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Assessment of Current Waste Management Practices, Illegal Dump Site Occurrence, and Solid Waste Composition in East Zone of Bruhat Bengaluru Mahanagara Palike (BBMP), Bangalore: A Geospatial Perspective

Salma Sultana[1,*], M. Inayathulla[1]
[1]Department of Civil Engineering, Bangalore University, Jnana Bharathi, Bengaluru-560056, India

Abstract
Rapid urbanization in Bangalore has led to increasing challenges in managing Municipal Solid Waste (MSW), particularly in East Zone of Bruhat Bengaluru Mahanagara Palike (BBMP), Bangalore. This study presents an assessment of current Solid Waste Management (SWM) practices, the occurrence of illegal dump sites, and the physical and chemical composition of solid waste at selected illegal dump sites. The illegal waste dumping in unauthorized locations has become a critical issue in BMMP, affecting both public health and environmental sustainability. Ten illegal dump sites were identified through systematic field survey and mapped using Global Positioning System (GPS) and Geo Informatics System (GIS) tools. This spatial analysis revealed dumping usually occurs in areas with poor waste collection infrastructure, high population density, and mixed land use patterns. Waste samples were collected from each selected site and subjected to both physical segregation and chemical analysis. Physical characterization revealed that organic waste was the dominant fraction, followed by plastic and glass waste. Chemical analysis showed an acidic pH of 4.59, a moisture content of 69.3% and a calorific value of 2900 cal/g, suggesting limited potential for energy recovery. Total volatile solids were recorded at 83.8%, indicating high proportion of decomposable organic material. The findings suggest that composting is suitable for organic waste due to its high moisture content and volatile solids. The assessment of BBMP's current waste management practices revealed several gaps in the enforcement of segregation rules, irregular door-to –door collection, and insufficient monitoring of illegal dumping. The study recommends the use of GIS-based surveillance tools, strengthening decentralized waste processing, and periodic monitoring of waste composition for effective policy formulation. This research provides essential insights to support scientific, data-driven planning for sustainable waste management in urban Bangalore.
Keywords: *Illegal waste dumping, Solid waste characterization, GIS mapping, Moisture content, Calorific value, Total volatile solids*

1. INTRODUCTION

The trends of unsustainable production and consumption have continued to accelerate in recent years, leading to a significant rise in waste generation globally. As per World Bank report, global Municipal Solid waste (MSW) generation in the year 2020 which was about 2.24 billion tonnes is expected to be 3.88 billion tones by 2050, making nearly a 70% increase [1]. Waste related diseases continues to pose serious public health issues, especially in low- and middle-income countries, where million people die each year from diseases linked to improper waste disposal, poor sanitation, and environmental contamination [2].

Solid waste management is a critical challenge for rapidly urbanizing cities, especially in developing countries where population growth, urban sprawl, and changing consumption patterns have led to sharp increase in solid waste generation. Though there is rapid economic expansion, the effective management of waste has remained difficult [3]. Bengaluru the capital city of Karnataka, which is one of the largest metropolitan areas, generates approximately 6000 metric tonnes of solid waste daily [4]. The Bruhat Bengaluru Mahanagara Palike (BBMP), which is the responsible body for waste collection, transportation, and treatment, facing significant operational and infrastructural challenges in this increasing volume of solid waste. Despite various waste management policies and infrastructural improvements, a substantial proportion of waste remains uncontrolled, resulting in the proliferation of illegal dumping sites across the city [5].

Municipal solid waste (MSW) in Bengaluru consists of approximately 64% organic waste, 28% dry recyclables (plastics, paper, and metals), and 3% domestic hazardous waste, and 6% inert waste [6]. While BBMP operates 7 wet waste processing plants with a combined capacity of 1570 tons per day (TPD), along with 13 bio-methanation plants with capacity of 65 TPD and a sanitary landfill having 3000 TPD capacity, the city's processing capacity remains insufficient to handle the total waste generated. Hence, a significant portion of waste remains uncollected due to logistical constraints and poor segregation at the source leading to illegal dumping.

Illegal dumping not only degrades environment but also imposes significant economic and social costs [7]. The accumulation of organic waste in open areas releases methane and other greenhouse gases, contributing to climate change and poor air quality [8]. Leachate from improperly disposed waste seeps into the soil, contaminating ground water and affecting local biodiversity [9]. The presence of plastic and hazardous waste further increases the toxicity of the environment, posing health risks to nearby residents. Moreover, the visual pollution and odour from these dump sites reduce the aesthetic value of urban space and affect property values [10].

The BBMP, known for its high population density, commercial activity, has witnessed a rise in illegal dumping along road side and in vacant plots. Although BBMP is working towards sustainable management of solid waste, community is still facing waste management issues due to inadequate waste collection infrastructure, poor waste segregation practices, gaps in monitoring and enforcement, and lack of awareness among residents and commercial establishments [11]. Also, the main reason for illegal dumping is, as truck collectors are not entering the locality early morning, so many households are not able to handover the waste to truck collector, leading to illegal dumping at nights and early morning. As a result, large amount of organic waste, plastics, and hazardous materials are improperly discarded, leading to soil and water contamination, air pollution, and increased risk for the local population [12].

The main objective of this study is to (i) describe and explain current waste management system and how effectively BBMP is working in making Bangalore cleaner, also the status of present landfill site is discussed, (ii) A pilot study is conducted on east zone of BBMP by locating the illegal dumpsites using hand held GPS and composition of the waste is determined by collecting solid waste from identified and selected illegal dumps.

2. MATERIALS AND METHOD

2.1 Study area: In the year 2007 BBMP was formed. BBMP is the municipal governing body which is responsible for administration, planning and providing essential civic services such as waste management, sanitation, public health and infrastructure development. It is the fourth largest municipal corporation of India which is responsible for population of 8.4 million as per 2011 census [13]. The city experiences tropically savanna climate. The region enjoys moderate temperature throughout the year, with summer temperature ranging between 28 °C to 36 °C, while in winter season temperature can go as low as around 15 °C to 20 °C. The city receives moderate to heavy rainfall, averaging about 900-1000 mm annually. These climatic conditions play a vital role in the generation, collection and management of MSW. Fig. 1 shows the study area. BBMP is the firm which is responsible for solid waste management in Bangalore city. It is divided into eight administrative zones, with East-Zone being dynamic and most urbanized part of the city. This zone comprises a mixture of residential, commercial, and semi-industrial developments, making it a significant contributor to municipal solid waste (MSW), with an estimated generation of approximately 800 TPD [14]. Due to these factors, this zone has been selected for the present study.

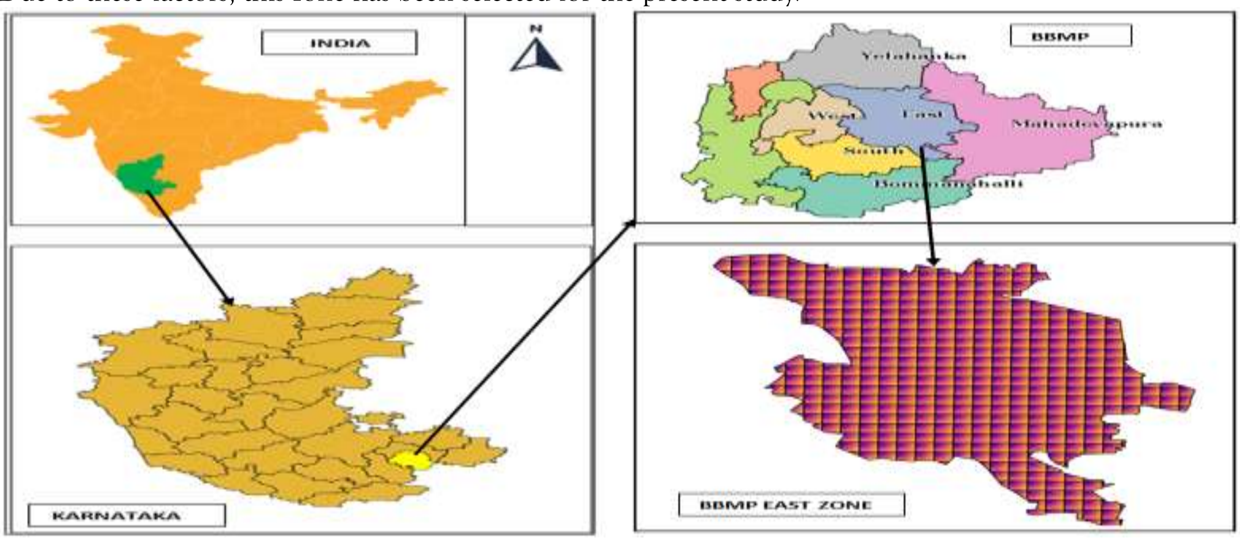

Fig. 1 Study Area: East Zone of BBMP

2.2 **Current solid waste management and treatment system:** India generates about 1,70,339 TPD of solid waste, of which only about 70-75% is collected and less than 30% is scientifically processed [15]. The current waste management approach is governed under the Solid Waste Management Rules, 2016, mandates the separation of waste into wet, dry, and hazardous/sanitary categories at the source. The primary collection of waste is done (i) from doorsteps of households, shops, small commercial establishments and offices (ii) from entry gate or any designated location on the ground floor, multi stored buildings or apartments, residential, commercial and institutional complexes (iii) from specified places of slums. The wet waste from domestic generators is collected everyday by the auto trippers. Then it is transferred to compactors at the transfer point with the help of hook loader. The dry waste is collected twice or thrice a week. It is separated into recyclable and non – recyclable, non – biodegradable waste and sent to dry waste collection centers for further processing [16].

According to the manifesto [17], BBMP can process only 2100 tonnes of solid waste on daily basis, while the waste generation rate has reached 6000 metric tonnes and likely to rise in upcoming years. The wet and mixed waste processing plants are located at Kannahalli having 500 TPD of capacity to treat solid waste, Seegihalli with 200 TPD, Doddabidarakallu with 200 TPD, Lingaderenahalli with 200 TPD, Subrayanpalya with 200 TPD, Chikkanagamangala with 500 TPD and Karnataka Composting Development Corporation Ltd (KCDC) with 500 TPD capacities [18]. But Seegihalli and Subrayanpalya processing plants have been stopped due to local issues and KCDC is working below capacity due to local protest. Dry waste collection centers (DWCC's) are operated by different agencies (NGO's, waste pickers and contractors) in Bengaluru in collaboration with BBMP. DWCC's are unevenly distributed across the city, some of the ward having no facility. Dry waste produced in each ward is collected, classified, and transferred to various recycling units for further recycling. Flow chart (Fig. 2) presents the currents waste management system followed by BBMP.

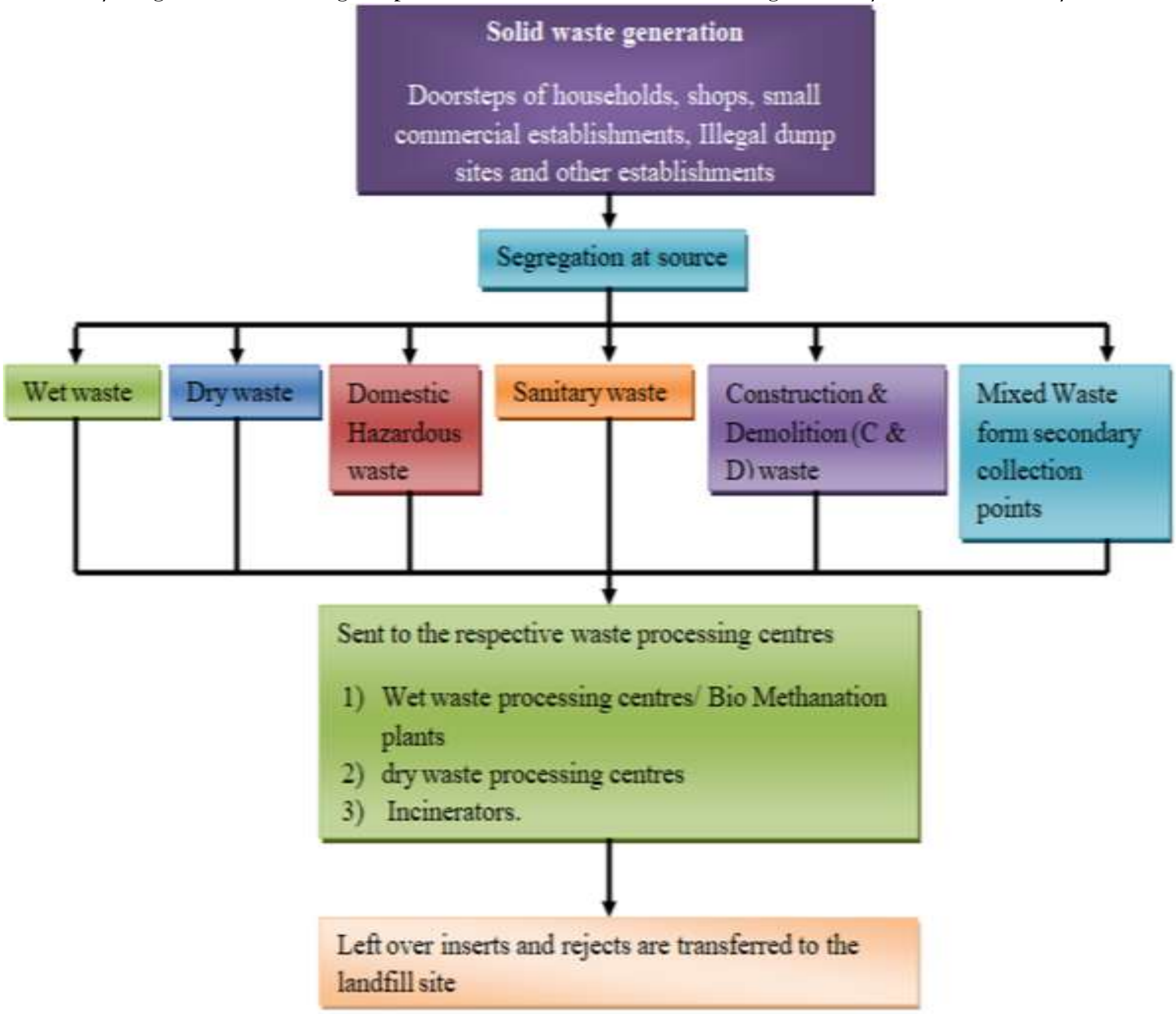

Fig. 2 Existing Solid Waste Management of BBMP

2.3 Survey of solid waste generation and segregation using Google Form: Google survey form was created to collect the information regarding solid waste generation and segregation in different zones of BBMP, it was noted that good amount of source segregated waste is collected from the households, but partial amount of population is unaware of waste segregation norms followed by BBMP and still many people's are dumping into the illegal dump sites, many are not segregating the waste and handing over unsegregated waste to the truck collector. A set of questions were asked and responses of the people were gathered. When asked about the reason why segregation is not happening on regular basis, reasons quoted by the people of different zones is depicted in (Fig. 3). 18.2% of the population is still unaware of the BBMP rules and regulations, 31.8% fails to segregate as there is no enforcement by BBMP, 27.3% due to non-availability of separate bins to segregate and other reasons like laziness, discomfort handling waste, lack of environmental consciousness.

2.4 Active landfill site of BBMP: A landfill site is a designated area of land use for the disposal of solid waste, it is one of the most commonly used method in the developing countries [19]. The difference between dump and landfill is that, dump is not separated from the underlying soil where both soil and ground waste will get polluted [20]. In contrast, landfills are engineered and regulated sites which follow scientific method of waste disposal. Scientific structure of landfill consists of bottom liner system, leachates collection system, gas collection system, waste layer and a final cover [21].

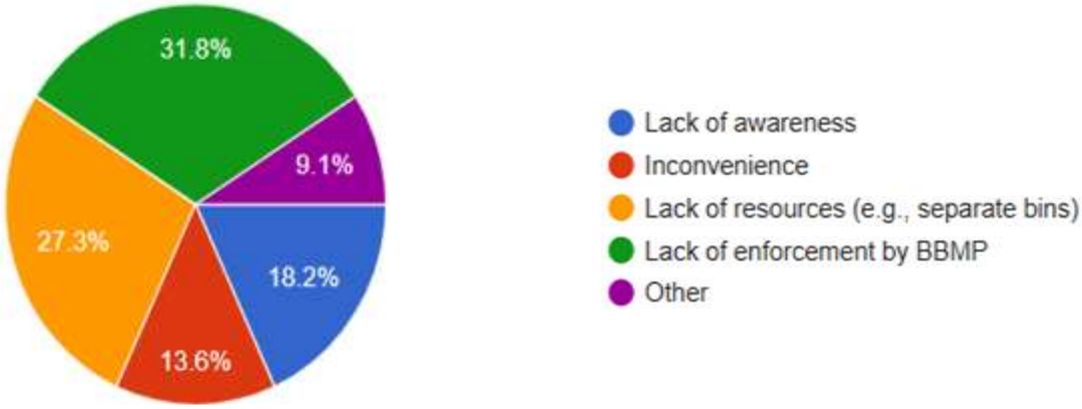

Fig. 3 Each percentage showing reason behind not segregation of waste

Mavallipur, Manduru, Terra Firma and KCDC are landfill sites located near Bengaluru [22], which are subjected to significant controversy as they are facing issues with overloading, unscientific dumping, and environmental impact leading to the closure of these sites form further dumping of solid waste [16].
Mittaganahalli landfill is the currently active landfill in the BBMP judistriction situated in the northern part of Bangalore, established in the year 2012 [23]. The landfill receives about 2000 – 3000 tonnes of mixed waste on daily basis, accounting for approximately half of the city's total waste generation. The landfill primarily receives unsegregated solid waste. Due to high volume of waste, the landfill is facing challenges related to overcapacity, leading to environmental concerns such as leachate formation and foul odours. Location of Mittaganahalli landfill is shown in Fig. 4.

Fig. 4 Location of Mittaganahalli landfill site

On visiting Mittaganahalli landfill site, it was noted that landfill is exceeding its actual capacity. The inhabitants living in and around the landfill are facing health issues, due to the generation of high volume of leachate leading to the contamination of groundwater; water bodies present near the landfill (Fig. 5 a,b). Ill effects of contaminated water can be seen in the form of dead fishes (Fig. 5c). People who reside in the vicinity utilize the same water to fulfill different needs such as washing clothes, bathing, *etc*. (Fig. 5d). There is only one leachate treatment plant which is insufficient to treat the leachate produced.

Fig. 5 a,b) Water bodies polluted near Mittiganahalli landfill getting polluted due to leachate; c) Death fishes in the polluted water bodies, and d) Public utilizing polluted water to meet their daily needs

2.5. Composition of MSW: Composition of MSW plays an important role in determining the choice of waste treatment technologies, resource recovery strategies and environment management approaches [24]. According to Hussein [23], the composition of solid waste changes from one place to another place such variation is mainly due to population, change in life style, economic situation, climatic condition, type of area commercial, residential, industrial. Many studies have been conducted all over the world to study the composition and characterized solid waste based on different categories. The current scenarios of MSW in India are characterized by a high proportion of food waste, garden trimming and biodegradable waste about 50%, inert silt and construction waste by 29%, followed by glass 5%, plastic 4%, clothes 7% and paper 5% [25].

Composition of MSW generated from 1999 to 2013 in Bangalore indicates that there is a radical expansion in natural (organic + other biodegradable) waste from 42% (1999) to 91% (2013) [22]. The information provided by BBMP on composition of MSW for the year 2017 is shown in (Fig. 6), indicated the depletion of natural waste from 61% in 2013 to 53% in 2017 this reduction is may be due to the rule and regulations being adopted by BBMP for waste management.

2.6. LULC classification as a Spatial Basis for illegal waste dumping site assessment: Google Earth Engine (GEE) is used to perform a supervised Land Use Land Cover (LULC) classification of the east zone of BBMP shown in Fig. 7, using Sentinel- 2A imagery. GEE is a platform to support spatial analysis related to illegal dumping of solid waste. The methodology for the code involves first loading the boundary of East zone BBMP followed by selecting high resolution multispectral imagery. The high-resolution image was selected to ensure minimal cloud cover and differentiate between land cover types. The preprocessing of satellite data was done by performing atmospheric correction using the Level-2A surface reflectance product and selecting relevant spectral bands such as B2 (blue), B3 (green), B4 (red) and B8 near infrared (NIR), which are selected to effectively discriminate between water, vegetation, built-up and barren land.

SL.NO	Category	Percentage
1	Vegetable	30
2	Paper	9
3	Plastic	12
4	Cardboard	4
5	Textiles	4
6	Grass/leaves/wood	6
7	Leather	0
8	Electronic Items	2
9	Metal	1
10	Organic	23
11	Glass	3
12	Debris	5
13	Biomedical	2

Source: BBMP(2017)

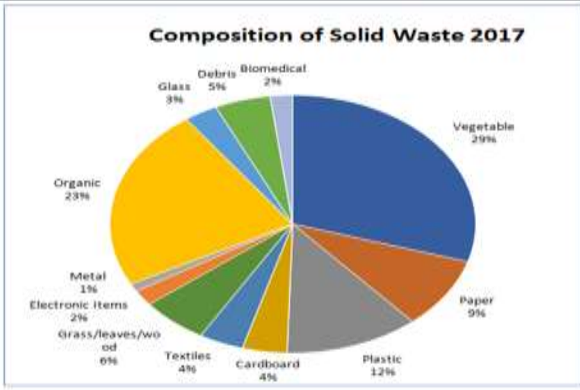

Fig. 6 Composition of MSW for year 2017

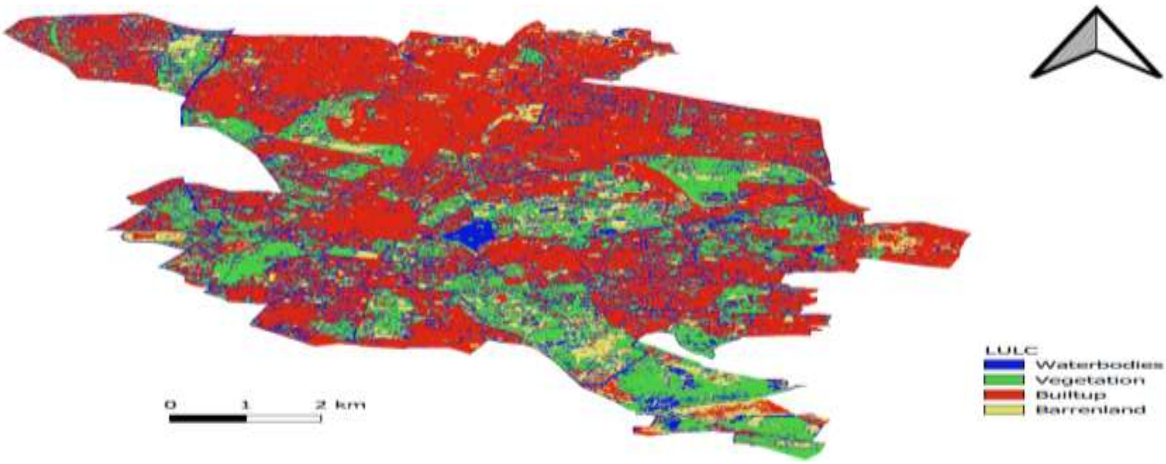

Fig. 7 LULC classification of East Zone of using GEE

2.7. Occurrence of illegal dump sites: Prior conducting the survey of East Zone, survey sheets were prepared to capture the data of illegal dump sites. The population distribution maps were developed using QGIS (version 3.8.2) (Fig. 8), which helped in identifying illegal dump sites, and also various economic, social, and cultural factors were considered during the survey as these are main contributors in the formation of illegal dumps [26]. Population density is directly proportional to the volume of waste generated [25].

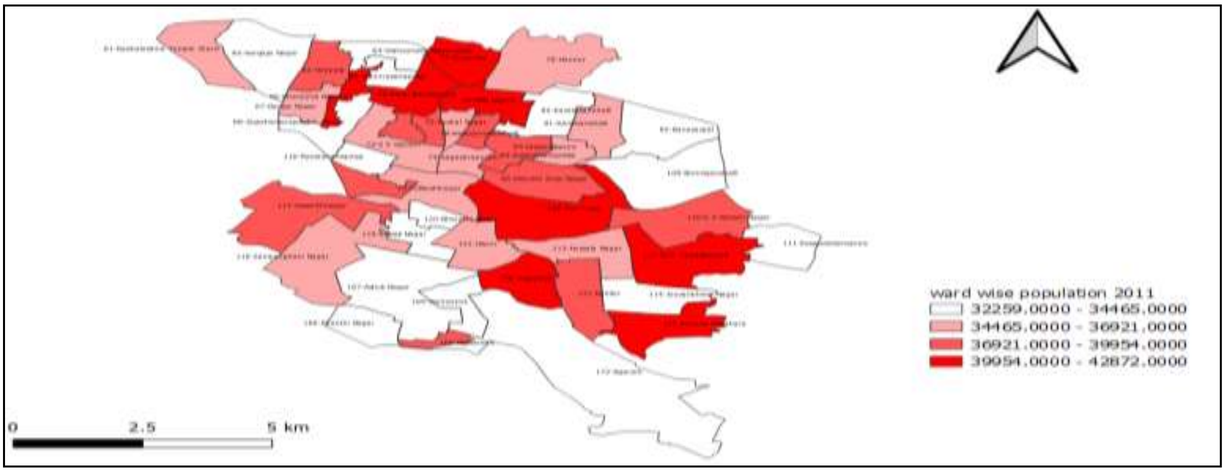

Fig. 8 Population Distribution map of East Zone of BBMP

Regardless of BBMP's practice of door to door collection. Disposal of waste on vacant plots, near railway lanes and commercial establishments has led to leachate formation which is polluting the environment. It is observed that wards having higher population are face challenges in waste segregation. Due to lack of infrastructural, logistical stress, untimely collection of waste and no bin facility, a large proportion of population tends to discard waste during late nights or early morning hours which lead in mushrooming of illegal dump sites

Global positioning system (GPS) device was utilized to determine the locations of dump sites. Maximum dump sites are located in densely populated residential areas with insufficient waste collection coverage. As most of the areas lacks formal waste collection infrastructures and are characterized by narrow lanes, making access for BBMP waste collection vehicles difficult. In this study, the surface composition of the waste is assumed to be the representative of the overall composition of the waste. During field survey it was observed that organic and plastic waste was present in maximum amount through visual observation, indicating a high prevalence of biodegradable and non-recyclable was being dumped at these illegal sites. The collection of waste sample was done in early morning, because after that BBMP autos or trucks used to collect waste from most of the dump sites. Out of the identified location, few locations were selected for the study of waste composition, where dumping is happening in large quantities, on regular basis, and are persisting from many years. The locations selected to study the characteristics of solid waste falls in highly populated areas. These are located on East Zone map of BBMP (Fig. 9) along with road and railway thematic layers, which is clearly indicating that dumping is happening along the road and railway network.

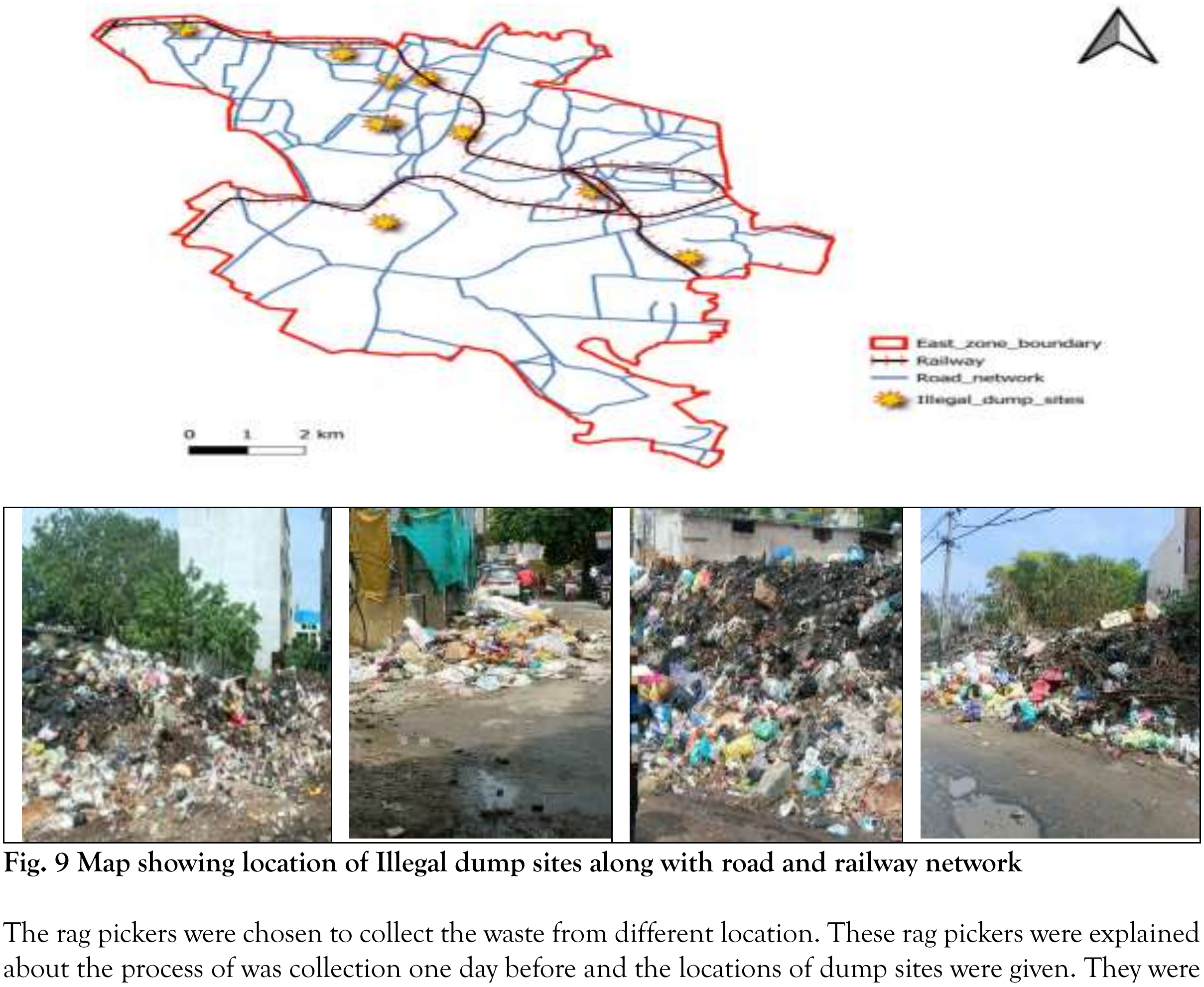

Fig. 9 Map showing location of Illegal dump sites along with road and railway network

The rag pickers were chosen to collect the waste from different location. These rag pickers were explained about the process of was collection one day before and the locations of dump sites were given. They were provided with the necessary protection, mask and hand gloves and were instructed to collect about 10 kg of mixed waste sample from each location. After collection the sample were brought to one particular location where segregation of waste was done. Details of the locations along with ward no, from where the samples were collected are shown in Table-1.

2.8. MSW sample collection and preparation to study physical and chemical composition: The characterization of solid waste was done by collecting the samples from the10 illegal dump sites identified in east zone and at different depth. Before collection of samples the size of each sample collected was determined. According to Lisa & Anders [27], there is no absolute recommendation on how to decide

Table-1 Locations of illegal dump site from where the sample was collected

Sl. No	Latitude (N)	Longitude (E)	Ward No.
1	13° 2'39.13"N	77°34'36.34"E	62
2	13° 2'13.16"N	77°36'6.90"E	64
3	13° 1'43.27"N	77°36'34.06"E	69
4	13° 1'46.66"N	77°36'55.01"E	77
5	13° 0'59.01"N	77°36'27.99"E	71
6	13° 0'59.75"N	77°36'33.04"E	71
7	13° 0'49.57"N	77°37'16.48"E	79
8	12°59'48.41"N	77°38'30.91"E	108
9	12°59'15.87"N	77°36'31.44"E	120
10	12°58'38.68"N	77°39'26.11"E	112

appropriate sample size and number of samples. Zeng *et al.* [28] suggest as a rule of thumb, a minimum 10 number of samples should be considered if the sample size is 100 kg or larger. In this study, around 100 kg of mixed waste was collected considering number of samples as 10, hence from 10 locations one sample was collected each of 10 kg. The collection of waste was done with the help of waste collectors who are basically involved in the collection of dry waste from the illegal sites. They were briefed regarding the procedure of waste collection and provided with the locations form where the waste needed to be collected. During the collection they were provided with the necessary precautions like hand gloves and mask. After collection it was emptied on the plastic sheet on flat ground and one representative sample was prepared using coning and quartering method [29]. Mixing of waste thoroughly before quartering will ensure each quarter represents the total waste sample [30]. Two opposite quarters were discarded, and remaining two quarters were utilized for further physical and chemical characterization. There is no standard specification used to categorize solid waste, researchers have characterized waste into different categories. In the present study the waste was categorized into seven broad categories namely: organic, plastic, paper & cardboard, textiles, glass, metal and mixed residue. After segregation each category was weighted individually. Manual sorting and weighing of individual category of the mixed waste is shown in Fig. 10.

Fig. 10 Sorting and weighing of MSW into different categories

Chemical characterization, of raw sample after coning and quartering was performed in laboratory. Proximate analysis was performed to obtain the percentage composition of moisture content, total volatile solids. The pH of the sample was determined, which is the fundamental indicator of degree of degradation [31]. Calorific value of the sample was determined, it is an important factor that exhibits energy content of solid waste [32].

3 RESULT AND DISCUSSION

3.1 Physical composition of MSW: Physical characterization of MSW was carried out at identified illegal dump sites of East Zone of BBMP shown in Table-2. As per the results the organic waste accounts for maximum about 44 wt.% compare to all other categories. It is followed by plastic, paper and cardboard waste.

Textile and glass accounted for 1 wt.% and 5 wt.% respectively. Metals accounted for 0 wt.% as most of the peoples sell it to scrap merchant and leftover metal from illegal dumpsites is collected by rag pickers. Due to the large quantity of organic and recyclable waste, organic waste treatment and recovery of recyclable materials seems to be economical and environmental method.

Table 2 Physical characteristics of MSW

Category	Percentage
Organic	44.00
Plastics	29.00
Paper and Cardboard	13.00
Textiles	1.00
Glass	5.00
Metal	0.00
Mixed Residue	8.00

3.2 Chemical composition of MSW: The chemical composition of MSW samples collected for illegal dumping sites revealed significant indicators of organic rich and biodegradable waste. MSW sample is acidic in nature with a pH of 4.59 it may be due to the dominance of food and kitchen waste undergoing aerobic decomposition. Moisture content found to be high about 69.3%, which indicates fresh and wet nature of the waste, contributing to faster microbial activity and leachate formation. High level of moisture content makes direct incineration inefficient, requires pretreatment for thermal processing. Calorific value obtained is 2900 cal/g (approximately 12.14 MJ/kg), which is lower than the optimal value for energy recovery. Furthermore, the volatile solids content is 83.8%, which suggest that the substantial portion of waste can be subjected to biological degradation processes such as composting or anaerobic digestion. Chemical composition of MSW is shown in Table-3.

Table 3 Chemical composition of MSW

Category	Percentage
pH value	4.59
Moisture Content, %	69.3
Calorific Value, cal/g	2900
Total volatile solids, %	83.8

3.3 **Integrating waste composition insights into management planning:** The physical and chemical characterization of MSW from illegal dumping sites in the East zone of BBMP provides a comprehensive understanding of its composition and treatment potential. Physically the solid waste is composed of maximum percentage of organic waste followed by plastic. The presence of high percentage of organic waste combined with higher moisture and volatile solids content makes the waste suitable for biological treatment such as aerobic digestion, vermicomposting or windrow composting, enabling nutrient recovery and production of compost or biogas. These processes can effectively reduce volume and helps in reducing environmental pollution from illegal dump sites. Composting is the process where the organic matter undergo biodegradation in the presence of oxygen, the end product obtained is a nutrient rich product that can be used for agricultural and horticultural products [29]. The high plastic content and moderate calorific value is appropriate to be used for the production of good quality refuse-derived fuel (RDF), especially can be used in cement kilns or industrial boilers, provided adequate segregation and drying are ensured. Paper and cardboard, can be routed to recycling units, contributing to resource recovery. The acidic pH of the MSW is the indicative of leachate generating and anaerobic microbial activities, which indicates there is a need for controlled biological processing and environmental safeguards. Thus, the physico-chemical profiling of MSW informs about the best suitable treatment method which can be adopted to make the environment sustainable.

4. CONCLUSION

The study provides a comprehensive assessment of MSW management challenges within BBMP. In the jurisdiction of BBMP, approximately 5000 tonnes per day (TDP) of MSW is generated. Out of this, only 2000 TPD of the waste is being processed, resulting in an unprocessed gap of 3000 TPD, which is typically sent to landfill. But the present Mitiganahalli landfill which is approximately 50- acre of land is currently grappling with multiple environmental and public challenges. One of the critical issues is the generation and accumulation of leachates. This leachate not only emitting a foul odour, but also pollute the ground water and nearby water bodies. The situation at Mitiganahalli underscores the urgent need for adopting sustainable waste management practices, including proper leachate management systems, enhanced waste processing infrastructure, and a reassessment of landfill site selection criteria in urban planning. The efficiency of solid waste segregation and collection is satisfactory in few wards, as most of the population is unaware of BBMP rules for solid waste management. So firstly, there is a need to educate the public regarding hazardous side of the solid waste and then they should be informed about the rules and regulation followed by BBMP to achieve sustainable goals. The study conducted in the East zone of BBMP presents a systematic investigation into the patterns and characteristics of illegal solid waste dumping. The findings reveal that unregulated dumping is prevalent across the zone, particularly in vacant land, near open drains, along roadside edges, and in proximity to informal settlements. A critical factor contributing to this issue is the absence of adequate waste collection infrastructure, specifically lack of community bins or designated collection points. The composition analysis of the collected waste indicated a dominance of organic matter followed by plastic, paper and cardboard, glass and other waste. The presence of high organic content poses significant risk, such as foul odour generation, vector breeding and leachate formation. The high moisture content and volatile solids indicate that composting or vermin composting is the most suitable treatment method, as it can divert substantial portion of biodegradable waste into nutrient rich compost foe use in agriculture and horticulture. This process helps in reducing the volume of waste entering landfills. The findings underscore the necessity for immediate and localized intervention by BBMP. Recommendations include the provision of accessible and well-maintained waste bins, enforcement of source segregation practices, deployment of mobile waste collection units, and improved public awareness. Moreover, the geospatial data generated from this study can support evidence based spatial planning and hotspot identification, facilitating focused actions in zones with high incidences of illegal dumping.

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