IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

# Towards Smarter Waste Management – A Survey on Novel Approaches, Technologies, and Challenges

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***Abstract:*** India's rapid economic growth has contributed to a significant increase in waste generation, posing serious challenges to environmental preservation and public well-being. This paper examines the problems, impacts, and solutions associated with the pressing need for effective waste management techniques. Currently, India generates approximately 62 million tonnes of solid waste annually, and projections indicate that this number could reach 165 million tonnes by 2030. However, only 70% of the waste produced is collected, and a mere 25% of the collected waste is properly treated, leading to environmental degradation and potential health risks. The primary objective of this paper is to analyze the complexities of waste management in India, highlighting the detrimental impacts of inadequate waste disposal practices. It explores the systemic problems, including insufficient waste collection and waste treatment infrastructure, limited public awareness, and weak regulatory frameworks. The paper also investigates the socioeconomic and environmental consequences of improper waste management, emphasizing the need for urgent action. Furthermore, the paper presents potential solutions and best practices to address the waste management challenges in India. It explores decentralized recycling units, improved coordination between stakeholders, and the utilization of innovative technologies. This paper underscores the importance of public awareness campaigns, sustainable financing, and strong regulatory frameworks to promote responsible waste management practices. Overall, this survey paper serves as a comprehensive resource, shedding light on the critical issues surrounding waste management in India. It offers valuable insights for researchers, policymakers, and practitioners, aiming to facilitate the adoption of effective waste management strategies that safeguard the environment and ensure the well-being of the population.

***Keywords*** **- Waste Management, Environmental Degradation, Public Awareness, Innovative Technologies**

## I. INTRODUCTION

India has experienced rapid economic growth, leading to a significant increase in waste generation, which necessitates urgent attention to proper waste management. This surge in waste poses environmental degradation and public health risks, becoming a critical concern for the government and society. Currently, India produces 62 million tonnes of solid waste annually, with projections indicating a rise to 165 million tonnes by 2030. Unfortunately, only about 70% of the waste is collected, and a mere 25% of the collected waste is treated, leaving the rest to be disposed of in landfills. Furthermore, predictions suggest that the volume of plastic in the ocean will double in the next 15 years, potentially surpassing the quantity of fish by 2050. To effectively address climate change, it is crucial to prioritize appropriate waste management practices, particularly focusing on plastic waste. Inadequate waste management techniques, such as open dumping, contribute to the release of greenhouse gases, exacerbating global warming. The substantial volume of waste generated, combined with a lack of accountability and transparency in waste management, has created a profitable industry for unscrupulous operators, further complicating waste management efforts.

While the Indian government has implemented initiatives and enforced regulations for effective waste management, the scale of the challenge makes efficient waste management difficult, despite these efforts. As a result, substantial community participation in trash management is required. Such involvement will raise awareness and educate individuals about the risks associated with poor waste management practices, including climate change, pollution, and the spread of infectious diseases. Additionally, it will highlight the benefits of waste recycling and promote the adoption of proper disposal habits. This paper aims to address the challenges faced by the government in managing solid waste in urban India by presenting a comprehensive analysis of problems, solutions, and opportunities. By exploring these aspects, the paper aims to contribute to the development of effective waste management strategies for India's urban areas.

The paper is constructed as follows: Section 2 explains the Motivation. Section 3 covers the Literature Review. Section 4 states the challenges and limitations of the current technologies and solutions. Section 5 outlines the conclusions, and Section 6 discusses future research.

## II. MOTIVATION

The motivation behind this survey paper lies in the urgent need to address the pressing challenges posed by waste management in India. The rapid economic growth experienced by the country has led to a significant escalation in waste generation, resulting in environmental degradation and risks to public health. Despite the implementation of initiatives and regulations by the government, effective waste management remains a daunting task due to the sheer volume of waste produced and the lack of accountability and transparency in the system. This paper aims to motivate and inspire change by exploring innovative solutions and opportunities for an end-to-end waste management model. By analyzing the problems, impacts, and potential solutions, this research seeks to shed light on the critical issues at hand and provide a comprehensive understanding of the current waste management landscape. Ultimately, the motivation is to contribute to the development of efficient, sustainable, and community-driven waste management practices that can mitigate environmental harm, improve public health, and pave the way for a cleaner and greener future.

The establishment of large hospitals where hundreds to thousands of patients are treated, it has created a serious problems of biomedical waste management. The seriousness of improper biomedical waste management was brought to the light during summer 1998. In India studies have been carried out at local / regional levels in various hospitals, indicate that roughly about 1-5 kg/bed/day to waste is generated. Among all health care personnel, ward boys, sweepers, operation theatre & laboratory attendants have come into contact with biomedical waste during the process of segregation, collection, transport, storage & final disposal. The knowledge of medical, paramedical staff & ward boys, sweepers about the biomedical waste management is important to improve the biomedical waste management practices. The biomedical waste requiring special attention includes those that are potentially infectious, sharps, example needle, scalpels, objects capable of puncturing the skin, also plastic, pharmaceutical & chemically hazardous substances used in laboratories etc.

## III. LITERATURE SURVEY

Several research studies and initiatives have been conducted on waste management, exploring various aspects of the subject.

### *A. Problems, Challenges, and Opportunities*

In research [2] (Joshi & Ahmed), a survey is given that focuses on the current situation of waste management practices in India. The authors outline systemic issues and suggested remedies. They see public awareness as a key concern and recommend teaching people about safe trash disposal practices and the harmful effects of using the wrong approaches. The inconvenient location of community bins is also acknowledged, and the authors advocate for decentralized recycling units to promote community participation. They emphasize the importance of recognizing the contributions of sweepers and rag pickers and propose involving the private sector to improve coordination between the State and Central government.

Another research article [3] addresses the challenges faced in waste management, including inadequate infrastructure, lack of education, insufficient resources and technologies, and weak regulatory frameworks. The research also identifies prospects for renewable energy, resource recovery, recycling, and employment development. Recommendations include treating waste as a valuable resource for increased value extraction and recycling, promoting sustainable financing, implementing strong regulation, encouraging waste segregation and education, establishing long-term planning, focusing on capacity building, and involving the informal sector. The responsibility of waste management lies with urban local bodies, which should prioritize it as an essential service. Furthermore, the authors stress the necessity of a robust and independent regulatory authority for fostering innovation and enforcement. They emphasize the importance of good waste management for India's long-term growth.

The research article [13] provides a complete assessment of the management of solid waste in India. The researchers examine legislative and institutional frameworks, as well as important concerns in solid waste management such as waste-to-energy conversion, greenhouse gas emissions, and health-related issues. Enhancing public awareness, developing clear laws and rules, encouraging ethical value systems, and using new tools such as artificial intelligence and machine learning for automated waste detection and sorting are among the recommendations. They propose implementing a circular economy-based framework for industrialized products and recycling to reduce greenhouse gas emissions. Additionally, actions such as reducing generated waste and managing harmful chemical disposal are proposed to alleviate health and environmental hazards.

According to research on sustainable e-waste management practices among young consumers in northwest China [4], there is a lack of knowledge among young consumers about the risks connected with e-waste and the necessity of sustainable e-waste management. The study found that gender, educational level, and income had a substantial impact on knowledge and engagement in sustainable e-waste management practices. Thus, the study emphasizes the need for tailored education and awareness programs targeting young consumers to promote sustainable e-waste management. The study emphasizes the significance of tackling e-waste management on a global level.

Furthermore, a study conducted in Nigeria [9] evaluates household awareness and participation in e-waste management. According to the data, most families are unaware of the dangers of e-waste to human health and the environment. The omission of e-waste management facilities and services in the region is also identified. However, households express their willingness to participate in

e-waste management programs if provided with adequate information and infrastructure. The study recommends the implementation of public education and awareness campaigns, as well as the establishment of e-waste collection centers in the area.

The authors of the study [10] analyze the current state of the management of municipal solid waste in Jaipur, India, and identify key challenges confronted by the city, including inadequate public participation, unregulated landfilling, and weak regulations. The authors propose various solutions to address these challenges, such as engaging the community in waste segregation practices, establishing waste-to-energy facilities, and promoting further research in the field. The authors of [11] stress the necessity of teaching people about waste management practices, particularly in developing countries where resources and awareness are limited. The paper highlights the primary challenges faced by such countries, such as insufficient infrastructure, and emphasizes the need for a multidisciplinary approach involving policymakers, educators, and community members. The authors recommend integrating waste management education into school curricula, fostering community engagement, and fostering partnerships to ensure effective implementation.

*B. Smart Waste Management Systems*

In a study conducted by the authors in [1], an IoT-based waste management system is proposed, utilizing infrared sensors to detect real-time fill levels of public bins, whether they have lids or not. The system includes a mobile application or website that displays the bin levels to users, aiming to reduce the frequency of waste collection, thereby saving time and costs. Additionally, the system allows residents to report any issues with the bins through the mobile application. The proposed system in [1] shows the potential in improving waste collection efficiency, reducing costs, and mitigating environmental impacts caused by waste. Another research article [5] introduces a waste management system for Malaysia that incorporates a smart waste collection box, a mobile application, and a central cloud server (Firebase). Ultrasonic sensors are utilized to monitor the garbage bin's real-time fill levels, and authorities are alerted through email when the bin reaches 80% full via the SMTP protocol, depicted in Fig. 1. The mobile application integrates GPS functionality to assist users in locating the nearest waste collection box and records the quantity of waste deposited, providing users with incentives in the form of points for proper waste disposal. The proposed waste management system in [5] exhibits the potential in enhancing waste collection efficiency and contributing to a cleaner environment.

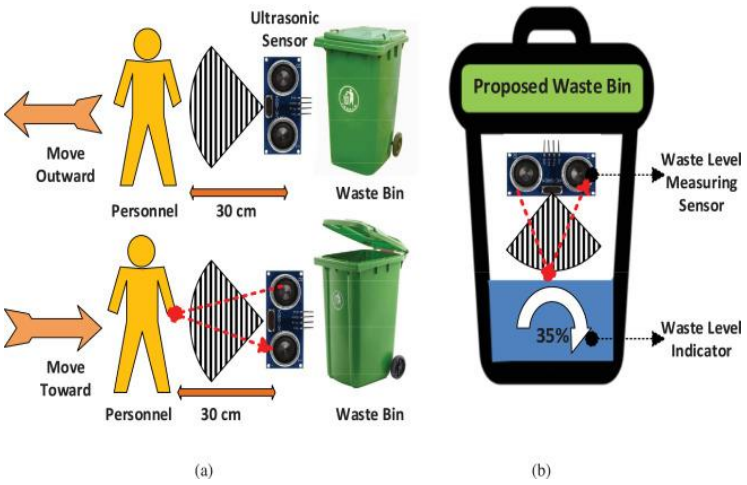


Fig. 1. IoT Based Smart Bin

In [6], the authors propose an IoT-based smart waste management system that emphasizes user engagement in waste management practices. The system includes a smart bin equipped with ultrasonic and infrared sensors to detect waste levels and alert users if waste is found outside the bin, respectively. Additionally, a mobile application called My Waste App is provided, enabling users to monitor real-time bin levels and report any waste dumps. The authors highlight the importance of involving users in waste management practices and propose incentivizing them through rewards and gamification. Their research provides useful information for scholars and practitioners interested in creating sustainable waste management systems that prioritize public participation. To address the challenges faced by conventional waste management methods in Bangladesh and improve waste collection efficiency, the authors in [12] propose a system that utilizes smart bins with microcontrollers and GSM modules to monitor real-time fill levels of public bins and notify authorities when the bins reach capacity. To meet user needs, the system recommends the use of low-cost ultrasonic sensors.

In [14], the authors present innovative solutions to enhance the municipal solid waste management system in Hong Kong. These solutions involve the adoption of a Reverse Vending Machine, smart bin technology, and route optimization algorithms. The Reverse Vending Machine is designed to collect plastic waste and offers rebates through e-payment methods. The smart bin technology incorporates sensors to monitor fill levels and optimize collection schedules, while the route optimization algorithm assists in efficient waste collection scheduling. The authors emphasize the need of promoting awareness and enforcing rigorous rubbish disposal legislation in order to maintain the long-term viability of Hong Kong's waste management system.

*C. Plastic Waste Recycling*

In [26], the authors explore the use of plastic as a feedstock for producing plastic crude oil, which can be further processed into diesel-range hydrocarbons. They employ various analytical techniques such as gas chromatography-mass spectroscopy, simulated

distillation, size exclusion chromatography, nuclear magnetic resonance, and Fourier-Transform infrared spectroscopy to characterize the chemical composition of the plastic oil fractions. Research article [27] focuses on different methods and processes for producing fuel from plastic, with an emphasis on process optimization. It investigates factors influencing conversion efficiency, energy and mass balance considerations, and kinetic studies to enhance understanding of the conversion process. The paper also includes an economic evaluation that considers the total cost of investment, return on investment (ROI), and overall feasibility of the process.

In [28], the authors present a two-stage pyrolysis-catalysis fixed bed reactor and examine the product yield and composition for different plastic types. They find that utilizing MCM-41 and ZSM-5 zeolite catalysts in a staged layered system is highly effective in producing a product oil with a high content of gasoline-range hydrocarbons. The working of pyrolysis is depicted in Fig. 2. The focus of paper [29] is on recycling fruit waste through fermentation to produce bio-enzymes for use as cleaning agents. The authors investigate the impact of various factors such as moisture content, pH, total carbohydrate content, reduced sugar content, and total protein content on the enzymatic process. Their analysis reveals that orange peels exhibit promising potential as a favorable source of enzymes compared to other investigated fruit waste materials.

In [30], the authors present a study on utilizing solar energy for fuel production through pyrolysis. They primarily focus on the theoretical aspects by incorporating thermodynamic equations. The study concludes that the LFR (Linear Fresnel Reflector) system shows promise as a solar pyrolysis reactor, offering advantages over conventional concentrating solar thermal systems. The comprehensive examination provided in the paper [31] explores various plastic types and their suitability for fuel production through thermal pyrolysis. The results indicate that the PS (polystyrene) category yields the highest output. However, caution is advised against pyrolysis of PVC (polyvinyl chloride) due to the release of highly toxic HCl (hydrochloric acid) fumes during the process.

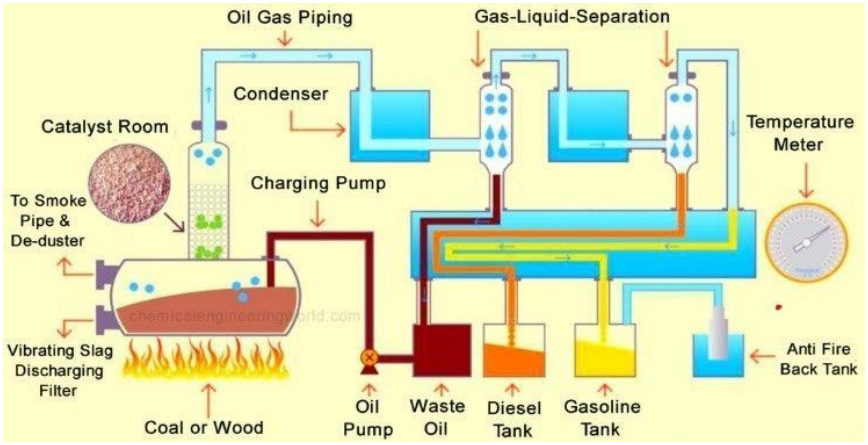


Fig. 2. Pyrolysis of Plastic Waste

The goal of [32] is twofold: to evaluate the performance of a plastic waste pyrolysis reactor and to construct a grid-connected solar photovoltaic (PV) power system to serve as a backup power source. In the paper [33], the authors address the significant challenges of plastic waste disposal and provide experimental details on plastic pyrolysis. They conclude that plastic pyrolysis holds tremendous potential for transforming plastic waste into fuel, offering significant economic and environmental advantages. The authors of [34] highlight the limitations of conventional pyrolysis processes, which involve high energy consumption and greenhouse gas emissions. They present a redesigned pyrolysis system that incorporates a solar energy-based pre-heating mechanism. The study demonstrates that the redesigned solar-based system significantly reduces fuel costs, energy consumption, and greenhouse gas emissions compared to traditional pyrolysis systems.

## IV. CHALLENGES AND LIMITATIONS

Despite the benefits offered by current technologies and solutions, there are several challenges and limitations that need to be addressed. These include:

1. Implementation and Infrastructure: Deploying smart waste management technologies requires significant investment in infrastructure, such as sensor installation, network connectivity, and data management systems. The initial setup costs and logistical challenges can pose barriers to widespread adoption, especially in areas with limited resources or outdated waste management infrastructure.
2. Compatibility and Interoperability: Integrating different smart waste management systems and technologies from various vendors can be complex due to compatibility issues. Ensuring seamless communication and data exchange between different components, such as sensors, mobile applications, and central servers, may require standardized protocols and interfaces.
3. Reliability and Maintenance: Smart waste management technologies heavily rely on sensors and IoT devices to collect real-time data. The reliability and durability of these devices can affect the accuracy and effectiveness of waste monitoring. Regular maintenance, sensor calibration, and battery replacements are necessary to ensure the continuous operation of the system.
4. Data Privacy and Security: Smart waste management systems collect and process large amounts of data, including fill levels, user information, and location data. Protecting this sensitive information from unauthorized access or data breaches is crucial. Implementing robust data privacy and security measures, such as encryption and access controls, is essential to maintain user trust and comply with data protection regulations.

5. User Adoption and Behavior Change: Encouraging residents and waste generators to actively participate in smart waste management practices requires a shift in behavior and mindset. Users may need to adapt to new waste disposal habits, interact with mobile applications, and embrace the concept of waste reduction and recycling. Overcoming resistance to change and promoting user adoption can be a significant challenge.

## V. CONCLUSION

This paper has explored the pressing issues surrounding waste management in the context of India's rapid economic growth and the subsequent rise in waste generation. The findings indicate that the current waste management practices are inadequate, leading to environmental degradation and risks to public health. The statistics revealing the volume of solid waste produced and the projected increase in the coming years emphasize the urgency for effective waste management strategies. Through an examination of various problems, impacts, and solutions, this paper has shed light on the need for a comprehensive and innovative End-to-End Waste Management system for urban India. This system must encompass key phases of waste management, including waste collection, segregation, and recycling, along with active community participation and the utilization of smart technologies. Moreover, this survey has underscored the significance of prioritizing appropriate waste management practices, particularly in relation to plastic waste, to address climate change and reduce greenhouse gas emissions. The involvement of all stakeholders, including the government, communities, and individuals, is vital in raising awareness, promoting behavioral change, and fostering sustainable waste management habits.

While the governments have implemented initiatives and regulations, challenges still persist due to the scale of the waste management problem. It is essential to enhance accountability, transparency, and enforcement measures to ensure the effective implementation of waste management strategies. In conclusion, this survey paper highlights the need for continued research and innovation in waste management practices, emphasizing the importance of sustainable solutions, community engagement, and technological advancements.

## VI. FUTURE ADVANCEMENTS

This paper provides a comprehensive overview of waste management technologies and their challenges. Based on the findings and analysis, the following future advancements can be considered:

1. Integration of Artificial Intelligence: Incorporating AI techniques such as machine learning and data analytics can enhance the efficiency and accuracy of waste management systems. AI algorithms can be used to enhance decision-making processes by anticipating fill levels, streamlining garbage collection routes, and finding patterns.
2. Blockchain Technology for Transparency: Implementing blockchain technology can bring transparency and accountability to waste management processes. It can facilitate the traceability of waste from generation to disposal, ensuring proper handling and promoting responsible waste management practices.
3. Internet of Things (IoT) Expansion: Expanding the use of IoT devices and sensors can further improve real-time monitoring of waste fill levels, temperature, and other relevant parameters. This can enable more precise waste collection scheduling, reduce operational costs, and enhance overall system efficiency.
4. Circular Economy Approaches: Putting a focus on the Circular Economy's principles can help with sustainable waste management. This involves promoting waste reduction, recycling, and resource recovery to minimize waste generation and maximize the value extracted from waste materials.
5. Public awareness and knowledge: It's important to educate and raise public knowledge about good waste management practices. Initiatives like community outreach programs, awareness campaigns, and educational resources can foster behavioral changes and encourage active participation in waste management.
6. Collaboration and Partnerships: Strengthening collaboration between government bodies, waste management agencies, private sectors, and research institutions can drive innovation and facilitate the implementation of effective waste management solutions. Sharing best practices, knowledge exchange, and joint initiatives can accelerate progress in this field.

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