste to energy.

⁴ [PIB: Omkareshwar Floating Solar Park](#)

⁵ Biomimetics or biomimicry is the emulation of the models, systems, and elements of nature for the purpose of solving complex human problems.

⁶ [MNRE: Year wise achievements](#)

Currently, India has installed 11583.32 MW of Bio Power capacity.

Energy Storage Solutions

To fully harness renewable energy, efficient storage solutions are critical. Emerging technologies in energy storage are helping India overcome the intermittency issues associated with solar and wind power.

The projected energy storage capacity requirement under the Scheme for Battery Energy Storage Systems is estimated to reach 82.37 GWh by 2026-27. This demand is expected to further rise to 411.4 GWh by 2031-32, supported by a budgetary allocation of Rs 3,760 crore through Viability Gap Funding (VGF).

Advanced Battery Technologies

Lithium-ion batteries, solid-state batteries, and flow batteries are rapidly evolving, offering higher storage capacities and longer lifespans. India is investing in battery manufacturing to support its renewable energy infrastructure.

Pumped Hydro Storage

Pumped hydro storage systems, which use surplus energy to pump water uphill and release it to generate electricity during high-demand periods, are being deployed in several states. These systems provide large-scale energy storage capabilities.

The Central Electricity Authority has estimated 103 GW of on-river pumped storage potential. Of the 4.75 GW installed, 3.3 GW is operational in pumping mode, with 44.5 GW under development⁷.

Smart Grids and IoT Integration

Smart grids equipped with IoT-enabled devices are revolutionizing energy distribution and consumption in India. These

grids optimize energy flow, reduce losses, and enhance reliability.

Blockchain Technology

Blockchain technology is being integrated into India's energy sector to enable peer-to-peer energy trading. By decentralizing energy distribution, blockchain fosters efficiency and transparency.

AI and Machine Learning

Artificial intelligence and machine learning are enhancing renewable energy operations by predicting energy demand, optimizing resource allocation, and improving maintenance schedules for renewable infrastructure.

Audit Reports on Renewable Energy Transition: The EU's industrial policy on renewable hydrogen



In 2024, European Court of Auditors released a special report on The EU's industrial policy on renewable hydrogen⁸ which highlighted following issues –

⁷ [The Energy and Resource Institute](#)

⁸ [European Court of Auditors](#)

- A. The Commission set unrealistic hydrogen production and import targets - the EU is not on track for achieving them.
- B. The legal framework is mostly complete, but its overall impact on the market is yet uncertain.
- C. There are multiple EU funding sources for hydrogen projects, but no guarantee that they will be appropriate for developing an EU-wide market.
- D. Insufficient coordination efforts by the Commission, both internally and with member states, but also with industry.

The European Court of Auditors also made following recommendations–

- A. Following a reality check, make strategic choices on the way ahead without creating new strategic dependencies.
- B. Set out an EU roadmap and monitor progress.
- C. Obtain reliable national funding data and assess the appropriateness of EU funding arrangements accordingly.
- D. Monitor permitting processes in the member states.
- E. Take a clear decision on support and coordination actions with and for the hydrogen industry.

Managing Queensland's transition to renewable energy

Queensland Audit Office published Audit Report No.5 for 2021-22 on Managing Queensland's transition to renewable energy⁹ in which following observations were made –



Managing Queensland's transition to renewable energy

Report 5: 2021–22



- A. The department reports on the growth in renewables but does not publish a clear definition on how the target is calculated.
- B. Beyond its 50 per cent target, the department has not yet set out its ambitions for the energy system towards 2030.
- C. The transmission network may need upgrades to accommodate increasing renewable generation.
- D. Reported progress in 2020–21 is higher than actual progress.
- E. Many early-stage projects may not be operational by 2030.

The European Court of Auditors also made following recommendations–

- A. **Publish a 10-year energy plan** with long-term vision, generation mix, ownership models.

⁹ [Queensland Audit Office](#)

- B. **By 2025, review progress** toward 2030 renewable energy target and update strategies.
- C. **Publish a clear definition and calculation method** for the renewable energy target.
- D. **Include all relevant energy sources** (e.g., diesel, small-scale solar) in calculations.
- E. **Provide transparent public reporting** on renewable generation by source and assumptions used.

Conclusion

India's journey towards renewable energy is marked by innovation, resilience, and determination. Emerging technologies are

not only helping the country meet its energy goals but are also setting an example for sustainable development worldwide.

While emerging technologies hold immense promise, India faces challenges such as high initial costs, regulatory hurdles, and the need for skilled manpower. However, with supportive government policies and international collaborations, these challenges can be transformed into opportunities.

Further, India has been adopting many of emerging technologies there are faster developments in field of renewable energy generation technologies. To keep the pace with the international growth, India needs to move faster to adopt latest technologies.



Exposome refers to the totality of environmental exposures an individual experiences throughout their life, from conception to death, and how these exposures influence health and disease



DID YOU KNOW?

Leveraging AI and Satellite Tools for Air Pollution Monitoring and Audit in India

By Shri Vijendra Tanwar, AAO

Air pollution poses a serious threat to public health and the environment in India. Despite national programs like the National Clean Air Programme (NCAP), the monitoring infrastructure is often inadequate, with limited coverage, outdated equipment, and data gaps. The use of AI and satellite-based tools has emerged as a powerful solution to enhance air quality monitoring and can be effectively integrated into environmental audits by Supreme Audit Institutions (SAIs).

Key Digital Tools and Systems

1. Air Quality Early Warning System (AQEWS) and Decision Support System (DSS)¹ for the Delhi National Capital Region (NCR) has been developed jointly by the scientists at the Indian Institute of Tropical Meteorology (IITM), Pune, India Meteorological Department, National Centre for Medium-Range Weather Forecasting (NCMRWF) and National Center for Atmospheric Research (NCAR), Boulder, USA. The warning system consists of:

- a) Real-time observations of air quality over Delhi region and details about natural aerosols like dust (from dust storms) and particulate matter using different satellite data sets.
- b) Predictions of air pollutants from two different air quality prediction systems based on state-of-the-art atmospheric chemistry transport models and

- c) Warning Messages and Alerts and Bulletins.

The modelling framework typically consists of a high-resolution weather prediction model with an atmospheric chemistry transport model. Both the models have data assimilation facility, which can assimilate data from satellites on dust aerosols, particulate matter from stubble burning and other air pollutants like SO₂ and NO₂. The model considers the background aerosols and pollutants, long-range transport of dust from dust storms and particulate matter from stubble burning. The predictions are now available up to 72 hours lead time.

The DSS issues timely alerts for impending air quality events and predicts source contributions for the following five days, enabling swift decision-making in alignment with the Graded Response Action Plan (GRAP) of the Government of India.

2. The System of Air Quality and Weather Forecasting and Research (SAFAR)² is an initiative by the Ministry of Earth Sciences (MoES) under the Meteorological and Air Quality Weather Services (MAQWS) program designed to provide real-time air quality information and forecasts for major metropolitan cities viz. Delhi, Pune, Mumbai, and Ahmedabad in India. The system provides real-time air quality data, forecasting for the next 1 to 3 days, and health advisories to the public. This initiative involves a high-resolution monitoring network with automated weather

¹ [Ministry of Earth Science: Air quality early warning system for Delhi](#)

² [MoES: System of Air Quality and Weather Forecasting and Research \(SAFAR\)](#)

stations and air quality monitoring instruments deployed across these cities. The SAFAR program integrates these data streams to model and predict air quality, helping local authorities and the public take proactive measures to mitigate the adverse effects of air pollution. The system's outputs are accessible to the public via a dedicated website(https://safar.tropmet.res.in/index.php?menu_id=1) and mobile applications, ensuring that timely and accurate information reaches citizens, enabling them to minimize exposure to harmful pollutants.

3. The Monitoring of Air Pollution Across the Nation (MAPAN) is a PAN India network under the MAQWS program that extends air quality monitoring beyond the metropolitan focus of SAFAR. This network is designed to provide a broader understanding of air quality across various geographical regions in India, capturing data from diverse environments such as urban, rural, industrial, and remote areas. MAPAN serves as a crucial tool in assessing the overall air quality scenario across India, identifying pollution hotspots, and understanding regional variations in air quality. The program is further revised as MAPAN-2 for Air Quality Monitoring Network over Himalayan and Oceanic Regions. In the Himalayan region, MAPAN-2 focuses on monitoring the impacts of transboundary pollution and the effects of local sources in high-altitude areas, which are crucial for understanding climate and environmental changes in these sensitive regions. Over the oceanic regions, the network contributes to the understanding of air-sea interactions and the transport of pollutants across the oceans. MAPAN-2 plays a significant role in filling the gaps in air quality data from these remote regions, providing a more comprehensive

understanding of India's air quality dynamics.

4. Real-time Ambient Source Apportionment of Gases and Aerosol for Mitigation (RASAGAM) is a cutting-edge initiative aimed at identifying and quantifying the sources of air pollution in real time. By providing real-time data on the composition and sources of pollutants, RASAGAM enables authorities to implement more effective air quality management practices and reduce public exposure to harmful pollutants. In addition to source apportionment, RASAGAM also focuses on assessing the toxicity of the air we breathe, particularly the harmful effects of metals and microplastics present in the atmosphere. This aspect of the program is essential for understanding the health risks associated with exposure to various pollutants. The RASAGAM program is pivotal in providing a detailed understanding of the air pollution landscape in India, particularly in urban and industrial regions where pollution levels are often high. By combining real-time source apportionment with toxicity assessments, RASAGAM equips policymakers, environmental agencies, and health organizations with the information needed to implement effective air quality management and mitigation strategies. This program plays a critical role in safeguarding public health by addressing both the sources of pollution and their toxicological impacts.

5. Urban Air Quality Assessment ³using Open-source data and tools

This research project is a collaborative effort between the Centre for Applied Geomatics (CAG) and the Space Application Centre (SAC), aims to revolutionize air quality monitoring across India by leveraging cutting-edge satellite remote-sensing

³ [CRDF: Urban Air Quality Assessment](#)

technology. In densely populated urban areas, limited air quality monitoring stations hinder effective pollution prevention at a micro-scale level. Traditional monitoring stations, sparsely distributed, fall short of mapping atmospheric pollution accurately. This project aims to explore satellite remote sensing as a game-changer in assessing and mapping air pollution, using satellite imagery to provide comprehensive synoptic views of pollutant variations and concentrations, specifically focusing on major pollutants such as NO₂, SO₂, PM 2.5, and O₃. Google Earth Engine (GEE) plays a pivotal role in this Urban Air Quality project, providing a powerful platform for comprehensive data collection. GEE integrates various satellite imagery datasets, including Tropomi, Sentinel-5P and MODIS products offering detailed insights into air pollutant concentrations and distribution that would be challenging to achieve through traditional ground-level measurements alone. The European Sentinel-5 Precursor Earth observation satellite provides daily global measurements of ozone, nitrogen dioxide, carbon monoxide, and aerosol and cloud properties. The data gathered by the TROPOspheric Monitoring Instrument (TROPOMI) instrument are freely available. Decision-makers, environmental authorities and scientists rely on high-precision data products to better understand and combat global challenges such as air pollution and climate change. Moderate Resolution Imaging Spectroradiometer (MODIS) is a satellite-based sensor used for earth and climate measurements. One of the main advantages of using GEE is its ability to provide both historical and real-time data, enabling thorough analysis of air quality trends over time and aiding in predicting future scenarios. The methodology involved feeding satellite imagery into GEE to identify pollutant-affected areas on a monthly, seasonal, and annual basis. Using JavaScript

within GEE, an application has been coded to utilize five pollution parameters from Tropomi Sentinel-5P and MODIS satellite images, alongside cloud-filtered images, to derive mean values. This approach allowed to calculate the Air Quality Index (AQI) following the guidelines of the Central Pollution Control Board, providing a standardized measure for air quality assessment.

Use of GEE, Sentinel-5P TROPOspheric Monitoring Instrument (TROPOMI), and Moderate Resolution Imaging Spectroradiometer (MODIS) products tools for Audit of Air Pollution

Though there are no explicit examples of dedicated use of these tools by SAIs, however, the same has been used successfully by researchers from other agencies and can be applied in audit of air pollution control measures by the SAIs.

Supreme Audit Institutions (SAIs) across the globe can leverage Google Earth Engine (GEE), Sentinel-5P TROPOMI, and MODIS products to effectively audit air pollution. These tools allow for large-scale, data-driven assessments of air quality, enabling SAIs to evaluate the effectiveness of environmental policies and programs, identify pollution sources, and assess compliance with emission standards.

GEE provides a cloud-based platform for accessing and processing vast amounts of satellite data, including Sentinel-5P and MODIS, eliminating the need for local storage and computation. SAIs can use GEE to analyze air quality trends across different regions and time periods, identifying areas with high pollution levels and temporal variations.

Sentinel-5P's TROPOMI instrument provides data on various atmospheric pollutants, including nitrogen dioxide (NO₂), carbon

monoxide (CO), ozone (O₃), sulfur dioxide (SO₂), and methane (CH₄). TROPOMI offers high spatial and temporal resolution, allowing for detailed monitoring of pollution plumes and their dispersion patterns. By analyzing the distribution and concentration of pollutants, SAIs can identify potential sources of pollution, such as industrial areas, traffic congestion, or agricultural activities.

MODIS data can be used to estimate Aerosol Optical Depth (AOD), which is a measure of the concentration of aerosols in the atmosphere, providing insights into particulate matter pollution. MODIS land cover data can be used to analyze the relationship between land use and air quality, helping to identify areas with high pollution potential.

Rationale for use of these tools in Air Pollution control measures audit in India

The use of air quality monitoring in India plays a foundational role in air pollution control—by informing policy, enabling enforcement, and guiding public awareness. However, despite its importance, India's air quality monitoring system has notable gaps in sufficiency, coverage, and data accuracy. Central Pollution Control Board is executing a nation-wide programme of ambient air quality monitoring known as National Air Quality Monitoring Programme (NAMP). The network consists of 966 operating stations in 419 cities/towns in 28 states and 7 Union Territories of the country as on 19.11.2024. Under N.A.M.P., four air pollutants viz., Sulphur Dioxide (SO₂), Oxides of Nitrogen as NO₂, Respirable Suspended Particulate Matter (RSPM / PM₁₀) and Fine Particulate Matter (PM_{2.5}) have been identified for regular monitoring at all the locations. Besides, a total of 562 Continuous Ambient

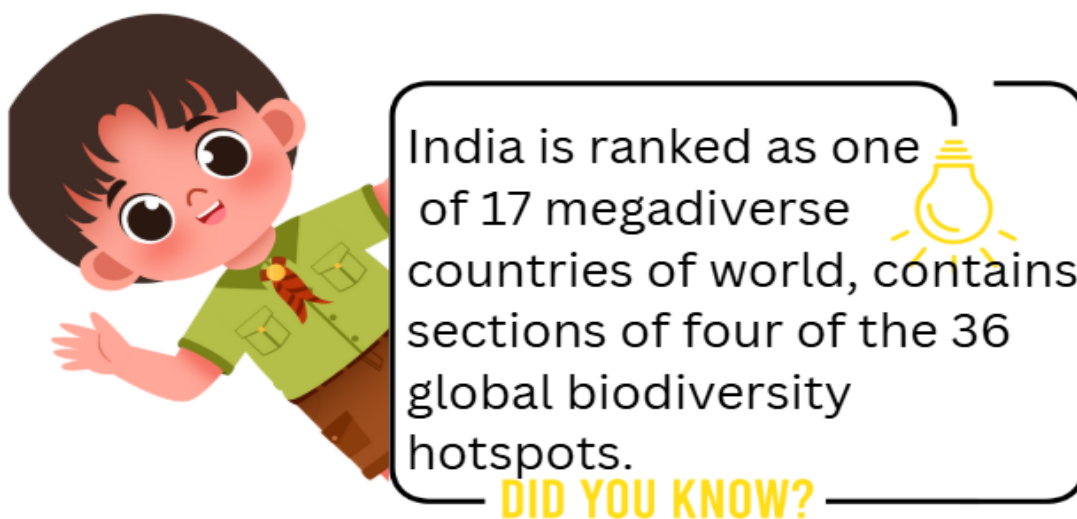
Air Quality Monitoring Stations (CAAQMS) across urban India measuring PM_{2.5}, PM₁₀, NO₂, SO₂, O₃, CO, NH₃, etc. at real-time frequency. India's air quality monitoring system faces several critical challenges that hinder its effectiveness in pollution control. While total monitoring stations (manual + CAAQMS) are now over 1,500, the distribution and data-quality gaps remain especially in rural and North-East regions.

Large parts of the country, particularly rural areas and smaller towns, lack any monitoring infrastructure. Moreover, there is an uneven distribution of stations, with metro cities like Delhi and Maharashtra heavily covered while northeastern and eastern states remain under-monitored. Data reliability is also a concern—manual stations under the National Air Quality Monitoring Programme (NAMP) provide low-frequency updates, and real-time CAAQMS often suffer from downtime, calibration issues, and poor maintenance. Inadequate quality assurance protocols further undermine data accuracy, and inconsistencies between official monitors and low-cost sensors create public confusion. Compounding these issues is the lack of source attribution, as monitoring data typically reveals pollutant levels without identifying their sources due to insufficient integration with emission inventories and source apportionment studies. Additionally, data transparency is limited: historical data is often difficult to access, many State Pollution Control Boards (SPCBs) fail to update their portals regularly. In view of this, use of GEE, Sentinel-5P (TROPOMI), and MODIS products tools can be an effective method for Audit of Air Pollution.

In a case study of Mundra has been presented in the “Report of the Comptroller and Auditor General of India on Performance Audit of Air Pollution Control by Government of Gujarat”

(Report No. 02 of the year 2022)¹, wherein identification of pollution hotspots in Mundra using satellite imagery has been mentioned. Mundra located in Kachchh district has 14 units of coal base Thermal Power Plants (TPPs) having total installed capacity of 8,620 MW which is 37 per cent of the total installed capacity of TPPs of Gujarat (November 2020). These units were commissioned between August 2009 and March 2013. The GPCB had conducted (May 2009) baseline environment quality studies through Gujarat Industrial and Technical Consultancy Organisation Limited (GITCO). The study report of the GITCO had mentioned that with the installation of TPPs in Mundra, the carrying

capacity of Mundra for SPM, SO₂, and NO_x would be exhausted and there would be a need to reduce the pollution level. Satellite imagery (by NASA) of SO₂ emission of 2016 over India showed that a high concentration of SO₂ was occurring over the Mundra Region. As per another study, based on data obtained from the TROPOMI for the period from February 2018 and May 2019, Mundra is the worst NO_x hotspot contributing hugely to air pollution. Thus, with the installation of 8,620 MW TPP in Kachchh, Air pollution has increased substantially and needs intervention like equipping units with Flue Gas De-Sulphurisation (FGD).



¹ [C&G of India: Report No. 2 of 2022](#)

Farming the Future: How Smart Agriculture is Transforming Rural India

“While the future of agriculture is undeniably shaped by machine-oriented innovations and digital technologies, ensuring access to safe, organic, and nutritious food remains a fundamental human imperative—necessitating a balanced approach that integrates technological advancement with sustainable and ecologically sound farming practices.”

– Mr. Rahul Yadav, AAO

Agriculture remains the backbone of rural India, employing¹ nearly 46% of the workforce (PLFS 2023–24) and contributing approximately 18% of GDP.

However, small farm sizes (87% farms are less than 3 acres), rising labour costs, climate change, and resource constraints challenge traditional practices. Smart agriculture, the use of advanced technologies like AI, drones, IoT, blockchain, and satellite analytics is rapidly transforming Indian farming. Government initiatives (e.g. Digital Agriculture Mission) and public–private projects (e.g. WEF’s AI4AI: Artificial Intelligence for Agricultural Innovation) are driving adoption of these tools to improve productivity, efficiency, and farmer incomes.

Image Source: World Economic Forum



Empirical results are encouraging AI-based

advisories in Telangana² doubled chili farmers’ incomes and boosted yields 21%; a Microsoft pilot in Andhra Pradesh saw 30% higher yields³.

Policy Framework and Digital Initiatives

The Government of India (GoI) has launched several flagship programs to build a **digital ecosystem for agriculture**. In September 2024⁴, the Union Cabinet approved the **Digital Agriculture Mission⁵ (DAM)**, an umbrella scheme with an outlay of ₹2,817 crore to integrate data, develop digital infrastructure, and enable farmer services. Key components include **AgriStack⁶** (farmers’ digital identity registry, geo-tagged village and crop maps) and a **Krishi Decision Support System** that overlays crop, soil, weather, and water data in a geospatial platform. Targets include creating digital IDs for **11 crore farmers** (6 Cr in 2024–25, 3 Cr in 2025–26, 2 Cr in 2026–27) and conducting a digital crop survey in **400 districts** in 2024–25 (expanding nationwide by 2026).

To complement AgriStack, the mission plans **soil-profile mapping⁷** at 1:10,000 scale for India’s 142 million hectares of farmland (with

¹ [PIB: Reverse Migration to Agriculture](#)

² [Weforum: AI-based advisories in Telangana](#)

³ [NITI Aayog: Intelligent inputs revolutionising agriculture](#)

⁴ [PIB: Digital Ecosystem for agriculture](#)

⁵ [PIB: Digital Agriculture Mission](#)

⁶ [Minister of Agriculture & farmers welfare: Agristack](#)

⁷ [PIB: Soil Profile Mapping](#)

29 million ha already mapped), and high-resolution satellite-based crop-cutting experiments (Digital General Crop Estimation Survey) for precise yield forecasts. These efforts leverage ISRO/NRSC remote sensing: for decades India has used satellite data (CAPE, FASAL programmes) to forecast yields of major crops and assess droughts.

Another major move was the creation of **Digital Public Infrastructure (DPI) for Agriculture**. In the 2024–25 Budget, the Government announced a DPI roadmap (with state partners) that extends digital IDs to farmers and lands, linking them with soil, livestock, and market data. This builds on earlier steps (e.g. Kisan ID, AgriStack pilots in six states) and aims for a fully digital platform of platforms for agriculture.

The policy framework strongly encourages technology use and by creating digital identities and data layers, the Government lays the foundation for precision farming, targeted advisories, e-marketplaces, and seamless scheme delivery.

Technological Interventions

Artificial Intelligence (AI): AI is being used in India to improve crop management and forecasting. Machine-learning models analyse soil tests, weather, and satellite data to optimize planting and inputs. Examples include mobile “bot advisors” that give personalized recommendations (e.g. optimal sowing dates, fertilizer doses) via SMS or apps. In Andhra Pradesh, Microsoft’s AI program with 175 small farmers led to **30% higher average yields**. AI-powered image analysis (from drones or phones) can detect pests, diseases or nutrient deficiencies early, enabling targeted treatments.

Unmanned Aerial Vehicles (Drones):

Drone use is scaling up for spraying, seeding, and surveying. Drones can spray a hectare in minutes with precise doses, saving labor and chemicals. A new nationwide initiative “Namo Drone Didi” (launched August 2023) trains rural women to operate agricultural drones. The scheme aims to empower women SHGs as drone service entrepreneurs, projecting income increases of over ₹1 lakh per year per person. Trials (for example by ICAR and private players) have shown drones can improve efficiency by 20–30% over manual spraying, though official data on nationwide impact is pending. Drone imagery is also used with AI to monitor field conditions and map plant health across large areas in real time.

Internet of Things (IoT) and Sensors:

Smart sensors (soil moisture probes, weather stations, automated irrigation controllers) are slowly proliferating. Though <1% of Indian farms have tractors, IoT devices can achieve precision even on small plots. For instance, farmers in arid regions use low-cost moisture sensors with drip systems to increase water-use efficiency and yields. Studies (Cisco/NASSCOM 2021⁸) highlight that IoT adoption is still nascent but promises “*game-changing*” improvements in alerts and resource use. The Government has begun supporting IoT pilots through programs like the Agriculture Infrastructure Fund and collaborations with startups; outcomes so far include localized yield gains (10–15%) and savings in water/fertilizer use.

Blockchain and Digital Marketplaces:

Blockchain is being explored to improve transparency and traceability in agri-supply chains. For example, WEF’s AI4AI⁹ initiative explicitly includes blockchain tools to link farmers with buyers securely. In India, pilot

⁸ [NASSCOM: IoT adoption in Indian Agriculture](#)

⁹ [NAASSCOM: AI4AI Plan](#)

projects (often via platforms like TraceX or national markets) are testing blockchain for seed certification, quality grading, and payment tracking. While still early-stage, blockchain holds potential to ensure fair pricing and reduce middlemen, complementing platforms like eNAM (the National Agriculture Market).

Satellite and Geospatial Analytics:

Remote sensing remains a cornerstone of Indian smart agriculture. ISRO's Bhaskara/Resourcesat series and SAR satellites provide high-resolution imagery for cropping patterns, yield forecasting (via MNCFC), soil moisture, and drought monitoring. The Agri-DSS under the Digital Mission will integrate these data (soil, crop acreage, weather) into maps for decision-support. For example, NRSC/ISRO¹⁰ systems currently estimate planting area and expected output for 9 major crops at state/district levels. Such analytics enable governments to target interventions (e.g. plan procurements) and can help farmers get advisories on remote sensing insights, improving accuracy of planning and insurance.

Overall, these technologies are often combined. For instance, AI models ingest satellite and weather data (DSS) to give farm advisories, drones collect field images for the same system, and IoT sensors provide ground truth. This convergence of 4IR (Fourth Industrial Revolution) tools is what defines modern “smart farming” in India.

Case Studies

- **Telangana “Saagu Baagu” (AI4AI)¹¹:** In 2020–23, WEF’s AI4AI initiative partnered with the Telangana government and industry to pilot an AI-driven program in Khammam district (7,000

chili farmers). Using bot-based advisories, soil sensors, AI-quality testing and a digital marketplace, the project dramatically improved outcomes. Over three crop cycles, participating farmers *doubled their incomes* – reporting net income of \$800 per acre per cycle (vs. half that baseline). Chili yields rose by **21%** and input use fell (pesticides 9%, fertilizer 5%), while better quality brought 8% higher prices. On success, Telangana scaled this “Saagu Baagu” model to **500,000 farmers** across multiple districts and crops. This case exemplifies how integrated digital services (AI, drones, blockchain for payments) can translate into concrete income and sustainability gains.

- **Andhra Pradesh Precision Farming Pilot:** A government–Microsoft collaboration equipped 175 farmers with AI-driven advisory tools. The project provided guidance on land preparation, fertilization (based on soil tests), irrigation timing, and crop choice. Results were striking: yields increased by **30%**, due to optimized inputs and plant varieties suited by AI algorithms. This was achieved in one season, demonstrating rapid benefits.
- **Drone Didis Empowerment:** The “Namo Drone Didi” initiative (see Policy) has begun training women self-help group members in drone operation and maintenance. In early demonstrations, trained drone operators completed spraying jobs 3× faster than teams of manual sprayers, covering an extra 2–3 hectares per day. Though formal impact evaluations are forthcoming, the scheme’s economic logic – adding a ₹100k+ income

¹⁰[ISRO: Crop Insurance Decision Support System \(CIDSS\)](#)

¹¹[World Economic Forum: Telangana “Saagu Baagu”](#)



potential per operator – indicates significant livelihood uplift. This can indirectly boost rural economies by creating tech-service microenterprises.

- **Blockchain in Basmati Supply Chains (pilot):** A consortium of government labs and startups is piloting blockchain-based traceability for Basmati rice from Punjab. Farmers scan seed packages and record cultivation data on a blockchain ledger. Early results: quicker quality certification and reduced disputes on authenticity, leading to 5–7% price premiums for verified organic basmati. (While still limited in scope, this illustrates blockchain’s promise in specialty crops.)
- **IoT-based Water Management (Madhya Pradesh):** In some regions of Madhya Pradesh, KVKs and agritech NGOs have helped farmers install soil-moisture sensors connected to drip systems for soy and pulses. Compared to farmer practices, trials saw water savings up to 25% and 10% higher yields. Such projects (supported by NABARD/ICAR grants) are expanding under the Digital Agri Mission’s climate-smart focus, though country-wide data remains to be published.

These cases demonstrate that **contextualized tech adoption** – blending local needs with modern tools – yields strong benefits. Key success factors include farmer training (Krishi Sakhis, KVKs), public–

private partnerships, and integration into existing schemes.

Impact Assessment

The early impacts of smart agriculture in India, based on pilot data and forecasts, are promising:

- **Yield and Productivity:** AI/drone interventions have reported yield increases of 20–30%. (Telangana chili +21%; AP pilot +30%.) Experts estimate that widespread precision farming (targeted inputs via sensors/AI) could raise average yields by 15–20% nationally over a decade.
- **Input Efficiency and Sustainability:** Precision targeting reduces overuse of water, fertilizers, and pesticides. In pilots, pesticide use fell 9% and fertilizer use 5% for chili. Nationally, digital soil-health cards and DSS could reduce fertilizer costs by over 10%, cutting greenhouse gas emissions and runoff.
- **Farmer Income:** The clearest impacts are on incomes: WEF-AI4AI farmers **doubled** net income. Even conservative estimates suggest that tech-driven improvements in quality and yields can raise average smallholder incomes by 10–30%. The Drone Didi scheme targets >₹100,000 additional income per operator. By reducing crop losses and improving market linkages (eNAM, blockchain platforms), farmers retain more profit.

- **Market Access and Prices:** Digital platforms (eNAM, GIS marketplaces) and blockchain improve price realization. Broader e-market adoption has integrated more than 1,400 mandis nationwide, helping farmers get competitive prices (though quality-assay labs must keep pace).
- **Adoption and Reach:** India has 125 million smallholding farmers. Currently only a fraction uses smart tools. However, GoI's targets (e.g. 11 crore Farmer IDs) indicate millions will be on digital platforms soon. The Digital Agri Mission is expected to create 250,000 new rural jobs (Krishi Sakhis, data analysts), further embedding tech in villages.
- **Food Security and Climate Resilience:** Better forecasting (e.g. MNCFC's use of ISRO data) means more timely buffer stocking and export decisions. Smart sensors help optimize irrigation under water stress. Cumulatively, these tools contribute to national goals of 2047 (achieving food security with 70–90% more efficiency) by enabling “climate-smart” practices.

In summary, while long-term, large-scale data is still emerging, pilot and program evaluations consistently show that smart agriculture **improves productivity and**

profitability. These outcomes align with global findings (small farms produce 70% of food), underlining that supporting them with technology benefits rural livelihoods and national food supplies.

India's agriculture is entering a technological revolution. By blending traditional knowledge with digital innovations, AI-driven advisories, drones, IoT sensors, blockchain records, and satellite analytics, farmers can overcome chronic challenges of yield stagnation, input inefficiency, and market barriers. The government's robust policy push (Digital Agri Mission, AgriStack, etc.) and successful pilots (e.g. Telangana's AI4AI, Drone Didi) demonstrate that smart agriculture tools can deliver substantial gains in productivity and income. For rural India, the result is not only higher yields but also improved climate resilience, reduced waste, and new business opportunities. Continued investment in technology, alongside training (Krishi Sakhis) and infrastructure, is essential to ensure these benefits reach all farmers. As evidence so far shows, **smart agriculture is indeed transforming Indian farms and illuminating the future of rural prosperity.**

Under the Surface: Tech Innovations for Groundwater Management in India

By Shri Saurabh Sharma, AAO

Groundwater is the water that sinks into the ground through soil and rocks. It gets stored in spaces between rocks which is called aquifers and are made of things like sand, gravel or limestone etc. These rocks have small holes or gaps that let water pass through easily. The part of the ground where all the spaces are filled with water is called the saturated zone and the top of this zone is known as the water table. The water table can be close to the ground or deep below, depending on the area. It rises when there is heavy rain and goes down when too much water is extracted through man-made activities.

Groundwater can be accessed through wells, springs or as base flows in rivers and streams. In a country like India largely dependent on agriculture, the groundwater has become the backbone of India's agricultural and drinking water systems over few decades as it fulfils around 62% of the country's irrigation needs, 85% of rural drinking water supply and 45% of urban water supply¹.

India having an area of 3.3 million square kilometres and being home to 16% of the global population, it has only 4% of the world's freshwater resources. This limited availability, combined with uneven distribution, overexploitation in some regions and changing climate scenario, it is need of the hour for sustainable and efficient management of groundwater in India to ensure water security for both current and future generations.

Institution framework for ground water management and regulation in India

Water being a State subject, the legislation for regulation and development of ground water is to be enacted by the State Governments/Union Territories (UTs). However, the regulation of ground water utilisation is issued both at the Central and State levels. At apex level, Ministry of Jal Shakti is nodal ministry responsible for laying down policy guidelines and programmes for development and regulation of the country's water resources². Under this ministry, the Department of Water Resources, River Development and Ganga Rejuvenation (DoWR, RD & GR) is mainly responsible for laying down policy guidelines and programmes for the development, conservation and management of water as a national resource³. Under this department, Central Ground Water Board (CGWB) is the National Apex Agency entrusted with the responsibilities of providing scientific inputs for management, exploration, monitoring, assessment, augmentation and regulation of ground water resources of the country⁴.

Assessment methodology and tech innovations for Groundwater management in India

Ground Water Resource Assessment is carried out at periodical intervals jointly by State Ground Water Departments and Central Ground Water Board under the guidance of the respective State Level

¹ [C&AG of India: Report No. 09 of 2021](#)

² [Ministry of Jal Shakti](#)

³ [Ministry of Jal Shakti: conservation and Management of Water](#)

⁴ [Central Ground Water Board \(CGWB\): CGWB Organogram](#)

Committee on Ground Water Assessment at State Levels and under the overall supervision of the Central Level Expert Group (CLEG) and from the year 2022, the exercise is being carried out annually.

The groundwater assessment looks at how much groundwater can be safely used each year (called the Annual Extractable Ground Water Resource), how much is actually being used (Current Annual Ground Water Extraction), and what percentage of the available water is being used (known as the Stage of Ground Water Extraction). Each region such as a block, taluka or mandal is assessed and classified based on how much of its groundwater is being used. These findings are then cross-checked with long-term trends in groundwater levels. Earlier assessments (before 2017) were based on guidelines of Ground Water Estimation Committee (GEC) - 1997, while from 2017 onwards, it is following the updated GEC 2015 methodology.⁵

The latest annual report titled "National Compilation on Dynamic Ground Water Resources of India, 2024" was released by the Central Ground Water Board (CGWB) in January 2025. This report gives a detailed state-wise picture of groundwater availability and use across the country. According to the report, India's total annual groundwater recharge is estimated at 446.90 billion cubic meters (BCM). Out of this, 406.19 BCM can be safely used. The current annual extraction is 245.64 BCM, which means that about 60.47% of the usable groundwater is being used per year⁶.

In recent years, several new initiatives have been launched in India that use modern technology to improve the way we estimate, monitor, and manage groundwater. The main goal of these efforts is to get a more accurate

and real-time picture of how much groundwater is available, where it is located, and what its quality, so that it can be used safely for drinking, farming and industrial purposes. These technological interventions help in identifying over-exploited areas, tracking changes in groundwater levels and planning recharge structures more effectively. Tools like satellite imaging, remote sensing, geophysical surveys, automated sensors and online data platforms are now being widely used by government agencies.

Some of the major technology-based initiatives currently being implemented in India are described below:

- **National Ground Water Monitoring Network:** The Central Ground Water Board (CGWB) regularly monitors groundwater levels across India. This monitoring is done four times a year usually in March/April/May, August, November and January to track seasonal changes in water levels. For this, CGWB uses a large network of around 25,000 monitoring stations, known as National Hydrograph Network Stations (NHNS). These stations include open wells and special piezometers (borewells made specifically to measure water levels). To make monitoring more efficient and real-time, CGWB is installing Digital Water Level Recorders (DWLRs) with telemetry systems under the National Hydrology Project (NHP). These devices record groundwater levels every six hours and automatically send the data to a central server through an online system called Water Information Management System (WIMS), managed by the National Water Informatics Centre (NWIC).

⁵[CGWB: National Compilation on Dynamic Ground Water Resources of India 2024](#)

⁶[PIB: India's Groundwater Resources](#)

The NWIC has also developed a user-friendly website called India-WRIS, where water level data is shared publicly for better access and transparency.

- **Climate Response Monitoring Network:** The Central Ground Water Board (CGWB) has set up a special Climate Response Monitoring Network (CRMN) under the National Hydrology Project. This network focuses on tracking groundwater levels and quality, especially looking at the problem of seawater intrusion along the coast of Tamil Nadu and the Union Territory of Puducherry. The main goal of CRMN is to understand how climate change and human activities such as over-pumping are affecting shallow underground water (called unconfined aquifers) and near-surface deeper aquifers. To do this, CGWB has installed 60 monitoring wells (called piezometers) fitted with Digital Water Level Recorders (DWLRs) that send data automatically. These piezometers are placed over a 450 km stretch of coastline, at distances ranging from 100 meters to 34 kilometres from the sea and are drilled to different depths (from 30 to 300 meters) depending on local geology.

The system collects and sends real-time data every six hours, including water level, water temperature, and water quality (measured by electrical conductivity, which can indicate seawater mixing) and this data is sent in real time to the Water Information Management System (WIMS) through the Regional Office Data Centre (RODC) in Chennai.

- **AI-based groundwater monitoring system⁷:** The Bangalore Water Supply and Sewerage Board (BWSSB) has collaborated with the Indian Institute of

Science (IISc), Central Groundwater Authority (CGWA) and Karnataka Groundwater Authority (KGWA) to implement an AI-based advanced groundwater monitoring to determine specific areas that need attention and monitor the fluctuations in groundwater levels so that targeted approach can be taken to minimize the impacts. non-government source

- **Bhuvan - Bhujal (Ground Water Prospects and Quality Information System)⁸:** Bhuvan-Bhujal is a web-based GIS platform developed by the National Remote Sensing Centre (NRSC) of ISRO in collaboration with the Department of Drinking Water and Sanitation, Government of India. It is designed to support groundwater management and planning, and this portal provides detailed maps of groundwater prospects, depth to water levels, geological structures and water quality across India. It also provides spatial data for identifying suitable zones for groundwater exploration and recharge, especially in rural and semi-arid regions. This platform integrates satellite imagery with field data to present user-friendly, interactive maps so as to provide an exact estimation about the groundwater availability, rock types and other crucial layers.
- **Master Plan for Artificial Recharge to Groundwater (2020):** CGWB has also prepared a Master Plan for Artificial Recharge to Groundwater- 2020 in consultation with States/UTs which is a macro level plan indicating various structures for the different terrain conditions of the country including estimated cost. The Master Plan has provisions for construction of about 1.42 crore Rain water harvesting and artificial

⁷[Times of India: AI-Based Groundwater Monitoring system](#)

⁸ [Ministry of Drinking Water and Sanitation: Bhuvan - Bhujal](#)

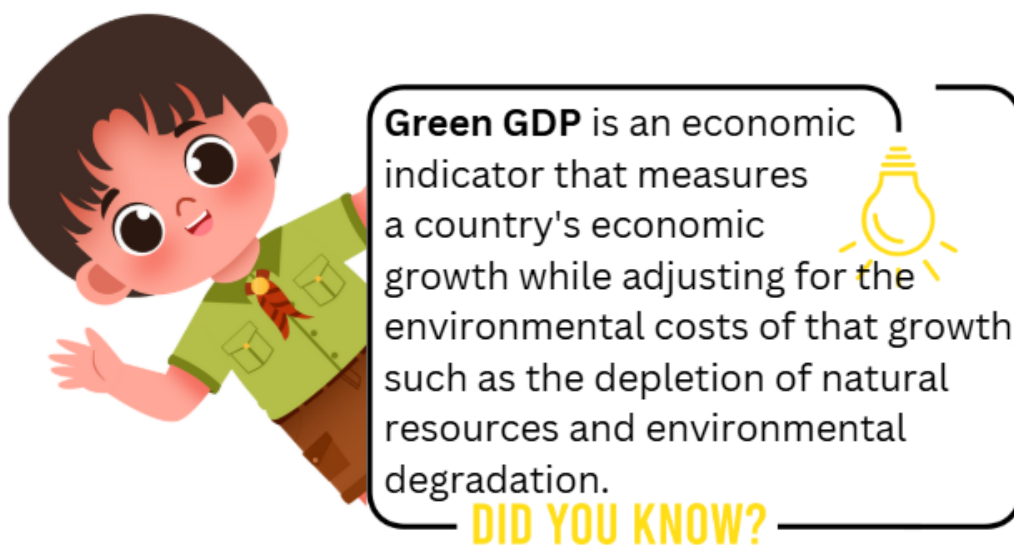
recharge structures in the country to harness 185 Billion Cubic Metre (BCM) of monsoon rainfall⁹.

Summing up & way forward

As elaborated above, India is increasingly using technology to manage its groundwater resources more effectively. Tools like satellite-based mapping (Bhuvan-Bhujal), GIS systems and digital water level recorders are helping to track the groundwater levels may be fulfilled and identify recharge Zones. Programs like NAQUIM¹⁰ map aquifers are supporting to have better planning.

In addition, there are several online platforms have been launched to make the process of giving and tracking permissions for

groundwater use more efficient. However, there are still some challenges in using technology for managing groundwater. Many areas do not have real-time monitoring systems and the data collected is not always shared in a way that local people can easily understand or use. So, there is need to train people at the village level, as many are not familiar with using such tools. To improve this, there should be more focus to expand the digital infrastructure so that groundwater data can be accessed more easily and the wise and sustainable use of groundwater, especially for important needs like drinking water and agriculture.



⁹ [PIB: Master plan of Artificial Recharge of Groundwater](#)

¹⁰ [PIB: National Aquifer Mapping Programme](#)

Innovations in Disaster Management and Early Warning in India

By: Shri. Vikas Dhir, AAO

Introduction

India is transforming disaster management by fusing AI, geospatial tech, and early warning systems to tackle frequent natural disasters. This article spotlights key innovations, national and regional successes, and insights from audits, Case studies and ISSAI 5510 standards. Through case studies and recommendations, it offers a concise look at India's progress, ongoing challenges, and its rising role in global disaster resilience.

Cutting-Edge Technologies Strengthening India's Early Warning Systems for Disaster Resilience

This section analyses the integration of AI, Remote sensing, mobile alerts, and geospatial tools in disaster management, highlighting implementation.

❖ Cyclone & Tsunami Early Warning Technology –

The India Meteorological Department (IMD), using advanced technology and real-time data, achieves 94% accuracy in cyclone prediction. Its early warning system, developed with INCOIS, has helped reduce cyclone fatalities by 90% since 1999, as demonstrated during Cyclone Fani with the pre-emptive evacuation of 1.2 million people.¹

The Indian Tsunami Early Warning Centre² (ITEWC) at INCOIS provides

24/7 tsunami alerts using seismic stations, Bottom Pressure Recorders, tide gauges, and real-time ocean data, supported by coastal vulnerability and inundation mapping for effective disaster response.

❖ Mobile Technologies & AI in alerts³

SACHET National Alert System: The Sachet App, developed by National Disaster Management Authority (NDMA), provides timely disaster alerts and updates in multiple regional languages. Highlighted by the Hon'ble Prime Minister India in 'Mann Ki Baat,' it covers floods, cyclones, landslides, and more, helping improve disaster preparedness nationwide.

❖ Remote Sensing and GIS Initiatives for Disaster Risk Reduction in India⁴:

Drone Operations: The National Innovation Challenge for Drone Application and Research (NIDAR), led by MeitY (Ministry of Electronics and Information Technology) and the Drone Federation of India under SwaYaan, invites 100+ student teams to develop autonomous drones for disaster management and agriculture, offering prizes, mentorship, and industry collaboration.⁵

¹ Ministry of Earth Sciences: [Cyclone Warning Systems](#)

² [Ministry of Earth Science: Indian Tsunami Early Warning System](#)

³ [PIB: Sachet App](#)

⁴ [PIB: Remote Sensing for flood prone states](#)

⁵ [PIB: SwaYaan initiative](#)

- **National Remote Sensing Centre (NRSC)** has developed flood atlases for major states and mapped 28,000 Himalayan glacial lakes for early warning.
- **Building Material & Technology Promotion Council (BMTPC)** has created a digital atlas for regional hazard risk mapping.
- **India Meteorological Department (IMD)** uses satellites and radars for real-time cyclone tracking and alerts.
- **Common Alerting Protocol (CAP)** integrates multi-agency remote sensing data for geo-targeted disaster alerts.

Current Status and Challenges of Early Warning Systems (As per the report on a case of Effective Early warning systems by CEEW)⁶

♦ **Impact of EWS on Lives and Mortality**

EWS have helped save lives and reduce mortality, but their availability remains limited, especially in India's most high-risk areas.

♦ **Population Vulnerability to Extreme Events**

One-third of India's population lives in coastal regions, making them highly susceptible to floods and cyclones. Overall, 75% of Indian districts are extreme event hotspots, with over 80% of the population living in districts prone to hydrometeorological disasters.

♦ **Flood Early Warning System Coverage**

For floods: 72% of districts are exposed to extreme flood events, but only 25% of these

have flood forecasting stations. This means two-thirds of exposed individuals lack flood EWS. Only 3 out of 12 highly exposed states have high EWS availability; 8 have low coverage. **Assam, Bihar, Uttar Pradesh, Odisha, and Sikkim perform best, while Tamil Nadu, Himachal Pradesh, Karnataka, and Telangana** have the lowest availability.

♦ **Cyclone Early Warning System Coverage**

For cyclones: Cyclone warning centres cover 11 states and reach 100% of the exposed population, making cyclone EWS highly effective.

♦ **Need for Investment in EWS and MHEWS⁷**

The coverage gap, especially for floods, highlights the urgent need for investment in EWS and MHEWS to build resilience in India's most exposed states and districts.

ISSAI 5510⁸: The Audit of Disaster Risk Reduction⁹:

- Guides SAIs on auditing disaster risk reduction (DRR) policies.
- Highlights cost-effectiveness of risk reduction over response.
- Focuses on pre-disaster activities like risk assessment and preparedness.
- Provides practical audit advice on strategies, coordination, and early warning.
- Supports improving DRR mechanisms and public fund use.

⁶ [CEEW: A case for Effective Early Warning system](#)

⁷ Multi-Hazard Early Warning Systems

⁸ [ISSAI 5510 explores the issues SAIs are faced with when planning or conducting an audit of disaster risk reduction.](#)

⁹ [INTOSAI: The Audit of Disaster risk reduction](#)

Key Findings and Recommendations from SAI India- Audit Reports

Audit Report (Report no 6 of 2021, Govt. of Kerala)¹⁰:

Kerala's 2008 State Water Policy lacked flood early warning measures and real-time data systems, leaving the state unprepared until after the 2018 floods. Key information was not provided to the Central Water Commission, resulting in no flood forecasting stations before 2018. The report recommends revising the State Water Policy, ensuring all flood management prerequisites are met, and closely monitoring projects for accountability.

❖ Review Report of Early Warning System in Bhubaneswar, Gangtok, Madurai, Navi Mumbai, Shimla, Thiruvananthapuram and Visakhapatnam¹¹

A review of Early Warning Systems (EWS) in seven Indian cities—**Bhubaneswar, Gangtok, Madurai, Navi Mumbai,**

Shimla, Thiruvananthapuram, and Visakhapatnam—was conducted to evaluate their governance, capacity, and preparedness for disaster risk reduction.

The study assessed EWS frameworks at ***national, state, district, and city levels using a Criteria Development Matrix***, and collected data through stakeholder consultations, workshops, city missions, and expert meetings.

Key findings revealed that while EWS are critical for urban resilience, most city agencies prioritize *response over prevention*, with limited technical capacity for hazard mapping, inadequate institutional coordination, and challenges in making forecasts actionable. To address these gaps, the review **recommends** integrating EWS into all disaster management plans, investing in infrastructure like Emergency Operations Centers, enhancing technical skills at the urban local body level, and fostering stakeholder engagement.

¹⁰C&AG Audit Report No. 6 of 2021

¹¹[TARU/UNDP: Review Report of Early Warning System in Bhubaneswar, Gangtok, Madurai, Navi](#)

[Mumbai, Shimla, Thiruvananthapuram and Visakhapatnam](#)

Biodiversity at iCED Campus

Oriental Magpie Robin (*Copsychus saularis*)¹



Image Source: Captured by Shri. Rahul Yadav, AAO

The Oriental magpie-robin (*Copsychus saularis*) is a small passerine bird widely distributed across South and Southeast Asia. Measuring about 19-21 cm in length, with males typically sporting a glossy black and white plumage, while females and juveniles have a duller grey and white coloration. One of its distinctive features is the white wing patch visible in both sexes. It can be distinguished from similar species within its range, such as the Indian robin (*Copsychus fulicatus*), by its contrasting black upperparts and white underparts. The Oriental magpie-robin is known for its varied and complex vocalizations. It is adept at mimicking the calls of other birds and even some mechanical sounds.

Gulmohar (*Delonix regia*)²



Image Source: Captured by Shri. Rahul Yadav, AAO

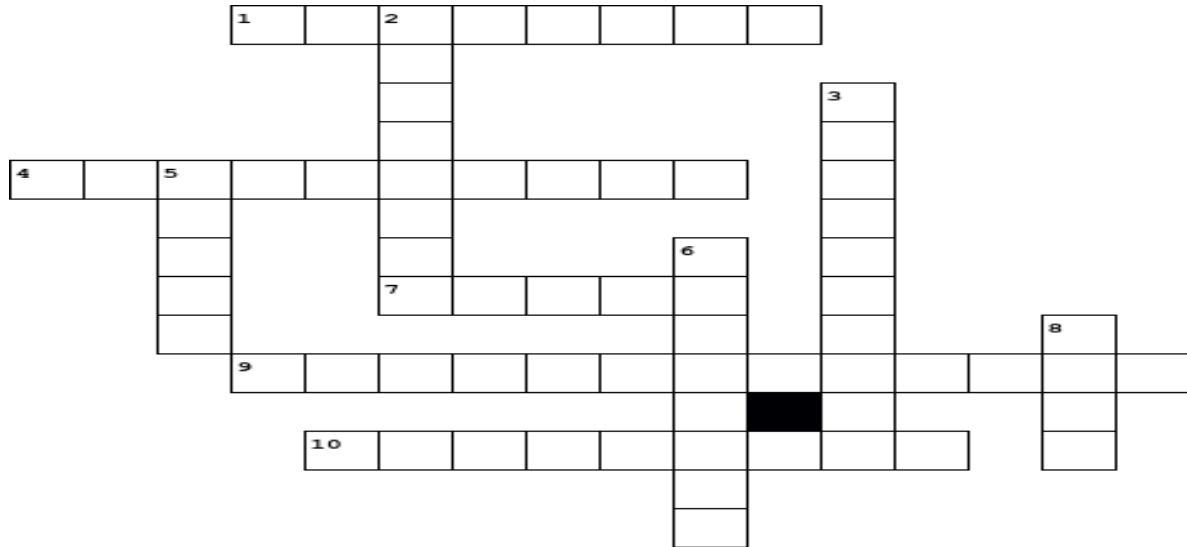
The Gulmohar tree (*Delonix regia*) is native to Madagascar and has become widely naturalized in tropical regions, including India, where it is favored for its ornamental value and striking flowers. This species belongs to the Fabaceae family and is noted for its vibrant flowers and feathery leaves. The Gulmohar was introduced to India during the British colonial era, around the mid-19th century, as an ornamental tree. It quickly adapted to the local climate and has since become a popular choice for landscaping in urban areas and roadside plantings. The tree can grow to about 30 feet tall and is characterized by its flamboyant display of scarlet or orange-red flowers that bloom primarily in the summer months.

¹¹ Picture is captured in the iCED Campus.

² Picture is captured in the iCED Campus.

Crossword Puzzle

By: Ms. Manju Godara, Auditor



Across

1. Region where no living organisms exist due to extreme pollution.
4. The layer of soil permanently frozen in polar regions.
7. This initiative by MoES provides 1–3 day air quality forecasts and health advisories for metro cities like Delhi and Mumbai.
9. State in India that recently used drones and GIS mapping to audit compensatory afforestation under the CAMPA scheme.
10. Soil conservation method on slopes.

Down

2. Natural underground reservoirs of freshwater.
3. Technology used to improve transparency in agri-supply chains and enable traceability.
5. Naturally occurring radioactive gas contributing to indoor air pollution.
6. Climate zone near the equator, typically warm and wet.
8. Indian space agency that provides satellite imagery and GIS data for forest cover assessment.

Answers of the crossword puzzle

Across
 1. Deadzone 4. Permafrost 7. SAFAR 9. Madhyapradesh. 10. Terracing

Down
 2. Aquifers 3. Blockchain 5. Radon 6. Tropical 8. ISRO