Solid Waste Management in Indore, Madhya Pradesh, India: Insights from a Survey of Literature

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Received	Reviewed	Revised	Published
13.10.2023	16.11.2023	21.11.2023	30.11.2023

https://doi.org/10.61275/ISVSej-2023-10-11-26

Abstract

Waste management is one of the biggest concerns plaguing the modern world. With rapid population growth, municipal solid waste management has emerged as a significant activity in urban regions. One of the mandatory responsibilities of municipal corporations and urban local bodies is the efficient reduction of solid waste. Due to the high percentage of municipal solid waste generation, density, Lack of awareness, lack of resources, and inadequate infrastructure, the majority of urban local bodies (ULBs) are unable to handle such a huge volume of solid waste. The prime challenges are waste source segregation, doorstep collection, recycling and reuse possibilities, treatment technology, land availability, and expertise in disposal. Indore, Madhya Pradesh was found the cleanest city in Swachh Survekshan's results in August 2020.

This study examines the existing scenario of solid waste management in Indore City that has contributed to Indore's success. This study also investigated how Indore has achieved 100% segregation, door-to-door collection, public awareness among residents, GPS-enabled system vehicles for waste collection, efficient transportation, and subsequent Processing.

The study employs a survey of published literature. The learnings from this study may be useful for municipal authorities, decision-makers, NGOs, and researchers in other metropolitan cities and developing countries.

Keywords: Solid Waste Management, Theoretical Framework, Garbage Transfer Station (GTS), Disposal, Circular Economy.

Introduction

One of the most significant issues is achieving sustainable solid waste management practices, as agreed upon by 193 nations in September 2015 in the Sustainable Development Goals (SDGs) (Hosono and Aoyagi, 2018). According to Rodi and Wilson (2017), it is clear why the waste management issue is important as it is directly related to 12 out of the 17 Sustainable Development Goals (SDGs) in the Agenda 2030. For sustainable development, municipal solid waste (MSW) is considered an important issue since all three areas of sustainability namely society, environment, and economy are associated with it (Pires *et al.,* 2018). Minghua et al. (2009) found that the increase in municipal solid waste (MSW) volumes

is largely related to the rate of urbanization and rise in population. As a result, for sustainable development, solid waste management cannot be ignored and requires immediate consideration for future planning. Bhoyar et al. (2014) identified that economic growth and the Industrial Revolution have drastically changed how people consume, which has resulted in a change in waste management because of the rise in the inorganic content of wastes and created a global issue. Furthermore, the proportion of inorganic wastes has increased due to a rapid increase in industrially produced materials like polystyrene, metals, glass, plastics, papers, and rags (Mor *et al.,* 2006).

As mentioned by Wilson, Velis and Rodic (2013), usually the uncollected waste is just burned outdoors close to homes or thrown into vacant land near watercourses and such practices harm the health of the people, especially children. Dumped waste also blocks drains, leading to flooding and the damage it causes to public health and property (Lamond, Bhattacharya and Bloch, 2012). Also, when it comes to other public utility services like health, water supply, etc., many developing nations place a very low priority on municipal solid waste (MSW) services (Gupta, Yadav and Kumar, 2015). As Joshi and Ahmed (2016) says the segregation practices at all phases of waste management in developing countries are either lacking or severely poor, posing a significant challenge for local authorities in terms of scientific waste treatment. Therefore, such practices are the root cause of improper waste management practices and services in many regions of the country (Talyan, Dahiya and Sreekrishnan, 2008).

According to Sharma and Jain (2019), in India, urbanization has increased from 27.8% in 2001 to 31.6% in 2011, and it is expected that about 50% of the country's population will live in cities by 2021. In India, municipal solid waste (MSW) management has been neglected despite urban local bodies (ULBs) working to enhance services including transportation, electricity, and water. As a result, it leads to a condition in which rapidly growing cities are covered by heaps of garbage left in the open (PWC, 2017). The quantity of waste generated in India has seen a rapid surge over the last few years. From January 2020 onwards, 84,475 wards in India generated an alarming 147,613 metric tons (MT) of solid waste per day. As per the Planning Commission, a study from "Task Force on Waste to Energy", it is estimated that urban India created 2,76,342 tons of garbage per day (TPD) in 2021 and will create 4,50,132 tons in 2031, 11,95,000 tons in 2050. Each person produces 450 grams of waste each day, and this quantity has increased by 1.3% yearly (Singh, 2020), furthermore, according to a July 18, 2019, Lok Sabha answer, cities with populations greater than 100,000 generate 67,000 tons of waste per day, which is around 44% of total waste produced by the country. According to Rasmeet (2021), it is mentioned that in relation to the required waste management, the overview of cleanliness in India is based upon ground confirmation, waste handling, advanced methodologies, economic sustainability, recovering the costs of solid waste administration, resident input, and the nature of execution and administration. Also, as mentioned by Kumar et al. (2017) there is an urgent requirement for proper MSW management in a nation where living standards are rising at an exponential rate, the concerned ULBs are at a loss for how to handle the problem.

In the context of an inadequate waste management system, according to Swachh Survekshan's results from August 2020, Indore was deemed to be the cleanest city out of all cities, making its waste management model a good example for other regions and towns (Paul and Paul, 2021). Therefore, this paper attempts to highlight the best practices and strategies of the Indore waste management model so that other cities can also learn and implement the strategies and practices.

The aim of this study is to investigate and gain a thorough understanding of the existing scenario of solid waste management in Indore City. The objectives of the study are:

1. To analyze the present situation of waste generation, composition, collection, transportation, and disposal in the Indore.
2. To identify the key challenges, recommendations for improvements, and opportunities for existing solid waste management systems.

Theoretical Framework

Integrated Sustainable Waste Management (ISWM) Model

Integrated solid waste management (ISWM) is one of the most well-recognized methods for municipal solid waste management. It enables an integrated and comprehensive analysis of the complex and multidimensional waste management system (Srivastava *et al.,* 2015). Tchobanoglous, Theisen and Vigil (1993) have defined ISWM as ‘‘the selection and application of suitable techniques, technologies and management programs to achieve specific waste management goals and objectives”. Integrated solid waste management (ISWM) is a systematic approach to managing solid waste, aiming for maximum benefits, optimal resource utilization, reusable and recyclable recovery, environmental and health standards, and social acceptability (van de Klundert and Anschütz, 2001). According to Guerrero, Maas and Hogland (2013), this model recognizes the importance of three dimensions when analyzing, developing or altering a waste management system. The dimensions are the stakeholders interested in solid waste management, the components or phases of the materials' transfer from the points of generation to the sites of treatment and final disposal and the components or "lenses" that are used to examine the system.

ORWARE (ORganic WAste Research) Model

ORWARE (ORganic WAste Research), an acronym for Organic Waste Research, is a computer-based tool for environmental systems analysis of waste management, calculating substance flows, environmental impacts, and costs, initially designed for organic waste management but now covering inorganic fractions in municipal waste (Eriksson *et al.,* 2002). The first description of the ORWARE model was described by Dalemo et al. (1997). Also, the ORWARE submodel is composed of several distinct submodels that can be used to create a waste management system for a corporation, city, or municipality. As mentioned by Eriksson et al. (2002), since the early 1990s, four different research institutions in Sweden (Royal Institute of Technology, Swedish Environmental Research Institute, Swedish Institute of Agricultural and Environmental Engineering, and Swedish University for Agricultural Sciences) have worked together to develop the ORWARE model. Also, as per (Eriksson et al. (2005), waste management is carried out from the cradle (waste sources) to the grave (utilization of waste treatment products). The ORWARE can compute financial expenses (investment and operations costs) and revenues for the entire management chain, as well as environmental costs (Eriksson and Bisaillon, 2011).

Multi-Attribute Decision System (MADS) Model

The simulation-planning model known as the Multi-Attribute Decision System (MADS) model consists of two modules that is screening and evaluation. The screening module helps to choose feasible MSW management options within the limitations that decision-makers have established. The evaluation module enhances the previous module by deliberating the economic and environmental impacts of MSW management and policy. Therefore, this model accounts only for environmental transportation costs in terms of vehicle emissions (Abou Najm *et al.,* 2002).

Life Cycle Assessment (LCA)

A life cycle assessment is a technique that looks at potential impacts on the environment at each stage in a product's life, from raw material procurement to manufacturing, usage, and disposal (ISO 14040, 1997). As mentioned by (Morrissey and Browne (2004), in order to analyze the product or service during its whole lifecycle, it can be paired with additional assessment methods, such as risk assessment, which also offers a broad overview of the product system. According to McDougall et al. (2001), Life cycle assessment provides a system map that sets the scene for a holistic approach, and then environmental improvements can be made by comparing such system maps for alternative possibilities, whether for new products or waste management systems.

Review of Literature

As mentioned earlier in the Introduction, due to socio-economic growth, technological advancement, shifting demographics, fast industrialization, and urbanization, the world's energy needs are increasing. (Soni, Mittal and Kapshe, 2017). According to Hemmelmayr et al. (2014), municipal solid waste management (MSWM) is the collective term for a wide range of interdisciplinary tasks including generation, collection, storage, transportation, disposal, treatment, and waste forecasting. Ayub et al. (2014) says that in order to effectively plan for waste management in India, it is important to evaluate the characteristics and volume of solid waste as well as forecast future waste generation. The adequate storage of waste in integrated waste management planning at remote locations in rural and urban areas is critical for efficient energy recovery from waste utilization (Chanakya, Ramachandra and Vijayachamundeeswari, 2007). Also, for an efficient and cost-effective collecting system, the number of transfer stations and their ideal location is essential (Bosompem, Stemn and Fei-Baffoe, 2016). The Municipal solid waste management (MSWM) system, facilitated by a transfer station, connects the community solid waste generation point to a disposal facility, enhancing system efficiency by minimizing pollution and system costs (Chang and Lin, 1997). In the context of the Indian city, 85 percent of total expenditure is on collection (Ghose, Dikshit and Sharma, 2006). Hence, the planning and designing of the transfer station based on the required context and composition of the household can be a possible solution. This transfer station helps to reduce traffic, volume (due to compaction), and transportation expenditures (Cui et al., 2011).

De Feo and De Gisi (2010), show that unscientific methods for waste disposal pose a significant challenge in effective municipal solid waste management due to financial constraints, inadequate organizational structure, and lack of public awareness. Solid waste management is a big issue in India because only a small percentage of the waste is disposed of appropriately (Kaushal, Chabukdhara and Varghese, 2012). Also, it is important as per Ramachandra and Bachamanda (2007) for citizens to understand the need to separate garbage at the source, avoid roadside littering, and fulfill their environmental responsibilities. In the cities, recycling is carried out by the unorganized sector, which includes rag-pickers. Sorting of recyclable solid waste materials from garbage bins and landfills is crucial.

This review identifies the gaps of insufficient waste management system, lack of public knowledge, insufficient organizational structure, waste disposal and ineffective planning and designing of the transfer station particularly in the Indian context. As a result, in the context of an inadequate and ineffective waste management system, it directs to study of the best example of Indore City as it was considered to be the cleanest city out of all cities as per Swachh Survekshan's results in August 2020. Also, the Indore waste management model can be a good example for other regions and towns to replicate (Paul and Paul, 2021).

Research Methodology

The research employs a literature survey. It was conducted across various databases for desktop searches like Google Scholar, ResearchGate, ScienceDirect, and the Wiley online library using keywords such as solid waste management in Asian cities, solid waste management in India, solid waste management models and theories, solid waste management in Indore, waste recycling in Indore, waste disposal in Indore, and circular economy. A total of 70 papers were identified, including conference papers, annual reports, journal articles, and specific government websites were referred for the same. Out of 70 papers, 50 were considered for further analysis of numerous issues, primary causes, and impacts of solid waste management in Indore.

The Case Study: Indore Solid Waste Management System

The Indore Municipal Corporation (IMC) has a population of 1.9 million (19 lakhs) people, with a floating population of 3-4 lakh persons per day, according to the 2011 Census. The city governs an area of 276 sq. km (Alappuzha, 2021). According to Rasmeet (2021) In addition to emphasizing visible cleanliness and waste management, the residents are regularly encouraged to change their behavior to ensure garbage separation. However, as mentioned by

Alappuzha (2021), Four years back, when the city corporation was primarily focused on C&T (collection and transportation) of residential garbage rather than source segregation, today the entire city also cooperates in separating its waste.

According to Paul and Paul (2021), Indore generates over 1,115 MT of waste daily which includes commercial units and households. The waste management system in Indore was previously inadequate, with over thousands of vulnerable waste points in the city (Rasmeet, 2021). However, hardly any waste was separated at the source resulting in many environmental and health issues because of the mixed garbage dumped at the Devguradiya trenching ground and additionally in public lands and open spaces (Vivekanand Gurlhosur, Wasif Quadri and Dohare, 2020). Hazardous waste was dumped into the Indore-bound River, Kahn, posed health risks to animals and waste pickers, turning the river into a sewage system and littering roads with foul-smelling garbage (Alappuzha, 2021). As per Paul and Paul (2021), the Indore Municipal Corporation (IMC) contracted a concessionaire to handle the transportation, processing, and disposal of rubbish, the waste management system needed to be improved due to a lack of financing, oversight, and institutional capacity to bring about change.

Fig 1: Vehicle for door-to-door waste collection.
Source: https://www.smartcityindore.org/solid-waste/

The "Swatch Bharat Mission" (SBM) was started on October 2, 2014, by the Indian government (Nidugala and Pant, 2017). As mentioned by Vivekanand Gurlhosur, Wasif Quadri and Dohare (2020), under the honorable leadership of the Prime Minister, Mr. Narendra Modi, the mission transformed into a national movement, which was individually applied to both, rural and urban areas. The aim of the mission was to achieve open defecation-free (ODF) communities within urban areas by starting individual and community public toilets along with scientific solid waste management (Nidugala and Pant, 2017). Finally, in December 2015, the scenario started to change when the door-to-door collection as a trial project was implemented by Indore Municipal Corporation (IMC) in Wards 42 and 71 (Alappuzha, 2021). The Corporation conducted awareness campaigns in these wards to encourage residents to separate waste into biodegradable and non-biodegradable fractions, it was found that individuals were willing to contribute (Agrawal, 2017). As mentioned by Alappuzha (2021),in January 2016 as a pilot experiment, the door-to-door service was started in two wards out of the city's 84 wards and was extended to ten wards and by October 2016. Indore Municipal Corporation (IMC) began collecting door-to-door waste and promoting source segregation at the same time (Rasmeet, 2021). However, it took almost over a year to achieve 100% door-to-door waste pickup. The increasing awareness and consistent efforts of Indore people helped to transform the city's cleanliness situation (Saba et al., 2022).

Fig 2: Compartmentalized vehicle for collection of biodegradables, non-biodegradable, sanitary, household hazardous and electronic.
Source: Alappuzha (2021)

However, with the ongoing Clean India Mission, the Municipal Corporation made people aware of the importance of waste separation at the source and the hazardous results of disposing it in open places, within a year (Alappuzha, 2021). Also, as a part of the new Swachh Survekshan toolkit in 2017, separate containers were used for sanitary and hazardous waste (Saba *et al.,* 2022). As per the Swachh Bharat Mission introduced a two-bin system for segregating waste, with green bins for biodegradable and blue bins for non-biodegradable. Also, during the pandemic, yellow bins were introduced for mask and glove disposal (Alappuzha, 2021). The city segregates presently its waste into six categories which are Biodegradable, Non-biodegradable (excluding plastic), Plastic, Sanitary, Household Hazardous, and Electronic (Rasmeet, 2021). Also, the solid waste management process in Indore consists of phases like waste generation, segregation, collection, transportation and disposal as depicted in Fig.3 below.

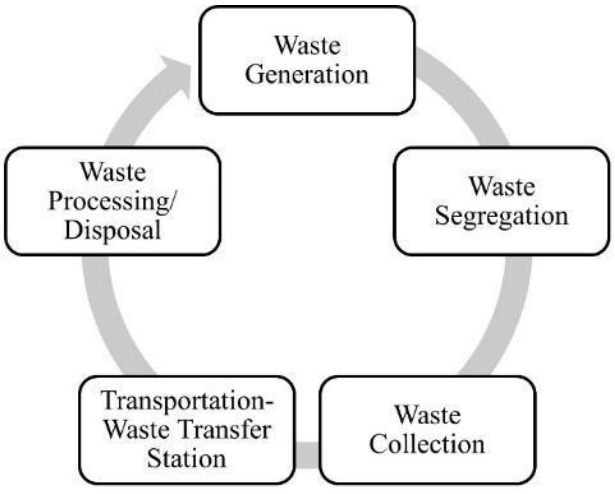

Fig 3: Solid Waste Management Process in Indore.
Source: Author

Showing outstanding teamwork, Indore managed to achieve 100% waste segregation at the source (Alappuzha, 2021). Indore's Swachhata story is one of true transformation through sincere community participation (Vivekanand Gurlhosur et al., n.d.). The paper will explain further briefly about the Indore Solid waste management activities such as waste generation, segregation, collection, garbage transfer station, and disposal techniques.

Municipal Solid Waste: Waste Generation and Segregation

There are 19 zones and 85 wards in Indore, each ward consists of 6,000 households and 600 commercial establishments on average (Paul and Paul, 2021). In the city, waste is collected separately which means that the generators at the source separate its waste. In total 1115 MTPD of trash is produced by the city (Alappuzha, 2021). Wet or organic waste constitutes 58.25% of the total waste, dry waste constitutes 41.75%, and domestic sanitary and hazardous waste constitutes 5%. Around 650 MTPD of wet garbage is produced in total and 465 MTPD of dry garbage (Jain et al., 2022).

Table 1: Waste types and their sources
Source: Rasmeet (2021)

Waste Type	Sources
Organic	Yard (leaves, grass, and brush) waste, Food scraps, and wood
Paper	Cardboard, newspaper, paper scrap, magazine, bags, wrapping paper, boxes, telephone books, shredded paper, and paper beverages cups.
Plastic	Containers, bottles, packing, bags, cups, and lids.
Glass	Bottles, light bulbs, glassware, and colored glass.
Metal	Cans, foil, non-hazardous aerosol cans, appliances (white goods), railing.
Others	Rubber, textiles, leather, multi-laminates, appliances, ash, e-waste, and other inert materials

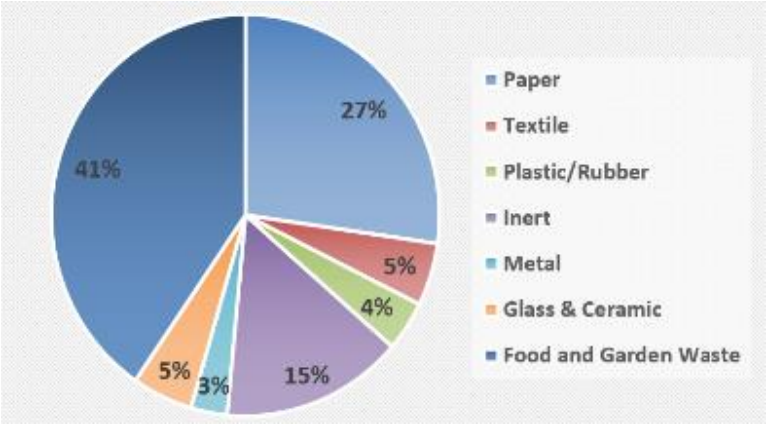

Fig 4: Municipal solid waste composition.
Source: Rasmeet (2021)

Depending on the volume produced, garbage generators are classified under three categories namely, Domestic, Semi-bulk, and Bulk generators. As mentioned in Fig. 5, the domestic generators are the ones that produce less than 25 kg of garbage per day, semi-bulk generators produce 25-100 kg of waste per day and the Bulk generators produce more than 50 kg of garbage per day (Vivekanand Gurlhosur, Wasif Quadri and Dohare, 2020). Domestic generators produce waste in three categories that is wet waste, dry waste, and domestic hazardous waste. Also, the bulk generators segregate the wet and dry waste (Paul & Paul, 2021).

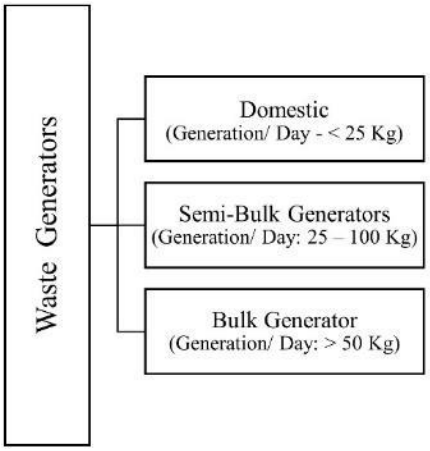

Fig 5: The waste generators Classification in Indore.
Source: Paul and Paul (2021)

Municipal Solid Waste: Waste Collection

Before 2016, the household waste collection system was majorly unorganized and unsystematic (Jain, Derashri and Jain, 2022). The primary and secondary solid waste collection was practiced. For the primary collection of waste, in some areas, municipal workers collected household waste, whereas housing colonies collected it in other areas under private contracts (Rasmeet, 2021). Private waste collectors were named "Jagirdars" who provided very low-quality services and frequently dumped waste on public property or vacant plots thereby endangering the health of the inhabitants (Nidugala and Pant, 2017). In the secondary collection, waste removal from central dustbins was a task undertaken by A2Z Infrastructure Limited, a private contractor, and then transported to an open dumping area at the Devguradia. The A2Z started experiencing a severe financial crisis, which had a negative impact on the transportation of secondary waste. As a result, poor residential waste transportation and collection together gave the city a dirty appearance (Rasmeet, 2021).

Fig 6: Divided Tipper for wet and dry waste collection.
Source: https://www.smartcityindore.org/solid-waste/

Presently, waste from household generators is collected at the source in a separate structure by divided tippers. The tippers collect both wet and dry waste in a separate chamber which is divided into 50:50, 60:40, or 85:15 proportions (Paul and Paul, 2021). Also, the Domestic hazardous waste is collected in a separate container attached to the tipper's back (Nidugala and Pant, 2017).

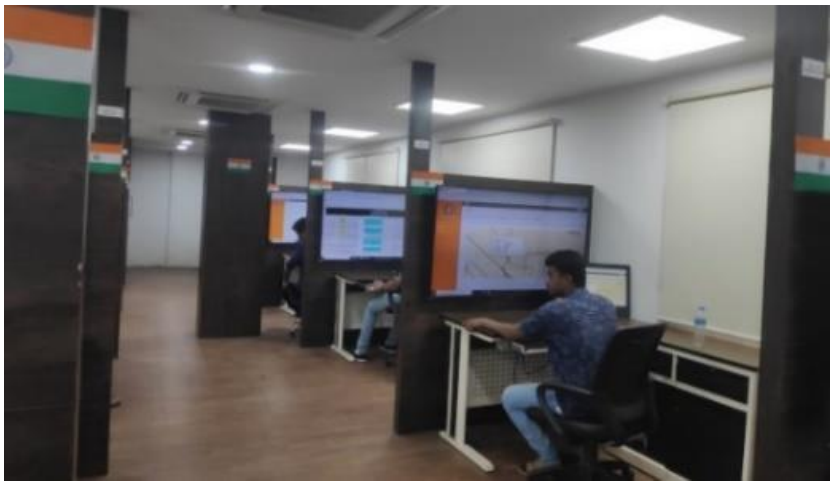

Fig 7: The command center of Indore Municipal Corporation to navigate the city's waste vans.
Source: Rasmeet, 2021

The command center navigates and controls all the tippers as depicted in Figure 7 and also has predefined collection routes in its waste management plan. All vehicles utilized in the process of waste collection and transportation are monitored by a GPS-enabled system (Rasmeet, 2021). The monitoring cell uninterruptedly keeps an eye on the GPS system. Post their route completion, the tippers travel to the designated Garbage Transfer Station (GTS) and dump the garbage in the designated compactor (Vivekanand Gurlhosur, Wasif Quadri and Dohare, 2020). Therefore, once the waste has been successfully compacted for further processing, it is placed into a hook loader and transferred to the central processing plant.

Under the bulk framework, two different vehicles are allocated to collect wet and dry waste separately. Furthermore, there are two classes of bulk generators based on the volume of waste they produce. The first category consists of waste generators that generate between 25 and 100 kilograms of waste. They are small bulk-mass foundations, similar to diners, coffee shops, and other businesses. Dumpers and compactors move along their route and keep collecting both, wet and dry waste from these generators while on the go. The category of generators that produce more than 100 kg of waste is RWAs, communal gardens, hotels, etc. These generators only collect dry waste because they dispose of the wet waste, they generate on-site (Rasmeet, 2021).

Municipal Solid Waste: Garbage Transfer Station (GTS)

Indore is not only Madhya Pradesh's financial capital but is also regarded as one of its most economically developed cities. The waste from the city is collected separately and then further the waste is separated at the source by garbage generators. In the 85 wards of the city, each ward has tri-partitioned garbage tippers stationed. Further, the collected waste has to be transferred to the designated garbage transfer station (GTS). Earlier, approximately 20-23 kilometers from the city the waste was transferred to the centralized processing facility, to curtail the cost of the secondary collection and transportation System (Rasmeet, 2021). Indore Municipal Corporation (IMC) has impressively set up eight ultra-modern garbage transfer stations of three types. These include ramp-based static garbage transfer stations (GTS), portable compactors-based garbage transfer stations (GTS), and semi-portable compactors-based Garbage transfer stations (GTS). These are installed at several locations throughout the city such as Star Square, Kabitkhedi, F-sector, Sangam Nagar, Sirpur, Dhar Road, Lalbagh, Crystal IT Park, and Rajshahi, DakkanwalaKua (Vivekanand Gurlhosur, Wasif Quadri and Dohare, 2020).

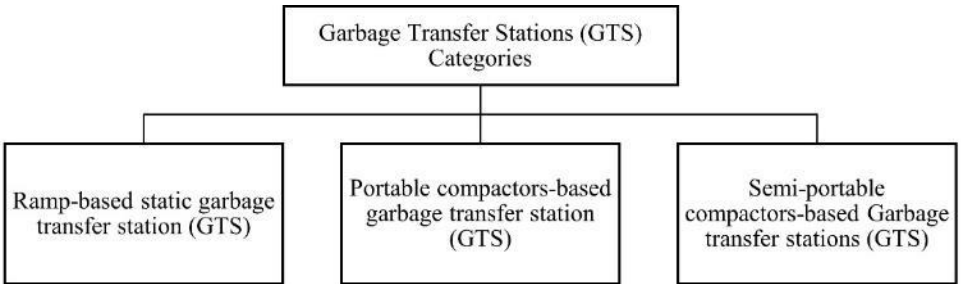

Fig 8: Types of Garbage Transfer Station in Indore.
Source: Author

Fig 9: Garbage Transfer Station
Source: Rasmeet (2021)

All of the aforementioned models can collect segregated waste and further transport it by hook loaders to the disposal site. Also, there are two types of hoppers used for the collection of dry waste (blue color) and the other wet waste (Green color). Door-to-door garbage tippers collect municipal solid waste in two steps. The wet waste is dumped into the green hopper and thereafter the dry garbage is dumped into the blue hopper (Agrawal, 2017). Afterward, the respective green and blue containers are attached to these hoppers. The appropriate containers are further compacted with the segregated municipal solid waste. Once the containers are full, they are lifted through a special hook loader and transported to the disposal site individually (Paul and Paul, 2021). Also, at the disposal site when the dry waste is transported to the Material Recovery Facility 1 or Material Recovery Facility 2, the wet waste is transferred directly to the Centralized Composting Unit via the hook loader. According to guidelines outlined in the Biomedical Waste Regulations 2016, the container for sanitary waste and domestic hazardous must be offloaded into designated drums and directed to the Common Biomedical Waste Facility (CBWTF) on a daily basis (Rasmeet, 2021).

Municipal Solid Waste: Disposal And Processing Techniques Composting

The method used to decompose wet waste is the Win drop composting method which is a 35-day process where wet waste is opened for seven days, and then turned into fine particles using organic materials like water, oxygen, and micro-organisms, breaking down the waste. Also, the material undergoes a filtration process to produce compost, with the remaining material being sent to landfill sites (Jadon, 2020). As Rasmeet (2021) says Bulk waste generators in Indore have installed an organic waste compost machine to handle bulk wet waste from temples, schools, hotels, and marriage gardens produces 40–50 kg of waste per day, which breaks down into humus daily after a period of 30 days, the waste is composted every day which is beneficial for the environment (Jadon, 2020).

The city's centralized processing unit processes approximately 600 MT of organic waste through a 32mm sieving trommel in a series with 16 mm sieving trommel, curing it for 12-15 days, and then screening it with a 5mm screening trommel machine. The rejects are sent to landfills (Vivekanand Gurlhosur, Wasif Quadri and Dohare, 2020). Thus, the wet waste produced in the city is entirely decomposable(Jain, Derashri and Jain, 2022). The compost is utilized as manure for gardening. To motivate the organizations IMC has rebated them on tax about 5–6% (Jadon, 2020).

Recycling

Dry waste is transported to a material recovery plant in Indore, where it is separated using various methods. The recovered materials include Glass, Rubber, Cloth, Paper, Various, Metals, Electronics, Thermocol and other materials. The recovered materials are sold to recycling plants, which generate bi-products. However, a large amount of the waste arises out of the material recovery plant which has no use other than as a fuel source for cement factories.130-150 MT/ day waste is transported to incineration plants, situated on the peripheries of Indore to be recycled as fuel (Jain, Derashri and Jain, 2022). The waste that passes through is classified as inert material, which cannot be recycled and must be disposed of in a landfill.

Indore Municipal Corporation (IMC) has installed India's first 300 MT Fully Automatic Material Recovery Facility- I at Devguradia Trenching Ground, designed by Turkish firm Disan. The facility, costing 30 crores, uses an automated sorting system to efficiently separate dry waste like plastic, metal, cloth, and paper. NEPRA Environmental Solutions Pvt. Ltd installed the unit, which includes three optical sorting machines from the German company Tomura. This automatic waste segregation machine has a conveyor belt, gravity separator, density sensors, and other components installed. The waste is picked up to 40ft and segregated using separators and conveyors. The recycling plant is divided into three phases sorting, shredding and cleaning, and Polymer flake sorting. Refuse-derived fuel, or RDF, is created by mechanically processing refuse and used as fuel in waste-to-energy plants. Thus, produced electricity is exported to the grid (Vivekanand Gurlhosur, Wasif Quadri and Dohare, 2020). Also, the Indore Municipal Corporation (IMC) has banned the usage of polythene in the city, but polythene is still utilized for certain reasons, hence three types of machines are employed to recycle this polythene that are Phatka machines, Aglo machines, and Gatta machines (Jadon, 2020).

Biomining

Devguradiya successfully cleaned the complete waste of 12 lakh MT of old waste through biomining process. The municipal corporation rented machines in 2018 in order to clean up the facility and separate the legacy waste. After that, trees were planted, and the area was turned into a park. 100 acres of land worth Rs. 300 crores were reclaimed, and all legacy waste was cleaned up. Currently, similar initiatives to clean up their dumping grounds are being carried out in Delhi, Ahmedabad, and several other cities (Vivekanand Gurlhosur, Wasif Quadri and Dohare, 2020).

Bio-methanation

Indore Municipal Corporation has established a 20 TPD bio-methanation plant in Choithram Mandi, a fruit and vegetable market, to produce and utilize Bio CNG from municipal solid waste processing (Rasmeet, 2021). The plant generates approximately 6 tons of organic manure daily and 2000m3 of raw biogas daily. The current biogas plant addresses thrust areas by providing greener fuel for transportation, treating wastewater with zero discharge, and enhancing amenity value by reducing pollution. ISCDL (Indore Smart City Development Limited) and IMC (Indore Municipal Corporation), in partnership with Mahindra, have initiated a Bio-methanation project to generate Bio CNG for public transport. (Vivekanand Gurlhosur, Wasif Quadri and Dohare, 2020).

Presently, 15 buses in Indore use Bio-CNG, consuming 500 kg of gas daily and running over 2000 km. A 15 TPD capacity bio-methanation plant is also present at the Kabitkhedhi sewage treatment plant (Rasmeet, 2021). Also, the city's hotel garbage is handled by this plant. A single 200 TPD bio-methanation facility at Trenching Ground has also been approved in light of future requirements (Vivekanand Gurlhosur, Wasif Quadri and Dohare, 2020).

Circular Economy: A Public-Private Partnership (PPP) Model in Indore

According to Kirchherr, Reike and Hekkert (2017), the Circular Economy has been defined as those actions that replace the end-of-life concepts by reducing, recycling and recovering materials in production, distribution and consumption processes. In February 2022 the 'lighthouse plant' was established by Indore Municipal Corporation (IMC) and Indo Enviro Integrated Solutions Limited (IEISL) under the Public-Private Partnership (PPP) model. It contributes to the waste-to-wealth initiative's twin goals of zero waste and a circular economy. This bio-CNG plant will be built to produce 17 to 18 metric tons of compressed biogas (CBG) as well as high-quality organic manure of 100 metric tons per day. It is founded on zero-waste models. A completely automated pre-treatment plant and separation hammer mill technology for preparing bio-slurry feed to power digesters are two innovative features of the project. Furthermore, The Continuous Stirred Tank Reactor (CSTR) technique is used in anaerobic digesters using agitators. In addition to achieving high-quality bio-CNG fuel recovery from raw biogas, vacuum pressure swing adsorption (VPSA) technology was employed (Municipal Solid Waste Management in India-A Compendium Report, 2022).

Conclusion

The aim of this study was to comprehensively investigate and gain a thorough understanding of the existing scenario of solid waste management in Indore City. The study reveals that India faces significant challenges and issues in solid waste storage, segregation, infrastructure, disposal, technology selection, and the need for trained personnel in waste management. However, India should prioritize a decentralized waste management system, focusing on organic waste for compost and biogas generation and inorganic waste for refuse-derived fuel, and establishing incineration processes at both central and decentralized levels.

The literature survey reveals that 100% waste source segregation, door-to-door collection and public awareness outline the benchmarks for success in Indore's waste management as per Swachh Survekshan's results in August 2020. It identified that composting and bio-methanation are considered the most suitable disposal methods for reducing waste at present in Indore. The incineration method of disposal is found inappropriate because of its negative impact on the environment, production of toxic fly ash, harm to public health, and high expense.

The study also shows that key organizational activities under public affairs that contributed to Indore's climb to the top of the cleanliness ranking were change management, corporate social responsibility, employee communications, external communications, and stakeholder management. The current solid waste management system in Indore has been found to be more in line with the Integrated Sustainable Waste Management System (ISWM) Model. Hence, for future practices or waste management systems, the ORWARE (Organic Waste Research) Model can be adopted for organic waste management. Also, adding a life cycle assessment (LCA) to future waste management systems will make a great contribution towards waste recovery, reuse, recycling and disposal.

It is concluded that community involvement is a necessity to replicate the Indore waste management model. It was also found that as long as the local governing bodies are dedicated to it, door-to-door collection of segregated waste is achievable in every city, town, and hamlet in India. Therefore, the practice of stakeholder engagement should be reinforced and the Indore Municipal Corporation (IMC)should develop a thorough strategic plan for successful stakeholder engagement in order to maintain its top ranking.

Municipal solid waste has a composition of 41% wet waste, which is sent further to composting plants for disposal that are at a distance from the urban local bodies (ULB)

boundaries or the site of waste generation, which increases the transportation cost, embodied energy, carbon footprint, and manpower as well in handling and transferring of waste from one place to another. Therefore, it is clear that there is a need to study and evolve the infrastructure requirements for wet waste disposal on-site in large-scale residential, commercial, and industrial complexes in order to reduce heavy loads on recycling plants and to reduce embodied energy and carbon footprint in long-distance transportation. This particular future research will be a great contribution to recycling waste on-site for large and medium-scale sources of waste in mega-cities like Delhi, Mumbai, Kolkata and others in developing nations.

References

Abou Najm, M., El-Fadel, M., Ayoub, G., El-Taha, M. & Al-Awar, F. (2002) An optimisation model for regional integrated solid waste management I. Model formulation, *Waste Management and Research*, 20(1), pp. 37–45. Available at: https://doi.org/10.1177/0734242x0202000105.

Agrawal, M.A. (2017) Solid Waste Management of Indore City: A Review, *International Research Journal of Engineering and Technology* [Preprint]. Available at: www.irjet.net.

Alappuzha (2021) *WASTE -WISE CITIES, Best practices in municipal solid waste management Waste-Wise Cities, A NITI Aayog-CSE survey 28 cities. Multiple initiatives*. Available at: www.cseindia.org.

Ayub, S., Singh, R.P., Yadav, D. & Siddiqui, A.A. (2014) Status and Challenges in Solid Waste Management: A case study of Aligarh City, 1(4), pp. 20–24. Available at: http://www.krishisanskriti.org/jceet.html.

Bhoyar, S.P., Dusad, S., Shrivastava, R., Mishra, S., Gupta, N. & Rao, A.B. (2014) Understanding the Impact of Lifestyle on Individual Carbon-footprint, *Procedia – Social and Behavioral Sciences*, 133, pp. 47–60. Available at: https://doi.org/10.1016/j.sbspro.2014.04.168.

Bosompem, C., Stemn, E. & Fei-Baffoe, B. (2016) Multi-criteria GIS-based siting of transfer station for municipal solid waste: The case of Kumasi Metropolitan Area, Ghana, *Waste Management and Research*, 34(10), pp. 1054–1063. Available at: https://doi.org/10.1177/0734242X16658363.

Chanakya, H.N., Ramachandra, T. V. & Vijayachamundeeswari, M. (2007) Resource recovery potential from secondary components of segregated municipal solid wastes, *Environmental Monitoring and Assessment*, 135(1–3), pp. 119–127. Available at: https://doi.org/10.1007/s10661-007-9712-4.

Chang, N.-B. & Lin, Y.T. (1997) An analysis of recycling impacts on solid waste generation by time series intervention modeling, *Resources, Conservation and Recycling*.

Cui, L., Chen, L.R., Li, Y.P., Huang, G.H., Li, W. & Xie, Y.L. (2011) An interval-based regret-analysis method for identifying long-term municipal solid waste management policy under uncertainty, *Journal of Environmental Management*, 92(6), pp. 1484–1494. Available at: https://doi.org/10.1016/j.jenvman.2010.12.006.

Dalemo, M., Sonesson, U., Björklund, A., Mingarini, K., Frostell, B., Jönsson, H., Nybrant, T., Sundqvist, J. & Thyselius, T. (1997) ORWARE—A simulation model for organic waste handling systems, Part 1: Model description , *Resources, Conservation and Recycling*, 21(1), pp. 17-37, Available at: https://doi.org/https://doi.org/10.1016/S0921-3449(97)00020-7.

Eriksson, O. & Bisaillon, M. (2011) Multiple system modelling of waste management, *Waste Management*, 31(12), pp. 2620–2630. Available at: https://doi.org/10.1016/j.wasman.2011.07.007.

Eriksson, O., Frostell, B., Björ, A., Assefa, G., Sundqvist, J.-O., Granath, J., Carlsson, M., Baky, A. & Thyselius, L. (2002) *ORWARE-a simulation tool for waste management*. Available at: www.elsevier.com/locate/resconrec.

Eriksson, O., Reich, M.C., Frostell, B., Björklund, A., Assefa, G., Sundqvist, J.O., Granath, J., Baky, A. & Thyselius, L. (2005) Municipal solid waste management from a systems

perspective, in *Journal of Cleaner Production*. Elsevier Ltd, pp. 241–252. Available at: https://doi.org/10.1016/j.jclepro.2004.02.018.

De Feo, G. & De Gisi, S. (2010) Domestic separation and collection of municipal solid waste: Opinion and awareness of citizens and workers, *Sustainability*, 2(5), pp. 1297–1326. Available at: https://doi.org/10.3390/su2051297.

Ghose, M.K., Dikshit, A.K. & Sharma, S.K. (2006) A GIS based transportation model for solid waste disposal - A case study on Asansol municipality, *Waste Management*, 26(11), pp. 1287–1293. Available at: https://doi.org/10.1016/j.wasman.2005.09.022.

Guerrero, L.A., Maas, G. & Hogland, W. (2013) Solid waste management challenges for cities in developing countries, *Waste Management*, 33(1), pp. 220–232. Available at: https://doi.org/10.1016/j.wasman.2012.09.008.

Gupta, N., Yadav, K.K. & Kumar, V. (2015) A review on current status of municipal solid waste management in India, *Journal of Environmental Sciences (China)*. Chinese Academy of Sciences, pp. 206–217. Available at: https://doi.org/10.1016/j.jes.2015.01.034.

Hemmelmayr, V.C., Doerner, K.F., Hartl, R.F. & Vigo, D. (2014) Models and algorithms for the integrated planning of bin allocation and vehicle routing in solid waste management, *Transportation Science*, 48(1), pp. 103–120. Available at: https://doi.org/10.1287/trsc.2013.0459.

Hosono, T. & Aoyagi, K. (2018) Effectiveness of interventions to induce waste segregation by households: evidence from a randomized controlled trial in Mozambique, *Journal of Material Cycles and Waste Management*, 20(2), pp. 1143–1153. Available at: https://doi.org/10.1007/s10163-017-0677-2.

ISO 14040 (1997) Environmental Management—Life Cycle Assessment—Principles and Framework *(ISO 14040:1997)*.

Jadon, M. (2020) Urban Mining and Sustainable Waste Management. *Springer Singapore*. Available at: https://doi.org/10.1007/978-981-15-0532-4.

Jain, D., Derashri, H. & Jain, H. (2022) A Study of Solid Waste Management in Indore and a Potential Solution to Treat Incineration Bound Waste, *International Journal of Innovative Research in Technology*, Available at: https://ijirt.org/

Joshi, R. & Ahmed, S. (2016) Status and challenges of municipal solid waste management in India: A review, *Cogent Environmental Science*. Taylor and Francis Ltd. Available at: https://doi.org/10.1080/23311843.2016.1139434.

Kaushal, R.K., Chabukdhara, M. & Varghese, G.K. (2012) Municipal Solid Waste Management in India-Current State and Future Challenges: A Review, *Article in International Journal of Engineering Science and Technology*. Available at: https://www.researchgate.net/publication/233894305.

Kirchherr, J., Reike, D. & Hekkert, M. (2017) Conceptualizing the circular economy: An analysis of 114 definitions, *Resources, Conservation and Recycling*. Elsevier B.V., pp. 221–232. Available at: https://doi.org/10.1016/j.resconrec.2017.09.005.

Kumar, S., Smith, S.R., Fowler, G., Velis, C., Kumar, S.J., Arya, S., Rena, Kumar, R. & Cheeseman, C. (2017) Challenges and opportunities associated with waste management in India, *Royal Society Open Science*. Royal Society. Available at: https://doi.org/10.1098/rsos.160764.

Lamond, J., Bhattacharya, N. & Bloch, R. (2012) The role of solid waste management as a response to urban flood risk in developing countries, a case study analysis, *WIT Transactions on Ecology and the Environment*, 159, pp. 193–204. Available at: https://doi.org/10.2495/FRIAR120161.

McDougall, F.R., White, P.R., Franke, M. & Hindle, P. (2001) Integrated Solid Waste Management: A Life Cycle Inventory, *Wiley*. Available at: https://doi.org/10.1002/9780470999677.fmatter.

Minghua, Z., Xiumin, F., Rovetta, A., Qichang, H., Vicentini, F., Bingkai, L., Giusti, A. & Yi, L. (2009) Municipal solid waste management in Pudong New Area, China, *Waste Management*, 29(3), pp. 1227–1233. Available at:

https://doi.org/10.1016/j.wasman.2008.07.016.
Mor, S., Ravindra, K., De Visscher, A., Dahiya, R.P. & Chandra, A. (2006) Municipal solid waste characterization and its assessment for potential methane generation: A case study, *Science of the Total Environment*, 371(1–3), pp. 1–10. Available at: https://doi.org/10.1016/j.scitotenv.2006.04.014.
Morrissey, A.J. & Browne, J. (2004) Waste management models and their application to sustainable waste management, in *Waste Management*, pp. 297–308. Available at: https://doi.org/10.1016/j.wasman.2003.09.005.
Municipal Solid Waste Management in India-A Compendium Report (2022), *International Centre for Environment Audit and Sustainable Development (ICED),* Jaipur, India In Collaboration With, n.d.
Nidugala, G.K. & Pant, A. (2017) Cleanest cities in India 2017: Indore's meteoric rise to no. 1 spot, *Journal of Public Affairs*, 17(4). Available at: https://doi.org/10.1002/pa.1674.
Paul, B. & Paul, D. (2021) 'Comparative analysis of municipal solid waste management in Kochi and Indore', *Nature Environment and Pollution Technology*, 20(3), pp. 1339–1345. Available at: https://doi.org/10.46488/NEPT.2021.V20I03.047.
Pires, A., Martinho, G., Rodrigues, S. & Gomes, M.I. (2018) Sustainable Solid Waste Collection and Management, *Springer International Publishing.* Available at: https://doi.org/10.1007/978-3-319-93200-2.
PWC (2017), Waste management in India—shifting gears. Available at: http://www.indiaenvironmentportal.org.in/files/file/waste-management-in-india-shifting-gears.pdf (Accessed: 11 November 2023).
Ramachandra, T. V. & Bachamanda, S. (2007) Environmental audit of Municipal Solid Waste Management, *International Journal of Environmental Technology and Management*, 7(3–4), pp. 369–391. Available at: https://doi.org/10.1504/IJETM.2007.015152.
Rasmeet, S. (2021) Municipal solid waste management in the City of Indore- A case study, *Journal of Civil Engineering and Environmental Sciences*, pp. 008–017. Available at: https://doi.org/10.17352/2455-488x.000039.
Rodić, L. & Wilson, D.C. (2017) Resolving governance issues to achieve priority sustainable development goals related to solid waste management in developing countries, *Sustainability (Switzerland)*, 9(3). Available at: https://doi.org/10.3390/su9030404.
Saba, N., Balwan, W.K., Rasool, N. & Kour, S. (2022) Future Perspective for Utilization of Municipal Solid Waste (MSW) in India: A Review, *Scholars Academic Journal of Biosciences*, 10(9), pp. 199–204. Available at: https://doi.org/10.36347/sajb.2022.v10i09.001.
Sharma, K.D. & Jain, S. (2019) Overview of Municipal Solid Waste Generation, Composition, and Management in India, *Journal of Environmental Engineering*, 145(3). Available at: https://doi.org/10.1061/(asce)ee.1943-7870.0001490.
Singh, S. (2020) Solid Waste Management in Urban India: Imperatives for Improvement.
Smart City Indore: Solid Waste Management, Smart City Indore | Solid Waste Management. Available at: https://www.smartcityindore.org/solid-waste/ (Accessed: 10 July 2023).
Soni, A., Mittal, A. & Kapshe, M. (2017) Energy Intensity analysis of Indian manufacturing industries, *Resource-Efficient Technologies*, 3(3), pp. 353–357. Available at: https://doi.org/10.1016/j.reffit.2017.04.009.
Srivastava, V., Ismail, S.A., Singh, P. & Singh, R.P. (2015) Urban solid waste management in the developing world with emphasis on India: challenges and opportunities, *Reviews in Environmental Science and Biotechnology*. Kluwer Academic Publishers, pp. 317–337. Available at: https://doi.org/10.1007/s11157-014-9352-4.
Talyan, V., Dahiya, R.P. & Sreekrishnan, T.R. (2008) State of municipal solid waste management in Delhi, the capital of India, *Waste Management*, 28(7), pp. 1276–1287. Available at: https://doi.org/10.1016/j.wasman.2007.05.017.
Tchobanoglous, G., Theisen, H. and Vigil, S. (1993) Integrated solid waste management: Engineering Principles and Management Issues, *New York: McGraw-Hill.*

van de Klundert, A. & Anschütz, J. (2001) Integrated sustainable waste management—the concept; tools for decision-makers—experiences from the urban waste expertise programme (1995–2001). *WASTE*.

Vivekanand Gurlhosur, S., Wasif Quadri, M. & Dohare, D. (2020) *Municipal solid waste management of Indore: A review*. Available at: www.ecologyjournal.in.

Wilson, D.C., Velis, C.A. & Rodic, L. (2013) Integrated sustainable waste management in developing countries, *Proceedings of Institution of Civil Engineers: Waste and Resource Management*, 166(2), pp. 52–68. Available at: https://doi.org/10.1680/warm.12.00005.