Innovations

Transforming Waste: A Comprehensive Review of Innovations and Challenges in Municipal Solid Waste Management in India

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Abstract: *Municipal solid waste (MSW) management is a critical challenge for urban areas in India, including Odisha. Rapid urbanization, population growth, and changing consumption patterns have led to increased waste generation, necessitating effective management strategies. This review examines the current state of municipal solid waste (MSW) management in Odisha, India, highlighting the challenges and best practices associated with waste generation, collection, segregation, and treatment. With urban areas producing approximately 3,000 tons of waste daily, effective management is crucial to address the increasing environmental and health concerns. Key challenges include infrastructure deficiencies, financial constraints, and inadequate public awareness regarding proper waste disposal. However, promising initiatives such as public-private partnerships, community composting, and recycling programs demonstrate potential for improvement. The review emphasizes the need for enhanced source segregation, investment in infrastructure, stronger policy enforcement, and increased community engagement to foster sustainable waste management practices. By adopting a collaborative approach, Odisha can transform its waste management landscape and ensure a cleaner, healthier environment for its residents.*

Keywords: *Municipal solid waste, management, segregation, waste management, environment*

Introduction:

Municipal solid waste (MSW) management has emerged as a pressing issue in urban areas across India, particularly in rapidly growing states like Odisha. As cities

expand and populations increase, the volume and complexity of waste generated pose significant challenges to local authorities and communities. Odisha, with its diverse urban landscape and rising waste generation—estimated at around 3,000 tons daily—illustrates the critical need for effective waste management strategies.
The composition of waste in Odisha is predominantly organic, often exceeding 50%, alongside significant proportions of plastics, paper, metals, and glass. This varied composition complicates waste management efforts, particularly in terms of segregation and recycling. Despite the existence of regulatory frameworks, such as the Solid Waste Management Rules, 2016, implementation remains inconsistent, and many municipalities struggle with inadequate infrastructure, financial limitations, and low public awareness.
Public participation and engagement are crucial for successful waste management, yet many citizens lack knowledge about proper disposal practices and the importance of waste segregation. Addressing these challenges requires a multi-faceted approach that combines policy enforcement, community involvement, and investment in sustainable waste management infrastructure.
The choice of a waste treatment strategy is a highly debated topic in the literature and lies at the heart of municipal solid waste management (MSWM). Waste treatment options typically include land filling and Waste to Energy (WTE) technologies. Sustainability involves evaluating the environmental, economic, and social impacts of the various waste treatment alternatives within the framework of MSWM [Soltani, et al., 2016]. Achieving sustainable waste management goals necessitates minimizing waste generation, reusing and recycling materials, and recovering energy, all aimed at conserving resources for future use. Energy recovery from disposed waste can provide municipalities with energy, substitute fossil fuels in various industries, and contribute to the reduction of greenhouse gases (GHG) and other harmful air pollutants. A detailed overview of Waste to Energy (WTE) technologies, along with their advantages and disadvantages, is provided in Table 1.

Table 1. WTE technologies along with its advantages and dis-advantages

Technology	**Advantages**	**Disadvantages**
Thermal treatment incineration	• Ideal for municipal solid waste that has a high calorific value • Generates thermal energy for electricity production or direct heating • Produces minimal odors and operates with low noise levels • Requires a small footprint	• Not well-suited for municipal solid waste that has high moisture content and low calorific value • Produces ash and emissions, such as particulate matter, NOx, SOx, and chlorinated compounds, which can

	• Lowers transportation costs by facilitating construction close to urban centers • Ensures hygienic conditions	include toxic metals • Necessitates skilled workers for effective operation • Involves substantial capital, operational, and maintenance expenses • Overall efficiency is often low for smaller power generation facilities • Energy recovery may be limited due to the high moisture content in the waste
Biochemical conversion	• Enables energy recovery alongside the production of high-quality soil conditioner • Operates without power for turning waste piles or sieving • Enclosed systems effectively capture gases produced for utilization • Aids in reducing greenhouse gas emissions • Free from rodent infestations, unpleasant odors, fly issues, social resistance, and visible pollution • Requires minimal land area due to its compact design • Provides overall positive environmental impacts • Can be implemented on a smaller scale	• Inappropriate for waste that has minimal organic material • Segregation of waste is essential to improve digestion efficiency
Land filling	• Economical • The gas generated can be used for generating electricity or for direct heating • No specialized labor is needed	• Surface runoff can lead to pollution during rainfall • Leachate contaminates soil and groundwater • Only 30% to 40% of the total gas produced is recovered • Requires a substantial land

	• Replenishes natural resources in the soil and facilitates recycling • Can transform marshy land into productive areas	area • Incur high transportation costs • Significant expenses may be associated with pre-treatment to upgrade gas to pipeline quality and for leachate treatment • Risk of spontaneous explosion due to methane gas accumulation

Developing countries currently experience a significant energy deficit, with available energy falling short of growing demand. Worldwide, around 84% of energy needs are satisfied through fossil fuels. The over-reliance and depletion of fossil fuel sources—such as coal, oil, and natural gas—underscore the urgent need for alternative energy solutions. Waste to Energy (WTE) technologies provides a viable option to address potential energy shortages in the future [Ouda et al., 2016]. WTE facilities require less land compared to landfill sites handling the same amount of waste. As a result, WTE technologies serve as an efficient approach to waste management, generating energy in a manner that is both eco-friendly and economically feasible.

In a study, Udomsri et al., 2011evaluated the role of municipal solid waste (MSW) incineration in Thailand as a means to address climate change and advance biomass-based electricity generation. Their research indicated that incinerating MSW could mitigate the environmental impacts associated with waste disposal while also enhancing biomass energy production. Later, Akinci et al.,2012 studied waste disposal methods in the Aegean region of Turkey, specifically in Izmir, Kula, and Uşak, and provided a framework for future planning. They assessed methane production from the biodegradation of green waste in Izmir and explored composting practices in Kula and Uşak.

In another extensive study, Phillips and Mondal, 2014 focused on MSW disposal in India, presenting a mathematical framework for exploring sustainable options. Their findings highlighted gasification as a viable and sustainable MSW treatment method, offering significant benefits for both local communities and the environment. Afterwords, Hossain et al.2014 extended the investigation of various types of MSW and underscored the importance of incineration technology in reducing the need for additional landfill space while also generating energy. They pointed out that the low heating value and high moisture content of certain wastes present challenges for effective energy generation through incineration. In the similar way, Korai et al., 2017 examined the potential for energy production from MSW in Pakistan, noting that waste is often openly burned or dumped in low-lying areas due to inadequate disposal practices. Their study revealed that solid waste in Pakistan could generate up to 265 million m^3/year via thermo-chemical processes and 50.35 million m^3/year through biochemical methods.

A study by Xiaoping et al., 2018 proposed a planning framework for a carbon-constrained MSW management system using a hybrid approach in Qingdao, China. Korai et al., 2017 also developed an optimization framework for a case study in Abu Dhabi, aiming to identify the most effective processing routes to convert MSW into energy and value-added products. Their results indicated that an integrated approach could yield economic benefits by recycling recoverable components of MSW and producing bioethanol from the remaining waste through gasification and subsequent catalytic transformation (Jia et al., 2018; Hossain et al., 2014).

Evangelisti et al., 2015 reviewed modern waste management practices in the UK, excluding mass-burn incineration and land filling. They compared three advanced dual-stage Waste to Energy (WTE) technologies—gasification with plasma gas cleaning, fast pyrolysis, and gasification combined with syngas combustion—against existing practices like land filling and incineration in terms of their environmental impacts. Their analysis showed that the dual-stage gasification and plasma technique significantly outperformed traditional waste treatment methods and was more effective than contemporary incineration plants, such as one currently under commissioning in Lincolnshire.

The current state of solid waste management in India, highlighting how population growth, urbanization, and industrialization have led to increased rates of MSW generation, creating major environmental challenges [Gupta et al., 2015]. Subsequently, a case study was conducted in Hong Kong, developing a mathematical model for MSW management tailored to the Asian context. They stressed the necessity for such models to facilitate cost savings and informed decision-making for policymakers [Lee et al., 2016].

A study by Fernández-González et al., 2017 explored various dimensions—economic, environmental, and territorial—of converting MSW to WTE in southern Spain. They compared anaerobic digestion, the production of Solid Recovered Fuel (SRF), and gasification with existing Biological Mechanical Treatment (BMT) methods, including landfill disposal and incineration with energy recovery. Their findings indicated that anaerobic digestion is the most environmentally friendly option in regions with medium to low waste output. In terms of territory, thermal processes showed more favorable outcomes for WTE alternatives, as they create more jobs and have fewer environmental restrictions, making suitable locations more accessible. Nonetheless, anaerobic digestion remains the best treatment option for areas with lower waste production.

Qualitative and quantitative analysis of MSW in India:

Municipal Solid Waste (MSW) includes a variety of categories such as food scraps, general rubbish, waste from commercial and institutional sources, debris from street cleaning, industrial refuse, materials from construction and demolition, and sanitation-related waste. Within MSW, you can find items that are recyclable (like paper, plastics, glass, and metals), hazardous materials (including paints, pesticides, batteries, and pharmaceuticals), compostable organic matter (such as fruit and vegetable peels), and contaminated waste (like blood-stained items, sanitary products, and disposable syringes) (Jha et al., 2003; Reddy and Galab, 1998; Khan, 1994).

The amount of MSW generated is influenced by several factors, including dietary choices, living standards, levels of commercial activity, and seasonal variations. Tracking changes in waste quantity is essential for effective waste collection and disposal planning. In India, rapid urbanization and evolving lifestyles have resulted in cities producing eight times the amount of waste compared to 1947. Today, approximately 90 million tons of solid waste is generated annually from various sectors, with per capita waste expected to increase by 1-1.33% each year. This escalating issue highlights the urgent need for sustainable waste management practices and infrastructure to effectively handle the growing volumes of MSW (Pappu et al., 2007; Shekdar, 1999; Bhide and Shekdar, 1998). Research indicates that municipal solid waste (MSW) generation is generally lower in small towns compared to metropolitan cities. In India, the per capita generation of MSW varies between 0.2 to 0.5 kg per day.

In 1991, it was estimated that the urban population of 217 million produced around 23.86 million tons of MSW annually. By 2001, this figure had surged to over 39 million tons, reflecting a substantial increase in waste production alongside urban population growth. This upward trend emphasizes the urgent need for efficient waste management solutions, particularly in rapidly urbanizing areas, to mitigate the environmental consequences of rising waste generation (Siddiqui et al., 2006; Sharholy et al.,2005; Kansal, 2002; Singh and Singh, 1998; Kansal et al., 1998; Bhide and Shekdar, 1998; Dayal, 1994).

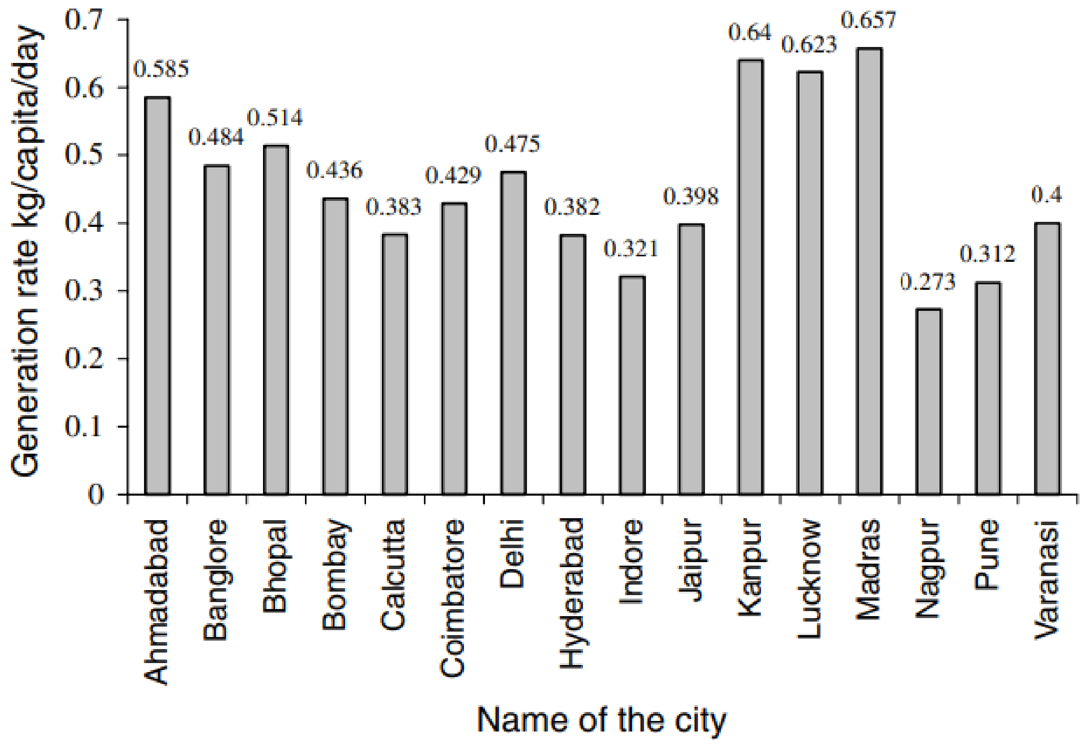

Fig.1 Per capita generation rate of MSW for Indian cities [CPCB 2004]

From Fig.1 it is reported that, in India, some states, including Gujarat, Delhi, and Tamil Nadu, as well as cities like Chennai, Kanpur, Lucknow, and Ahmedabad, show higher per capita rates of municipal solid waste (MSW) generation. This increase is likely linked to elevated living standards, rapid economic development, and high levels of urbanization in these areas.

On the other hand, states such as Meghalaya, Assam, Manipur, and Tripura, along with cities like Nagpur, Pune, and Indore, tend to have lower per capita MSW generation rates. This variation underscores the differences in socio-economic conditions and urban growth across various regions of the country.

Collection of MSW

The responsibility for collecting municipal solid waste (MSW) falls to local corporations and municipalities. Most cities rely on a system of communal bins placed along streets, which can sometimes lead to the formation of unauthorized open collection areas.

In a positive shift, several megacities, such as Delhi, Mumbai, Bangalore, Chennai, and Hyderabad, are beginning to adopt house-to-house collection methods, often with the assistance of NGOs. Additionally, many municipalities are hiring private contractors for the secondary transportation of waste from these communal bins to

disposal sites. Some have also enlisted NGOs and community committees to manage the segregation and collection of waste, ensuring it flows smoothly from the generation source to intermediate collection points before reaching dumpsites.
In certain neighbourhoods, welfare associations coordinate waste collection for a set monthly fee. Street sweepers are assigned specific areas, typically around 250 square meters, where they manually clean the streets. They collect waste in wheelbarrows and transport it to designated dustbins or collection points, contributing to the overall cleanliness of the urban environment (Colon and Fawcett, 2006; Nema, 2004; Malviya et al., 2002; Kansal et al., 1998; Bhide and Shekdar, 1998).
Effective municipal solid waste collection is essential for maintaining public health and promoting environmental sustainability. By fostering community engagement, implementing efficient systems, and adhering to regulations, we can significantly reduce waste and its impact on our surroundings. Together, we can create cleaner, healthier communities while moving towards a more sustainable future.

MSW disposal and treatment

Municipal solid waste (MSW) encompasses a wide variety of waste materials generated by households, commercial establishments, and institutions within a community. As urban populations grow and consumption patterns evolve, the volume of waste produced continues to rise, posing significant challenges for effective waste management. Proper disposal and treatment of MSW are critical not only for safeguarding public health but also for minimizing environmental impact.
Disposal and treatment methods for MSW vary widely, ranging from landfilling and incineration to recycling and composting. Each method has its own advantages and disadvantages, making it essential to adopt a comprehensive, integrated approach that considers the specific needs and characteristics of the community. Effective waste management not only mitigates pollution and health risks but also promotes resource recovery and sustainability.

Different method of disposal and treatment are:

- Land filling
- Recycling of organic waste
- Thermal treatment techniques of MSW
- Recovery of recyclable materials

In numerous urban areas, municipal solid waste (MSW) is commonly disposed of in low-lying regions beyond the city limits, often neglecting the essential guidelines of sanitary landfilling. Practices such as waste compaction, leveling, and proper soil coverage are seldom implemented. Consequently, these disposal sites usually lack vital infrastructure, including leachate collection systems and equipment for monitoring and collecting landfill gases. This inadequate management can lead to significant environmental problems, such as contamination of groundwater and air quality issues. Improving waste management practices is essential for protecting public health and the environment [Bhide and Shekdar, 1998; Gupta et al., 1998].

Conclusion:

The effective management of municipal solid waste (MSW) is crucial for urban health and environmental sustainability, particularly in rapidly urbanizing countries like India. The Municipal Solid Waste Management (MSWM) Rules established in 2000 provide a stringent regulatory framework aimed at addressing the complexities of waste management. However, significant gaps exist between these policies and their actual implementation. Challenges such as inadequate producer responsibility, lack of reliable data, insufficient resources, and weak community engagement hinder the effectiveness of current waste management systems. Addressing these issues is essential for creating a robust MSWM strategy that not only meets the demands of increasing waste generation but also promotes sustainable practices.

In light of these considerations, the following conclusions highlight key strategies for improving municipal solid waste management in India.

1. Strengthened Producer Responsibility: Enhance extended producer responsibility (EPR) to ensure manufacturers design products that are easier to recycle or dispose of sustainably.
2. Comprehensive Data Collection: Conduct updated surveys to characterize MSW generation across diverse regions, ensuring statistically reliable data for effective management.
3. Increased Resource Allocation: Address the lack of financial resources and infrastructure by boosting investments in waste management systems at the municipal level.
4. Capacity Building and Leadership: Invest in training and leadership development for municipal staff to improve policy implementation and service delivery.
5. Data-Driven Decision Making: Establish robust data collection and analysis systems to better understand waste patterns and optimize resource allocation.
6. Community Engagement: Foster public participation in waste management initiatives to improve compliance and reduce pressure on municipal services.
7. Public-Private Partnerships: Encourage collaboration between public authorities and private entities to drive innovation and efficiency in waste management operations.

8. Transition to Sustainable Practices: Move from open dumping to controlled disposal practices, focusing on sanitary landfilling and the promotion of composting and recycling.

By implementing these strategies, India can bridge the gap between policy and practice, leading to a more effective and sustainable municipal solid waste management system.

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