Chapter

Solid Waste Management: Current Scenario and Challenges in Bengaluru

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Abstract

Municipal solid waste management (MSWM) has become one of the significant environmental issues, particularly in developing countries. Bengaluru, the state capital of Karnataka, is one of the fastest growing cities in Asia. The Bruhat Bengaluru Mahanagara Palike (BBMP) with an area of 2190 km^2 and a population of about 10.18 million generates around 5000 metric tons per day of solid waste at an average generation rate of 0.5 kg per capita per day (kg/capita/d). Presently, Bengaluru City is facing significant problems due to existing disposal practices of generated waste, incurring high cost due to lack of proper infrastructural facilities; also, the open dumping in the expanding zone of the city poses severe problems to the structures constructed on these old dumps. In the meantime, groundwater quality deteriorated due to improper leachate management. Intending to assess the possible impacts on the water environment and suggest a better waste management strategy, the present paper discusses the potential for handling the wastes, thereby reducing the amount of waste to be transported to the landfill. If this waste is used for energy and nutrient recovery, decentralization could also become commercially viable and address the technology-wise deficiencies in the existing MSWM system of Bengaluru City.

Keywords: collection, disposal, transportation, processing, management, strategy

1. Introduction

In ancient times, a harmonious and balanced relationship between humans and nature on this earth is necessary for livelihood. As civilization advanced, humans directly or indirectly interfered with the natural environment. This led to an imbalance in the human-nature relationship, finally leading to environmental problems like soil, air, and water pollution and accumulation of municipal solid waste (MSW).

In olden days, MSW disposal did not pose significant problems because the population was very less and the availability of land for the dumping of wastes was large. But these days MSWM is a serious problem everywhere. Due to rapid industrialization and increased population levels, the generation rate of MSW in metropolitan cities accelerates. This has led to the migration of people from villages to cities, which generates thousands of tons of MSW daily with rapid change in the quantity and character of the waste in line with the changing lifestyle of the people and also with the changes in the market technology, building technology, and fuel technology.

The environmental degradation and energy crisis are two significant issues for global sustainable development. Due to rapid urbanization, industrialization and increase of the growth of population have led to severe substantial waste management problems in several developing countries like India, Malaysia, Nepal, and Bangladesh. As the village develops into towns and cities, in developing countries the disposal of solid waste onto access ways, empty lands, and waterways has been witnessed. Presently, more materials are consumed than required to meet their daily needs by a greedy human. Human beings generate domestic, agricultural, industrial, and medical wastes at every level of development. This waste comprises of both solid and semisolid organic wastes, which may be biodegradable and non-biodegradable. Hence, proper collection and subsequent disposal of waste assumed vital importance in community environmental sanitation programs.

MSW has become one of the significant environmental issues, particularly in developing countries. The solid waste generation mainly consists of biodegradable and non-biodegradable waste materials produced due to several societal activities. The improper dumping of solid waste pollutes the air, soil, and water. The BBMP with an area of 2190 km^2 and a population of about 10.18 million generates around 5000 metric tons per day of waste at an average generation rate of 0.5 kg per capita per day (kg/capita/d). Presently, Bengaluru is facing significant problems due to existing disposal practices of generated waste incurring high cost due to lack of proper infrastructural facilities; also the open dumping in the expanding zone of the city poses severe problems to the structures constructed on these old dumps. In the meantime, groundwater quality deteriorated due to improper leachate management [1].

In Bengaluru, there are more than 60 illegal dumpsites identified. While BBMP and the Karnataka State Pollution Control Board (KSPCB) close these dumpsites, the new ones emerge elsewhere, posing health risks to residents in their vicinity. The MSW (Management and Handling) Rules, 2000, recommend source-specific waste collection and transportation in addition to appropriate processing and disposal. There is a lack of knowledge of the quantity and characteristics of reliable waste aids in the preparation of a long-term plan for an MSWM system. So, it was deemed necessary by the BBMP to assess the current status of the municipal solid waste management system in Bengaluru [2].

In this context, the present study discusses the potential improvement in handling the wastes and reduces the amount of waste to be transported and dumped in the landfill. If this waste is used for energy and nutrient recovery, decentralization could also become commercially viable. Moreover, it also addresses the wise technology deficiencies in the existing MSWM system of Bengaluru.

2. Bengaluru scenario

The city of Bengaluru (12.98°N and 77.58°E) in Karnataka is the state capital, and it has a mild and salubrious climate. It is located at an elevation of 900 m. Since the 1980s, Bengaluru has enjoyed the reputation of being one of the fastest developing cities in Asia [3]. The Bengaluru Metropolitan Area covers an area of 1258 sq. km and is the fifth largest city in India. However, with an increased population level, rapid economic growth, and a rise in community living standard, the generation rate of MSW in metropolitan cities accelerates. The local authorities are struggling to provide the proper solid waste management system to a satisfactory level. Recently the authorities have taken initiatives and measures to organize the MSWM sector. This research would help to identify techniques suitable for the current scenario, the loopholes in the adopted methods, and the possible alternatives.

3. Municipal organization

The BBMP has a city council that consists of 123 elected members or councilors, each representing a ward. Both the mayor and deputy mayor are chosen from among councilors for a 1-year term. The BBMP has 15,000 employees and is headed by the commissioner. The commissioner is the head of the BBMP, appointed and deputed by the State Government of Karnataka and responsible for performing duties and functions.

Presently, the Bruhat Bengaluru Mahanagara Palike is the agency vested with responsibility for effective solid waste management system for the Bengaluru City. For a more efficient and effective approach, the Bengaluru City has been divided into different administrative units. There are 294 health wards within the BBMP. Presently, in Bengaluru, there are 198 such administrative or political wards (**Figure 1**). Within the BBMP, there are two departments, namely, the health department and engineering department. The health department is mainly responsible for the collection, transportation, and disposal of solid waste. The engineering department handles the removal of construction and demolition waste, while they also provide technical and infrastructural support to the health department.

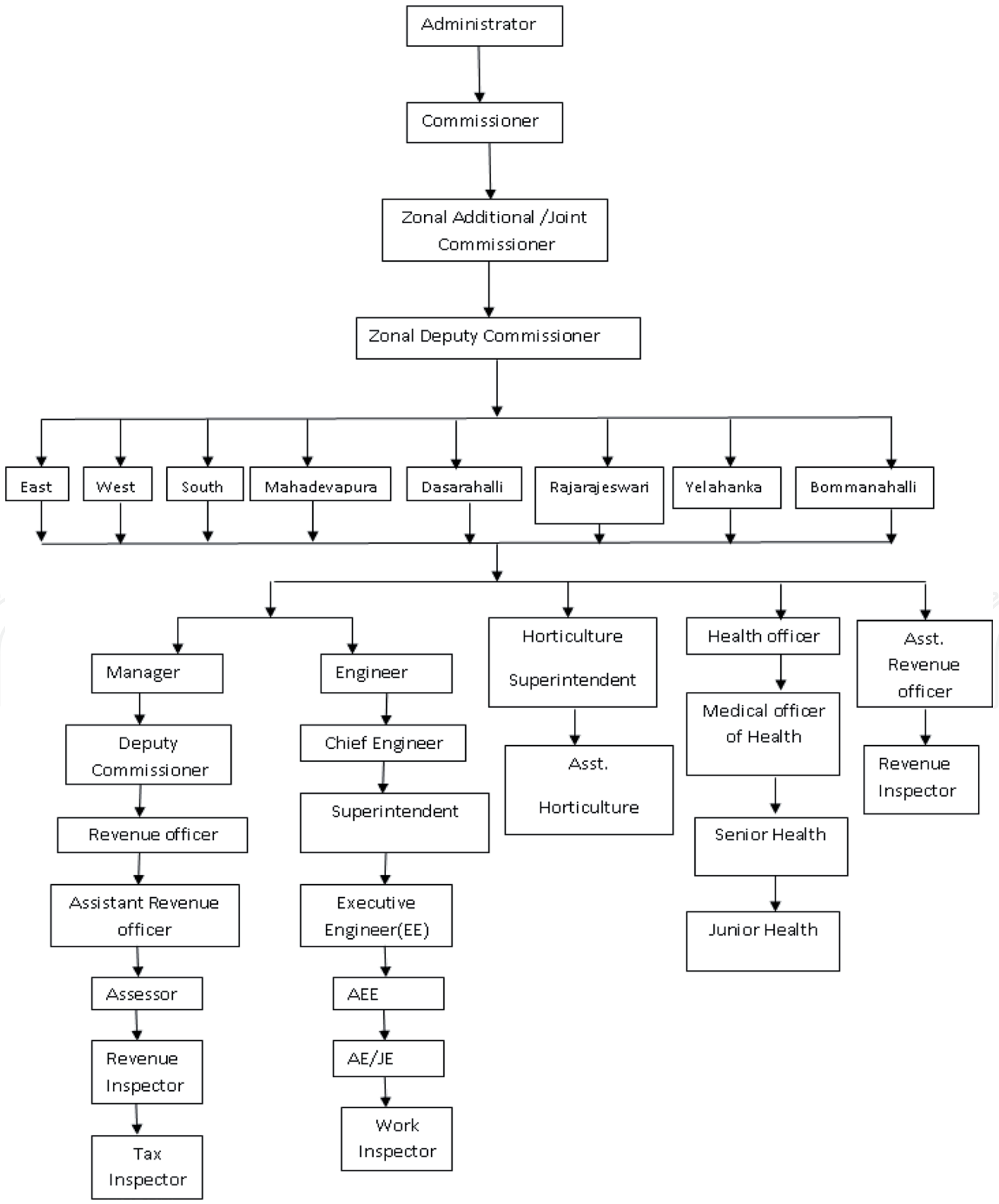


Figure 1.
BBMP Zonal organization chart.

4. Waste generation

At present, 10% of solid waste is recycled in Bengaluru. Most of the literature reported that the waste generation rate is 0.4–0.6 kg/capita/day. The proposed waste generation rate is about 0.5 kg/capita/day in Bengaluru [4]. Since 1990, the composition of India's urban wastes has changed drastically. At present, the waste generation is about 5000 metric tons, and waste generation is likely to grow over the coming years. Going by the present trend of increase in the quantity of waste, the waste quantity projected for the next 20 years is shown in **Figure 2**.

4.1 Waste composition

The changes in the composition of MSW should form essential criteria for any waste management system. Hence, the data available on the composition of the waste from different sources over the years have been collected and analyzed. **Figure 3** shows variation in MSW composition from 1999 to 2013 in Bengaluru City. With the increase in urbanization and change in food habits and lifestyle, the amount of MSW has been multiplying, and there is variation in waste composition.

The changes in the composition of MSW should form essential criteria for any waste management system. Hence, the data available on the composition of the waste from different sources over the years has been collected and analyzed. The data presented in **Table 1** was statistically analyzed to get the variations of a different type of waste in rapidly growing cities like Bangalore.

The MSW composition generated in Bengaluru has changed considerably from 1999 to 2013, which is evident in **Table 1**. It was observed that there was an increase in the biodegradable percentage in Bengaluru City from 42% in 1999 to 61% in 2013, indicating increased organic waste generation in the city, which may be primarily due to increasing population, improper solid waste management, or accumulation of green waste. Similarly, there was a 16% decrease in the paper, cardboard, and leather wastes in Bengaluru City, indicating recycling activities of paper and

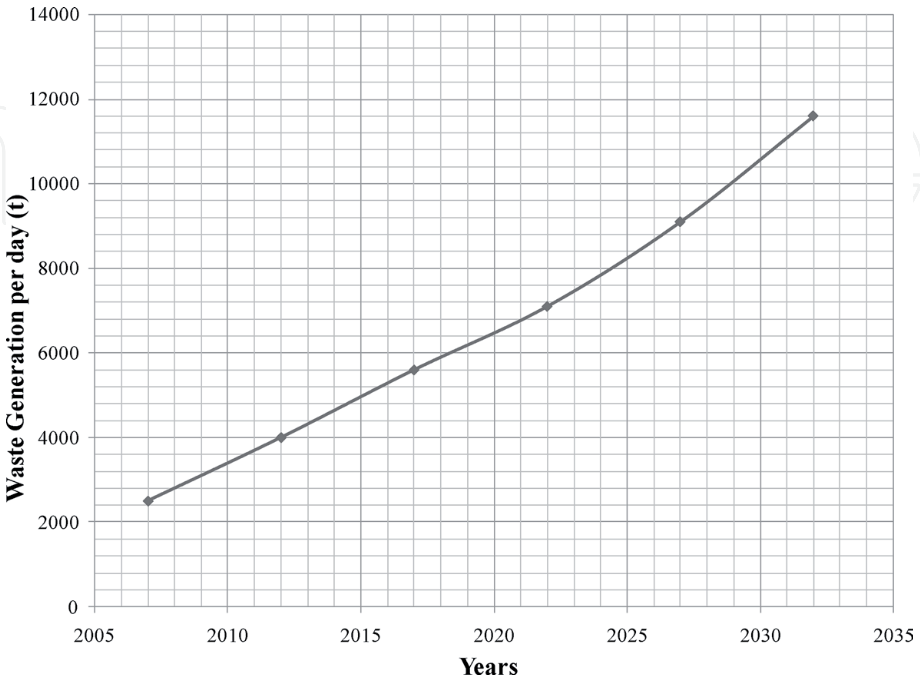
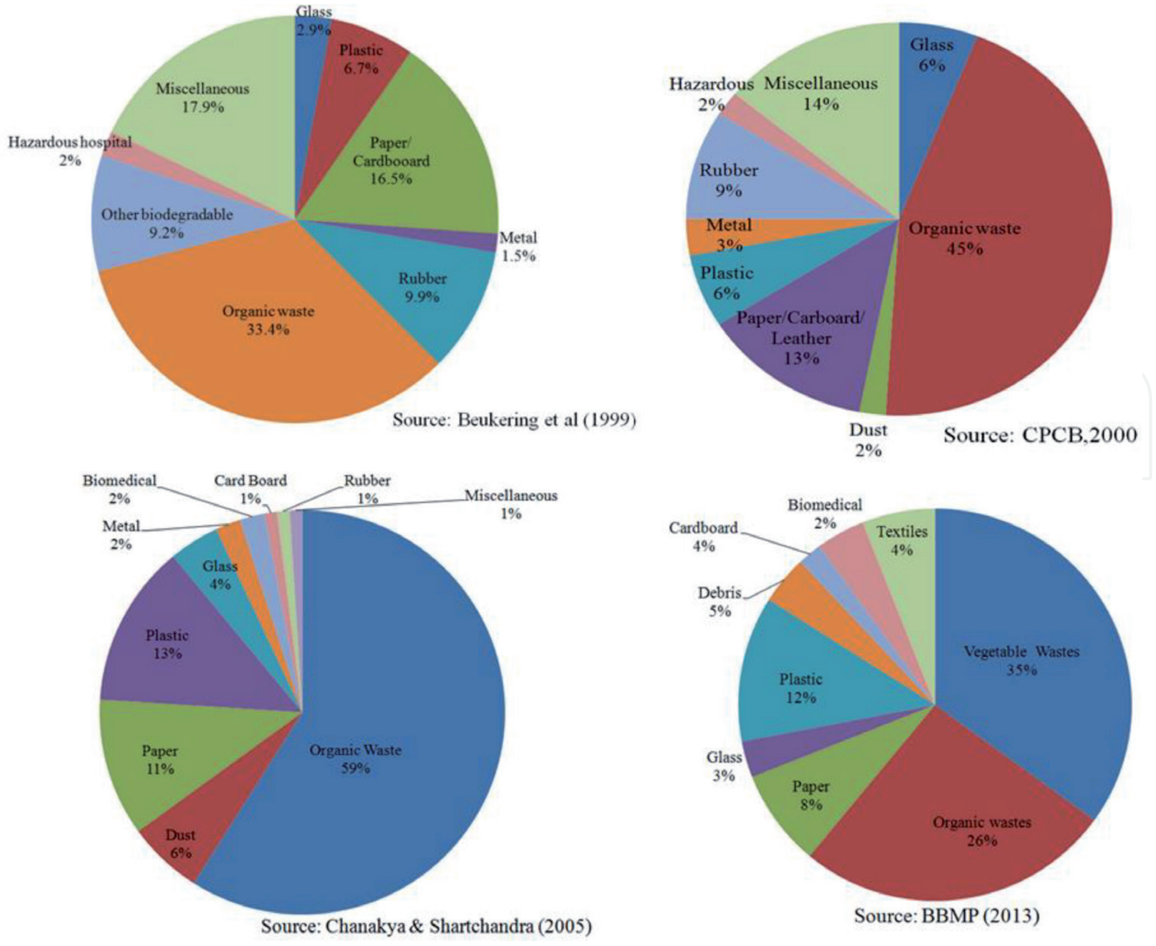


Figure 2.
Waste quantity expected for the next 20 years.



Source: Beukering et al (1999)

Source: CPCB,2000

Source: Chanakya & Shartchandra (2005)

Source: BBMP (2013)

Figure 3.
Bangalore's urban waste composition.

Year	Biodegradable	Paper/leather/ cardboard	Rubber/ debris	Glass	Plastic	Metals	Others
1999	42	16	10	3	7	2	20
2000	45	13	9	6	6	3	18
2007	59	12	5	3	12	1	8
2013	61	9	4	1	7	1	16

Source: data extracted from Bangalore's Urban Waste Composition [4–7]
#All components of MSW are expressed in %.

Table 1.
Variations in MSW composition in Bangalore City from 1999 to 2013.

cardboard. A considerable increase in plastic wastes was also observed in 2007, which might be due to the urbanization and increased use of plastic carry bags. In 2013, the percentage of plastic waste decreased to 7%, which may be attributable to the effective ban of plastics carry bags below 40microns within city limits in 2012. The glass, metals, and rubber fraction observed a decrease in MSW composition, indicating the decreased use of glass and metal products and effective recycling of glass and metal products by segregation at sources itself.

The variations in MSW composition shown in **Figure 4** can be utilized in choosing the best method of MSW disposal in Bengaluru City. Biodegradable percentage (61% in 2013), more than 50%, suggests employment of methods, such as windrow composting, community composting process, pyrolysis, and vermicomposting, which assists in manure generation for agricultural practices; also, biomethanation

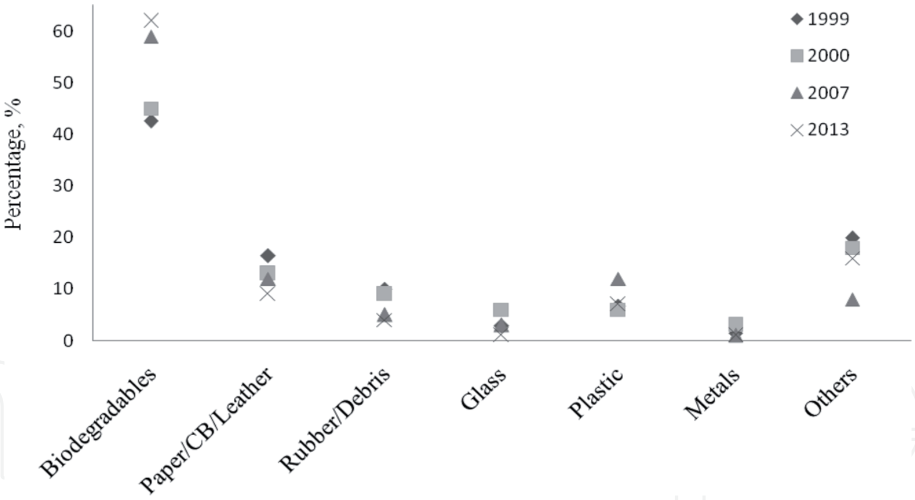


Figure 4.
Variations in MSW composition from 1999 to 2013 in Bangalore City.

can be employed to produce biogas, which can be utilized as a fuel or alternative source for electricity generation. As the significant composition of MSW is organic, waste treatment options like composting were successful in Bangalore, and 3.14% waste reduction was achieved through composting [8].

5. Collection and transportation of waste

The objective of solid waste management is to remove discarded materials from inhabited places promptly to prevent the spread of disease, to reduce esthetic results arising from purifying organic matter, and, equally important, to dispose of the discarded materials in a manner that is environmentally acceptable [9].

5.1 Collection

Currently, in Bengaluru, source segregation is still a concern through awareness in picking up slowly. BBMP handles about 30% of solid waste, and the remaining waste activity is outsourced (starting from primary collection to disposal). Solid waste collection is carried out in two phases. The first phase is a primary collection, in which the solid waste is collected on auto tipper and pushcarts. An auto tipper has been provided for every 1000 households and a cart for every 200 homes. About 20,000 pourakarmikas are being utilized (both BBMP and contractors) in the door to door collection, street sweeping, and transportation of MSW. The collected solid waste from houses is brought to a common point, i.e., secondary locations from where the waste is transferred to landfill sites/treatment through tipper lorries and compactors. **Figure 5** indicates a typical scheme of how the collection and transportation are being practiced in most of the wards.

This activity is assigned to self-help groups (SHGs), which are basically below poverty women's groups. BBMP has allocated 3197 pourakarmikas (sweepers) and 18,562 pourakarmikas from a contractor who performs door to door collection and sweeping activities. Annually about 250 crores are spent on solid waste management, i.e., BBMP pourakarmika salary, contract payment, and tipping fees (**Figure 6**).

The survey carried out in Malleswaram by [10] indicated that no norms/guidelines had been followed in setting up waste segregation practices adopted in this ward. There is a lack of awareness among people that leads to confusion. The six

Figure 5.
MSW collection system.

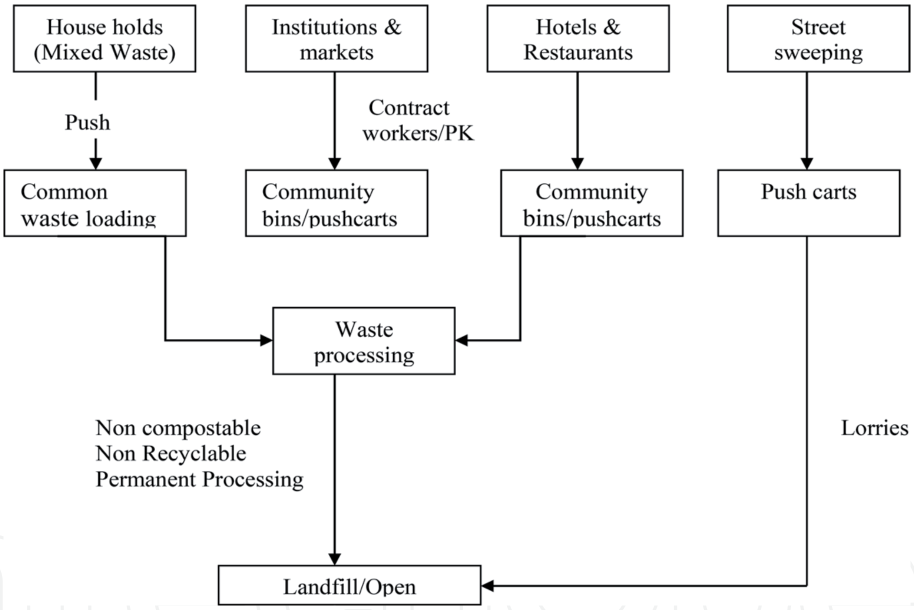


Figure 6.
MSW collection process in a typical residential/commercial area.

categories for segregation mandated by BBMP are overwhelming and are a deterrent to segregation. The waste collectors (pourakarmikas) lack training in proper segregation practices and its importance. Incomplete segregation is the predominant practice currently, and steps to realize a higher level of compliance and efficiency need to be effected.

5.2 Transportation

Transportation of waste from collection centers to the landfill site is another crucial step in waste management. At present, waste transportation is using pushcarts, auto, etc., which bring waste to primary collection centers. From there, trucks collect the municipal solid waste and transport it to waste disposal sites/landfill.

The issues in transporting waste are mentioned below:

- The waste spills from the trucks due to open beds in trucks and tractors, during transport, thereby causing a nuisance.

- Solid waste loaded manually in a truck without using the protective gears is dangerous to the health of workers.

- A secondary storage system is not well synchronized with the transport system. Problems arise when a transport fleet is modernized because waste at a secondary storage system is still dumped on the ground.

- The area cannot be appropriately serviced due to an inadequate number of vehicles.

- Due to inadequate workshop facilities and maintenance procedures, the vehicles are poorly maintained. This problem leads to a breakdown of trucks, and they become out of service for a long time.

5.3 Effective solid waste management

Based on the above-presented data and analysis, for effective solid waste management, the following suggestion can be made:

1. Establish the segregation at the source itself, and encourage by giving incentive to the contractors with the performance in segregation.

2. Establish the wet waste processing units for composting, and encourage decentralized processing for dry waste collection center at the source.

3. Set up the segregation units and zone-wise processing facilities to ensure 100% processing of municipal solid waste, and minimize the solid waste quantity going to the landfill sites.

4. Reduce transportation of municipal solid waste using the above measures of decentralized as well as zone-wise processing units.

6. Waste disposal practices in Bengaluru

Currently Bengaluru does not have any appropriate scientific treatment techniques for waste generated by municipal and industries around Bengaluru. This has led to the development of various unauthorized dumpsites. The solid waste, generated from hotels, restaurants, Kalyana mandapas, markets, etc., is being directly collected and transported to the treatment/disposal facilities. The treatment facilities have been developed around the city, and their spread over the zone is set out in **Table 2**.

7. Decentralized waste processing plant in Bengaluru

For making effective solid waste management services, it is essential to select appropriate technology, which can suit and work in the given area successfully.

Sl. No	Zone	Existing disposal site/facility
1	South	Bingipura, Mavallipura, KCDC
2	East	MSGP, Mavallipura, KCDC
3	West	Terra firma, Mavallipura, KCDC
4	Yelahanka	Mavallipura, Terrafirma
5	Bommanahalli	Bingipura, Laxmipura
6	Mahadevapura	Terrafirma
7	Dasarahalli	MSGP
8	Raja Rajeshwari Nagar	MSGP/Terrafirma

Table 2.
Existing treatment and disposal facilities in BBMP.

Simultaneously, proper measures have to be considered for institutional strengthening and internal capacity building. Institutional strengthening can be done by adequately decentralizing the administration, delegating adequate powers at the decentralized level, providing training to the existing staff, and assigning the responsibility for the workforce as well as for supervisory staff. NGO/private sector participation is necessary for making service competitive and efficient. The land is scarce, and public health and environmental resources are precious.

In this direction, many decentralized facilities are being established. The decentralization of administration has to be implemented in large cities to make solid waste management service effectively. Decentralization can be divided into three tiers—one at the ward level, second at the zone level, and third at the city level. The BBMP established the decentralized processing units for dry waste; details are as follows.

7.1 Dry waste collection center

Dry waste materials like batteries, tin cans, plastic-coated milk cartons, nylon, cigarette butts, and leather all take varying lengths of time to degrade: not less than 10 years. Hence, the best way to dispose of these dry waste items is to reuse/recycle them. Nearly 70% of all the dry waste thrown away can be safely disposed of this way.

The aim of Dry Waste Collection Centers (DWCCs) is to keep as much waste out of the landfills/waste dumps as possible and to help make waste useful and profitable. DWCCs run by various agencies in Bengaluru in coordination with the BBMP is decentralized bulk sorting and processing facilities. About 185 DWCCs have been established and functional. DWCCs are set up on municipal/government/private lands and various NGOs, waste pickers, and contractors; self-help groups have been involved for effective functioning. The dry waste generated in the wards is collected and further segregated and sent for recycling from these recycling centers. Receiving in bulk provides these informal sector workers with more significant returns and creates more jobs.

7.2 Sanitary landfill site

Currently, Bengaluru can handle the waste of about 2100 TPD. The existing capacity of waste treatment facility at Mavallipura is 600TPD, Karnataka Composting Development Corporation Ltd. (KCDC) is 300TPD, and Terra Firma is about 1500 TPD as shown in **Figure 7**. For achieving 100% processing of solid

Figure 7.
Sanitary landfill sites in Bangalore.

waste, the government has identified new landfill sites. These sites are being set up at the following locations: Kannahalli (500TPD), Seegihalli (200TPD), Doddabidarakallu (200TPD), Lingaderenahalli (200TPD), Subrayanpalya (200TPD), Chikkanagamangala (500TPD), and KCDC (upgradation) (500TPD). Majorly we waste composting plants with a provision to screen compost out of mixed MSW and provision also to store the non-compostable/non-recyclable materials. These materials can be used for co-incineration in cement industries/power generation [4].

8. Emerging technologies for wet waste disposal

Once the solid waste is collected from the different sectors of the community, the next problem is regarding the safe, economical, and efficient disposal options. Suitable decisions have to be made in this regard to avoid illegal dumping and open dumping of solid wastes that are dangerous and a threat to the environment. Open burning of solid wastes releases smoke containing pollutants harmful to human health and the environment. Therefore, the community has to face severe inconveniences due to illegal dumping practices. Hence, conventional methods employed to safe disposal options of MSW include composting, waste to energy (such as biogas production and incineration), and landfilling. Incineration and composting of MSW are a standard solid waste treatment or processing methods, as they produce secondary waste such as non-biodegradable material rejects from composting and ash from incineration that needs to be disposed of further [11].

8.1 Aerobic composting

Aerobic composting process involves piling up of waste and requires regular turning, manually or by mechanical devices, and sufficient air, and oxygen has to be provided during the decomposition by bacteria, fungi, and microorganisms like actinomycetes. A mesophilic bacterium is an initial process, which oxidizes the organic matter to carbon dioxide and generates the heat and temperature rise to about 45°C. In the next process, thermophilic bacteria continue the decomposition; in this phase, temperature further rises to about 60°C. Three weeks is required for stabilized compost and fall in temperature of the compost mass. The final product of the compost should have a dark brown color and earthy smell.

8.2 Windrow composting

The waste is dumped in the windrow platform; large items like woods, plastics, clothes, thermocol, etc. are removed; and inoculum will be sprayed on the waste. The inoculum will be prepared using the mixture of bacteria, cow dung, and water. The treated waste is then heaped in windrows with long rows approximately 2 meters in height and 3 meters in width; length will be depending on the size of the landfill site. There are seven rows, each row for each day of the week. Every week these rows are turned for 5 weeks. These rows are turned to remove moisture, improve porosity and oxygen content, and redistribute hotter and colder portions of the pile. As time passes, the sizes of the rows get reduced due to the decomposition of the waste and the resultant volume reduction. Hence, the number of final rows will be decreased than the number of initial rows. Composting will be completed in 25–30 days. This interval is known as maturation in which waste will undergo mechanical process operation. In mechanical processing, sieving occurs in three stages: in the first stage, sieve employs 36 mm mesh, the second stage applies 16 mm mesh, and the third stage has a 4 mm mesh, as shown in **Figure 8**. At each stage of sieving the reject, materials are separated and either reused or disposed of at the landfill. Any leachate or runoff created must be collected and treated. To avoid problems with leachate or runoff, waste piles can be placed under a roof, but doing so adds to the initial costs of the operation [11].

The following are the challenges in windrow composting:

1. Minor mechanical fault leads to a breakdown due to the unavailability of spare parts.

2. The major difficulty is due to the nature of waste. Pulverizers get frequently clogged with pieces of plastic, rubber, leathers, etc., and due to metal and glass pieces, the blades breakdown. If waste is mixed with soil, it causes a problem in the process, lowering the quality produced.

3. Lack of continuous power supply.

4. In the rainy season, the process cannot be carried out.

8.3 Community composting

In this process, daily wet waste is collected by the housekeeping staff, directly dumping into the tank. After filling, the tank is covered with a layer of refuse 15–20 cm deep. The materials are allowed to remain in the pit without turning and watering for 3 months. To keep the decomposers working, the aeration aid is needed during the initial pile construction. As long as plenty of air is available, aerobic decomposers work faster and more efficiently, providing you with finished compost on a more rapid time. Charcoal is placed in the tank. Hence, foul smell is avoided. It takes about 3 months to obtain the finished product. Community composting process is shown in **Figure 9**.

Figure 8.
Windrow composting process.

Figure 9.
Community composting process.

8.4 Biomechanical composting

In this process, organic waste such as vegetable and fruit peels and food leftovers, bones, meat, eggshells, household sweeping dry leaves, garden waste, cattle dung, etc. collected from the apartments and other places were identified for segregation for removal of plastic, glass, clothes, paper, leather, etc. for recycling purposes. After segregation of organic waste, it is then fed into the mechanical unit (i.e., organic waste converter) which converts this into a homogenized, crushed, odor-free output (**Figure 10**). The output goes to the curing system for stabilization. Aerobic microbial decomposition controls the entire process; the transition takes place from low pH levels to high pH levels and then stabilizes. This manure is free from weed, foul smell, and pathogen as the process is aerobic. This is environment-friendly operation; this system takes only 15 min to convert the organic waste into a homogenized output.

8.5 Vermicomposting

More than 50,000 populations of worms can support the moist compost heap of 2.4 m by 1.2 m and 0.6 m high. Organic residues such as straw and other crop residues, animal manure, green weeds, and leaves are filled in the pit and covered loosely with soil and kept moist for a weak. On the top of the heap, well-watered, the worms will be introduced, and air is provided for quick decomposition. *Lumbricus rubellus* (red worm) and *Eisenia foetida* are thermo-tolerant and are particularly useful for vermicomposting. Ideally, the compost pits were left for 2 months, and such pits should be shaded from hot sunshine and kept moistly. 1 kg of worms can produce 10 kg of castings within 2 months. Then the pit will be excavated to the extent of about two-thirds to three-quarters, and worms will be removed by hand (**Figure 11**). The remaining worms will be left in the pit itself for further composting with fresh organic residues. To get a good quality of compost

Figure 10.
Biomechanical process.

Figure 11.
Vermicomposting process.

material, sun-drying and sieving have to be carried out. The end product of compost is an ideal constitution and structure. For vermicompost, the unit has to be protected against chicken, other birds, rodents, and heavy rains.

The following are challenges in vermicomposting:

1. This concept is suitable for only small-scale applications and not an appropriate solution for large-scale application, e.g., 100–300MT/d capacity plants.

2. The exotic species are found to be costing between Rs. 500 and 1000/kg, and indigenous species of earthworms are not found useful.

3. The raw waste cannot be fed directly to earthworms, thus necessitating the pre-processing of waste to avoid toxicity.

4. Earthworms are so sensitive to temperature (ideally between 20 and 28°C); worms die due to heat built up in the rotting pile or summer.

9. Waste-to-energy technology

Some demonstrated technology approaches are available for waste-to-energy (WTE) projects today which are anaerobic processing/biogas production, refuse-derived fuel (RDF), and plasma gasification.

9.1 Biogas production/anaerobic processing

Biomethaization plants are being established for wet solid waste at 16 locations, out of which 8 have been made functional. 400 units are generated per day per plant. The biogas produced from the bio-mechanization of plants is being utilized to light the street lights in that locality.

Biogas is produced in the absence of oxygen or an anaerobic environment, due to the decomposition of organic material through certain bacteria. The whole process is referred as anaerobic digestion because biological decomposition takes place in a reactor, where bacteria produce biogas. This biomass can stay in the reactor for about 2–3 weeks. In the end, the by-product produced in this process is a solid residue that is high-grade manure. Generally, in the biogas plant, biomass like vegetable wastes and animal excreta undergo decomposition in the absence of oxygen and form a mixture of gasses. Biogas consists of about 2/3 methane (CH_4), 1/3 carbon dioxide (CO_2), a little hydrogen sulfide (H_2S), and a low hydrogen (H_2). It is created by the decomposition of manure and other forms of organic waste from households or industries in anaerobic tanks where it is heated (**Figure 12**). The biogas is used for cooking and lighting purposes.

The following are the disadvantages of anaerobic processing:

1. In a large industrial scale, this process is not very economical compared to biofuel.
2. It is challenging to increase the efficiency of biogas systems.
3. The gasses come out from biogas as impurities, which are corrosive to the metal parts of internal combustion engines.
4. Not feasible to locate at all the locations.

9.2 Refuse-derived fuel

RDF plants are in the initial stage of development in India. In this process, plenty of combustible components of MSW, such as plastic, cardboard, paper, and biodegradable waste, are converted into fuel pellets. It mainly involves drying, separation of combustion from MSW, size reduction, and pelletization after mixing

Figure 12.
Biomethanation process.

with binder and additives as required. If MSW contains 35–40% moisture content, then it involves air-drying for 2 days. Then the waste is spread, and manual inspection is carried out to remove large size debris, tires, tree stones, tree trunk, etc. The air-dried MSW is fed uniformly into a rotary drying system, i.e., hot air generation burning oversized wastes. 10–12% moisture content is suitable to be maintained in MSW for densifying into fuel pellets.

After air-drying, MSW is passed through screening equipment (below 8 mm) to separate heavier combustibles and ferrous materials; it may cause harm to process equipment. Fine fraction contains organic matter, and it is already proven to be useful as garden manure.

Air-dried waste is then passed through the density separator; here light combustibles and an air barrier separate dense fractions (e.g., stones, glass, etc.). Parallel MSW is passed over a magnetic separation unit to remove magnetic materials. The binder and additives are mixed with ground solid waste in the mixer before pelletizing. Once pellets are coming out from the pelletizer, they are cooled and stored for dispatch. The RDF pellets are used as a coal substitute at a lower price.

9.3 Plasma gasification

In plasma gasification, the process converts all types of wastes into a synthesis gas composed of hydrogen, nitrogen, carbon monoxide, and water. This synthesis gas can be used to generate electrical power and useful liquid fuel, such as ethanol.

The following are the advantages of plasma gasification:

1. No segregation of MSW needed.

2. Waste to energy.

3. A 120 megawatt (MW) facility will require, on average, consuming 3000 tons of garbage per day (Mt garbage/d).

4. The plasma system can be retrofit on the existing power-generating plants, reducing time, and greenhouse gas emission.

5. Plasma systems can use old landfills, thoroughly cleaning up and beautifying our landscape.

6. Plasma gasification is an affordable, cost-effective solution compared to other alternative energy solutions.

The following are the disadvantages of the plasma gasification:

1. Lack of regulations needed for permits

2. Financial risk

3. Technical risk

4. Economics

10. Options available for waste disposal

In this section are some of the options available for waste disposal. However, it should be noted that the option selected for waste disposal must mesh with the existing sociocultural milieu, infrastructure, etc.

10.1 Incineration

It is a thermal process for burning highly combustible waste like plastics, cardboard, paper, and rubber and combustible wastes like cartoons, wood scrap, floor sweepings, and food wastes at a very high temperature. The method does not apply to Indian conditions due to high dust and ash content of wastes; high capital costs, especially for adequate control of emissions; high operation and maintenance costs; and the need for skilled human resources. However, incineration is also associated with the production and release of carcinogenic and toxic compounds. Therefore, the incineration process is not environmentally friendly and is hence usually not recommended as a solid waste disposal technique.

10.2 Pyrolysis

Pyrolysis is also known as thermal pyrolysis. The combustion process is highly exothermic (releasing heat on burning in the presence of oxygen) in nature, whereas pyrolysis is highly endothermic (consuming flame) in the environment. Hence, the process of pyrolysis is known as destructive distillation. In this method, the solid wastes are heated under anaerobic conditions (i.e., burning without oxygen). The organic components of the solid wastes split up into volatile liquid and gaseous fractions (CO, CO_2, CH_4, tar, charred carbon). Pyrolysis cannot handle a wide variety of wastes that exists and will only have a small impact on the overall processing of waste.

11. Problems with existing MSW disposal practices

Transportation is a necessary function for solid waste management activities since municipal solid waste, recyclables, yard waste, and other materials must be collected and transported to be managed. There are various methods for collecting and transporting waste, the choice of which depends on the type of solid waste, the source of solid waste, and the proper management method used.

A vital component of a reliable and well-run solid waste management system is to set up an efficient sanitary landfill and customer-responsive collection and disposal of solid waste. Waste collection services are provided to residents in all cities, either private or self-government agencies. In the meantime, the rapid increase in disposal costs across the city, the cost of collection, and the transfer of wastes continue to raise disposal as a percentage of overall service costs for most communities.

For collection and transfer, waste systems are often complex and challenging to design, because several factors must be considered and a wide range of collection and transfer options are available. The community participation is essential for an efficient MSWM system. However, the municipal authorities have failed to mobilize the community and educate citizens on the principles of handling waste and proper practices of storing it in their bins at the shop, household, etc. Due to the lack of an essential facility of collection of waste from source, citizens are likely to dump waste on the streets, open spaces, drains, and water bodies in the vicinity, creating insanitary conditions. Later, the pourakarmikas will collect the discharged waste through street sweeping, drain cleaning, etc. Street sweeping has thus become the principal method of primary collection.

The tools used for street sweeping are inefficient and outdated. For instance, the broom with a short handle is still in use, forcing sweepers to bend for hours, resulting in fatigue and loss of productivity.

Transportation of waste from the waste storage depots to the disposal site is done through a variety of vehicles, such as three-wheelers, tractors, and trucks. Most of the transport vehicles are old and open. They are usually loaded manually. Due to inadequate workshop facilities and maintenance procedures, the vehicles are poorly maintained. This leads to the breaking down of vehicles, resulting in failure of services for a long time.

The various technological options available for processing, treatment, and disposal of MSW are composting, vermicomposting, AD, incineration, gasification and pyrolysis, production of RDF, and sanitary landfilling.

The main benefits of composting include improvement in soil texture and augmenting of micronutrient deficiencies. It also increases the moisture-holding capacity of the soil and helps in maintaining soil health. However, it is an age-old concept for recycling nutrients to the soil. It does not require significant capital investment compared to other waste treatment options.

The technology of waste-to-energy projects and its viability and sustainability have been proven worldwide. WTE projects involve higher capital investment and are more complicated than other options of waste disposal. These plants are financially viable in developed countries mainly because of the tipping fees charged by the facility for the service of waste disposal, in addition to its revenue income from power sales. However, at present, in Bangalore, revenue from power sales is the only source of income for WTE plants. Technologically, it is feasible to set up even smaller capacity projects of the 1–5 MW range, corresponding to around 100–500 metric tons per day waste treatment. The significant role in making a WTE facility financially viable is the segregation of waste at the source to avoid the mixing of undesirable waste streams.

12. Impact of solid waste on soil and water bodies

MSW landfills are essential in modern-day society because the segregation and disposal of solid waste materials into decentralized locations helps to minimize risks to public health and safety. Currently, in Bengaluru, MSW landfills remain open for decades before undergoing closure and post-closure phases, during which steps are taken to minimize the risk of environmental contamination. Although MSW landfills are an essential part of everyday living, they may present long-term threats to surface water and also hydrologically interlinked groundwater bodies. The impact of leachate on groundwater and surface water bodies has attracted much attention because of its enormous environmental significance. In the olden days, landfills were constructed without leachate collection systems and liners. Once leachate enters the groundwater, it will migrate downward through the unsaturated zone until it finally reaches the saturated area. This resulted in creating significant leachate-contaminate groundwater plumes that follow the hydraulic gradient of the groundwater system.

Unscientific management of MSW leachate will lead to contamination of the soil and water bodies. The presence of a contaminant in the soil can change the engineering properties of the soil. The leachate potential to contaminate the soils and groundwater and surface water bodies assumes significance in the context of existing MSW practices, which have many drawbacks.

Considering the importance of the problem discussed, this research mainly focuses on the characteristics of leachate generated from municipal solid waste landfill sites and its effect on surrounding water bodies near the Mavallipura landfill area in Bengaluru.

13. Reclamation of waste dumps for development in Bengaluru

Many cities, including Bengaluru, are also facing the problems due to old dump yards situated close to the expanding cities. These dump yards need to be reclaimed for the growing needs of the city infrastructure development. This is the case for many cities in India with an alarming rate of the urbanization process. Also, they create a nuisance in the town, and the same needs to be stabilized or reclaimed. The waste sites that were earlier in the periphery of the corporation limits of Bengaluru City are now in the development zone of a more magnificent Bengaluru City, as shown in **Figure 13**. It can be seen from a satellite image that the built-up area has come near and around the earlier dump sites. Thus, it is clear that most of the old dumpsite which is existing around Bengaluru has become potential places for development.

These structures built on these dumpsites can undergo distress due to the high settlement and cause failures due to the low strength of the dumped waste. These dumps can also cause groundwater contamination due to leaching of waste by the percolation of rainwater (**Figures 14–16**).

Naveen [12] carried out a detailed experimental program to study the variations in geotechnical properties for different wastes with a time of dump yard, i.e., in turn with the age of the waste. The data provided on geotechnical properties of the waste with varying degrees of decomposition helps to plan for the reclamation of waste dumps.

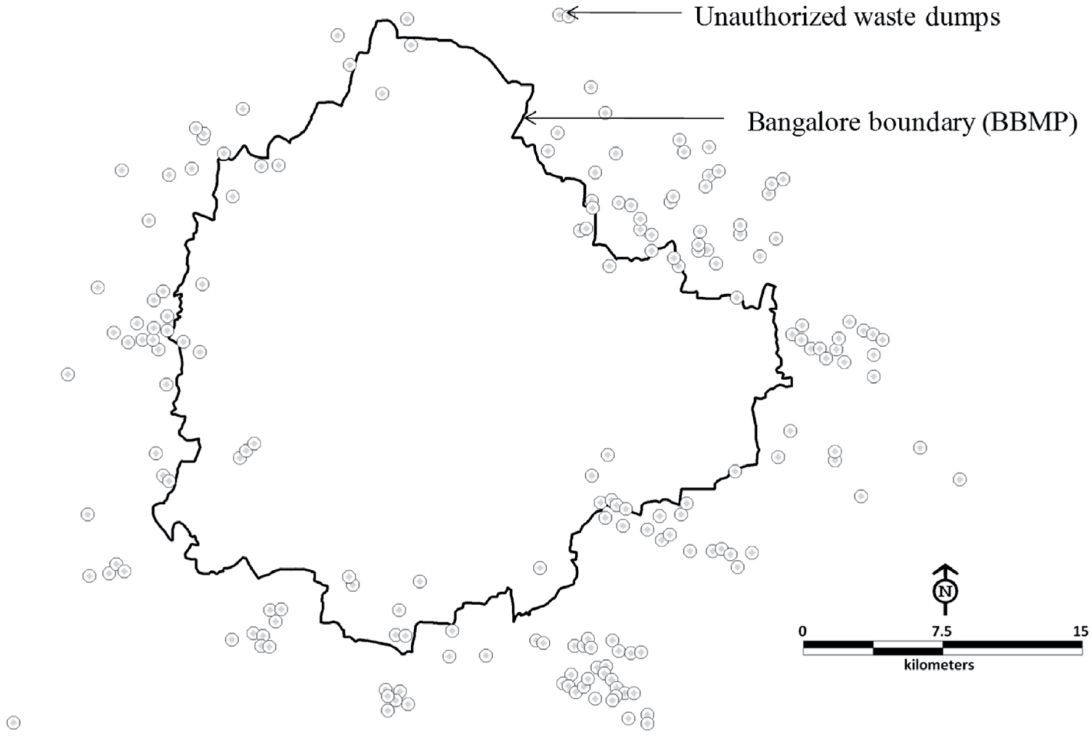


Figure 13.
Location of unauthorized dump sites in and around Bangalore City (Chanakya et al., 2011).

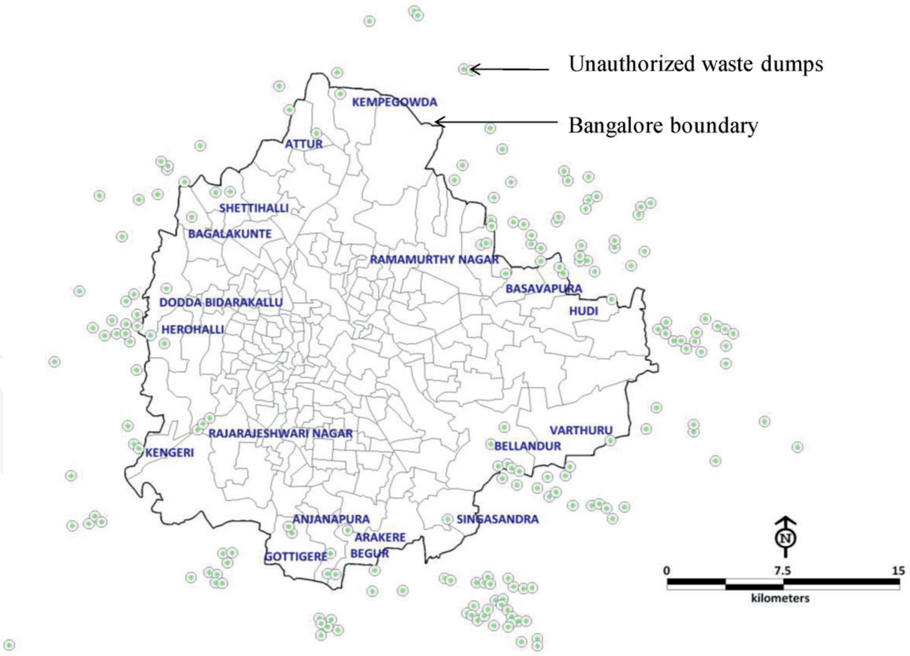


Figure 14.
Unauthorized dumping along with wards in and around Bangalore City.

Figure 15.
Major arterial and sub-arterial road network along with dump sites in and around Bangalore City.

14. Reclamation of MSW landfill

The objective of the reclamation is to return the MSW landfill to a condition as close as possible to leave the site in a state compatible with the surrounding ground. MSW landfill reclamation is a new approach used to expand the MSW landfill capacity and minimize the cost of acquiring additional land. The significant factors influencing the success of reclamation include chemical, hydrologic, and physical conditions of the fill materials, climate, availability of suitable plant species, and proper management of reclaimed sites [13].

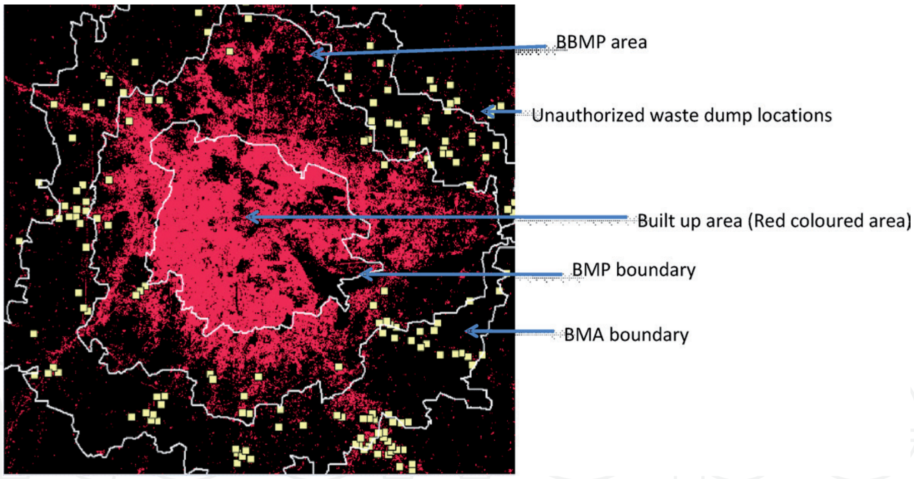


Figure 16.
Satellite image of built-up area along with dump sites in Greater Bangalore.

The essential benefits may include a reduction in closure costs and reclamation of land for other purposes and recovered materials such as recyclables, soil, and waste, which can be burned as fuel. Some drawbacks exist in MSW landfill reclamation. This technology may release methane and other gasses from decomposing solid wastes. Also, the excavation work process involved in reclamation may cause adjacent landfill areas to collapse/sink. Hence, it is necessary to conduct a site characterization study. The site characterization should assess facility aspects, such as geotechnical and geological features and the stability of the surrounding area and identified groundwater, and determine the fractions of good soil, recyclable waste materials, and hazardous waste at the site [14]. Based on the available information from the site characterization, it provides project planners with a basis for assessing the potential economic benefits of a landfill reclamation project.

The economic benefits associated with landfill reclamation are indirect; they may include the following: increased disposal capacity; avoided or reduced cost of landfill closure; revenues from recyclable and reusable materials like ferrous metals, aluminum, plastic, and glass; combustion waste sold as fuel; reclaimed soil used as cover; and land value of sites reclaimed for other uses.

Geotechnical properties of municipal solid waste presume great importance in their reuse, disposal, as well as reclamation of waste and dump sites. Because of the high demand for land, the abandoned, closed landfills have to reclaim to meet the growing needs of the society. Due to several reasons, the population around the improperly operated landfills is demanding the closure of the landfill. However, just leaving the landfill without proper closure cannot be allowed. Thus any attempt to reclaim land for development should come after the characterization of waste for their physical and chemical composition and geotechnical properties. Therefore, these studies constitute the first step to successfully implementing a comprehensive waste management system.

15. Conclusions

Based on the above context, the following conclusions can be drawn:

- For setup, the WTE plants require higher capital investment and are more complicated than the other options of waste disposal.

- WTE plants are suitable in developed countries mainly because of the tipping fees/gate fees charged by the facility for the service of waste disposal, in addition to its revenue income from power sales.

    ○ Due to the high content of biodegradable waste in Bengaluru, a biological process is needed such as anaerobic digestion and composting to treat the waste, gasification, and pyrolysis.

- Plasma gasification technology can reduce the need for landfills; it can create more renewable energy than the projected energy from solar, wind, landfill gas, and geothermal energies combined.

- RDF plants are in the initial stage of development in India. It is beneficial in preparing an enriched fuel feed for thermal processes like incineration. The RDF pellets are used as a coal substitute at a lower price.

- The pyrolysis process cannot handle the wide variety of wastes, and the end products of pyrolysis are carbon black oil that can be resent to a refiner and hydrocarbon gasses that can be used to make electricity or stream.

- Sanitary landfill is the cheapest, simplest, and most cost-effective method for disposing of waste.

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