

Tackling Waste Management in India's Smart Cities: A Circular Economy Approach

Nagesh Nandal*, Manisha Paliwal**

Abstract

India's urbanization process has caused waste management problems in its smart cities, with 62 million tons of municipal solid waste annually. Linear waste management practices, founded on a "take-make-dispose" paradigm, accelerate environmental, social, and economic problems, prompting a transition to circular economy models. This research identifies the ways circular economy strategies—waste reduction, material reuse, and recycling—can be applied to India's smart city waste management in order to meet these challenges. Using qualitative analysis, the research examines secondary data from government reports, academic research, and case studies using thematic content analysis. The research finds poor segregation of waste, a lack of adequate recycling facilities, and low public awareness as the key constraints. Circular economy strategies like source segregation, Extended Producer Responsibility (EPR), and waste-to-energy (WtE) technologies provide promising ways to increase sustainability. IoT-enabled intelligent bins and data-driven collection systems enhance the efficiency of operations, like in Indore, the cleanest city of India. Public awareness campaigns and community involvement are essential to create a behavioral shift towards sustainable waste management. Regulatory systems such as the Solid Waste Management Rules (2016) need to be enforced more forcefully for circular economy uptake promotion. By waste-as-a-resource conversion, smarter cities can minimize landfills, promote economic gains, and realize sustainable urban growth. The limitations include dependence on secondary data, which could be out of date, and non-uniform implementation by cities. Future studies must emphasize scalable, tech-driven solutions and inclusive policies to address urban-rural chasms. Implementing circular economy approaches puts India's smart cities at the vanguard of sustainable waste management, enabling cleaner, greener urban futures.

Keywords: Circular Economy, Recycling, Waste Management, Smart Cities, Sustainability

Introduction

India's cities are being remapped by accelerating urbanization and population growth. 35% of India's population is now urbanized and generates more than 60% of India's 62 million tons annually of municipal solid waste (MSW) (Kumar et al., 2017). This new level of growth, fueled by growing consumerism, has stretched existing waste management infrastructure to choking landfills, environmental degradation, and acute public health issues. The conventional waste management method, which adopts a linear "take-make-dispose" philosophy, is progressively becoming unsustainable, augmenting resource depletion and environmental deterioration (Tanveer et al., 2022; Hossain et al., 2022). The linear model consumes raw materials, creates products, and throws away waste, leading to inefficiencies and environmental degradation. On the other hand, the circular economy is a sustainable option by focusing on waste reduction, reuse of resources, and recycling to create a closed-loop system (Fusco Girard & Nocca, 2019). Through the re-mapping of waste as a resource, practice also offers an opportunity to reduce the urban waste problem and maximize economic and environmental returns (Cheela et al., 2021).

India's Smart Cities Mission launched in 2015 is a visionary step towards solution of urban ailments by technology and sustainability. The vision is to develop 100 smart cities through the use of information and communication technology (ICT) in an effort to improve governance, engineering, and servicing of cities (Butsch et al., 2017). Dispose waste is at the heart of such a concept, because good process is what's required for a sustainable city system to thrive. India's smart

* Research Scholar, Sri Balaji University, Pune, Maharashtra, India. Email: Nagesh.Nandal@sbup.edu.in

** Head, R&D Cell, Sri Balaji University, Pune, Maharashtra, India. Email: mnpaliwal@gmail.com

cities, though, are fighting desperate problems of bad segregation, bad recycling, and bad public awareness. These are complemented by the illegal waste recycling industry dealing with waste disposing of 60–70% of the country's waste in unhygienic ways with no formal care or concern (Breukelman et al., 2019). The face of India's waste management system's strength and weakness is informal labor.

The circular economy has been a strong solution to waste management worldwide, with instances that India can adapt to its scenario. It has proven to be a challenging task for the European Union to shift toward a circular economy by 2050, aimed at reducing waste and recycling resources (Aceleanu et al., 2019). Other cities like Amsterdam and Singapore have managed to integrate circular economy practice into daily work and have achieved highly rare recycling rates coupled with efficient WtE technology (Amenta & van Timmeren, 2018). Kamikatsu in Japan, for instance, has achieved more than 80% reduction in landfill-waste through stringent community-level sorting and recycling exercises (Awino & Apitz, 2023). The international case studies hold lessons for India, where circular economy initiatives can convert wastage into an asset, minimize landfills dependence, and generate economic value for urban dwellers.

In the context of India, circular economy aligns beautifully with Smart Cities Mission goals for sustainability and productivity. Source segregation, Extended Producer Responsibility (EPR), and using WtE technology can be mechanisms for managing complex waste problems in such a manner as to also achieve recovery of resources (Ddiba et al., 2021). For example, Indore has demonstrated that technology-based solutions can be optimized, using IoT-connected smart trash cans and data-driven collection networks to make waste collection more efficient and less expensive (Pardini et al., 2019). These technologies demonstrate the ability of technology to overcome infrastructural shortcomings and enhance waste management performance. There is, however, a need to optimize circular economy with the need to overcome humongous challenges such as infrastructural shortages, uneven policy implementation, and cultural aversion to processes such as segregation of waste. Overcoming such constraints involves an integrated strategy that packages technological innovation, good policy frameworks, and involvement of people.

The aims of this research are four in total: (1) to assess the waste management schemes currently running in India's smart cities, (2) to gain some insight into the challenges to come for effective waste management, (3) to know about circular economy solutions in the light of the Indian scenario, and (4) to make recommendations for implementing such solutions in the smart city environment. The research questions are as follows: How is circular economy to be deployed in waste management in India's smart cities? What are the main opportunities and challenges of such a transition? What are the roles of technology, policy, and public participation towards enabling such a transition? To these research questions, the study seeks to gain an in-depth understanding of how circular economy indicators can be utilized in improving waste management in Indian cities.

The paper structure has been designed with the purpose of answering the research questions and attempts to address them in a step-by-step manner. Section 2 is an extensive literature review that presents the research's theoretical framework and reveals gaps in the studies. The chapter weaves together Indian studies and global studies to contextualize the circular economy in the context of planning smart cities. Section 3 outlines the qualitative research approach utilized, including analysis and data collection procedures. Section 3 fosters transparency of research process and is the anchor of findings. Section 4 contains findings, providing a critical examination of present waste management and the destiny of India's smart cities. Section 4 demonstrates success and shortcomings of current systems. Section 5 addresses the necessity of embracing circular economy practices, benchmarking international best practice to identify best practice and where innovation needs might be targeted in India. This section also describes the interface between technology, policy, and public engagement in promoting sustainable waste management. Section 6 concludes the paper by highlighting key findings, summarizing the study's contribution to existing literature, admitting its limitations, and paving the way for further research.

Through the analysis of the convergence of circular economy values and city planning, this study attempts to offer policymakers, urban planners, and concerned stakeholders some practical guidance on the future of Indian cities. The marriage of circular economy principles with smart city planning can revolutionize waste management, decrease the environmental footprint, and

increase the standard of life in urban areas. Urbanization in India is taking place at a rapid rate, and the viability of inclusive, green, and resilient cities will be contingent on the implementation of circular economy principles for sustainable waste management. With this study, the literature on sustainable urbanism becomes enriched a bit more with an addition regarding how the principles of the circular economy can be the foundation upon which India's smart cities are built. This will finally usher in the era of more sustainable and more efficient utilization of urban resources.

Literature Review

The circular economy is a complete shift away from the linear “take-make-dispose” model, which depletes resources and generates wastage, to one reliant upon a closed-loop system that endeavors to reduce wastage and maximize resource utilization through reuse, recycling, and regeneration (Fiksel et al., 2021). Through the conversion of wastage to an asset, the system lends support to economic and environmental sustainability. The circular economy has acquired unprecedented pace everywhere in the world. European Union has also shown a vision for reaching a closed circular economy by 2050, where policy would focus on reducing waste, recovering materials, and sustainable product design (Aceleanu et al., 2019). Japan's Kamikatsu is more than 80% diverted from landfill due to local sorting and recycling programs and Singapore's very advanced WtE plants have good examples of successful resource recovery (Awino & Apitz, 2023). These international case studies demonstrate the promise of circular economy thinking in solving urban waste management issues, with significant learnings for India's urbanizing smart cities.

India's population growth and urbanization have worsened waste generation exponentially, with cities generating 62 million tons of municipal solid waste (MSW) every year, which is expected to grow immensely (Chen et al., 2020). Organic waste that makes up 60–70% of MSW has enormous potential for composting, but the process is not being utilized to its fullest potential because of poor infrastructure, lack of public awareness, and uneven policy implementation (Ddiba et al., 2021). The unorganized sector, i.e., rag-pickers and kabadiwalas, also has a very major contribution, meeting 60–70% of recycling activities. However, they work under perilous conditions, are unofficially acknowledged, and are

ineffective because they are not systematically integrated in waste management infrastructure (Breukelman et al., 2019). Plastics waste is estimated to account for 9 million tons yearly, and is a serious environment issue, while single-use plastic is blamed for widespread pollution in urban and rural areas (Hossain et al., 2022). E-waste, which has emerged as a new issue quite recently, is not treated and there are no secure recycling and recovery facilities available for valuable components, which are also responsible for health and environment hazards (Shahab & Anjum, 2022).

Rules in India pertaining to waste management, like Solid Waste Management Rules (2016), provide specifications for source segregation, recycling, and waste disposal in biodegradable, recyclable, and hazardous categories. But there is disparity in the enforcement, especially in rural areas and small cities where there are limited resources and inferior infrastructure (Singh et al., 2018). Swachh Bharat Mission (SBM), initiated in 2014, has encouraged cleanliness, waste segregation, and civic participation, and the effects are visible in cities such as Indore, which is today a clean model city in urban areas. Nevertheless, there exists extensive behavior change that is challenging, whereby numerous homes fail to sort waste at source, thereby creating downstream recycling and composting inconvenience (Curtis, 2019). Extended Producer Responsibility policies introduced under the E-Waste Management Rules (2016) and Plastic Waste Management Rules (2016) are intended to hold manufacturers accountable for the handling of their products throughout the product life cycle. Though these policies have the potential to minimize waste and foster green design, there are constraints in implementation as well as poor monitoring that divert from the purpose, especially for the informal recycling industry (Shahab & Anjum, 2022).

Circular economy uses existing solutions to solve India's waste management problem. Household and community-level source segregation improves the efficiency of recycling by lowering contamination, facilitating better material recovery rates of products like plastics, paper, and metals (Breukelman et al., 2019). EPR schemes promote producers to design products that are durable, repairable, and recyclable, lowering the environmental impact of consumer products (Khosla & Bhardwaj, 2019). Waste-to-energy technologies like anaerobic digestion of organic waste and incineration of non-recyclable waste convert waste to usable energy, thus lowering landfill

dependency and supplementing municipal energy demand (Shah et al., 2021). Decentralized community-driven composting programs can also turn urban waste into usable fertilizer for city farming as observed in pilot programs in Bengaluru (Ddiba et al., 2021). IoT and data analytics-based smart bin technologies minimize collection routes and operational expenses. Indore, India's cleanest city, is a best practice example that utilizes IoT sensors to track the waste level and optimize collection in an efficient manner, and consequently achieves high rates of segregation and recycling (Pardini et al., 2019).

Globally, cities like Amsterdam have adopted circular supply chains with an emphasis on sustainable material and local production to minimize waste (Amenta & van Timmeren, 2018). Copenhagen achieves waste minimization and energy efficiency with the help of data analytics because it aims to be carbon-neutral by 2025 (Sosunova & Porras, 2022). All such global role models focus intensely on high stakeholder collaboration, technological advancement, and policy backstopping towards achieving circularity. India's waste management infrastructure, however, faces special challenges, including overdependence on the informal economy, infrastructural weaknesses, and cultural hindrances to waste segregation that limit direct transfer of best practices from across the globe (Breukelman et al., 2019). The informal economy needs to be mainstreamed through targeted interventions that integrate such workers into formal systems and improve working conditions and income security.

Most of the secondary data-based studies rule out direct access to up-to-date information on waste management practice, especially within the changing urban environment. City-focused studies also don't consider rural waste management concerns critical to understanding India's waste system comprehensively. These gaps necessitate more research in an attempt to develop scalable and inclusive interventions that will neutralize India's smart cities' socio-economic and cultural push factors. The principles of circular economy, with the support of local and foreign data, can be adapted to build flexible sustainable waste management structures that complement India's urban development goals.

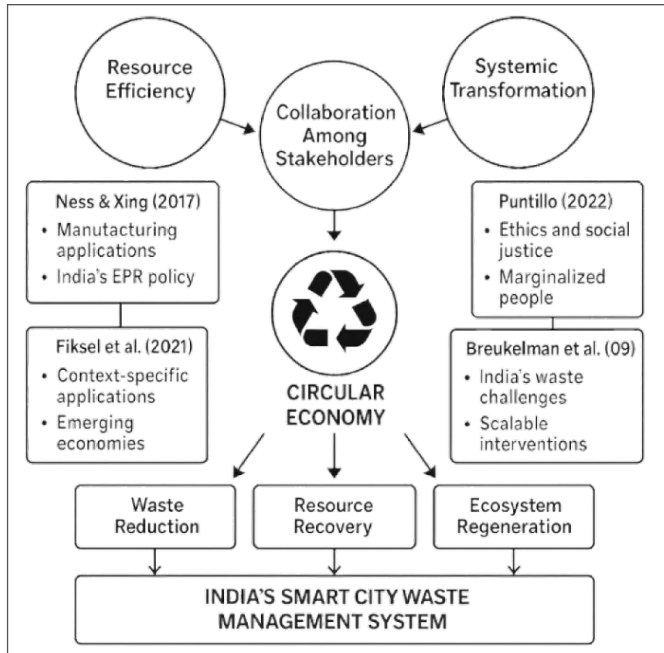
Research Gap

In the context of circular economy practice in innovation in waste management globally, the specific socio-economic reality of informal recycling, infrastructural

deficiency, and cultural constraints is a real research gap that can be seen to exist. There is available research, e.g., Breukelman et al. (2019) and Ddiba et al. (2021), that is inclined towards urban cities and identifies issues of poor segregation and absence of recycling plants. They are secondary data, though, and lack therefore the immediacy of new perspective on what actually is going on in plural Indian smart cities. This constrains the development of context-responsive scalable technology-driven solutions. The literature also concentrates mainly on urban waste management and de facto excludes rural and semi-urban environments, which are part of India's Smart Cities Mission. The informal sector that contributes 60–70% recycling is cited voluminously but rarely researched from official integration schemes that promote labor security and productivity (Breukelman et al., 2019). Cross-national case studies, for instance, Amsterdam's circular supply chains or Singapore's WtE facilities, are rich in best practice but low on implementation owing to India's resource limitations and societal resistance towards waste segregation (Amenta & van Timmeren, 2018; Sosunova & Porras, 2022). Public awareness campaign and behavior change intervention impacts are limited in the literature, although these are of paramount significance (Curtis, 2019). This present research tries to fill this knowledge gap by examining the IoT-based circular economy projects, EPR, and stakeholder participation that can be articulated for India's smart cities with urban as well as rural realities in perspective. It will give policymakers and planners convenient guidelines to bridge the gap between global best practice and local context and guarantee the backing of sustainable waste management regimes.

Theoretical Framework

Theoretical framework of the study is based on circular economy principles, where resource efficiency, systemic transformation, and collaboration among stakeholders through economic, environmental, and social perspectives are prioritized (Puntillo, 2022). Fiksel et al. (2021) address circular economy applications, with specific focus on waste reduction, resource recovery, and ecosystem regeneration. They emphasize the need for context-specific applications, especially in emerging economies such as India, where socio-economic and infrastructure limitations influence implementation. This viewpoint informs the research agenda in this research: adapting circular economy approaches to India's context-specific waste challenges.



Source: Author's own work.

Fig. 1: Circular Economy Framework for Smart City Waste Management in India

Ness and Xing (2017) offer manufacturing applications of the circular economy that are relevant to insights into waste management, e.g., on product design, supply chain operation, and material reuse. They contend that strategic circular methods need harmonized strategies that also converge business interests with environmental objectives, a principle that can be translated into policies such as India's Extended Producer Responsibility (EPR). Puntillo (2022) highlights the ethics and social justice aspect of circularity, advocating for inclusive action that brings relief to marginalized people, aligning with India's informal waste pickers. This aspect guides the study in this research focus on fair waste management systems.

In the Indian context, Breukelman et al. (2019) identify flaws in segregation of waste, recycling infrastructure, and public awareness, with scalable interventions such as Indore's IoT system being noted. Ddiba et al. (2021) highlight the promise of WtE and composting technologies, considering that the informal sector is dominant. Khosla and Bhardwaj (2019) advocate for public-private partnerships and policy incentives towards stimulating circularity with a focus on multi-stakeholder collaboration. These views form a solid ground for investigating the use of circular economy concepts in India's smart city waste management system.

Research Methodology

The study herein employs a qualitative research design approach to explore the implementation of circular economy concepts in India's smart cities' waste management framework. Qualitative research approach is best in exploring intricate social and environmental issues, allowing comprehensive analysis of secondary data for the discovery of implicit findings (Williams, 2019). The study aims to review existing waste management systems, understand problems, and propose circular economy-driven solutions by drawing on a wide array of secondary sources for an objective view.

Data Collection

Systematic secondary data were collected from credible sources to build a strong database for the analysis:

- *Journal Articles:* Peer-reviewed journal articles of smart city planning, circular economy models, and waste management were accessed from prominent databases such as Scopus and Web of Science. They are the theoretical frameworks and empirical facts regarding waste management in global and Indian settings, which form a concrete scholarly backdrop.
- *Government Policies and Reports:* Official reports of Ministry of Housing and Urban Affairs, Swachh Bharat Mission, and Central Pollution Control Board (CPCB) were gathered. Sources offer information about waste generation trends, government policies, and smart city missions, which offers credible information about India's waste management sector.
- *Industry Reports:* NGO, consultancy company, and trade association reports were consulted. Industry reports bring to light pragmatic aspects of recycling programs and circular economy practice, delivering actionable information on strategy and industry trends.
- *Case Studies:* In-depth examination of waste management projects in Indian cities like Indore and world cities like Singapore were examined. Case studies pin-point successful methods and issues, offering comparative lessons in integrating circular economy principles.
- *Public Documents and News Articles:* Public documents and news articles were utilized to access

recent trends in urban waste management, smart city policies, and sustainability policies. The sources offer real-world context and validate government and academic data.

The multi-source strategy guarantees a comprehensive dataset, integrating theoretical, policy-oriented, and practical views to tackle the research objectives in response.

Data Analysis

Thematic content analysis was used to search systematically for the data collected, using a clearly established process to derive meaningful information:

- *Identification of Key Themes:* The data were used to discover key themes such as waste segregation, recycling, waste-to-energy (WtE) technologies, e-waste management, and public awareness. The identified themes are in accordance with circular economy dynamics and are used as a model to interpret waste management dynamics.
- *Categorization:* Information were grouped into themes to investigate relationships between smart city waste management strategies and circular economy strategies. By doing this, rigorous analysis of how these strategies can solve particular problems was attained.
- *Comparative Analysis:* Indian smart city waste management approaches were compared with international smart city waste management practices to learn the best practices and to determine their applicability in the prevailing socio-economic and cultural context of India. This cross-city comparison presents transferable lessons and situation-specific constraints.
- *Policy and Practice Review:* The efficacy and scalability of current waste management practices and policies were reviewed, with focus placed on the consistency with which they aligned to circular economy principles. This measure contrasted the capabilities of current schemes in enabling successful transition to sustainable waste management.

Ethical considerations were always given the highest priority throughout the research process. Data credibility

has been maintained by cross-verifying several sources to verify against any potential bias, most notably government reports that are likely to be a reflection of official thinking. The research is also aware of the potential bias of viewpoint in secondary data, i.e., discrepancy between independent and official reports, and tries to be objective by taking a large and mixed set of valid sources. Clarity of data analysis and sourcing also adds to the study's integrity.

Limitations

The methodology also has some limitations that must be acknowledged:

- *Data Availability:* Secondary data in the form of government reports and academic journals may not capture recent developments in India's smart cities, which may limit the currency and applicability of the study to new trends.
- *Generalizability:* Findings from data at hand may not always be applicable to all smart cities, particularly smaller or less documented ones, where waste management operations may be very different.
- *Bias of Sources:* Secondary data may have inherent biases based on the line of thinking of the source, e.g., optimistic government reports or perceptive NGO reports. Although attempts have been made to balance these with diversified sourcing, there may still be some bias.

This research offers a solid context to learn about how circular economy thought can improve waste management in India's smart cities. Qualitative approach with thematic content analysis enables rich evaluation of challenge, opportunity, and solution despite the limitation of secondary data. Using primary sources and good analysis, the research attempts to offer pragmatic knowledge to the sustainable urban waste management literature.

Results

This study examines circular economy principles in Indian smart cities' waste management using secondary data gathered from research articles, government publications, case studies, and industry magazines. Findings provide an insight into best practice, challenges, and opportunities in sustainable waste management.

Display Waste Management Practices

India's urban cities generate an estimated 62 million tonnes of municipal solid waste (MSW) annually because of rapid urbanization and population growth (Schellenberg et al., 2020). Large cities like Mumbai (9,200 tons/day) and Delhi (8,500 tons/day) are the highest contributors, while per capita wastage ranges from 0.40 to 0.53 kg/day (Central Pollution Control Board, 2019). Table 1

summarizes waste generation and composition, with organic waste being the most common at 60–70%, followed by plastics (15–22%), paper, and metals. Composting of organic waste is possible but with low recycling levels at 20–25%, primarily due to poor source segregation. Approximately 80% of city waste is dumped in inadequately regulated open dumps or landfills, which results in health risks and environmental pollution (Sahoo et al., 2023; Ddiba et al., 2021).

Table 1: Waste Generation in Major Indian Cities (2020)

City	Waste Generated (Tons/Day)	Per Capita (kg/day)	Composition
Mumbai	9,200	0.53	Organic (60%), Plastics (20%), Paper (10%), Others (10%)
Delhi	8,500	0.44	Organic (58%), Plastics (22%), Paper (12%), Metals (8%)
Bengaluru	4,500	0.42	Organic (65%), Plastics (15%), Paper (12%), Others (8%)
Chennai	3,500	0.45	Organic (62%), Plastics (18%), Paper (10%), Others (10%)
Kolkata	4,000	0.48	Organic (63%), Plastics (17%), Paper (10%), Others (10%)
Hyderabad	3,200	0.40	Organic (60%), Plastics (18%), Paper (15%), Others (7%)

Source: Adapted from Central Pollution Control Board (CPCB) and municipal reports.

The kabadiwalas and rag-pickers, the unorganized sector, handles 60–70% of recycling but in unsafe manners without any official recognition, decreasing efficiency (Breukelman et al., 2019). Composting remains underutilized due to limited infrastructure and population awareness even with the high percentage of organic waste (Ddiba et al., 2021). Government initiatives such as the Swachh Bharat Mission (SBM) launched in 2014 and the Solid Waste Management Rules (2016) promote segregation and recycling but remain unevenly enforced, particularly in small towns (Singh et al., 2018).

Provisions under the EPR for e-waste and plastics under the E-Waste and Plastic Waste Management Rules (2016) hold potential but are thwarted by weak implementation (Shahab & Anjum, 2022). Waste-to-energy (WtE) plants, which are supported by the National Clean Energy Fund, aim to convert non-recyclable waste into energy but are negatively impacted by conditions like prohibitively high costs and resistance from people (Schellenberg et al., 2020). Table 2 presents key government initiatives and their limitations.

Table 2: Key Government Initiatives and Regulations for Waste Management in India

Initiative/Regulation	Year Launched	Key Features	Impact/Challenges
Swachh Bharat Mission (SBM)	2014	Focus on cleanliness, waste management, and segregation	Improved urban cleanliness but limited rural impact due to infrastructure gaps
Solid Waste Management Rules	2016	Mandates source segregation and recycling	Uneven implementation, especially in smaller cities
Plastic Waste Management Rules	2016	Aims to reduce plastic waste and promote recycling	Enforcement challenges in rural and unregulated areas
E-Waste Management Rules	2016	Introduces EPR for e-waste Ascertainable EPR for e-waste	Slow adoption and informal recycling risks
National Clean Energy Fund	2010	Supports WtE projects	High costs and public opposition limit progress
National Action Plan for Climate Change	2008	Includes waste management for sustainability	Lacks effective local implementation

Source: Adapted from MoEFCC, CPCB, and government documents.

Challenges

The study mentions some severe challenges:

- *Inadequate Effective Source Segregation:* Inadequate segregation practices, despite SBM efforts, result in commingled waste flows, complicating recycling and composting (Cornea et al., 2017).
- *Insufficient Infrastructure:* Without recycling, composting, and WtE infrastructure, landfill dependency is common, particularly for e-waste (Shahab & Anjum, 2022).
- *Dominance of the Informal Sector:* Uncontrolled informal workers expose themselves to hazardous working conditions and inefficiencies and thus need formal integration (Breukelman et al., 2019).

Low Public Awareness: Low awareness hinders behavioral change towards segregation and recycling, undermining waste management (Curtis, 2019).

Opportunities

Circular economy solutions present viable alternatives:

- *Source Segregation:* Training and incentives maximize recycling rates, as in Indore's community-based model (Pardini et al., 2019).
- *EPR:* Enhancing EPR policies can reduce e-waste and plastic burdens by adopting sustainable product design (Hossain et al., 2022).
- *WtE Technologies:* WtE plants in Delhi and Bengaluru treat non-recyclable waste to generate energy, reducing landfilling (Shah et al., 2021).
- *IoT and Smart Technologies:* Indore's IoT-connected smart bins with AI-based sorting maximize collection and recycling, offering a scalable solution (Pardini et al., 2019).

Discussion and Findings

India's smart cities are threatened by an accelerating waste crisis brought about by urbanization, growing populations, and changing consumption patterns, necessitating a transition away from linear and towards circular waste management systems. The results show that urban agglomerations produce nearly 62 million tons of municipal solid waste (MSW) per year, with 60–70%

being organic waste but with a low recycling rate of 20–25%, while 80% waste is sent for landfilling (Central Pollution Control Board, 2019; Sahoo et al., 2023). Plastic pollution, amounting to 9 million tons yearly, accelerates the deterioration of the environment, and per capita urban waste of 0.40–0.53 kg/day occurs in cities such as Mumbai and Delhi (Schellenberg et al., 2020; Hossain et al., 2022). The challenges however universal are exaggerated in India through socio-economic conditions such as the predominance of informal sectors, infrastructural inadequacies, and cultural oppositions to segregation, which differentiate the Indian scenario from that of the developed world (Breukelman et al., 2019).

Inadequate source segregation in Bengaluru pollutes waste streams, lowering efficiency in recycling and composting (Cornea et al., 2017). The 60–70% informal waste sector recycling rate works under risk conditions without formal integration, and its potential is restricted (Breukelman et al., 2019). It reflects other issues in Global South countries but is at odds with the formal European systems (Acelandu et al., 2019). Deficiencies in recycling, composting, and WtE infrastructures guarantee landfill reliance, dumpsites being ill-managed, resulting in contamination of soil, water, and air (Shahab & Anjum, 2022). Awareness among the people, even under the Swachh Bharat Mission, continues to be weak, and behavioral change is being influenced by India's multi-dimensional socio-cultural scenario, a state deeper than that during initial world recycling revolutions (Curtis, 2019; Sosunova & Porras, 2022). Lack of effective execution of the Solid Waste Management Rules (2016), especially in small cities, contributes to the challenges, vis-a-vis tough arrangements in Singapore (Singh et al., 2018).

Circular economy approaches present effective interventions. Source segregation, augmented by proper training and rewards, enhances the efficiency of recycling, as noted by high rates of segregation in Indore through IoT-based smart dustbins and civic participation (Pardini et al., 2019). This is in line with global models such as Japan's Kamikatsu zero-waste initiative, which can be replicated for India with some adjustments (Awino & Apitz, 2023). Implementing Extended Producer Responsibility (EPR) legislation more rigorously may reflect Europe's plastics and e-waste reduction success in India's context, targeting the plastic waste issue in particular (Acelandu et al., 2019; Hossain et al., 2022). Waste-to-Energy (WtE) technology,

like that in Delhi and Bengaluru presently, generates energy from non-recyclable wastage, reducing landfills' pressure and supplementing urban energy demand, although scalability is uncertain (Shah et al., 2021; Sosunova & Porras, 2022). Decentralized composting diverts organic wastage to urban agriculture, minimizing municipal pressures, as is the case with pilot experience (Ddiba et al., 2021).

Enabler-critical technological innovations. Indore's AI-powered and IoT-based sorting-capable smart bins maximize collection and reduce recycling rates, similar to Singaporean infrastructure (Zhang et al., 2020; Pardini et al., 2019). Ahmedabad's digital route planning platforms show cost and efficiency benefits, with scalable designs (Shaban et al., 2020). Yet the digital divide between the small cities threatens at risk of uneven access, prompting particular investment (Shaban et al., 2020). Public-private partnerships (PPPs), like London smart waste schemes, have the potential to fill gaps by raising private finance (Yigitcanlar & Kamruzzaman, 2015). Policy reforms, like South Korea's pay-as-you-throw, can encourage rubbish reduction, while legalizing the informal sector, from Amsterdam's examples, would make it more effective and enhance workers' conditions (Sosunova & Porras, 2022; Amenta & van Timmeren, 2018). Smart Cities Mission (2015) offers the following platform to integrate circular values, yet urban-rural disparity necessitates inclusive policy (Butsch et al., 2017; Ravishankara et al., 2020). What these findings indicate is the need and potential of indigenous innovation in addressing India's waste crisis, while learning can be transferred for other emerging economies.

Implications

Academic Implications

This research advances circular economy (CE) theory by availing a Global South perspective on waste management in Indian smart cities, challenging Eurocentric paradigms that fail to factor in informal systems and socio-cultural processes. It necessitates the localization of CE strategies to contexts in which informal sectors deal with as much as 70% of recyclables and resist waste segregation strongly. Highlighting Indore's participatory spirit, the study illustrates how inclusive urban sustainability arises from citizen engagement and decentralized frameworks (Pardini et al., 2019; Amenta & van Timmeren, 2018).

Integrating urban planning, environmental policy, and governance, the study promotes whole-system smart urbanism and sustainable transformation. In addition, it expands CE theory beyond limitations such as digital divides, infrastructure gaps, and exclusion of informal labor (Shaban et al., 2020). This study shifts academic focus to context-specific and balanced models of sustainability, bottom-up innovations and informal actors at the core, instead of the margins. Future research should explore how these local models can be replicated, assess long-term impacts of policies like EPR and WtE, and enable comparative studies across Global South cities. Lastly, this study calls for an interdisciplinary, open-ended research agenda that rethinks circularity through the lens of informality, participation, and socio-economic conditions—offering a crucial gap in the literature.

Practical Implications

This research offers implementable solutions for integrating circular economy (CE) concepts into Indian smart cities, where 80% of municipal waste continues to be dumped in landfills and just 20–25% is actually recycled (CPCB, 2019; Sahoo et al., 2023). Indore's civic-led segregation and smart bins demonstrate how community action coupled with simple tech can power effective source-level sorting (Pardini et al., 2019). Ahmedabad's AI-powered waste sorting and route optimization optimize logistics (Shaban et al., 2020), whereas Delhi and Bengaluru's Waste-to-Energy (WtE) plants transform non-recyclables into usable energy, reducing landfill load (Shah et al., 2021). Decentralized composting systems deal with organic waste efficiently and support urban agriculture (Ddiba et al., 2021). Structuring and mainstreaming the informal economy—already treating most of the recyclables—through training, legal security, and health cover improves system performance and social equity (Amenta & van Timmeren, 2018). The activities create green jobs, public health improvement, and heightened citizen participation. Public-private partnerships (PPPs), learning from experiences like London, can deliver infrastructure while driving sustainability (Yigitcanlar & Kamruzzaman, 2015). Overall, this research prescribes a grounded, scalable waste management model that respects India's unique urban ecosystem—leveraging informal strengths, enabling circularity, and building Indian cities as replicable models for other Global South nations.

Conclusion and Future Outlook

In this research, the transformative power of circular economy thinking in solving waste management problems in Indian smart cities is identified to enable sustainable urban development. High waste quantities, low recycling rates (20–25%), and high landfill dependence (80%) due to consumption trends and urbanization characterize urban locations (Central Pollution Control Board, 2019; Sahoo et al., 2023). These are hindered by poor segregation, informal sector issues, lack of infrastructure, poor awareness, and poor policy enforcement, thus calling for transitioning towards circular systems (Cornea et al., 2017; Breukelman et al., 2019; Singh et al., 2018).

Circular solutions—source segregation, EPR, WtE technologies, and decentralized composting—are the solutions, supplemented by IoT and AI advancements (Pardini et al., 2019; Aceleanu et al., 2019; Shah et al., 2021). Regulation of the informal sector, policy enhancement, and public-private partnerships, supported by the Smart Cities Mission (2015), fill gaps, but urban-rural inequalities demand inclusive strategies (Amenta & van Timmeren, 2018; Yigitcanlar & Kamruzzaman, 2015; Butsch et al., 2017). They help cities minimize pollution, decrease health hazards, and provide employment, with the success of Indore showing the potential of localized innovation globally (Pardini et al., 2019).

Circular systems save money economically and create revenue. They reduce emissions and ensure cleaner ecosystems environmentally. Socially, they enhance the living of informal workers and address ethical aspects. Such effects make India an emerging circular waste management leader that helps build strong urban futures.

Limitations are secondary data dependence, restricting real-time inquiry, and varied city landscapes, restricting generalizability. The digital divide threatens uneven use of technology (Shaban et al., 2020). Primacy must be given to primary data gathering, cross-validate scalable models with smaller cities, and compare lasting effects of EPR and WtE. Scalable tech and inclusive policies to the marginal will maximize efficiency.

India's smart cities can lead the world standard to sustainability by embracing circular methods of working, calling for stringent policy implementation, technological innovation, and citizens' engagement. Firmed-up rules

and heightened cooperation are crucial to creating a sustainable, just urban habitat.

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Conflict of Interest

The authors declare no conflict of interest that could influence the publication of this article.

AI Disclosure

The authors confirm that no AI-based tools were utilized in conducting this research or writing the manuscript. All content is original and reflects the authors' own work.

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