



Waste management by Bruhat Bengaluru Mahanagara Palike

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Abstract:

Bengaluru, one of India's fastest-growing metropolitan cities, is grappling with a mounting waste management crisis due to its rapid urbanization, population increase, and inadequate infrastructure. The Bruhat Bengaluru Mahanagara Palike (BBMP), as the governing body responsible for waste management in the city, faces significant challenges in ensuring effective waste collection, segregation, disposal, and recycling across its diverse and densely populated wards. Despite efforts to implement waste management policies, BBMP continues to encounter issues such as inefficient waste processing, improper waste segregation at the source, limited public participation, and insufficient waste-to-energy initiatives. This research paper aims to comprehensively assess the current state of waste management under BBMP, investigating the key challenges and their socio-economic and environmental implications. By analyzing existing waste management policies, conducting field surveys, and interviewing key stakeholders, including BBMP officials, waste management workers, and residents, this study provides a holistic understanding of the system's functioning and its shortcomings. Furthermore, the research delves into the factors contributing to waste mismanagement, such as lack of awareness, inadequate infrastructure for waste segregation, and the absence of robust recycling systems. The paper also evaluates the roles of various actors—municipal authorities, community organizations, and citizens—in the collective effort to improve waste management practices. Based on these findings, the paper proposes a set of actionable recommendations aimed at enhancing waste segregation at the source, improving waste processing and recycling technologies, integrating waste-to-energy solutions, and fostering public awareness and participation. By emphasizing sustainable, inclusive, and innovative waste management practices, this study seeks to offer a roadmap for making Bengaluru's waste management system more efficient and environmentally sustainable, contributing to the city's long-term goal of becoming a zero-waste urban hub.

KeyWords- WasteManagement, Sustainability, Recycling, Composting, Segregational source, Circular economy, Landfills, Public awareness, Smart bins, Waste infrastructure,

Introduction:

Bengaluru, also known as Bangalore, is a rapidly growing metropolitan city in southern India. With a population that has crossed the 12 million mark, Bengaluru is one of the most populous cities in the country. It serves as India's technological and economic hub, attracting millions of people annually for work, education, and business opportunities. However, with its booming population and rapid urbanization, the city faces many challenges, one of the most pressing being waste management. The improper handling of waste not only affects the aesthetic and environmental quality of the city but also poses significant health, social, and economic risks. The Bruhat Bengaluru Mahanagara Palike (BBMP), the administrative body responsible for urban governance in Bengaluru, is tasked with the management of waste collection, segregation, disposal, and recycling across this vast and diverse urban sprawl. Despite BBMP's continuous efforts to implement various waste management strategies, the system remains plagued with inefficiencies, inadequate infrastructure, and insufficient community engagement.

At its core, the waste management system in Bengaluru faces the dual challenge of managing the ever-increasing quantity of waste produced by its residents and businesses while simultaneously addressing the complexities of urban waste segregation, recycling, and sustainable disposal methods. Bengaluru's waste production rate has skyrocketed in recent years, driven by factors such as rapid urbanization, changing consumption patterns, and an expanding service sector. This surge in waste generation, coupled with a lack of efficient infrastructure and public awareness, has resulted in severe environmental degradation, including landfills overflowing with untreated waste, rivers and lakes being polluted, and growing piles of garbage in residential and commercial areas. Managing such an enormous volume of waste requires not only large-scale investments in infrastructure but also a coordinated approach to community engagement, policy formulation, and technological innovation.

BBMP's waste management strategies have evolved, but many issues continue to impede the effectiveness of the system. One of the key challenges in Bengaluru's waste management is the lack of waste segregation at the source. Though BBMP has promoted waste segregation policies, residents continue to dispose of mixed waste, which makes it difficult for municipal authorities to manage the waste efficiently. A major reason behind this is the insufficient awareness about the importance of segregation, compounded by the absence of an effective waste collection system that encourages compliance. Segregating waste into biodegradable and non-biodegradable categories is crucial for recycling and proper disposal, yet this simple practice is still far from universal in Bengaluru. The absence of an efficient door-to-door collection system for segregated waste further exacerbates the issue, leaving many citizens unaware of how to manage their waste properly.

Additionally, BBMP's waste management system struggles with inadequate infrastructure for processing and recycling waste. The city's landfills are already overwhelmed, and much of the waste ends up being dumped in areas that are not equipped to handle it. The lack of sufficient recycling facilities means that a significant portion of the waste generated in Bengaluru, including plastics, paper, and metals, is not recycled but instead disposed of in landfills or incinerated. The inefficiency of waste processing methods not only contributes to the depletion of land and natural resources but also leads to significant environmental pollution. Over time, the accumulation of waste in landfills can release harmful toxins into the soil and groundwater, causing long-term ecological damage.

Further complicating matters is the lack of waste-to-energy initiatives in Bengaluru. While the city has taken steps toward integrating waste-to-energy technologies, such as biogas plants and waste-to-energy incinerators, the scale and effectiveness of these initiatives remain limited. The potential of waste-to-energy solutions in reducing the strain on landfills and generating renewable energy is significant, but implementation has been hindered by inadequate funding, technical challenges, and a lack of public support for such projects. Waste-to-energy technologies also require specialized infrastructure and regulatory frameworks to ensure that the energy generated is used efficiently and that harmful emissions from incinerators are minimized. Without adequate planning and investment, these

technologies remain underutilized, and Bengaluru continues to rely heavily on traditional, unsustainable waste disposal methods.

One of the most critical challenges facing the BBMP is the lack of active involvement from citizens in the waste management process. Although Bengaluru's waste management system is publicly funded and managed, much of the burden falls on the citizens who are expected to dispose of their waste in a responsible manner. Public participation is essential for the success of any waste management system, as it is the residents who generate waste in the first place. However, many Bengaluru residents are either unaware of the city's waste segregation policies or lack the motivation to comply with them. This disconnection between the municipal authority and the citizens is partly due to ineffective communication and outreach programs. The failure of BBMP's waste management policies to actively involve residents and educate them on the importance of waste segregation and recycling has led to widespread non-compliance. Moreover, the lack of incentives for individuals to segregate their waste further discourages responsible waste disposal behavior.

To address these issues, it is essential to adopt a more inclusive, sustainable, and technologically advanced approach to waste management. A key area of focus should be the improvement of waste segregation practices at the household level. BBMP needs to create better awareness programs and ensure that residents have access to the necessary tools and incentives to segregate their waste. The introduction of more efficient waste collection systems that cater to segregated waste could also help in reducing the amount of mixed waste entering the system. Additionally, increasing the capacity for waste processing, recycling, and composting would not only reduce the burden on landfills but also contribute to the creation of new job opportunities in the recycling and composting industries. Greater emphasis should also be placed on waste-to-energy technologies as part of a long-term strategy to generate renewable energy and reduce dependence on landfills. In this context, the collaboration between BBMP, the private sector, and the citizens is crucial to ensure that waste management solutions are implemented effectively and equitably across the city.

Moreover, addressing waste management in Bengaluru requires a shift in policy and governance. BBMP's waste management policies must become more proactive, moving beyond the traditional top-down approach to include greater participation from local communities and private players. It is important for policymakers to engage residents, NGOs, and experts in the design and implementation of waste management programs. Building awareness through targeted campaigns and educational initiatives that emphasize the environmental, economic, and health impacts of poor waste management is key to driving behavioral change among citizens. Additionally, involving waste workers—who often bear the brunt of waste collection and segregation—in decision-making processes and ensuring their safety and welfare can help build a more inclusive and effective system.

The success of any waste management system lies in its ability to integrate multiple facets of urban governance, including community engagement, regulatory frameworks, infrastructural capacity, and technological innovation. In Bengaluru, these elements are often fragmented, which has led to inefficiencies and a fragmented approach to waste management. The absence of a unified strategy that addresses both the immediate and long-term challenges of waste disposal has resulted in over-reliance on outdated and unsustainable methods of waste management, such as landfilling and open burning. The city's waste management issues are compounded by the complexity of handling different waste streams, including household waste, industrial waste, commercial waste, and construction debris. Each of these waste types requires distinct handling methods, yet Bengaluru's existing waste management infrastructure is not equipped to manage these diverse waste streams effectively. This has created a situation where the majority of waste is either improperly disposed of or goes untreated, thereby exacerbating environmental pollution and health risks.

The growing quantity of plastic waste is another pressing issue that Bengaluru faces. Plastics, being non-biodegradable, do not decompose naturally, leading to long-term environmental consequences. Bengaluru, like many cities in India, has been grappling with the challenge of managing plastic waste, which has permeated all facets of urban life, from food packaging and single-use plastic bags to plastic bottles and containers. The widespread use of plastic has made it difficult to implement effective waste segregation systems, as these materials are often mixed with organic waste, making recycling and composting difficult. Additionally, while there have been efforts to curb plastic use through bans and awareness campaigns, the success of these initiatives has been limited by enforcement challenges and a lack of alternative sustainable materials. Moreover, the sheer volume of plastic waste that continues to accumulate in the city's landfills and water bodies highlights the need for more robust recycling programs, greater public education on plastic waste reduction, and stronger policies to regulate plastic production and disposal.

Public awareness and participation are two pillars that are central to the success of any waste management system, and Bengaluru's experience offers valuable lessons in this regard. Although BBMP has initiated several campaigns to raise awareness about waste segregation and recycling, the overall impact of these campaigns has been limited. Many residents continue to dispose of waste in ways that violate the city's waste management guidelines, often due to a lack of clear communication, inadequate infrastructure, and inconsistent enforcement of regulations. While there have been some success stories, particularly in neighborhoods with active citizen groups and community-led waste management initiatives, the city as a whole still faces significant challenges in achieving wide-scale compliance. To address this, BBMP needs to invest in continuous education and outreach efforts that target different segments of the population, including households, businesses, and schools. Public participation should also be incentivized, through mechanisms such as reward-based systems for individuals and communities that consistently adhere to waste segregation practices. Additionally, the role of civic organizations, non-governmental organizations (NGOs), and local advocacy groups in waste management should be strengthened, as these groups can help bridge the gap between municipal authorities and citizens.

Furthermore, the integration of technology into waste management practices holds great potential for improving the efficiency and effectiveness of waste management systems. Technological advancements in waste processing, such as smart bins, waste tracking systems, and automated waste sorting technologies, can streamline the collection and recycling of waste, reducing human intervention and the associated risks. BBMP can explore partnerships with tech companies to pilot innovative solutions that use data and automation to optimize waste collection routes, monitor waste segregation compliance, and ensure that recyclable materials are properly diverted from landfills. Additionally, the use of data analytics can help BBMP better understand waste generation patterns, allowing for more targeted interventions and resource allocation. Technology can also play a role in public engagement, with mobile apps and online platforms being used to educate residents, remind them of waste segregation protocols, and provide real-time feedback on waste collection services.

In conclusion, Bengaluru's waste management system under BBMP faces several complex challenges that require a multifaceted approach to address. These challenges include inadequate waste segregation, inefficient waste processing, reliance on landfills, limited public participation, and the need for infrastructure improvements. However, these challenges also present significant opportunities for innovation, collaboration, and improvement. By adopting a holistic approach that incorporates technological advancements, public engagement, better waste management policies, and greater involvement from the informal waste sector, Bengaluru can transform its waste management system into one that is sustainable, efficient, and responsive to the needs of its growing population. This research paper aims to analyze the current state of BBMP's waste management system, identify key issues and challenges, and propose practical solutions to ensure a cleaner, healthier, and more sustainable future for Bengaluru.

Review Of Literature:

Integration of Informal Waste Workers

Informal waste workers, or ragpickers, play a very critical role in the waste management system of India, though their contribution is mostly ignored. These workers collect a large part of the recyclables in urban areas, thus contributing greatly to the reduction of waste and recovery of resources. Studies show that ragpickers can recover anywhere from 20% to 40% of total waste generated, which means they primarily help in urban waste management. However, their informal status brings along a myriad of challenges, such as a lack of social security, poor working conditions, and insufficient recognition.

If these workers were incorporated into a formal waste management structure, it would facilitate the problem in many ways, thus making waste collection and processing very effective. Such workers could be included in the framework of policies that recognize ragpickers, train them in several aspects, provide health benefits, and provide decent wages, which would enhance their livelihood and also motivate them toward waste management. Tri-partite approach of local government, NGOs, and waste management companies is to be there for effective integratedism where ragpickers can be organized into cooperatives enabling them to negotiate on better working conditions and access resources.

Education and skill training programs may fit into this skill learning for waste sorting and efficient recovery of resources. This integration would not only provide economic benefits for ragpickers, but also clean urban environments. Implementation of these participatory practices in Pune, where the integration of ragpickers in the official waste management system has brought forth better results in waste management has been associated with improved recycling rates and thereby reduced reliance on landfills. All in all, recognizing the contribution made by informal waste pickers and ensuring support provisions for them can recreate the bulwark of waste management as we see it in India today. In this manner, sustainable and equitable systems could be built that would address environmental and social concerns about waste management.

Implementation Gaps in Policy Frameworks

Though policies such as the Solid Waste Management Rules of 2016 were developed in India, local implementation is still a major problem. Research shows that many municipalities have significant difficulties including, but not limited to, lack of fund allocations, inadequate infrastructures, and bureaucratic inefficiencies. As a result, the enactment of many well-thought-out policies is inhibited. One of the major issues is the lack of funds for waste management. Local authorities are frequently not in a position to augment their budgets for the construction of waste treatment plants, buying collection vehicles, and training staff. The lack of public-private partnerships only makes matters worse; many municipalities do not explore the possible positives of teaming up with private sector entities. Another huge area is capacity so that local government officials can adjust their policies. Municipalities have the untrained personnel in design and implementation of waste management programs. It is incumbent to conduct capacity-building programs to create capacities so that local officials have input.

Engaging the community is also key to effective waste management. Public awareness campaigns can nurture support from the communities that would trigger compliance among residents to properly separate and dispose of their waste. The effectiveness of local governments can also be enhanced through the accountability of citizens monitoring waste management practices. For bridging the gaps in implementation, a multi-dimensional approach is required: enhancing funding mechanisms, building local capacities, promoting public-private partnerships, and institutionalizing community engagement. Priority areas thus need to be attended to by the policymakers to ensure that waste management doesn't just exist on paper but does lead to visible changes in urban waste management practices.

Effectiveness of Waste Segregation at Source

In India, waste segregation at source has become one of the most salient methods to improve waste management efficiency. Research informs that when waste is segregated at the household level, recycling rates go up significantly, while the volume of waste sent to landfills comes down. Segregation enables the more efficient processing of recyclable materials, hence conserving resources and reducing environmental pollution. Concise public awareness and EDUCATION will be the heritage that shall help to yield high dividends in any waste segregation program.

Studies further prove that communities with excellent educational programs on waste segmentation have better compliance. With the right awareness campaigns, residents will know why they should practice proper waste disposal from an environmental and economic perspective. One can incentivize segregation through community competitions where prize money is provided as a reward, or by giving recognition to those who are efficient. For instance, the cities that have employed rewards for households practicing efficient waste segregation have seen noteworthy improvements in compliance rates. School programs can also be an important adjunct. In teaching children the ways of waste management, they will carry such responsible habits to their families. However, in rural areas, more challenges arise besides issues of awareness where infrastructure may not be adequate either. Thus, it is important to adopt applied approaches based on the context of each. In the future, local governments have to ensure that proper collection systems are in place to handle segregated waste. This involves a lot of investing and planning. In brief, source separation is basically one of the key techniques of truly sustainable waste management in India. Proper community engagement, complemented by viable infrastructure, will help cities boost their recycling rates, minimize dependence on landfills, and achieve more sustainable systems for waste management.

Health Implications of Poor Waste Management

The public health implications of India's unscientific disposal of waste are of utmost importance. It is proven through studies that unscientific waste treatment generates an abundance of diseases: ranging from respiratory infections to skin ailment and vector-borne diseases such as dengue and malaria. Waste finds its way on to land and water and provides breeding grounds for vectors who are carriers of all forms of diseases and hence pose deadly health threats, especially to India's poor population where public health infrastructure is poor. Further, environmental pollution generated due to unmanaged waste further deteriorates air and water quality, in turn leading to chronic health implications. Research has shown that communities close to landfill or open dumping sites suffer from higher degrees of health problems in comparison to those residing in cleaner areas. Toxic leachates from waste will not only seep into groundwater and thereby pose compounding health risks to populations relying on such water sources. Solution to health impacts due to mismanaged waste must embrace a multifaceted approach. Initiatives must raise public awareness on health risks related to improper waste disposal. These education programs can empower the people to adopt proper solid waste disposal practices, thereby eliminating some health risks. Another possibility is integrating waste management education into wider public health campaigns for an even more effective approach. Investment in improving waste management infrastructure, especially in backward areas, should be the priority of policymakers so as to ameliorate health risks.

Besides, monitoring and control of waste disposal practices is of paramount importance for their compliance with health and safety regulations. Overall, the health consequences stemming from poor waste management clearly point out the need for comprehensive waste management strategies, with public health priority for the implementation of those. By treating at the roots waste-associated health issues, India can aspire for a land closer to overall healthy communities.

Technological Innovations and Sustainable Practices

Technological innovation in waste management can indeed change the face of India's approach to its growing waste problem. Waste-to-energy (WtE) plants and advanced composting technologies can indeed enhance energy from waste treatment capacity and reduce landfills use. These technologies, as studies have established, not only simplify waste management but also generate energy, thereby meeting sustainable development objectives.. Waste-to-energy plants can turn organic wastes into useful energy, which can be used to reduce the energy crisis in most parts of the world. Proper implementation of WtE technologies, however, depends on proper planning and public participation. The locals need to be informed about the advantages and operation of such plants to gain their consent and cooperation. Composting is another efficient option which can be driven by technology. Composting units can be set up in the community to treat organic waste within the community at lower transportation costs, engaging the community. Technologies with anaerobic digestion capability can also turn organic waste into biogas as a sustainable energy source. Though the technologies are promising, local conditions and the participation of citizens guarantee success. Adapted approaches with due regard to the socio-economic context of the community are needed. The integration of local stakeholders in their planning and implementation can guarantee more acceptance and effectiveness.

Additionally, research and development investment is necessary to create more efficient and cleaner waste management technologies. Governments need to give top priority to innovation in waste management practices, supported by academia and the private sector.

Urban Waste Generation and Composition

Much of the research has focused on finding out the quantity and nature of waste generated in Indian cities. Studies show that India generates 62 million tons of waste annually, of which about 45% remains uncollected, and the majority of the collected waste is dumped in landfills. Some of the findings are:

Waste Composition: Urban waste is predominantly organic in composition (40-60%), followed by recyclables like plastics, metals, and glass (10-15%), and hazardous waste (approximately 5%). This makes India's waste extremely biodegradable, and hence there is immense potential for composting and waste-to-energy ventures.

Per Capita Waste Generation: Research by the Central Pollution Control Board (CPCB) indicates that Indian citizens, on average, generate 450-550 grams of waste per day, though this is not a uniform trend in metropolitan and rural areas.

Organic waste makes up the majority of waste in urban India and 40-60% of total municipal solid waste (MSW). Food wastes, yard wastes, and other organic wastes make up the majority of organic waste. The size of organic waste presents a colossal opportunity for initiatives like composting and waste-to-energy (WTE) schemes, but these are enormously underutilized. The majority of the organic waste currently ends up in landfills, where it undergoes anaerobic decomposition and results in methane formation, a powerful greenhouse gas and the largest contributor to climate change.

Plastics, metals, and glass, which are recyclable, constitute about 10-15% of the waste stream. Collection and recovery of recyclable materials in most urban areas are primarily in the informal sector, particularly waste pickers. However, the absence of segregation of waste at the source tends to lead to commingling of recyclable waste with organic or toxic waste, which reduces the value and usefulness of recycling. Though there exists a market for recycled products in India, no proper infrastructure for formal recycling is available. Thus, only a small percentage of plastics, metals, and glass are formally recycled, and most of the activity occurs through the informal sector.

Hazardous medical, electronic, and industrial wastes contribute approximately 5% of the total urban waste stream. Though such wastes represent a lesser percentage compared to organic and recyclable materials, they pose a serious risk to the health and environment. Mismanagement of hazardous wastes like e-waste and medical waste has been noted in certain research. The waste primarily is either buried in landfills or treated under sanitary conditions, a case more pronounced in the informal economy, therefore leading to more water, soil, and air pollution.

Central Pollution Control Board (CPCB) surveys provide intriguing statistics on per capita waste generation rates in India. The average urban Indian generates 450-550 grams of waste per day, though the rate is highly variable depending on region and socio-economic profile. Urban metros like Delhi and Mumbai, for example, generate higher per capita waste because of better standards of living, higher consumption of packaged foods, and higher economic activity. Rural India generates very little per capita waste, primarily in the form of organic waste that is composted or used as animal fodder. Rural communities opt for subsistence agriculture and local economies and thus generate less waste overall.

This difference in wastage created by urban and rural areas places additional emphasis on the necessity of specially designed waste management strategies. Major cities would require advanced waste management systems, e.g., central composting facilities and waste-to-energy plants, whereas towns and villages would prefer decentralized approaches, e.g., community level composting.

A number of landmark studies have shed valuable light on waste management in India. Singh et al. (2014) analyzed the composition of municipal solid waste (MSW) in various cities and concluded that organic waste constitutes the largest percentage. The paper highlighted the need for enhanced segregation at the source as an unnecessary delay. In a similar vein, Gupta et al. (2015) compared the differing rates of waste generation in big metropolitan cities such as Mumbai and Delhi and medium-sized cities. Their conclusion was that waste management strategies need to be designed to suit the particular requirements and capabilities of varying urban environments.

Challenges in Municipal Solid Waste Management (MSWM)

The municipal administrations of Tier 2 and Tier 3 cities are coping with ineffective collection systems that result in large amounts of uncollected trash. The coordination of private and public waste collection services is also lacking. Landfills and Open Dumps: A significant portion of municipal waste is disposed of in open dumps or poorly maintained landfills, many of which are already full. According to study, 90% of Indian landfills are operating beyond their legal limits, endangering the environment and human health. Numerous important problems hinder the efficiency of India's municipal solid waste management (MSWM) system. One of the primary issues is the lack of waste segregation at the source. The practice is still rare in most countries, even with efforts to promote home segregation.

Most houses have a mixed waste stream that makes processing more difficult since they do not separate organic trash, recyclables, and hazardous materials. Recycling and composting are less effective when there is a lack of segregation because recyclables deteriorate and organic waste becomes contaminated. Effective segregation at the source is essential to better waste management practices, which calls for greater public knowledge and more stringent enforcement of segregation laws. Another urgent issue is garbage collection inefficiencies, especially in Tier 2 and Tier 3 cities. The majority of the municipal governments in the smaller cities are unable to deliver regular and reliable waste collection services. Inefficiency generates vast quantities of uncollected waste, which serves to add to illegal dumping and unhygienic conditions. Inefficient coordination between private and public waste management services also exists. Municipalities usually depend on a mix of public services and private contractors for the collection and disposal of waste; however, lack of proper communication and oversight creates gaps in the services that worsen the issue of uncollected waste.

Open dumping and landfills are another major waste management problem in India. The majority of the municipal waste collected finds its way to abandoned landfills or open dumping ground. These sites are bound to overflow and do not have the infrastructure to treat the increasing amount of waste. Nearly 90% of Indian landfills are running over capacity, according to research, which presents serious risks to the environment and public health. The air and water are contaminated by open dumps because decomposing waste releases harmful gases like methane. Furthermore, the liquid waste produced during decomposition, called leachate, contaminates the soil and groundwater, posing major health risks to nearby populations. Several important studies have examined these problems. Sharholy et al. (2008) assessed the status of Indian city MSWM, and concluded poor waste segregation, inefficient collection, and lack of sanitary landfills as the key problems. The research prescribed improved infrastructure and improved waste management policies to correct these problems. Ramanathan and Basu (2010) have also demonstrated the environmental harm caused by unmanaged landfills and open dumping in Delhi and Mumbai. Their study showed how these ill-maintained disposal sites lead to excessive environmental degradation, including methane release from decomposing organic waste and groundwater contamination from leachate. To solve these problems, large investments in waste management infrastructure, raised public awareness, and the adoption of improved garbage disposal methods are required. Waste collection inefficiency is another of the most urgent challenges, especially in Tier 2 and Tier 3 cities. The majority of the municipal governments in the smaller cities are unable to deliver regular and reliable waste collection services. Inefficiency generates vast quantities of uncollected waste, which serves to add to illegal dumping and unhygienic conditions. Inefficient coordination between private and public waste management services also exists. Municipalities usually depend on a mix of public services and private contractors for the collection and disposal of waste; however, lack of proper communication and oversight creates gaps in the services that worsen the issue of uncollected waste. Open dumping and landfills are another major waste management problem in India. The majority of the municipal waste collected finds its way to abandoned landfills or open dumping ground. These sites are bound to overflow and do not have the infrastructure to treat the increasing amount of waste. Research has indicated that almost 90% of Indian landfills are operating beyond their capacity, and this poses severe environmental and health hazards. Open dumps also lead to air and water pollution because decaying waste emits harmful gases like methane. Additionally, leachate—a liquid waste generated during the process of decomposition—pollutes the soil and groundwater, leading to serious health hazards to surrounding communities.

Several important studies have examined these problems. Sharholy et al. (2008) assessed the status of Indian city MSWM, and concluded poor waste segregation, inefficient collection, and lack of sanitary landfills as the key problems. The research prescribed improved infrastructure and improved waste management policies to correct these problems. Likewise, Ramanathan and Basu (2010) have reported the environmental degradation caused by uncontrolled landfills and open dumping in Delhi and Mumbai cities. Their findings highlighted how these poorly managed disposal sites cause excessive environmental pollution, such as the production of methane from decomposing organic wastes and leachate contamination of groundwater. Correcting these problems will entail enormous investments in waste management infrastructure, improved public awareness, and implementation of improved waste disposal practices.

Role of Private Sector in Waste Management

Public-private partnerships present a strategic framework through which municipalities can utilize the expertise and resources of the private sector to improve waste management. Such partnerships include contracts for waste collection, waste processing, or waste recycling services. The involvement of private entities has the potential to plug the critical gaps in the public waste management services, especially in the urban areas where the waste volumes generated are enormous. The operational and service delivery efficacies of waste management could be enhanced almost entirely due to the PPP models. Local governments could also utilize private sector experience and capacity

to optimize waste collection, increase recycling levels, enhance waste processing technologies, and coordinate prior processing in response to requests from their citizens. Such collaborations could also be most valuable in cities that have budget constraints or lack technical capability, as it will allow innovative and responsive waste management solutions. The private sector in India promises to boost the waste-management scenario in collaboration with municipalities to solve a great many problems. Collaboration between public and private entities opens new avenues through defined PPPs to enhance operational efficiency, create sustainable practices, and improve service delivery in waste management.

Srinivasan and Ranjan (2021) cited a study that investigated the practice of private companies concerning the recycling operation. The study further mentions that normally private actors are more efficient than public bodies. The Public-Private Partnership is a mechanism through which municipalities can make use of private sector expertise and resources to strengthen waste management. The arrangements can be in the form of contracts for waste collection, processing, and recycling services. The private sector is meant to fill critical gaps in public waste management service, mostly in urban settings with huge waste generation levels.

Socio-Cultural Factors Influencing Waste Management

Socio-cultural practices greatly affect waste management in India and govern the attitude of communities toward disposal and resource recovery. It is, therefore, important to consider these aspects while designing the appropriate waste management programs; beliefs and practices associated with culture could either enable or hinder a community's involvement and compliance with waste management. Patel and Kumar (2019) researched how culturally different settings across the various communities influenced certain waste disposal behaviors across India. Most importantly, where customs and traditions of local people have been catered to, the levels of participation become greater. For example, in communities where waste was traditionally regarded as a resource to be reused or composted, the promotion of recycling and composting took root far earlier. Such an approach aligns well with the mainstream notion that, effaced of obsolete biases, the recycling and composting initiatives are worthy of support.

Another important aspect of these socio-cultural factors that influence waste management are issues of gender. Rani and Singh (2021) looked into the role of gender concerning waste management in households and larger community settings. Their study finds that women carry the bulk of responsibility for waste disposal, initiated by sorting it out at home, removing it, and sometimes even transferring it to recycling plants. The findings suggested that empowering women through training and access to resources could bring greater improvements in community-wide waste management practices. With suitable training from local governments on waste management and the importance of waste segregation, communities can powerfully utilize women's roles in their own households toward enhanced waste disposal practices. Additionally, the provision of avenues for women to share their experiences and solutions would provide a platform benefitting from a collaborative women-centered mechanism for waste management. The research indicated a strong need for targeted programs that engage women as key players in efforts to manage waste, as they have huge power in decision-making within households and community affairs.

.By training women on efficient waste management methods and waste segregation, communities can work out their existing roles in advocating for better disposal practices. The experiences and solutions of women can be platformed to enhance collaborative approaches to waste management. The study brought out the need for initiatives targeted towards engaging women as key players in waste management, given their ability to influence household decisions and community participatory efforts.

Modern Waste Management Technologies

This literature study discusses the following kinds of efficiency in trash management. The authors point out that for the solution of the worldwide problem of waste, such technologies as robots, AI, and smart bins have much to offer. Just as with smart bins that use sensors embedded in them and Internet of Things tech, these innovations help monitor the level of waste in real-time, bring savings in operational costs, and optimize the collection route. These technologies appear revolutionary for they brought solutions to many hinterlands in traditional waste collection methods. The study primarily emphasizes the role of robotics and AI in automating trash sorting operations nowadays. Robots that use camera vision and AI for improved accuracy in the sorting of recyclables can largely reduce the pollution of recyclable materials. Integrating informal workers in the waste management system and setting up these technologies are similar in working towards enhancing the efficiency of waste processing. The study presents electronic waste, or e-waste-that is, fast-growing, one of the key-researched areas of modern waste management. Technologies such as cryo-milling and chemical separation are recognized for their capacity to reclaim valuable from electronics, assumingly while they consume much energy. The review provides for the fact that implementing new age technology within regional waste management system would prevent e-waste from causing adverse environmental effects. The article concludes by discussing the roles of waste-to-energy systems, which harvest organic waste for renewable energy production. Just like any other waste management effort, however, whether or not a waste-to-energy plant is successful will also depend very much on the support and cooperation of the community. In conclusion, the analysis depicts the way toward more sustainable and efficient waste management options in consideration of operational and environmental problems.

Research Methodology

Research Approach

This study employs a mixed-method approach, integrating both qualitative and quantitative techniques to comprehensively analyze the challenges and innovations in waste management in India. By utilizing secondary data from academic journals, industry reports, and government policies, along with primary data collected through structured surveys and interviews, this research aims to provide a holistic view of the current waste management landscape and emerging solutions.

Research Design

A systematic literature review was conducted to explore existing research on municipal solid waste management (MSWM) in India. The review synthesized findings from previous studies, examining technological advancements, policy frameworks, and socio-economic challenges in waste management. Additionally, empirical data were collected through surveys and interviews to assess public awareness, policy effectiveness, and the role of technological interventions.

Data Collection Methods

. Secondary Data Collection

Secondary data were sourced from:

- Academic databases such as ScienceDirect, Springer, and MDPI.

- Government reports, including policies from the Ministry of Environment, Forest, and Climate Change (MoEFCC) and the Central Pollution Control Board (CPCB).
- Industry reports and case studies detailing advancements in waste-to-energy (WtE) technologies and AI-driven waste sorting mechanisms.

Primary Data Collection

A structured questionnaire survey was conducted to evaluate public awareness, waste segregation habits, and participation in waste management initiatives. The questionnaire included:

- Demographic Details (age, occupation, education level)
- Waste Segregation Practices (household and community-level segregation)
- Participation in Waste Management Programs
- Awareness of Waste-to-Energy Technologies
- Perceptions on Policy Effectiveness

The survey followed a five-point Likert scale, where responses above 3 indicated agreement and below 3 signified disagreement. Data were collected through online Google Forms and in-person interviews with 30 respondents from Bangalore, selected through stratified random sampling.

Statement of problem

Bengaluru, one of India's fastest-growing metropolitan cities, faces significant challenges in waste management due to rapid urbanization, population growth, and increasing waste generation. The traditional centralized waste management system has proven to be inefficient in handling the vast amounts of waste produced daily, leading to overflowing landfills, environmental pollution, and public health concerns. Despite various initiatives by the Bruhat Bengaluru Mahanagara Palike (BBMP), issues such as uncollected waste, improper segregation, and a lack of adequate waste processing facilities persist. The existing infrastructure is often overwhelmed, and inefficient waste disposal methods contribute to land and water contamination, posing severe environmental hazards. Additionally, the unscientific dumping of waste has led to growing concerns over methane emissions from landfills, further exacerbating the city's environmental footprint.

To address these challenges, BBMP has transitioned to a decentralized waste management approach, establishing Dry Waste Collection Centers (DWCCs) and biomethanation plants to improve waste segregation and processing. However, despite these efforts, inefficiencies in the operational framework of DWCCs, inadequate monitoring, and a lack of streamlined management systems continue to hinder the effectiveness of decentralized waste processing. Many DWCCs struggle with financial sustainability, improper handling of recyclable waste, and limited participation from local communities. Furthermore, waste collection vehicles often face logistical issues, resulting in delayed waste pickups and irregular service delivery. The inefficiency in waste segregation at the source also remains a major challenge, as a large proportion of waste collected is mixed, making it difficult to process effectively.

In response to these challenges, BBMP has integrated technology-driven waste monitoring systems, including RFID-based tracking for waste collection and GPS-enabled monitoring of waste disposal vehicles. While these advancements have improved accountability and transparency to some extent, their implementation has faced

technical and administrative challenges. The RFID tracking system, for example, requires active participation from residents

and effective coordination among waste collection agencies. However, poor adoption, technical glitches, and a lack of awareness among citizens have limited its overall impact. Similarly, while mobile applications and web dashboards provide real-time monitoring, their effectiveness is constrained by inadequate enforcement mechanisms and resistance from waste management workers and contractors. These technological solutions, though promising, require further refinement, community engagement, and policy enforcement to ensure their success.

Another critical issue in Bengaluru's waste management system is the lack of public participation and awareness. Despite Information, Education, and Communication (IEC) campaigns promoting waste segregation, citizen involvement in waste management remains low. Many residents are either unaware of proper waste disposal methods or unwilling to comply with segregation guidelines. The role of resident welfare associations (RWAs), non-governmental organizations (NGOs), and informal waste pickers is crucial in ensuring the success of waste segregation and recycling initiatives. However, there is often a disconnect between these stakeholders and BBMP's policies, leading to ineffective implementation of waste management programs. Moreover, penalties for non-compliance with segregation rules are not strictly enforced, reducing the incentive for residents to adhere to waste management guidelines.

The challenges in Bengaluru's waste management system highlight the need for a more holistic approach that combines decentralized waste processing, technological interventions, stricter policy enforcement, and greater public participation. While BBMP has taken steps to improve waste management, persistent issues such as inefficiencies in waste collection, financial sustainability of DWCCs, gaps in technological implementation, and low citizen engagement continue to hinder progress. Without a well-coordinated and research-driven strategy, Bengaluru risks further environmental degradation, posing long-term threats to public health and urban sustainability.

Objectives of the study

To assess public awareness and participation in waste segregation and disposal practices by evaluating knowledge of BBMP guidelines, frequency of segregation, and engagement in waste management initiatives. To analyze the effectiveness of BBMP's waste management awareness campaigns and communication strategies in promoting sustainable waste practices among Bengaluru residents. To identify key challenges in waste collection and recycling infrastructure based on public perception, including irregular collection, inadequate facilities, and enforcement of segregation rules. To evaluate public satisfaction with BBMP's waste management services by measuring perceptions of collection efficiency, infrastructure adequacy, and the impact of waste management policies on environmental and public health conditions.

Scope of Study

The study examines Bengaluru's waste management system, focusing on BBMP's decentralized approach, technological interventions, community engagement, and policy framework. It evaluates the effectiveness of Dry Waste Collection Centers (DWCCs) and biomethanation plants in reducing landfill dependency, along with challenges like financial sustainability and logistics. The role of technology, including RFID tracking, GPS-enabled monitoring, and mobile applications, is assessed for efficiency and adoption barriers. Public participation is explored through RWAs, NGOs, and awareness campaigns, identifying behavioral factors affecting waste segregation. Additionally, the study analyzes policy effectiveness, enforcement mechanisms, and institutional challenges. By

highlighting gaps and opportunities, it aims to provide insights for improving urban waste management in Bengaluru and similar cities.

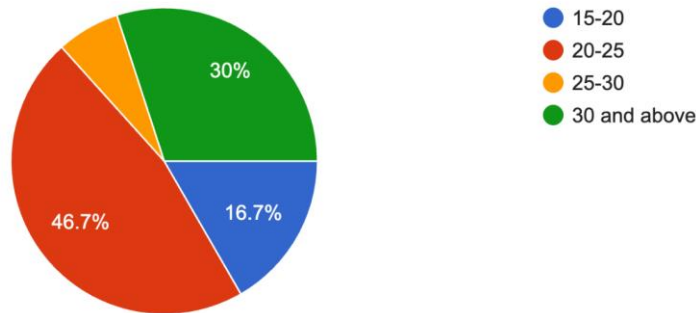
DATA ANALYSIS AND INTERPRETATION

Survey Data on Waste Management Awareness and Practices

Question :1

Age

30 responses



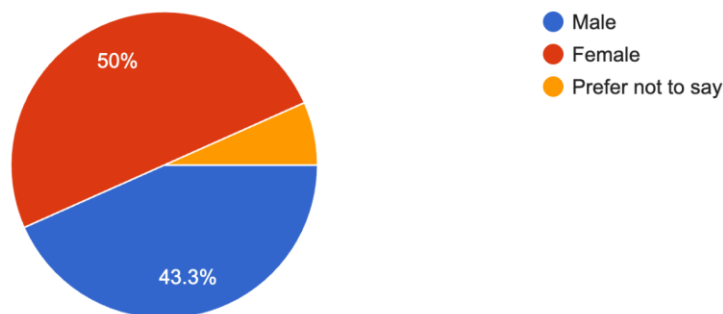
The survey collected 30 responses on which age group has more awareness about waste management.

- . Blue (15-20 years old): 16.7% of respondents
- . Red (20-25 years old): 46.7% of respondents (the largest group)
- . Orange (25-30 years old): A smaller portion compared to the others
- . Green (30 and above): 30% of respondents

Question: 2

Gender

30 responses

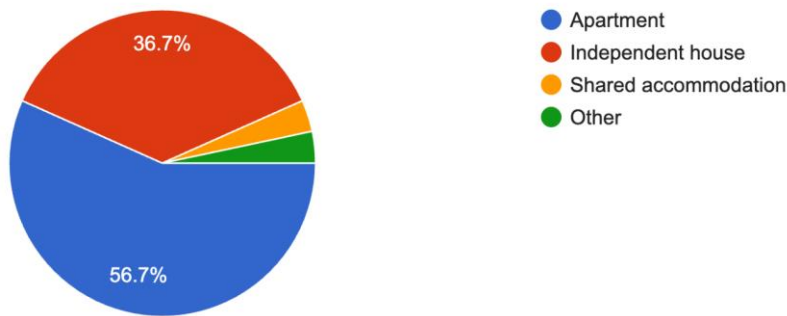


The survey collected 30 responses based on three gender criteria.

- . Male (Blue): 43.3% of respondents
- . Female (Red): 50% of respondents (the majority)
- . Prefer not to say (Orange): A small percentage, indicating respondents who chose not to disclose their gender

Question : 3

Type of Residence
30 responses

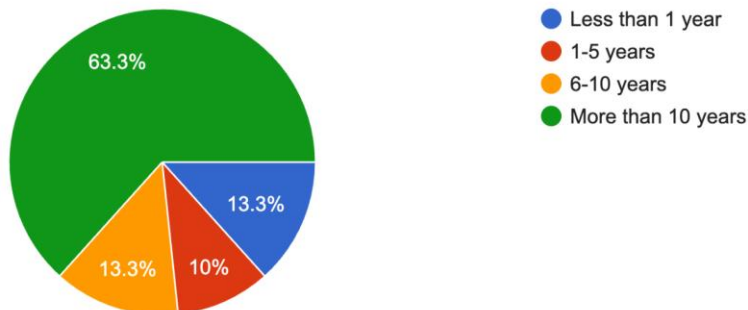


Based on the survey given the data has been collected based on 4 types of residences the following data shows

- . Apartment (Blue): 56.7% of respondents live in an apartment (the majority).
- . Independent house (Red): 36.7% of respondents live in an independent house.
- . Shared accommodation (Orange): A small percentage of respondents live in shared accommodations.
- . Other (Green): A very small percentage of respondents selected “Other” as their type of residence.

Question: 4

How long have you been residing in Bengaluru?
30 responses



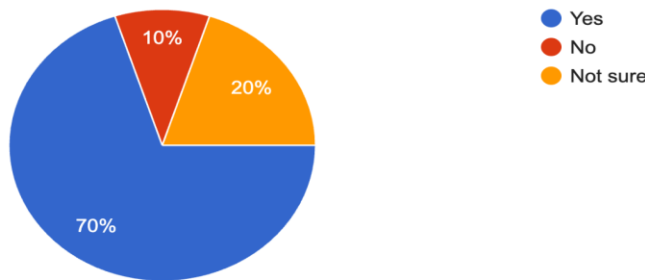
The following survey shows how many years residents have been living in bangalore . The data basically explains

- . Apartment (Blue): 56.7% of respondents live in an apartment, making it the most common type of residence.
- . Independent house (Red): 36.7% of respondents live in an independent house, which is the second most common choice.
- . Shared accommodation (Orange): A smaller percentage of respondents live in shared accommodations.
- . Other (Green): A very small percentage of respondents selected “Other” as their residence type.

Question: 5

Are you aware of the waste segregation guidelines provided by BBMP?

30 responses



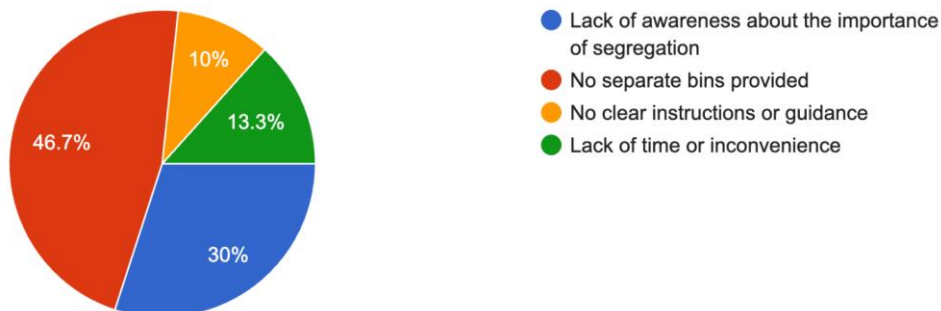
The following data shows the awareness of waste segregation guidelines provided by BBMP
The data basically explains

- . Yes (Blue): 70% of respondents are aware of the guidelines (the majority).
- . No (Red): 20% of respondents are not aware of the guidelines.
- . Not sure (Orange): 10% of respondents are uncertain about the guidelines.

Question:6

If you do not segregate waste, what are the main reasons?

30 responses



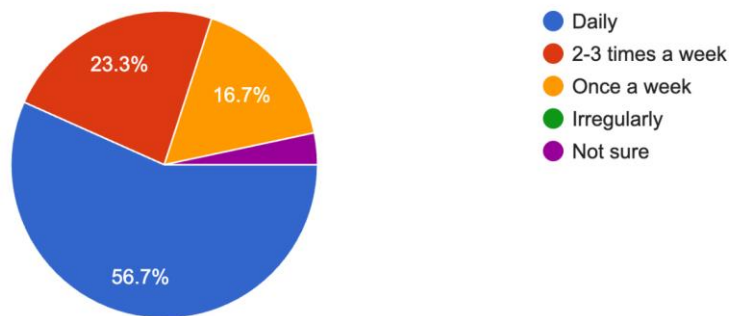
The survey states the reason why residents don't segregate waste. The following are the opinions

- . No separate bins provided (Red): 46.7% – This is the most common reason.
- . Lack of awareness about the importance of segregation (Blue): 30% – The second most common reason.
- . No clear instructions or guidance (Orange): 13.3%
- . Lack of time or inconvenience (Green): 10%

Question:7

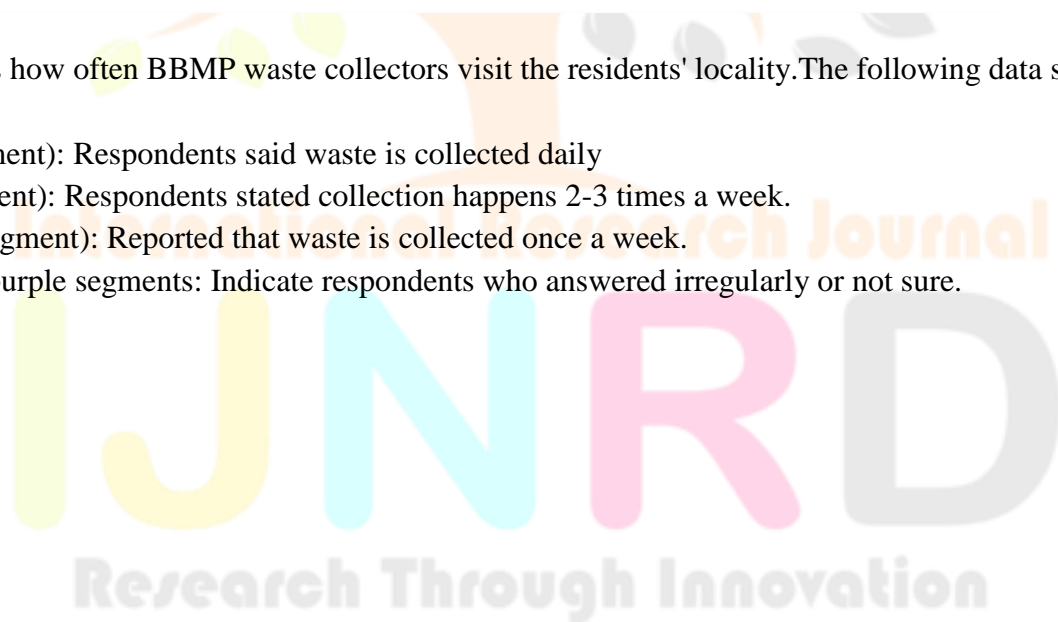
How often do BBMP waste collectors visit your locality to collect waste?

30 responses



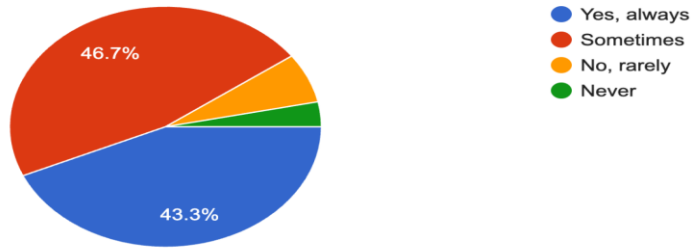
The data represents how often BBMP waste collectors visit the residents' locality. The following data shows.

- . 56.7% (Blue segment): Respondents said waste is collected daily
- . 23.3% (Red segment): Respondents stated collection happens 2-3 times a week.
- . 16.7% (Orange segment): Reported that waste is collected once a week.
- . Small green and purple segments: Indicate respondents who answered irregularly or not sure.



Question:8

Do you think BBMP waste collectors follow proper protocols while collecting waste (e.g., segregating wet and dry waste)?
30 responses

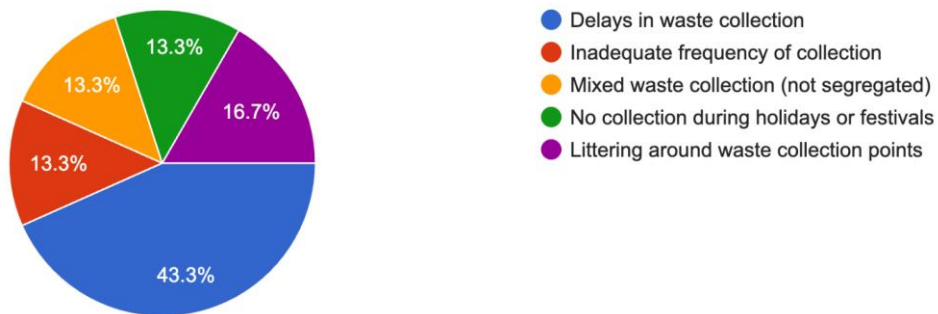


The following survey shows whether the waste collectors follow protocols or not. Here is what the data says.

- . 43.3% (Blue segment): Respondents believe waste collectors always follow protocols.
- . 46.7% (Red segment): Respondents said collectors sometimes follow protocols.
- . Small portions:
- . Yellow (No, rarely): Some respondents feel collectors rarely follow protocols.
- . Green (Never): A small percentage believes protocols are never followed.

Question:9

Do you face any issues with waste collection in your area?
30 responses



The following survey shows if residents had faced any issues in waste collection. Based on the data it shows.

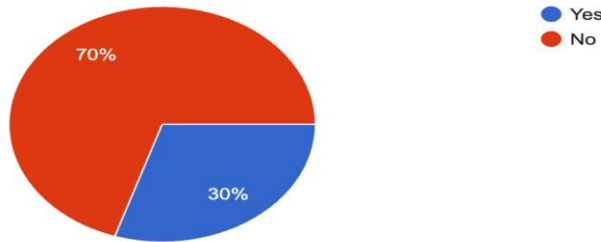
- . 43.3% (Blue segment): The majority of respondents reported experiencing delays in waste collection.
- . 16.7% (Purple segment): Some respondents identified littering around waste collection points as an issue.

- . 13.3% (Red segment): A portion of respondents cited inadequate frequency of collection.
- . 13.3% (Orange segment): Others reported that waste is not properly segregated (mixed waste collection).
- . 13.3% (Green segment): A similar percentage stated that there is no collection during holidays or festivals.

Question:10

Have you participated in any of BBMP's waste management awareness programs or initiatives?

30 responses



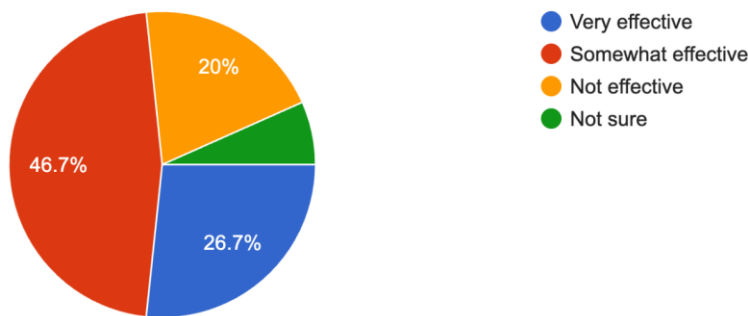
The data shows if there is any participation in BBMP waste management awareness programs and initiatives. Based on the data

- . 70% (Red segment): The majority of respondents have not participated in any BBMP waste management awareness programs.
- . 30% (Blue segment): A smaller portion of respondents have participated in these initiatives.

Question:11

How would you rate the effectiveness of BBMP's waste management awareness campaigns in your locality?

30 responses



The following data explains whether there is any effectiveness in BBMP waste management

- . 46.% (Red segment): Respondents find the campaigns somewhat effective.
- . 26.7% (Blue segment): Consider the campaigns very effective.

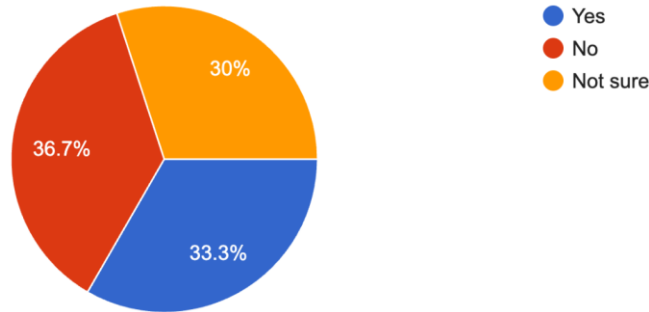
. 20% (Orange segment): Believe the campaigns are not effective.

. 6.6% (Green segment): Are not sure about their effectiveness.

Question :12

Do you feel that BBMP adequately communicates waste management rules and regulations to the public?

30 responses



The following survey shows if there was any communications on rules and regulation of waste management towards the public. Based on the chart

. 36.7% (Red segment): No, BBMP does not adequately communicate waste management rules.

. 33.3% (Blue segment): Yes, they believe BBMP communicates effectively.

. 30% (Orange segment): Not sure, indicating a lack of awareness or mixed opinions.

Key Findings:

Decentralized Waste Management Success – BBMP’s transition from centralized to decentralized processing has improved waste management efficiency.

Technological Integration – RFID tagging and GPS-enabled waste collection have enhanced tracking and transparency in waste management.

Limited Public Awareness – Despite awareness campaigns, many residents lack proper knowledge about BBMP’s waste segregation guidelines.

Gaps in Policy Enforcement – While regulations exist, inconsistent enforcement leads to continued non-compliance with waste segregation laws.

Operational Challenges in Dry Waste Collection Centers (DWCCs) – The efficiency of DWCCs varies, with some centers facing logistical and staffing issues.

Public Participation Remains Low – Despite IEC campaigns, community engagement in waste segregation and recycling initiatives remains suboptimal.

Inconsistent Waste Collection Services – Residents report irregular waste collection, leading to waste accumulation and environmental hazards.

Informal Sector Contribution – Informal waste pickers play a significant role in recycling efforts but lack formal recognition and support.

Data-Driven Waste Estimation Improves Planning – Using data analytics, BBMP has optimized resource allocation for waste management.

Need for More Recycling and Composting Facilities – Limited infrastructure for recycling and composting restricts the potential of sustainable waste management.

Suggestions:

Strengthen Awareness Campaigns – Increase outreach through digital platforms, schools, and RWAs to promote waste segregation education.

Enhance Policy Implementation and Enforcement – Implement stricter monitoring mechanisms to ensure compliance with waste management regulations.

Expand DWCC Operations – Improve infrastructure, funding, and staffing at DWCCs to maximize waste processing efficiency.

Encourage Community Involvement – Foster partnerships with local NGOs and RWAs to improve citizen participation in waste segregation initiatives.

Improve Waste Collection Scheduling – Implement AI-based scheduling to optimize waste collection frequency and reduce inconsistencies.

Integrate Informal Waste Pickers into the Formal System – Provide training, financial support, and recognition to informal waste workers to enhance efficiency.

Develop More Waste-to-Energy Facilities – Invest in waste-to-energy plants to reduce landfill dependency and generate renewable energy.

Expand Use of Smart Technology – Increase the adoption of real-time monitoring systems, such as mobile apps, to track collection and report waste-related issues

Invest in Recycling and Composting Infrastructure – Build additional recycling plants and composting facilities to divert waste from landfills.

Promote Incentive-Based Waste Management – Implement reward programs for households and businesses that consistently follow waste segregation guidelines.

Conclusion

This study highlights the critical role of sustainable waste management in addressing the growing challenges posed by urbanization in India, with a specific focus on Bengaluru's waste management strategies. By employing a mixed-method approach, including literature reviews, surveys, and interviews, the research provides valuable insights into the effectiveness of existing policies, technological advancements, and community engagement initiatives in waste management.

The findings reveal that while the Bruhat Bengaluru Mahanagara Palike (BBMP) has made significant progress in adopting decentralized waste management, several challenges persist. The integration of smart technologies such as RFID tagging and GPS tracking has improved waste collection efficiency, yet irregular collection schedules and limited enforcement of waste segregation policies remain barriers. Additionally, public awareness and participation in waste segregation programs are relatively low, despite the implementation of various educational campaigns. The informal waste sector plays a crucial role in recycling, but its potential remains underutilized due to a lack of formal recognition and support.

To enhance the efficiency and sustainability of waste management, this study suggests several improvements, including stricter enforcement of waste segregation policies, increased investment in waste-to-energy and recycling infrastructure, and better community engagement through targeted awareness programs. Strengthening partnerships between government bodies, NGOs, and residents can further improve waste management outcomes. Integrating informal waste workers into the formal sector and leveraging smart technologies for real-time monitoring can also enhance operational efficiency.

In conclusion, achieving a sustainable waste management system requires a multifaceted approach involving technological interventions, policy enforcement, and community participation. By addressing existing gaps and implementing data-driven solutions, Bengaluru and other Indian cities can move towards a more resilient, environmentally sustainable waste management framework, ultimately contributing to cleaner cities and improved public health. The study underscores the need for continued innovation, collaboration, and regulatory enhancements to ensure long-term success in sustainable waste management practices.

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Research Through Innovation