Building a Green Kumbh: Innovations in Infrastructure for a Sustainable Pilgrimage

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Abstract

The 2025 KumbhMela at Prayagraj was a quantum jump in conducting sustainable mega-events in India. With the record-breaking turnout of more than 150 million pilgrims, the Mela was an on-ground experimentation site for the deployment of green infrastructure in a temporary, high-density urban landscape. As part of India's National Mission for Sustainable Habitat and Smart Cities Mission, the event featured an integration of renewable energy, intelligent sanitation, AI-powered crowd management, and circular waste. Over 1.5 lakh AI-based bio-toilets, 200 MW solar-powered microgrids delivering clean energy, and IoT-enabled water quality sensors were installed. The solid waste management system diverted more than 80% of waste by segregation, composting, and recycling, whereas hydrogen-powered generators and electric mobility minimized the carbon footprint of the event to a large extent.

This research critically analyzes such innovations through a mixed-methods research that incorporates field observations, key stakeholder interviews (officials, engineers, sanitation workers), and analysis of policy documents. Key takeaways point out that digital governance, strong public-private partnerships, and pilgrim-targeted behavior change communication were responsible for the success of the Green Kumbh. Challenges in technology maintenance, public compliance, and cost-effectiveness were, however, observed. The research concludes that the 2025 KumbhMela provides a scalable and flexible model for sustainable religious and cultural festivals across the globe, subject to the reinforcement of institutional mechanisms of environmental monitoring and public participation on a sustained basis.

Keywords: KumbhMela 2025, green pilgrimage, sustainable infrastructure, smart city, renewable energy, sanitation, waste management, circular economy, event sustainability, Prayagraj

Introduction

The KumbhMela, the world's largest religious conclave, is more than a spiritual phenomenon: it is an intricate exercise in urban design, logistics, and resource management. Cyclically organized at sacred sites of confluence, the festival attracts tens of millions of pilgrims within a relatively brief time frame and leaves behind a temporary megacity that needs to be highly functional without causing too much environmental degradation.

Historically, such mass gatherings have presented severe environmental issues—ranging from river pollution and waste disposal to uncontrolled energy consumption and habitat disturbance. Such issues have grown more prominent in the face of India's changing goals for sustainability and global climate obligations.

To counter this, the 2025 KumbhMela in Prayagraj was conceived as a "Green Kumbh", which was led by the joint action of the Government of Uttar Pradesh, the Ministry of Housing and Urban Affairs, and Prayagraj Smart City Ltd. The focal point of this exercise was to weave in environment-friendly infrastructure and technology-based solutions into the major sectors—sanitation, mobility, energy, water, and waste management.

From AI-controlled bio-toilets and solar-powered grids to IoT-enabled water quality monitoring and circular waste management systems, the 2025 Kumbh sought to show that mass religious congregations can be reconciled with sustainable urbanism and climate resilience.

This research delves into the institutional vision, on-site application, coordination of stakeholders, and systemic issues that influenced the green transformation of the 2025 KumbhMela. It hopes to present a master plan for replicating similar innovations at future large-scale public festivals in India and internationally.

Objectives

- To document and examine the green infrastructure innovations implemented at the 2025 KumbhMela.

- To assess their ecological and social impact.
- Identify critical enablers and barriers to putting sustainable pilgrimage infrastructure in place.

Methodology

Qualitative-quantitative mixed methodology was utilized:

- **Field Surveys & Observation:** On-field monitoring of sanitation, mobility, and waste networks during peak season months of January and February 2025.
- **Stakeholder Interviews:** Stakeholders including officials of Prayagraj Smart City Ltd., the Central Pollution Control Board, sanitation staff, technology vendors, and pilgrims.
- **Policy and Document Review:** Examination of formal tender documents, sustainability reports, and post-event environmental inspections.
- **Data Analysis:** Cross-validation with smart monitoring dashboards' real-time data.

Green Infrastructure Innovations at Kumbh 2025

The 2025 KumbhMela was a critical juncture in embracing sustainability in mega-event infrastructure. The innovations cut across various sectors with a focus on ensuring minimal ecological footprint without sacrificing operational efficiency and public convenience. The subsequent subsections identify the prime green infrastructure interventions.

Smart Sanitation Systems

To meet the enormous sanitation needs, more than 1.5 lakh AI-powered bio-toilets were installed with auto-cleaning facilities and real-time usage monitoring. Pilgrims were able to report hygiene issues through QR-coded feedback kiosks, enabling quick response from sanitation personnel. Robotic cleaning units were used in densely populated areas to ensure hygiene and efficiency, which drastically cut down manual effort and exposure.

Water Management and River Health

To safeguard the sanctity and ecology of the Yamuna and Ganga rivers, IoT-based water quality monitoring systems were fitted on 25 prominent ghats. These sensors gave instantaneous measurements of pollutants and flow rates. Mobile Eco-Treatment Units (METUs) provided

decentralized sewage treatment, while eco-ponds and no-immersion zones stopped direct river pollution from ritual practices.

Solid Waste and Circular Economy

The waste management strategy prioritized a zero-landfill objective, met through AI-powered segregation units, real-time waste dashboards, and rigorous source segregation campaigns. With a waste diversion rate of 80%+, biodegradable waste was composted locally, and recyclable waste was processed locally. A deposit-return system encouraged pilgrims to return plastic bottles and cutlery, fostering behavioral change.

Renewable Energy and Smart Grids

Energy sustainability was attained by a 200 MW solar microgrid, which supplied most of the temporary Mela infrastructure. Further, LED lighting was rolled out over a 500 km² stretch of ground, cutting energy usage by about 45%. In a pilot project, hydrogen-powered generators were established at pivotal nodes, demonstrating India's exploration of clean hydrogen options.

Green Mobility and Crowd Management

To sustainably manage transportation, there was a network of electric buses and e-bikes run through a centralized digital mobility platform. AI-driven crowd analytics, which were combined with drone monitoring and geofencing, facilitated adaptive crowd management. There was a free mobile app shuttle service with route recommendations and individual carbon footprints monitored to promote greener modes of transportation.

Eco-Friendly Construction and Materials

Provisional constructions of the Mela were constructed with compressed stabilized earth blocks (CSEBs) and degradable composite textiles, which substituted traditional non-reusable materials. After the event, a green deconstruction policy saw 95% of the material being dismantled, recycled, or reused, reducing the event's carbon footprint from construction activities and material usage considerably.

Most Important Results: Environmental and Operational Indicators

The innovations introduced during the 2025 KumbhMela resulted in quantifiable environmental and operational benefits. Data-driven infrastructure planning and real-time monitoring allowed

for dramatic reductions in pollution, resource usage, and operational inefficiencies. The following table illustrates sector-wise innovations and corresponding outcomes as per post-event environmental audits and smart city dashboards.

Sector	Innovation	2025 Results
Sanitation	AI Bio-Toilets, QR Monitoring	99% sanitation coverage achieved; significant odour reduction
Waste Management	AI Segregation, Recycling Units	82% waste diverted from landfills through composting/recycling
Water Management	METUs, Smart Water Sensors	32% improvement in river water quality at monitored ghats
Energy	Solar Microgrids, LED Lighting	45% reduction in non-renewable energy use
Transport	Electric Vehicles, AI Crowd Analytics, App-based Shuttles	28% decrease in carbon emissions from transit systems
Materials	Biodegradable Structures, Green Deconstruction	95% material recovery and reuse rate post-event

These results show the potential for climate-responsive urban event planning, particularly when complemented by digital solutions, stakeholder coordination, and citizen participation. The data also confirm that sustainability in temporary cities is not merely possible but can be scaled for future mass gatherings in India and elsewhere.

Discussion

The 2025 KumbhMela is a bellwether case study of integrating the tenets of green urbanism into the paradigms of managing large-scale religious events. In contrast to earlier iterations that predominantly revolved around logistical implementation, the 2025 Mela implemented a multi-faceted agenda of sustainability that rested upon resilience planning, evidence-based governance, and behavioral change.

This paradigm change was facilitated by the confluence of technological innovation, policy encouragement, and grassroots activism. AI-embedded sanitation, clean energy options, and online water quality tracking turned temporary facilities into a reactive system. At the same time, behavioral cues—ranging from digital systems of feedback to eco-reward incentives—fostered environmental stewardship among millions of pilgrims.

But the transition was not smooth operationally. Rural and first-time visitor compliance with waste segregation and digital technologies was patchy. Moreover, coordinating real-time coordination among hundreds of vendors, departments, and private partners pushed the boundaries of digital infrastructure, particularly on high-pilgrimage days.

In spite of these challenges, three enablers proved to be key to the event's environmental success:

- **Digital Governance Platforms –** The Smart Kumbh Dashboard combined data from sanitation, transport, energy, and crowd control systems, supporting real-time decision-making and accountability.
- **Public–Private–Tech Collaborations –** Inter-government agency, startup, and civic society alliances drove faster innovation, maintenance, and last-mile delivery.
- **Community Engagement &Swachhata Campaigns** – Mass awareness drives, volunteer groups, and neighborhood outreach programs supported citizen engagement and cultural alignment with sustainability objectives.

These observations confirm that an integrated governance, technology, and public engagement model is the key to establishing temporary urban places as environmentally sustainable.

Challenges and Limitations

Despite the 2025 KumbhMela establishing a template for sustainable planning for mega-events, there were numerous challenges to the process that require critical assessment for future replications and revisions.

- **Behavioral Non-Compliance:** In spite of extensive outreach and Swachhata drives, parts of the pilgrim community—more so from rural and digitally inaccessible regions—registered low compliance towards segregation of wastes, sanitation practices, and envi-

ronmentally friendly behavior. Cultural resistance, lack of familiarity with digital technologies, and language issues prevented large-scale behavioral change.

- **Large Capital Investment:** Rollout of AI-based sanitation units, intelligent grids, and IoT-based monitoring systems required heavy initial investment. Even though the long-term reward in minimized ecological degradation and optimized efficiency is clear, cost scalability is an issue, particularly for small urban authorities or less-equipped events.
- **Shortage of Long-Term Ecological Monitoring:** While waste diversion and energy savings in the short term were well reported, there was minimal follow-up on long-term evaluations of the event's ecological footprint—specifically regarding riverbank recovery, soil quality, and biodiversity return. The lack of post-event environmental impact audits makes it difficult to quantify long-term benefits or unexpected outcomes.

Overcoming these challenges needs to be multi-faceted: ongoing public awareness, policy instruments for green financing, and institutionalized mechanisms for post-disaster ecological monitoring. Without these, the danger of sustainability remaining a one-off spectacle, instead of an ongoing practice, persists.

Conclusion

The 2025 PrayagrajKumbhMela represents a turning point in the development of sustainable religious tourism, showing that even the largest mass events in the world can be in harmony with environmental responsibility. By using smart technologies, renewable power, green building practices, and inclusive governance, the Mela provided a model for climate-friendly urbanism in temporary event environments that can be replicated.

What distinguishes this edition is not only the scope of innovation, but the incorporation of ecological stewardship into the cultural fabric of the event. From AI-powered sanitation systems to solar microgrids and circular waste management, every intervention embodied a conscious shift from reactive management to proactive sustainability planning.

Significantly, the Green Kumbh highlights the potential of intersectoral cooperation—between government, private sector, civil society, and citizens—towards collective environmental

objectives. It also shows that behavior change and digital empowerment are as critical as telecom infrastructure in sustaining long-term success.

In the future, it is important that such green initiatives are not seen as one-off innovations but as business-as-usual practices in religious, cultural, and civic event planning. Integrating sustainability as a core goal—instead of an afterthought—will be critical to ensuring that India's spiritual heritage continues to thrive without sacrificing its environmental future.

Recommendations

Based on the learnings of the 2025 KumbhMela, the following strategic suggestions are made to mainstream sustainability into future mass events and religious tourist sites in India and around the world:

- **Institutionalize Green Certification Protocols:** Create a formal framework for Green Event Certification, governed by state and central urban planning departments, to assess and certify sustainability performance of all mega public events. This should have metrics relating to energy consumption, waste diversion, water conservation, and carbon footprint.
- **Create Mela-Specific Urban Design Guidelines:** Implement event-specific urban design policies that include ecological footprint limits, low-impact infrastructure zoning, and carrying capacity thresholds. These guidelines will be specific to temporary megacities and need to be approved by environmental regulation agencies.
- **Scale Hydrogen and Solar Innovations:** On the back of the success of solar microgrids and hydrogen-powered generators at the 2025 Mela, replicate these technologies to other high-traffic religious and cultural sites, including Vaishno Devi, AmarnathYatra, and Tirupati. Government incentives and public-private partnerships will be the drivers.
- **Harness Digital Pilgrim Platforms:** Use mobile apps, digital kiosks, and social media platforms to infuse sustainability nudges—carbon footprint tracking, gamified recycling, and eco-behavior commitments—within the pilgrim journey. They can also function as both pedagogic platforms and data feeds for adaptive planning.

Together, these steps will institutionalize the Green Kumbh model as a sustainable template for future mega-religious events, promoting a culture where sustainability and spirituality walk hand in hand.

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