

## Municipal Solid Waste Characterization and Management Assessment in Bhiwani City, Haryana, India

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### Abstract

Municipal solid waste generation has escalated due to urbanization and altering consumption habits, posing major urban waste management challenges. The study presents the status of municipal solid waste management in Bhiwani City, Haryana, with an emphasis on waste quantification, its composition, physico-chemical properties, and available collection, transportation, treatment, and disposal approaches. Primary data were collected through field survey and a short-term waste audit executed during 2024, followed by laboratory analysis of representative waste samples to evaluate pH of leachate, moisture content, bulk density, dry density, and calorific value. Secondary data were obtained from national regulatory guidelines, census data, and municipal records. During the study period, the per capita waste generation rate was determined to be 0.460 kg/person/day, corresponding to approximately 128 tonnes of solid waste produced in the city. The high moisture content (49%) and pH (4.5) in waste stream demonstrated the predominance of biodegradable organic fractions. The bulk density and dry density were determined as 311.52 kg/m<sup>3</sup> and 214.4 kg/m<sup>3</sup>, correspondingly, whereas the calorific value was determined as relatively low (870.23 cal/g). Field survey showed limited source segregation, unplanned bin placement, uncovered transportation services, open dumping, and minimal material recovery facilities. The results establish a baseline dataset for municipal solid waste management planning and highlight key areas requiring improvement for sustainable waste management.

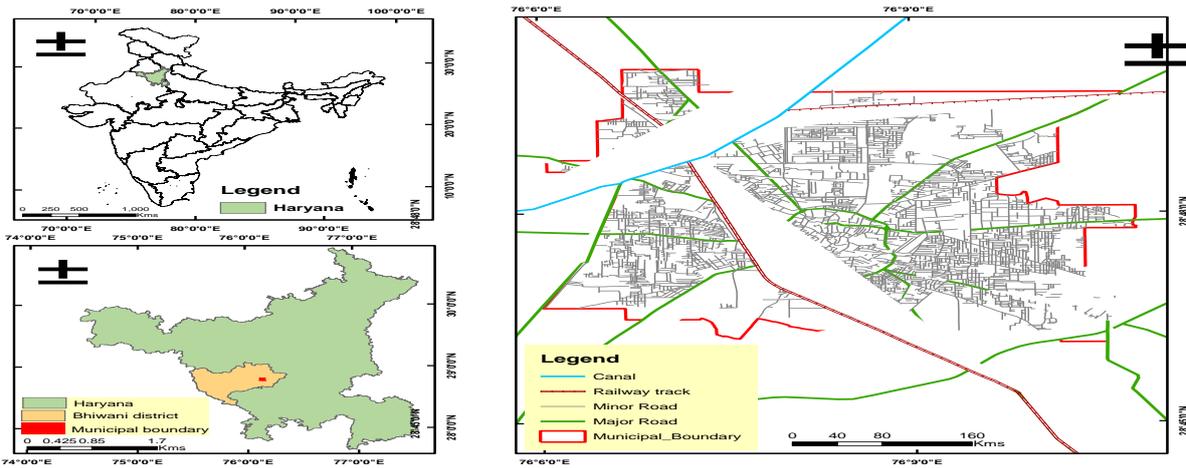
**Keywords:** municipal solid waste management, waste audit, waste composition, physico-chemical properties, material recovery facility, Bhiwani

### 1. Introduction

The enormous quantities of waste generated every day in India have made the management of municipal solid waste (MSW) a major public health, environmental and aesthetic concern (Yadav et al., 2016; Zand & Heir, 2019; Kiran et al., 2023). Rapid urbanization accelerates production and utilization of goods and services; therefore, societies continuously produce and discard solid materials consistently from industrial, institutional, agricultural, domestic, and commercial sectors (Deswal & Laura, 2018). By 2030, the urban population in India has been estimated to increase from 31% of the country's population to 40% (Ministry of Housing and Urban Affairs [MoHUA], 2018). India produces approximately 150,000 tonnes of municipal solid waste per day, and this amount keeps escalating as population grows (Centre for Science and Environment, 2023). The composition and classification of municipal solid waste differ significantly among municipalities. However, it comprises mainly the biodegradable and non-biodegradable fractions from organic and non-organic sources, respectively (Nanda & Berruti, 2021). The efficiency of collecting waste and treating waste in India is about 90 % and 27 %, respectively (Prajapati et al., 2021). Municipal solid waste management is an organized approach that includes various aspects involving on-site waste sorting, storage in containers, waste collection and transportation, treatment, waste-to-energy recovery, and final disposal to a landfill. In India, municipal solid waste is often disposed of in open dumps or low-lying locations without the required safety measures (Khanna & Chauhan, 2022). Thus, in Indian megacities, Municipal Solid Waste Management (MSWM) is among the most difficult environmental problems (Devi et al., 2016). The quantity and characteristics of solid wastes generated depend on the income level of the family, living standards, eating habits and lifestyles, and climatic conditions of the geographical area (Bhatia, 2007). Moreover, the majority of Indian cities, continue to collect mixed waste and dispose of it unscientifically, restricting the efficiency of waste treatment and resource recovery (Mani & Singh, 2016; Ahluwalia & Patel 2018; Kumar & Agrawal 2020). A deep analysis of the waste generation, current practices and strategies, and characterisation of solid waste is necessary for the planning of solid waste management facilities (Agrawal et al., 2005; Ramakrishna et al., 2016). Since most urban local bodies do not properly examine the waste management planning before proposing and putting the strategies and policies into practice, their condition has become worse (Kumar & Agrawal, 2020). Thus, without proper treatment, the valuable solid waste ultimately goes to non-scientific disposal sites. In view of this, the current study emphasizes on solid waste quantification, composition and its characterization, and management along with identification of associated challenges and shortcomings, and possible improvement measures for municipal solid waste management in Bhiwani.

### 2. Description of the study area

Bhiwani is a municipal council situated in the state of Haryana, India, had a population of 1,96,057 as per Census 2011. The city is situated approximately 285 km from the state capital Chandigarh and 128 km from national capital New Delhi, having latitude 28° 46' 48.00" N and longitude 76° 07' 48.00" E. The city had a population growth rate of 14.32% for 2001-2011 (Census, 2011). In the district, the average rainfall is 766 mm. Most precipitation occurs in August (150 mm). For the remaining year, the rainfall is low. Bhiwani is a rapidly developing medium-sized city, with increasing population and increased urban activities have significantly modified municipal solid waste generation and management methods. The semi-arid climate and poor annual rainfall affect the waste characteristics like moisture content, decomposition rate, and availability of appropriate waste treatment and disposal methods. The present study was conducted in 2024; the findings illustrate the prevailing municipal solid waste management conditions in Bhiwani City during the study period.



**Figure 1.** Location map of Bhiwani City

### 3. Materials and methods

#### 3.1 Data collection

##### 3.1.1 Estimation of population

Based on Census 2011 data, the population of study area for the reference year was projected using the geometric growth method. The annual population growth rate and estimated population was determined using the following equations.

$$\text{Annual growth rate (r)} = (P_{\text{final}}/P_{\text{initial}})^{1/n} - 1$$

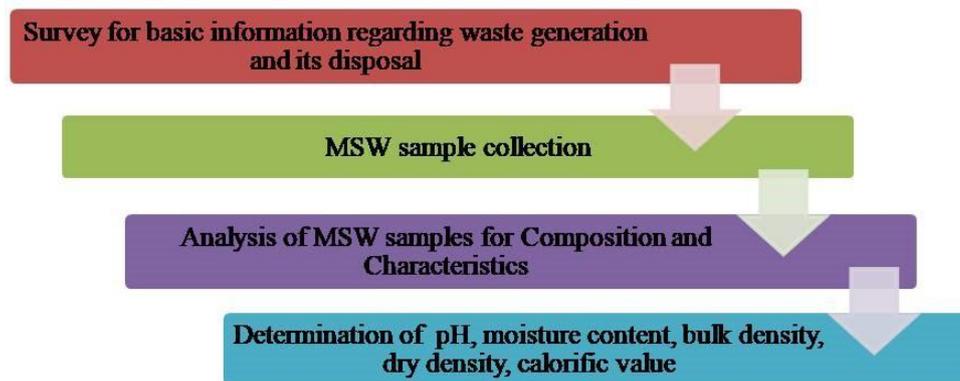
$$P_{\text{final}} = P_{\text{initial}} \times (1+r)^t$$

ated population,  $P_{\text{initial}}$  denotes population of base year,  $r$  denotes annual growth rate,  $n$  denotes number of years between initial and final population, and  $t$  denotes time period in years. The estimated population was used for estimation of solid waste generation during study period.

##### 3.1.2 Primary data

###### Field survey and waste audit

A field survey was carried out in the city to evaluate generation and management methods for municipal solid waste. A waste audit was conducted for one month period, in which waste was collected from households of the city. The collected samples were taken as representative samples of total waste generation in the city during the study period. The samples were sorted into different categories, weighed, and represented as the percentage by weight of the original sample size. The audit was done to quantify waste generation and evaluate its composition. The outline of waste audit is presented in Figure 2.



**Fig.2** Steps to conduct a waste audit

###### Per capita waste generation

Per capita waste generation (kg/person/day) was determined to evaluate the average daily waste generated per person using the formula:

$$\text{Per capita waste generation} = \text{Total waste generated} / \text{Total population}$$

##### 3.1.3 Secondary data

Secondary data were collected from municipal records of Municipal Council Bhiwani (MCB), Census of India 2011 reports, and national guidelines, rules and regulations associated with solid waste management enforced by Central Pollution Control Board (CPCB) and Ministry of Environment, Forest and Climate Change (MoEFCC). The data were utilized to collect information on existing solid waste management strategies, manpower, and regulatory provisions, and to assess compliance with Solid Waste Management Rules, 2016.

##### 3.2 Waste sample analysis in laboratory

Representative municipal solid waste samples collected in waste audit were analyzed in the laboratory to assess the physical and chemical characteristics.

- (a) *Moisture content*: Moisture content was determined by taking 100 g of mixed municipal solid waste sample in a pre-weighed petridish. The sample was dried in an oven at 105°C for 24 hours and cooled in a desiccator. The final weight was noted after drying and moisture content was calculated by using the following equation (CPHEEO, 2016; Kumar & Goel, 2009):

$$\text{Moisture Content (\%)} = \frac{\text{Wet weight} - \text{dry weight}}{\text{Wet weight}} \times 100$$

where, Wet weight is initial weight of sample before drying and Dry weight is weight of the sample after drying the sample.

- (b) *Bulk density*: The bulk density is determined as the ratio of the sample weight by volume of the vessel having sample without compaction (CPHEEO, 2016)

$$\gamma = \frac{W_2 - W_1}{V}$$

$\gamma$  is bulk density (Kg/m<sup>3</sup>), W<sub>1</sub> is weight of empty vessel, W<sub>2</sub> is weight of the vessel with the sample, V is volume of vessel (m<sup>3</sup>).

- (c) *Dry density*: Dry density was determined using bulk density and moisture content of mixed solid waste, by using the following equation.

$$\gamma_d = \frac{\gamma}{1+m}$$

$\gamma_d$  is dry density (Kg/m<sup>3</sup>),  $\gamma$  is bulk density of substance (Kg/m<sup>3</sup>), m is moisture content (%)

- (d) *pH determination*: for pH determination, a heterogeneous waste sample of 100 g was dried in an oven at 105°C for 24 hours and cooled in a desiccator. Distilled water was added to the sample in a 1:5 ratio (waste to water). After mixing, the sample was allowed to stand for 24 hours at room temperature for leachate extraction. The mixture was filtered and pH was measured with pH meter following the standard procedures (APHA, 2017).

- (e) *Calorific value*: The calorific value of waste samples was determined using a Metrex digital Bomb Calorimeter. Before performing sample analysis, the instrument was standardized with benzoic acid pellet to calculate the water equivalent. A representative sample of solid waste in pellet form was placed inside the crucible, ignited using a nichrome wire of 6cm and cotton thread (10 cm), and burned in an oxygen filled bomb at a pressure of 26 kg/cm<sup>2</sup>. The temperature difference was noted, and the calorific value was calculated using the equation:

$$W = \frac{H \cdot M + (CV_t + CV_w) \cdot T}{T}$$

$$CV = \frac{T \cdot W - (CV_t + CV_w) \cdot M}{M}$$

where, W is water equivalent in calories per degree centigrade, H is known calorific value of benzoic acid in cal/g, M is mass of sample in grams, CV is calorific value of thread, CV<sub>w</sub> is calorific value of ignition wire, T is final rise in temperature in degree Celsius, and CV<sub>s</sub> is calorific value of sample.

### Methodological framework

The overall methodological framework adopted for study, comprising of primary and secondary data collection, waste audit, laboratory analysis of waste samples, and monitoring of municipal solid waste management practices, is presented in Figure 3.

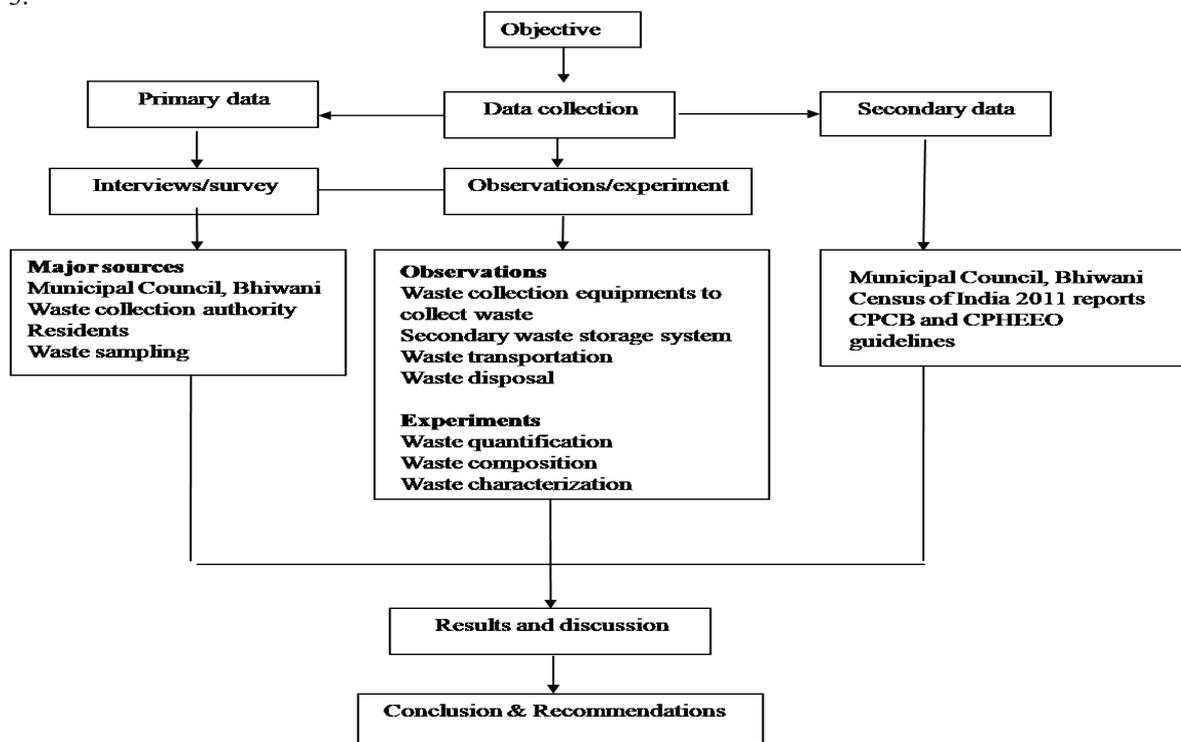


Figure 3. Flowchart of methodology adopted for study

## 4. Results and discussion

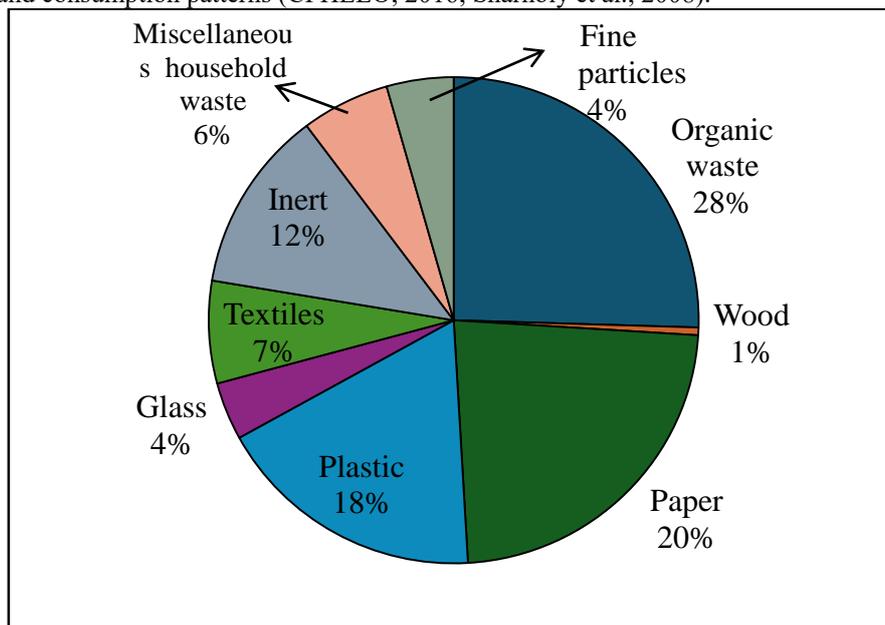
### 4.1 Sources and quantification of Municipal Solid Waste

Municipal solid waste in Bhiwani City was produced from multiple sources, including residential areas, commercial areas, educational institutions, hotels, restaurants, medical facilities, government offices, and street sweeping activities. Administratively, the city was divided into 31 municipal wards, all adding to the total waste produced.

On the basis of Census 2011 and annual population growth rate of 2.23%, the total population of Bhiwani City at the time of study was projected to be approximately 280,000 persons. The calculated per capita waste generation was 0.460 kg/person/day, resulting in a projected municipal solid waste generation of approximately 128 tonnes per day (TPD). The results were comparable with the reported range of medium-sized Indian cities, where per capita waste generation rate generally lies between 0.3 to 0.6 kg/person/day based on urbanization and income status (CPCB, 2020; Kaza et al., 2018).

### 4.2 Composition of Municipal Solid Waste

As a result of survey conducted in the city, the composition of municipal solid waste is shown in Figure 4. The waste stream was predominantly composed of organic waste (28%), including kitchen waste, food waste, and other biodegradable materials. A high proportion of organic waste has been observed in Indian municipal solid waste stream because of ineffective source segregation and consumption patterns (CPHEEO, 2016; Sharholy et al., 2008).



**Figure 4.** Composition of municipal solid waste in Bhiwani

Paper waste (20%) consisting of magazines, cardboard, paper bags, and packing materials, accounted for the second largest fraction of waste stream. The significant fraction of paper waste highlighted increased use of packaged products and developing commercial activities in the city. Plastic waste (18%) composed bottles, containers, plastic bags, and other types of plastic products, also constituted a considerable fraction of waste stream, illustrating increased use of plastic based items (CPCB, 2020; Kumar & Samadder, 2017). Textile waste (7%) included rags, discarded clothing, wool, carpets, threads, and ropes, whereas glass waste (4%) comprised bottles, broken glassware, and containers. Wood waste (1%), which accounted for a small fraction and included plywood, wooden packaging material etc. The inert proportion (12%) included stones, bricks, crockery, ceramics, dirt and Construction and Demolition (C&D) waste. Fine particles (4%) such as ash, silt were primarily generated from street sweeping activities and waste handling methods. Miscellaneous household waste (6%) included all types of household, car batteries, paint products, medicines, and non edible oils and fats. The comparatively high fraction of inert and fine particles showed the occurrence of mixed municipal solid waste, a trend also documented in other Indian cities (CPCB, 2020). The waste compositional analysis showed that a substantial quantity of municipal solid waste was composed of biodegradable and recyclable materials, reflecting the potential for composting and material recovery if efficient segregation practices were implemented.

### 4.3 Solid waste characteristics

The determination of composition and characteristics of waste is also an important aspect to figure out its potential environmental impacts on nature as well as humans (Verma & Tripathi, 2016; Alamgir et al., 2005). The physical and chemical characteristics of the city's solid waste are presented in Table 1. Bulk density and dry density analysis are physical properties, whereas, pH, moisture content, and calorific value are chemical properties of waste. pH is a vital factor to determine biodegradability and stability of waste for composting and biogas production (Policastro & Cesaro, 2023). The waste samples had the average pH of 4.5, which showed its acidic nature and a large fraction of organic content such as food waste and biodegradable materials. The moisture content of the waste was found to be 49%, showing the high amount of water in the waste stream. High moisture content in municipal solid waste results in lower calorific value, making it unsuitable for incineration without pre-treatment and drying and also increased transportation and collection costs. The bulk density and dry density was determined 311.52 kg/m<sup>3</sup> and 214.4 kg/m<sup>3</sup>, respectively. The density determines the storage and transportation requirements for solid waste management (CPHEEO, 2016). Transportation cost is increased by low bulk density and more

trips are required to carry the waste. Calorific value or energy content determines waste’s potential to recover Refuse-Derived Fuel (RDF) and its uses in power, cement, and waste-to-energy projects (Sharma & Jain, 2019). The low calorific value of 870.23 cal/g represented a waste stream mainly composed of organic matter and low energy combustible components.

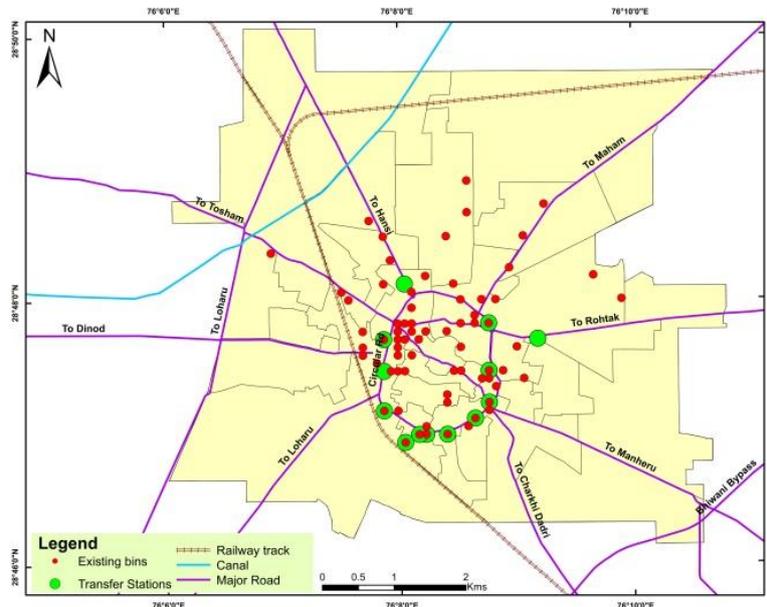
**Table 1** Physico-chemical properties of municipal solid waste

Parameters	Values
pH of waste leachate	4.5
Moisture content (%)	49
Bulk density (kg/m <sup>3</sup> )	311.52
Dry density (kg/m <sup>3</sup> )	214.4
Calorific value (cal/g)	870.23

The findings of the study showed that municipal solid waste management in Bhiwani City was dominated by a large fraction of biodegradable organic waste, a significant proportion of recyclable material, high moisture level, and low calorific value.. These attributes indicate that biological processing methods like composting and biomethanation are comparatively suitable than thermal waste to energy techniques (Tchobanoglous et al., 1993; Ahsan et al., 2014).

**4.4 Storage, Collection and Transportation of solid waste**

At the time of study, a total of 36 community bins were placed throughout the city to manage solid waste in commercial areas. Figure 5 depicts the spatial distribution of community bins in the city. Each bin had a capacity of 3 m<sup>3</sup> with a volume of approximately 3000 litres and could hold about 1000 kg of waste. Additionally, 13 transfer stations or secondary collection points were used for secondary waste storage. Similar multi-stage storage system have been observed in many medium-sized cities in developing nations, where transfer stations are often designated to minimize direct transport distances and improve operational logistics (Guerrero et al., 2013).



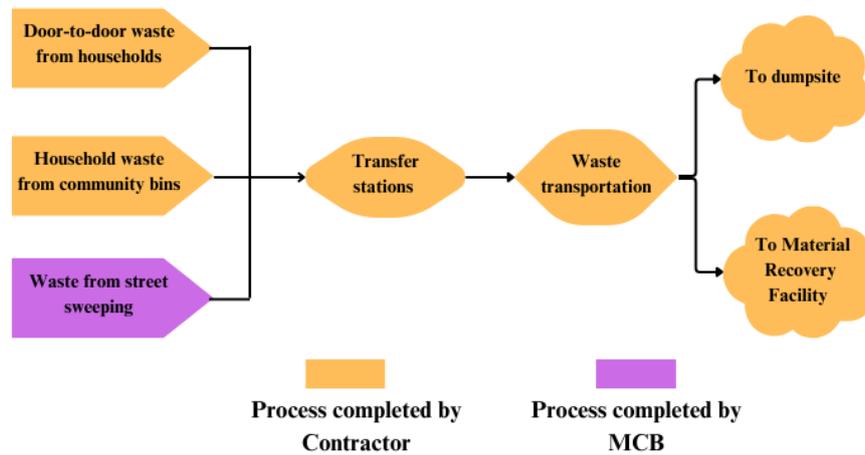
**Figure 5.** Location map of transfer stations and community bins

The waste collection operated in two phases; door to door collection and collection from community bins. Street sweeping was managed by the Municipal Council, Bhiwani (MCB) itself and a private agency Shree Shyam Waste Management Pvt. Ltd. was responsible to manage the waste from door to door collection and community bins. As per the MCB records, door to door facility for waste collection was operational throughout the city. However, field observations revealed that less populated areas in the outer city and some congested streets were not covered by the door-to-door pickup services. The waste collection systems in many developing cities have been shown to face such challenges because of similar service coverage deficiencies (Henry et al., 2006).

Auto tippers, dumper placers, tractor trolleys, loaders, and JCB machines were utilized to transport the waste from community bins and transfer stations to the dump site. A total of 84 vehicles (owned by MCB) were engaged in solid waste collection and transportation. These included 60 auto tipper, 14 tractor trolley, 4 JCB machine, 4 loader machine and 2 dumper placers. Tractor trolleys made 3-4 rounds per day, auto tippers 1 round and dumper placer made 4 rounds every day to the dumpsite. The waste handling capacities of a tractor trolley and dumper placer were approximately 1 ton and 2 tons, respectively. The flowchart of waste collection mechanism is shown in Figure 6. Figure 7 and 8 shows the waste transport by these vehicles. The waste was transported in multiple trips by tractor trolleys and dumper placers, which were uncovered on the top. During waste transportation, occasional spillage of waste was observed.

Construction and demolition (C&D) waste was not managed by a separate collection system during the study period. Instead, the waste was used to fill low lying areas or disposed of along roadsides. The mixing of C&D waste into municipal solid waste contributed to high proportion of inert material in the waste stream. Such practices of mixing C&D waste into municipal

solid waste hinders the collection, transportation and disposal planning, have been reported in many rapidly expanding cities (Wilson et al., 2015).



**Figure 6.** Municipal solid waste management in Bhiwani

Municipal Council, Bhiwani employed sanitary inspectors, supervisors, sweepers, and drivers for municipal solid waste management activities. Table 2 summarizes the manpower, included permanent and contractual both.

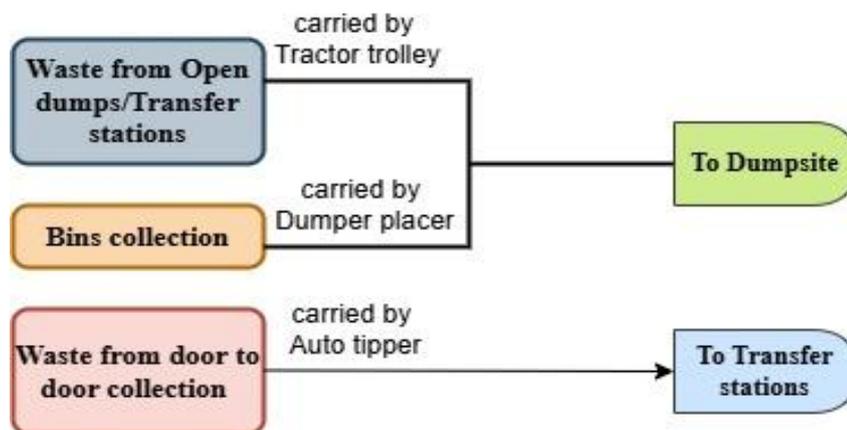
Table 2 Staff employed for waste management at MCB (2024)

Sr. No.	Post	Number	Working status	Working hours
1.	Sanitary Inspector	1	Permanent	-
2.	Supervisor	6	Permanent	-
3.	Sweepers	205+64	Permanent and Contractual	8
4.	Driver	12+60	Permanent and Contractual	8

Source- Municipal Council, Bhiwani



**Figure 7.** (a) Tractor trolley collecting waste from a transfer station, (b) Dumper placer holding community bins, (c) Auto tipper

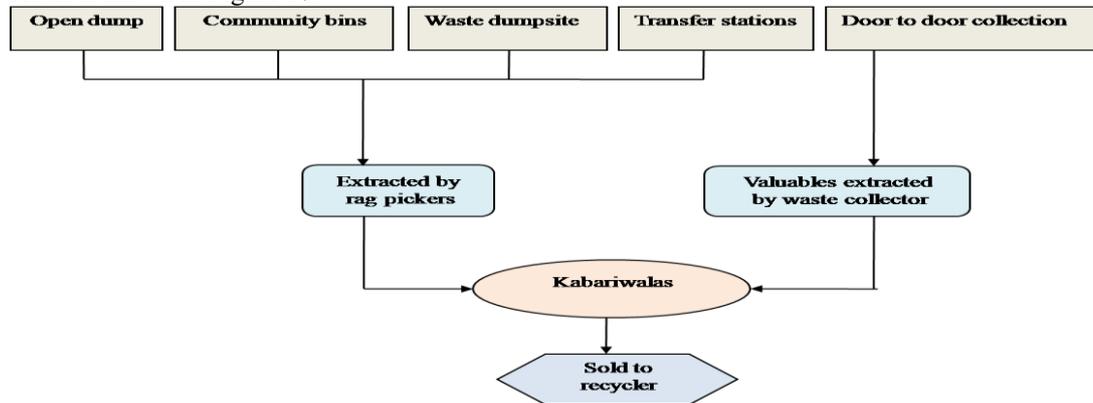


**Figure 8.** Transport of municipal solid waste

During the study period, these field observations showed the operational framework and coverage of storage, collection, and transportation system in Bhiwani City.

### 4.5 Waste Processing and Disposal Material Recovery Facility (MRF)

Municipal solid waste processing in Bhiwani city during the study period was largely based on manual sorting. One Material Recovery Facility (MRF) was operated by the Municipal Council and was located along Dadri Road adjacent to the dumpsite. As defined under the Solid Waste Management Rules, 2016, Urban Local Bodies (ULBs) may temporarily store solid waste at a material recovery facility prior to disposal. At this facility, the informal sector played the important role in waste management system. Ragpickers and workers of private management agency manually separated valuable and recyclable materials from mixed waste at the MRF center. The recyclable materials such as paper, plastic, and metal were retained and sold to recyclers, while remaining mixed waste was dumped to the dumpsite. The flowchart of waste sorted by the informal sector is shown in Figure 10.



**Figure 10.** Waste segregation by informal sector

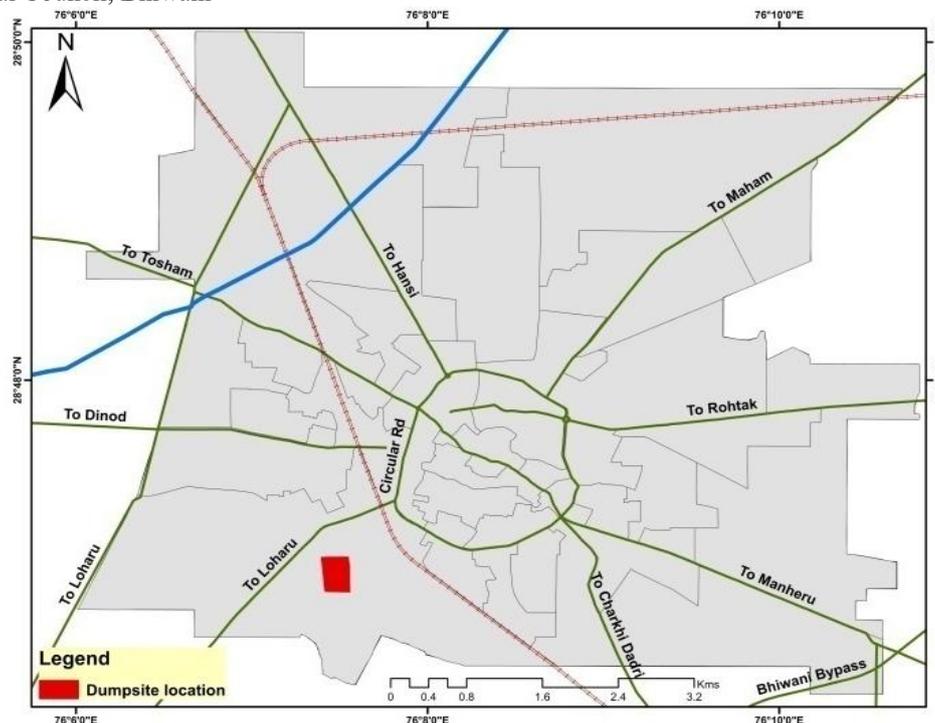
#### Disposal of solid waste

The dumping site was located along Dadri road, Bhiwani, at longitude 76°07'27.4"E and latitude 28°46'49.5"N. It was approximately 5 km from the city bus stand and 1.5 km away from village Haluwas. The total area of the site was approximately 24 acres or 97,124.554 square meters. Shree Shyam Waste Management Pvt. Ltd., a private company managed the municipal solid waste treatment operations at the site. Table 3 lists the specifics of the employees that work at the disposal site during study period. Figure 11 and 12 shows the dumpsite location and flow of solid waste and its processing, respectively.

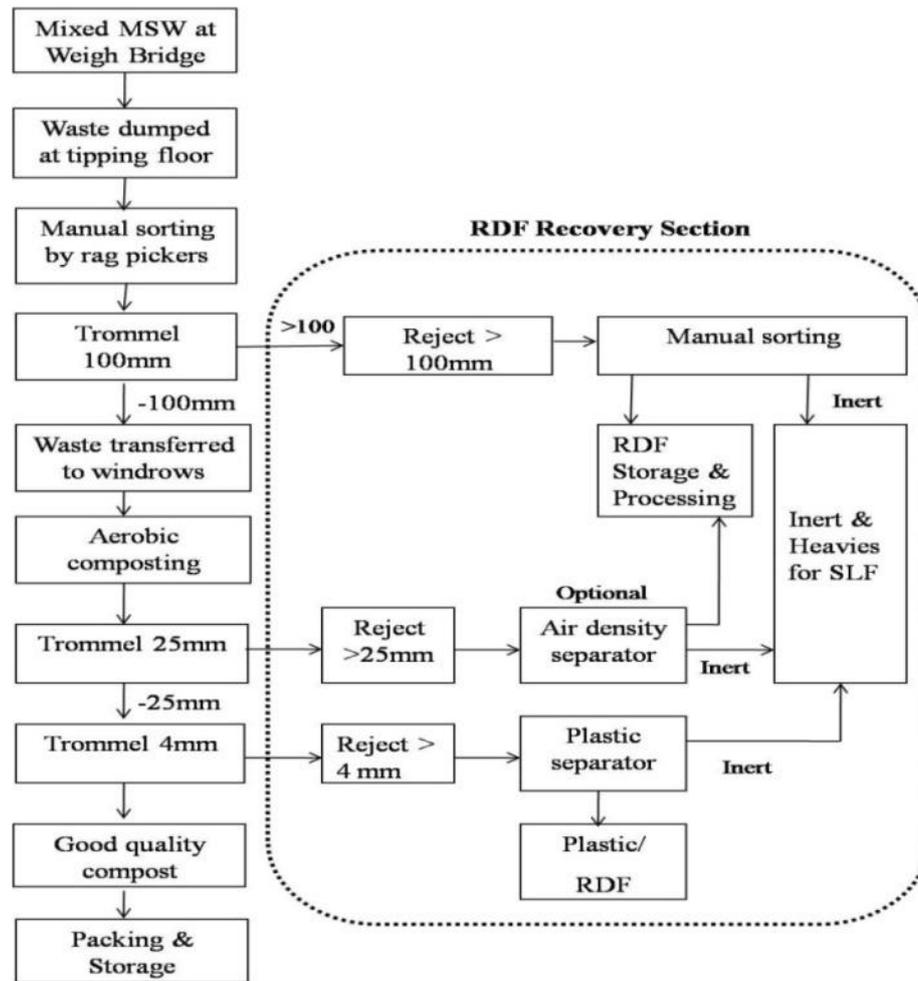
**Table 3** Working staff employed at the dumpsite (2024)

Post	Processing site incharge	Supervisor	Driver	Helper	Data operator	JCB operator
Number	1	2	3	12	2	1

Source- Municipal Council, Bhiwani



**Figure 11.** Location map of dumpsite in Bhiwani



**Fig.12** Process for MSWM in Bhiwani city

**4.6 Biomedical Waste**

During the study period (2024), a total of 190 health care facilities (HCFs), including hospitals, dispensaries and nursing homes were operational in the city and altogether generated about 270 kg/day of biomedical waste, as documented by Municipal Council, Bhiwani. The biomedical waste plant was located near village Hetampura, which was about 28 km away from city bus stand. Following the Biomedical Waste Management Rules 2016, hospitals and other healthcare facilities used four color-coded plastic bags-yellow, red, and blue, for segregation of biomedical waste depending on the type of waste. The segregation practices have been documented as mandatory to reduce health concerns and increasing treatment efficacy of biomedical waste management systems (Datta et al., 2018, Windfeld & Brooks, 2015). Maruti Biomedical Waste Management Company had been appointed for collection and management of biomedical waste. The company had employed 18 workers and 3 vehicles to collect medical waste. The biomedical waste was transported by specialized vehicles owned by the authorized processing agency. The field observations showed discrepancies in monitoring and enforcement of biomedical waste management approaches, especially in smaller healthcare facilities. During the study period, the biomedical waste management was found to be partially compliant with recommended guidelines of Biomedical Waste Management Rules, 2016, with segregation reported in larger healthcare facilities but irregular practices in smaller facilities.

**4.7 Shortcomings of municipal solid waste management**

The analysis of waste management systems is incomplete without defining the key drawbacks or limitations that affect the operational performance and sustainability. The major system level shortcomings identified during the study are discussed in this section. The waste characteristics showed that the waste was not suitable for incineration as the moisture level was high and calculated calorific value was below the threshold of 1500 cal/g for waste to energy process (CPCB, 2000). The segregation of waste at source was not complied with, leading to mixed waste streams and decreased the effectiveness of collection and transportation practices. Open waste burning was widely observed at many places causing public health and environmental concerns. The inadequate number of community bins and their unscientific placement further result into open dumping in public areas. Waste transportation was done in completely uncovered vehicles, causing waste spillage on the roads. The transfer stations were observed as open secondary waste storage system; and increased the multiple handling of waste,resulting in environmental contamination. Many community bins and transfer stations were designated near to schools, water bodies, and hospitals, reflecting no consideration of regulatory compliance while planning.

The efficiency of MRF was limited due to zero source segregation and absence of mechanical sorting. As a result, a significant fraction of recyclables and biodegradable waste skipped treatment and reached to the dumpsite without processing. The resource recovery was mainly informal and opportunistic instead of systematic, as documented by the limited role of formal waste treatment facilities. The dependence on informal recovery activities, although supporting waste recycling, usually leads

to variable recovery rates and occupational health risks to waste pickers (Velis et al., 2012). Additionally, no safety measures and protective equipments for sanitation workers were provided, causing occupational health concerns to them. The field survey demonstrated that the dumpsite was lacking vital components of an engineered sanitary landfill, like bottom liners, surface water drainage, leachate collection system, and landfill gas recovery system. Waste was dumped immediately on the ground without compaction and daily covering of soil. Therefore, a significant amounts of legacy waste had accumulated over time. The continued open dumping caused risks to the environment and public health, such as leachate infiltrate into the soil, breeding diseases vectors, and continuously odors and greenhouse gases emissions from dumpsite.

### 5. Conclusion

The study evaluated municipal solid waste and biomedical waste management strategies in Bhiwani City to assess the efficiency of management systems and their compliance with regulatory guidelines. The outcomes demonstrated that regulatory waste management practices were in place, but system effectiveness and environmental sustainability was limited by operational inadequacies related to segregation, treatment, and disposal. The analysis illustrated that the observed management challenges in the city were mainly associated with improper implementation rather than the absence of policies or infrastructure. Bhiwani city's waste treatment and disposal facility during the study period was characterized by low treatment capacity, dependence on informal recycling, and unscientific waste disposal methods. These factors considerably limited the resource recovery potential and increased the possibility of environmental risks. Overall, the study suggests that regulatory compliance with the Solid Waste Management Rules, 2016 and Biomedical Waste Management Rules, 2016 depends on improving operational strategies, promoting stakeholders interaction, and adopting region specific solutions. The results contribute to better understanding of waste management problems in medium-sized Indian cities and may support the municipal authorities in planning and decision-making processes.

### 6. Recommendations

To improve the solid waste management efficiency in Bhiwani City, source segregation should be effectively implemented to enhance collection and transportation efficiency. To avoid multiple waste handling, secondary waste storage points should either be upscaled with covered infrastructure or minimized in municipal solid waste management planning. Instead, large capacity vehicles must be utilized to minimize repeated waste handling stages during waste transportation. Waste transportation vehicles should be properly covered to prevent spillage during transportation and related environmental risks. Community bins should be installed on cemented floors to improve hygiene and prevent leachate infiltration. Furthermore, the effective treatment practices reduce unscientific waste disposal and provides a sustainable approach to municipal solid waste management problems, government support to improve waste treatment facilities should be enhanced.

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