A SUSTAINABLE SOLID WASTE MANAGEMENT APPROACH

M M Mamun Hasan[1] and Md Zahid Hossain Khan[2*]

[1] Upazila Engineer, Local Government Engineering Department (LGED), Bangladesh,
e-mail: mamunce.04@gmail.com
[2] Executive Engineer, Local Government Engineering Department (LGED), Bangladesh,
e-mail: zahid_lged@yahoo.com

***Corresponding Author**

ABSTRACT

Solid waste is gradually increasing with population growth. Additionally, several constraints, such as a lack of public awareness, efficient technology, and financial limitations, have made the solid waste management system more complex. The situation is more severe in urban areas than their rural counterparts. Consequently, the Khulna City Corporation, Bangladesh, aspires to address the issue, aiming for a clean and eco-friendly green city. The present study focused on the Sonadanga Thana area to identify safe and sustainable solid waste management solutions. Municipal solid waste (MSW) amount and composition, current waste management practices, requirements and priorities for effective waste management, necessary system coordination between the different parties with waste management responsibilities, and measurements of progress in achieving targets in the focused area are discussed in this study. The present study proposes an effective and economic collection and transportation system based on the amount and type of waste. In addition, it proposes three treatment methods: a 50-ton-per-day capacity composting plant, recycling facilities (10-ton-per-day for paper and 5-ton-per-day for plastic), and a sanitary landfill with a leachate treatment plant. Several recommendations on waste minimization, collection and transportation systems, waste treatment and disposal, operations, monitoring and evaluation processes, and policy formulations are also included. Implementing these suggestions could resolve most MSW management issues in densely populated areas, resulting in a pollution-free and healthy environment for urban dwellers.

Keywords: *Municipal solid waste management, Khulna City Corporation, waste treatment method, waste planning, environmental sustainability*

1. INTRODUCTION

1.1 Overview

The term “waste” refers to unavoidable by-products of human activity. The quantity and complexity of waste have increased due to economic development, urbanization, and efforts to improve city living standards. Bangladesh's rising solid waste generation rate can primarily be attributed to rapid urbanization and population growth (Abedin et al., 2015). Nevertheless, the available waste management system might negatively impact city dwellers, planners, and other stakeholders. The urban Bangladeshi population has been significantly and rapidly increasing at approximately 6% per annum (Alamgir et al., 2007). Severe financial constraints, limited appropriate advanced technology, low awareness, motivation, and public participation from the public, along with ineffective legislation and law enforcement to protect the environment and handle waste contributed to the current substandard waste management (Alam et al., 2020). Consequently, a government autonomous body named Khulna City Corporation (KCC) actively seeks a safe and sustainable solution for managing solid waste to maintain a clean, hygienic, and environmentally friendly city.

The present study focused on addressing the solid waste management issues in the Sonadanga Thana area, a small part under KCC management. Furthermore, this study aimed to determine a safe and sustainable solution for the area of interest. An overview of the quantity, composition, and current practices of municipal solid waste (MSW) management is included in this study. The requirements for effective waste management and critical areas for action are also identified. Furthermore, this study suggests a coordinated system involving various stakeholders and a process outlining evaluations of progress toward achieving waste management targets in specific areas.

1.2 The Study Area

The KCC manages waste from five police stations called “Thana” in Bengali, including the specific area of focus in this study, Sonadanga Thana, which is 8.42 km^2 (Khanam, 2012). According to (KCC, 2023), the highest recorded temperature in Sonadanga Thana was 35.50°C, while the lowest was 12.50°C. The summer seasons in the area are considerably humid, whereas the winters are generally pleasant. Sonadanga Thana receives 1605 mm of rainfall on average (WorldData.info, 2023).

A total population of 172,079 inhabit Sonadanga Thana, contributing to its 20,437 people per km^2 population density in 38,859 households (BBS.Report, 2011). According to (BBS.Report, 2011), the population growth rate recorded in the locality in 2018 was 1.03%. The area's literacy rate is 68.91% (Khanam, 2012).

No specific rules or regulations exist for managing solid waste in Sonadanga Thana. Nevertheless, effective waste management practices for all waste types have been successfully implemented. The methods are per the citizen’s charter provided by the KCC, 1995 Environmental Conservation Act, 1997 Environmental Conservation Rules, and 2000 Bangladesh Environment Court Act. KCC controls medical waste management in the area by the guidelines provided by the Hospital Waste Management and Processing Rules (2008). The KCC is also responsible for managing all solid waste types.

1.3 Sources of MSW

The MSW comprises various waste components, including organic and inorganic. The source of waste includes residential, commercial, institutional, and municipal services (Alamgir et al., 2007). In Khulna city, different sectors contribute varying percentages to the overall waste generation. The residential sector accounts for approximately 85.87%, while the commercial industry contributed 11.60% of the overall output (Alamgir et al., 2007). The institutional sector generated 1.02% of the total waste and other sectors are responsible for the rest (Alamgir et al., 2007).

1.4 Current MSW Management

1.4.1 Overview

The MSW management in large cities is under city corporations, while municipalities are responsible for smaller towns. Only 30–40% of city dwellers employ source storage and separation, which is an unofficial, unregulated practice (Khanam, 2012). Recently, numerous non-government organizations (NGOs), community-based organizations (CBOs), and private organizations have collaborated with local officials in MSW management. Nevertheless, the efficiency of the current system could be improved considerably. The NGOs, CBOs, and city authorities gather garbage via door-to-door collecting systems, where the waste is collected from the sources, primarily residences, before disposing of a sizable amount at the closest secondary disposal sites (SDS). The conservancy section primarily handles street sweeping, drain cleaning, and street lighting (Khanam, 2012). Subsequently, the city authorities collect waste from SDS and transfer it to the ultimate disposal site (UDS). Despite its limited coverage, the method significantly positively affects waste management.

1.4.2 The UDS

Significant sections of MSW still require disposal in a landfill post-reusing and recycling. Open dumping sites are inherently incompatible with the surroundings. Waste is scattered across the area due to the lack of proper management and containment systems. Furthermore, the wind carries litter outside the designated site, including surface water. The phenomenon poses a significant threat to the health of the residents and the environment. The local community also relies on groundwater for drinking, bathing, and washing. The leachate from UDS could contaminate groundwater resources in the areas, as hand pumps and tube wells are commonly located near the sites, approximately 300 m away (A. Ahsan et al., 2015; Alamgir et al., 2007). Landfill sites in Bangladesh are located in and around its cities, specifically in low-lying open spaces, unclaimed lands, riverbanks, and roadsides (Waste Safe, 2005). For example, the Rajbandh site, operated by KCC, is located 7 km from the city center.

Figure 1: The transport of MSW to a landfill site (left) and crude open dumping area near surface water (right)

1.4.3 The MSW Recycling and Treatment

Authorities should support recycling, reuse, and reduction efforts. In Bangladesh, recovery or recycling is conducted in three phases. In the first phase, various types of waste are separated into catagories based on their market value by generators. The paper and paper products, bottles, fresh containers, plastic materials, tin, glass, metal, old clothes, and shoes separated during the phase are sold to street hawkers. Impoverished children living in slums or on the streets, commonly called “Tokai”, gather minimal market-worthy items from storage bins, containers, and open storage areas in phase two. The *Tokais* collect broken glass, cans, cardboard, waste papers, polythene, rags, plastic bottles, coconut shells, metals, and miscellaneous commercial waste discarded by households. In the third and final phase, reusable and recyclable materials are recovered from the UDS. Scavengers, or Tokais, primarily salvage recyclable waste by unloading collection vehicles at UDS sites.

Composting offers potential waste treatment and minimization solutions in low-income and developing countries (LDACs) due to the nature of MSW. Nevertheless, composting failed to achieve the desired goals due to inadequate planning (Ali et al. 2004; Sinha & Enayetullah 2000; Enayetullah & Sinha

2003). Consequently, organizations, including city corporations, NGOs, and CBOs, have initiated well-organized pilot-scaled composting activities in Khulna.

In the cities of Bangladesh, windrow or active pile systems are the most commonly adopted waste management processes. Barrels or small containers composting approaches are also been introduced, especially in urban slums and colonies. Although the Bangladeshi authority does not require payment from city dwellers to transfer waste from the SDS to the UDS, the residents typically pay annual taxes to city corporations. Khulna City requires an incineration plant for MSW combustion. An effective waste segregation system that segregates hospital waste into hazardous and non-hazardous categories is also necessary. Properly segregating hazardous waste and establishing dedicated treatment facilities are vital to co-disposing hazardous waste with MSW prevention.

2. DISCUSSION

2.1 Components and Characteristics of MSW

Understanding the components and characteristics of solid waste is essential when planning solid waste management strategies. Debris, such as paper, textiles, food, and vegetables, are categorized as degradable, while moderately degradable waste includes cardboard and wood. Leather, plastics, rubbers, metals, glass, and electronics are non-degradable waste (Ashikuzzaman et al., 2020).

The bulk density of the garbage collected in the study area was 1115 kg/m^3, with an 8.2 pH. The waste grains were between 2 and 200 mm. The volume of rapidly biodegradable waste collected in the study area, organic waste, were the most significant, followed by paper, plastic, polythene, metal, and tin were the recyclable materials. Dust, ash, and other materials, such as mud, contributed the least amount. A total of 56% of the waste was also volatile solids, while 44% were ash leftovers. The moisture content of the waste collected in Sonadanga Thana was relatively high, at 67%. On average, the waste from the study area documented 11.50% carbon, 0.91% nitrogen, 0.76% potassium, and 0.33% phosphorous (Alamgir et al., 2007).

Alamgir et al. (2007) suggested that waste originate from five sources. The waste in the area of study originated from residential (85.87%), commercial (11.60%), institutional (1.02%), municipal services (0.55%), and others (0.96%) (Table 1). A total of 78.90% of the waste were food and vegetables, 9.50% were paper and paper goods, and 3.10% were plastics and polythene, while items of dust, ash, and mud comprised 3.70% of the MSW and other waste types contributed 4.80% (Table 2).

Table 1: The total MSW generated by different sources in KCC, Bangladesh (Alamgir et al., 2007)

Source	MSW generated daily (%)
Residential	85.87
Commercial	11.60
Institutional	1.02
Municipal services	0.55
Others	0.96

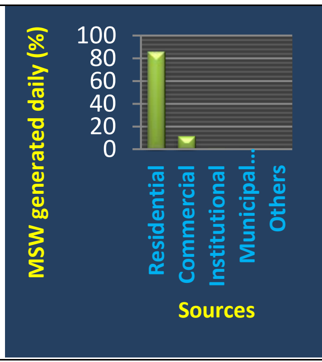
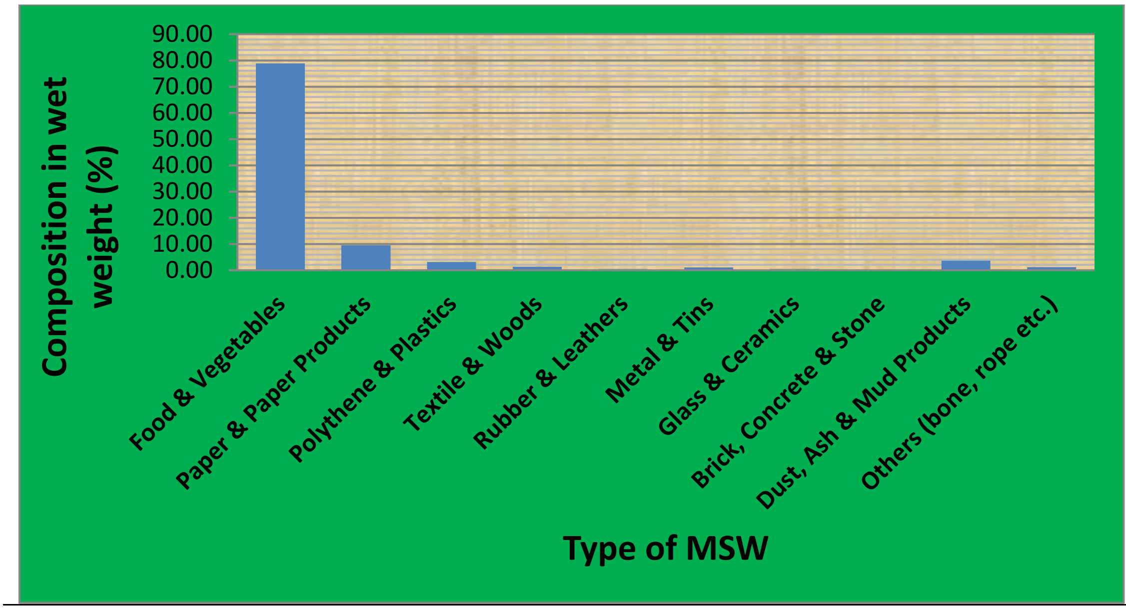


Table 2: The physical compositions of MSW generated in Sonadanga Thana, Bangladesh (Alamgir et al., 2007; Ghosh, 2016)

Type of MSW	Composition in wet weight (%)
Food and vegetables	78.90
Paper and paper products	9.50
Polythene and plastics	3.10
Textile and wood products	1.30
Rubber and leather products	0.50
Metal and tin products	1.10
Glass and ceramics	0.50
Brick, concrete, and stone	0.10
Dust, ash, and mud products	3.70
Others (i.e. bones, rope)	1.20
Total	100.00



2.2 Estimating Waste Generation

Although rising population directly contributes to MSW generation, the amount of solid waste produced primarily relies on human behavior, economic development, and the effectiveness of recycling and reuse systems (Ding et al., 2021; Khan et al., 2022). The total MSW collected in the study area was 520 tons daily, with a 0.346 kg per capita MSW generation rate (Table 3) (Alamgir et al., 2007). In 2011, 172,079 individuals resided in the focus area of the current study (Khanam, 2012), producing 59.54 tons of waste per day. The amount of garbage collected in the municipality increased to 94.90 tons in 2019 (Table 4).

The urban population in the locality has been significantly and rapidly increasing at approximately 6% annually (Alamgir et al., 2007). The total future population in Sonadanga Thana could be calculated based on Equation 1. In 2028, the estimated amount of waste generated in Sonadanga Thana is 169.95 tons daily. The data demonstrated in Table 4 suggests that the total amount of waste would approximately double in 10 years, which could present a significant challenge for the city corporation regarding waste management.

$$oneP_t = P_0 \, (1 + K)^n \tag{1}$$

Where P_t denotes the future population number, P_0 represents the present or initial population, K is the average percentage increase, and n indicates the projection period in a decade.

Table 3: The amount of MSW generated in Sonadanga Thana, Bangladesh (Alamgir et al., 2007)

MSW generation	**Amount**
MSW generation (ton/day)	520
MSW generation rate (kg/capita/day)	0.346

Table 4: The predicted MSW generated in Sonadanga Thana, Bangladesh

Year	**Population (Nos.)**	**MSW generation rate (kg/capita/day)**	**Total waste (kg/day)**	**Total waste (ton/day)**
2011	172,079	0.346	59,539	59.54
2019	274,268	0.346	94,897	94.90
2028	491,172	0.346	169,945	169.95

2.3 Collection and Transportation System Design

Bangladesh's city corporations and municipalities are legally responsible for providing SWM services. The collection and transportation systems provided by the companies are designed to regulate residential, commercial, institutional, and municipal waste, which constituted the commonly generated waste within the target area of this study. The system has been designing the waste management collection and transportation strategy in the locality for the past ten years.

Organic waste accounted for 78.90% of the total waste collected in Sonadanga Thana, while 21.10% was of inorganic origin. Consequently, the present study proposes a curbside collection system, where household owners are required to separate their waste (organic and inorganic) before placing them in designated bins. In small areas with single-story or high-rise apartment buildings, the homeowners could select a person to collect and transport their waste to the nearest bin. Subsequently, the city corporation or municipality-designated collectors would gather the waste from each container individually and transport them to separate locations.

In the proposed system, 20-kg capacity bins are necessary as waste transfer from the container to the truck is performed manually. The present study also calculated the total number of compressor trucks required based on the assumption that 5-ton trucks would be employed to transport 60% of the total waste (organic), while 3-ton trucks would transfer the remaining 40% of the waste (inorganic). Only 5- and 3-ton trucks are recommended as vehicles over five tons might face challenges navigating the narrow roads in different areas of the focused region and villages near the landfills. Furthermore, small-capacity trucks are cost-effective. This study suggests that authorities collect organic waste daily and inorganic waste every other day. Consequently, the trucks would transport the litter twice daily.

Table 5 summarizes the calculations for human resources and equipment necessary for the system proposed. The total number of waste bins required to collect the amount of organic and inorganic waste in 2019 is 3744 and 1001, respectively. Consequently, 14 truck drivers would drive four five-ton and five three-ton trucks to deliver the organic and inorganic garbage gathered from the bins. Concurrently, another 34 individuals would serve as ordinary laborers.

Table 5: The estimated MSW generation and bins required for Sonadanga Thana, Khulna City

Year	Total waste (kg/day)	Organic waste (kg/day)	Number of bins required	Number of compressor trucks required	Inorganic waste (kg/day)	Number of bins required	Number of compressor trucks required	Total staffing required (number of individuals)
2019	94,897	74,874	3744	5 tons = 4 3 tons = 5	20,023	1001	5 tons = 2 3 tons = 3	Truck driver = 4 Laborer = 34
2020	106,626	84,128	4206	5 tons = 5 3 tons = 6	22,498	1125	5 tons = 3 3 tons = 3	Truck driver = 17 Laborer = 42
2021	113,024	89,176	4459	5 tons = 5 3 tons = 6	23,848	1192	5 tons = 3 3 tons = 3	Truck driver = 17 Laborer = 42
2022	119,805	94,526	4726	5 tons = 6 3 tons = 6	25,279	1264	5 tons = 3 3 tons = 3	Truck driver = 18 Laborer = 45
2023	126,993	100,198	5010	5 tons = 6 3 tons = 7	26,796	1340	5 tons = 3 3 ton = 4	Truck driver =20 Laborer = 49
2024	134,613	106,210	5310	5 tons = 6 3 ton = 7	28,403	1420	5 tons = 3 3 ton = 4	Truck driver = 20 Laborer = 49
2025	142,690	112,582	5629	5 tons = 7 3 ton = 8	30,108	1505	5 tons = 4 3 ton = 4	Truck driver = 23 Laborer = 57
2026	151,251	119,337	5967	5 tons = 7 3 tons = 8	31,914	1596	5 tons = 4 3 tons = 4	Truck driver = 23 Laborer = 57
2027	160,326	126,497	6325	5 tons = 8 3 tons = 8	33,829	1691	5 tons = 4 3 tons = 5	Truck driver = 25 Laborer = 62
2028	169,945	134,087	6704	5 tons = 8 3 tons = 9	35,859	1793	5 tons = 4 3 tons = 5	Truck driver = 26 Laborer = 64

2.4 Waste Treatment

The focus area in this study generated 94.90 tons of waste daily, where organic waste accounted for 74.87 tons, while 20.03 tons were inorganic. Food and vegetables were the primary waste generated in Sonadanga Thana, followed by paper and paper products. The current study proposes three treatment methods for organic waste: composting and recycling plants and landfills with leachate treatment facilities. The proposed treatment approaches are described in subsequent sections.

Table 6: The amount of different types of waste generated in Sonadanga Thana, Khulna City, Bangladesh (A. Ahsan et al., 2015)

Type of MSW	Composition in wet weight (%)	Waste amount (ton/day)
Food and vegetables	78.90	74.87
Paper and paper products	9.50	9.02
Polythene plastics	3.10	2.94
Textile and wood products	1.30	1.23
Rubber and leather products	0.50	0.47
Metal and tin products	1.10	1.04
Glass and ceramics	0.50	0.47
Brick, concrete, and stone	0.10	0.09
Dust, ash, and mud products	3.70	3.51
Others (i.e. bones, rope)	1.20	1.14

2.4.1 Composting plant

2.4.1.1 General

Compost is the final stable product of various biological degradation processes, such as composting and anaerobic digestion. Composting is an aerobic decomposition where organic materials break down into carbon dioxide (CO_2) and water and stabilized products, primarily humic substances. Organic materials include dead leaves, plant matter, kitchen scraps, or leftover vegetables. Consequently, composting is a valuable tool that effectively manages and expedites natural activities. The current study proposes a composting plant developed through a public-private partnership project to treat the waste produced in the study area. The KCC would oversee the construction of the infrastructures, while private organizations would assume maintenance responsibilities.

2.4.1.2 Factors influencing the selection

The present study suggests composting as waste treatment due to its significant portion of the total waste generated in the focus area. Composting is an environmentally friendly method for treating organic waste. Furthermore, the waste management hierarchy revealed that composting is the second preferred option for managing organic waste.

2.4.1.3 Information

Estimating the necessary capacities of the equipment is essential in determining the appropriate processing tools (such as grinders and screens) required to ensure a working composting plant. The estimation should also consider factors such as design throughput, specific characteristics of the materials intended for composting, and any seasonal or daily variations in the feedstock flow. Furthermore, suitable methods are critical to ensure the health and safety of the workers. Accordingly, noise and airborne emission control procedures should also be implemented. The composting plant proposed in this study utilizes static piles and active windrows with a 50-ton daily capacity. According to Savage (2020), approximately one acre is necessary to operate a composting plant. The area should include 15-foot windrows of 81 cubic feet per unit and 15-foot fire lanes for a 30-day composting period.

2.4.1.4 Budget

The total initial investment cost for the composting plant proposed in this study is 2.87 million USD.

2.4.2 Recycling Plants

2.4.2.1 General

Recycling involves transforming waste materials into new substances or objects. Strictly, recycling a material translates to creating a fresh supply of the same material. For instance, used office paper could be recycled and transformed into a new form, while polystyrene foam could be repurposed into new polystyrene (Wikipedia(Recycling), 2023)]. The technique offers an alternative approach to traditional waste disposal, aiding resource conservation efforts and reducing greenhouse gas emissions. Recycling is also an effective way to prevent the wastage of still-useful materials and decrease new raw material requirements (Yang et al., 2023). Furthermore, the method reduces energy usage, air pollution from incineration, and water pollution due to landfilling (Wikipedia(Recycling), 2023)].

Recycling is essential in contemporary waste reduction efforts. The approach is also the third element in the waste hierarchy, “Reduce, Reuse, and Recycle” (Wikipedia(Recycling), 2023). The approach contributes to environmental sustainability by replacing the employment of new raw materials and diverting waste away from the economic system. Consequently, the present study proposes a public-private partnership program to build a recycling plant to manage waste in the study area. The KCC would construct the required infrastructures, while private organizations or NGOs would operate and maintain the plant.

2.4.2.2 Factors influencing the selection

According to the physical composition of the waste collected in the Sonadanga Thana locality, paper and paper products were the second most collected waste. In contrast, polythene and plastic products rank fourth in quantity. Consequently, this study suggests prioritizing recycling as a waste treatment plan.

2.4.2.3 Information

The current study recommends establishing two recycling plants. One plant would specifically manage paper and paper products, while the other would be dedicated to polythene plastic products. The paper recycling plant would have a 10-ton daily capacity, while its plastic counterpart would recycle five tons of waste daily.

2.4.3 Landfill with Leachate Treatment Facility

2.4.3.1 General

A landfill site is an area designated for waste materials disposal through burial. Although burial is a modern practice, the waste treatment segment of the landfill approach is the oldest method. Previously, waste was either left in piles or thrown into pits. Throughout history, landfills have also been widely employed as the primary technique of organized waste disposal. The practice prevails in numerous places worldwide. In the system suggested in the present study, the KCC would construct, operate, and maintain the landfill.

2.4.3.2 Reason for selection

As Bangladesh develops, the authorities in the country must secure additional funding to invest in various sectors. Landfills are considered the most cost-efficient method for waste disposal. Furthermore, landfill gas could be upgraded to natural gas as an additional revenue source. Another advantage of utilizing landfills is the availability of a designated disposal location that allows close monitoring. The approach also enables effective separation and removal of recyclable materials before final disposal during waste processing.

2.4.3.4 Information and design

Table 7 demonstrates the total remaining waste requiring transfer to landfills after being processed in the composting and paper and plastics recycling plants suggested. According to the proposed landfill design, the total waste generated in 10 years would be 244,612 tons (Table 5). (Alamgir et al., 2007) revealed that the bulk density of waste is 1115 kg/m^3. Consequently, a landfill of 219,383 m^3 could retain a 10 m-deep compacted solid waste. Each intermediate layer of the landfill would be 2 m thick with a 50 cm soil cover and 1 m soil for the final layer. The total area of the landfill would be 21,938.30 m^2 or 5.42 acres. The landfill proposed requires 8.25 acres of land, which would house the management office, operational area, and leachate treatment plant.

Table 7: The predicted annual remaining waste amount to be delivered to landfills post-composting and recycling

Year	Total waste (ton/day)	Composting plant (ton/day)	Paper recycling (ton/day)	Plastic recycling (ton/day)	The remaining amount for landfill (ton/day)	The remaining amount for landfill (ton/year)
2019	94,897	50	10	5	30	10,912
2020	106,626	50	10	5	42	15,193
2021	113,024	50	10	5	48	17,529
2022	119,805	50	10	5	55	20,004
2023	126,993	50	10	5	62	22,627
2024	134,613	50	10	5	70	25,409
2025	142,690	50	10	5	78	28,357
2026	151,251	50	10	5	86	31,482
2027	160,326	50	10	5	95	34,794
2028	169,945	50	10	5	105	38,305
				Total waste for 10 years (ton)		244,612

2.4.3.5 Resources and equipment necessary for the landfill

Human resource

Possessing appropriate qualifications is vital when considering staffs for the suggested SWM system. Training is also critical, including educating the personnels on proper landfill procedures, identifying particular waste, and appropriate handling practices. Consequently, staff members could attend courses. Several excellent one-week courses on waste management are available, including the programs offered by the Asian Institute of Technology (AIT) in Vietnam and other locations.

Machinery

Prioritizing a suitable plant selection is vital in upgrading landfill activities. Regular availability of heavy earthmoving plants is also necessary to cover waste and procure sanitary landfills. Accordingly, the operation and maintenance requirements of the machinery necessitate consideration. The potential outcomes of collection services employment primarily rely on the availability of the vehicles, hence utilizing a waste compactor truck is ideal.

Services

The analytical laboratory facilities in Bangladesh are limited to essential evaluations, including pH, conductivity, fecal coliform, available chlorine, and only limited numbers of metal selection. Assessing the impacts of waste disposal sites on the environment becomes problematic due to the constraints. Typically, samples are sent offshore, incurring costs and logistical challenges. Consequently, the present study recommends constructing a laboratory capable of monitoring leachate. The laboratory should be able to assess parameters, including pH, electrical conductivity, chloride ion, ammoniacal nitrogen, nitrate nitrogen, total phosphorus, zinc (acid soluble), biochemical oxygen demand (BOD5), and heavy metals, such as (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), iron (Fe), magnesium (Mg), manganese (Mn), and nickel (Ni).

2.5 The Environmental Impact Assessment (EIA) Related to the Treatment Options Proposed

2.5.1 The Environmental Impacts of Composting

Composting add nutrients and introduce valuable organisms to the soil, recycling kitchen and yard waste, and reducing landfill waste, thus good for the environment. Furthermore, composting food scraps and green waste in bins might aid in eliminating numerous issues. Nevertheless, also has disadvantages (Ayilara et al., 2020; Lee et al., 2023), as follows.

(i) The products obtained are heavy and bulky, hence expensive to transport.

(ii) The nutrient value of compost is low and considerably vary compared to chemical fertilizers. The rate of nutrient release could be faster. Consequently, the nutrient requirements of crops are not commonly met in a short time, resulting in nutrient deficiency.

(iii) Agricultural users might be concerned about potential levels of heavy metals and other possible contaminants in compost, primarily mixed in MSW. Possible contamination could be severe when the compost is utilized on food crops.

2.5.2 The Environmental Impacts of Recycling

Recycling minimizes pollution and global warming, protects the environment, and conserves natural resources. The waste management method also diminishes waste in landfill sites. Furthermore, recycling old and used materials into reusable products significantly reduces the possibility of choking and ensures sustainable use of resources. Practicing recycling could contribute to job opportunities and reduce energy consumption. Nonetheless, recycling requires significant upfront capital costs. Recycling sites are also often unhygienic, unsafe, and unsightly. Products of recycled waste are also reportedly less durable.

2.5.3 The Environmental Impacts of Landfills

Landfills are the most efficient and practical solution when a governing body requires sufficient funds to manage waste with advanced technology effectively. The approach also offers a cost-effective means of addressing the issue. Methane (CH_4) and CO_2 are produced in a 60-to-40 ratio under anaerobic conditions, including landfills. The CH_4 is an essential component of landfill gas due to its high calorific value, 33.95 MJ/Nm3, thus rendering it valuable to generate energy (Catriona Bogan, 2002; Serutla, 2016).

Toxins from landfills negatively impact the environment. Over time, the toxins in landfills gradually seep into the soil and groundwater, posing long-term environmental hazards. Furthermore, numerous discarded materials often contain harmful substances. For instance, electronic waste, such as televisions, computers, and other electronic appliances, have significant ecological risks due to their various hazardous substances. The harmful substances include Hg, arsenic, Cd, polyvinyl chloride (PVC), solvents, acids, and Pb.

Leachate is a liquid produced when waste decomposes in landfills and water passes through the garbage. The highly toxic liquid could contaminate the surrounding land, groundwater, and waterways. Greenhouse gas is also emitted when organic materials, including food scraps and green waste, are disposed of in landfills. Typically, the organic waste in landfills is compacted and covered, eliminating oxygen supply and leading to anaerobic breakdown. The anaerobic process releases CH_4, which is 25 times more potent greenhouse gas than CO_2. The implications of global warming and climate change are significant. Furthermore, CH_4 is a flammable gas that could be hazardous in high concentrations.

2.6 Integrated Solid Waste Management

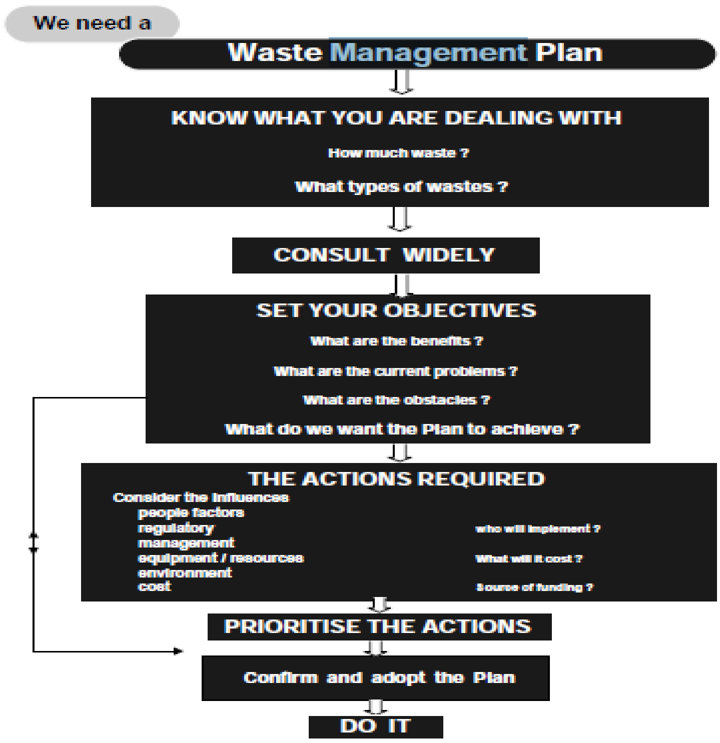


Figure 2: The steps for confirming an integrated solid waste management system

3. CONCLUSION

The population growth in Sonadanga Thana has led to daily increments of MSW, which KCC manages. The present study focused on a residential neighborhood with a large bus stand and various commercial and educational institutions. Approximately 78.90% of the total waste the Sonadanga Thana locals disposed of is organic, specifically food and vegetables. Paper and paper products accounted for approximately 9.50% of the total waste. The city's total waste generated is 94,897 tons per day, which could rise to 169,945 tons per day in 10 years.

The inhabitants of Sonadanga Thana reported preferring their current collection, transportation, treatment, and disposal facilities. Nevertheless, this study suggests implementing a distinct system for collecting and transporting MSW. The proposed plan would require 3744 bins for organic waste and nine trucks to transport the accumulated waste. At the same time, 1001 bins would be necessary for collecting inorganic waste and serviced by five trucks. For transporting the waste, 14 truck drivers and 42 laborers are required.

The present study recommends collecting organic waste daily, while inorganic waste would be collected every other day. Three treatment methods proposed in this study include a composting plant with a daily capacity of 50 tons, recycling plants of 10 tons/day capacity for paper and five tons/day for plastic, and a landfill with a leachate treatment plant. The composting plant suggested in this study requires an acre of land, while the landfill necessitates 8.25 acres.

The current study proposes waste minimization, collection and transportation, treatment and disposal, operation, monitoring and evaluation, and policy or regulation strategizing recommendations. The MSW management issues in the focus area could be resolved upon implementing the recommendations, achieving a green environment free from pollution and promoting good health.

4. RECOMMENDATIONS

4.1 Waste Minimization

A waste minimization strategy encompassing actions to reduce waste requiring disposal could be developed. Nevertheless, the success of waste reduction programs primarily relies on the individuals involved, including the willingness, motivation, and ability to reduce waste. Potential barriers to successful waste minimization projects include a low caring attitude, limited incentive to reduce waste with free disposal, and unreliable and poorly promoted waste recycling and collection services. Critical factors for successful waste minimization are as follows (Ashikuzzaman et al., 2020; McAllister, 2015).

(i) Carry out waste analysis survey to characterize waste stream. (It starts from the second year and will be carried out once every year. It may be done by KCC and KUET jointly).

(ii) Performing “waste audits” of key waste generators, such as government offices, businesses, and hotels. The evaluations could start in the second year and be conducted annually. The building owners could perform the task.

(iii) Identifying and assessing the practicality and economics of possible waste minimization measures of targeted waste generators or streams. Each situation requires specific assessments that might necessitate research. The step could be within the next two years of the waste management program proposed. An expert consultant could be the candidate for the evaluations.

(iv) Raising awareness about waste minimization through training and campaigns in educational institutions, such as schools, colleges, universities, and religious places, including mosques, temples, churches, and pagodas, is also crucial. The campaign could be effectively conducted through mass media platforms like radio and television. The current study suggests starting the initiative during the third year, focusing on waste generators or specific streams selected to minimize and sustain. The KCC or other private organizations could assume the responsibility.

(v) Introducing laws and regulations related to MSW is vital for a successful waste management program. The KCC and Members of the Bangladesh Parliament could participate in this step. The program would be implemented in the third year, focusing on specific waste generators or streams.

4.2 Waste Collection and Transportation

The present study recommends providing attention to rubbish collection from bins, including the regular bins placed in public places. Separate collection and transportation of organic and inorganic waste are also vital. The KCC officials would commence both steps immediately and regularly. Source separation could also be incorporated into SMW laws and regulations. The present study proposes achieving the objective during the second year, involving the KCC and Members of Parliament.

Raising awareness on separating and managing waste management among the public is critical. Conducting training and awareness campaigns in educational institutions, such as schools, colleges, universities, and religious places, including mosques, temples, churches, and pagodas, could ensure the achievement of the objective. The campaigns could be effectively performed through mass media platforms like radio and television. The initiated event should be continued. The KCC and private organizations could perform the task.

Using GPS, the KCC could enhance collection routes and determine the optimal bin locations for specific areas. The KCC or a consultant specializing in the field could assume the responsibility, which this study recommends to complete in the second year. Government authorities must also improve their management practices to address the issue of managing and transporting MSW effectively. Considering that the government could not solely perform the task, a collaborative effort involving NGOs, external support agencies, institutional members, entrepreneurs, and communities is necessary. The current study suggests initiating the step in the second year. The concerned entities, including KCC, could also involve waste pickers in the collection and transportation processes, linking them to the formal sector. This study proposes that the KCC initiate the task immediately.

4.3 Waste Treatment and Disposal

The SWM management practices necessitate improvement to address the issue of waste disposal and treatment effectively. The responsibility could be undertaken by more than the government, requiring a collaborative effort involving NGOs, external support agencies, institutional members, entrepreneurs, and the community. The present study suggests initiating the enhancements in the second year.

The KCC could plan and design effective composting, recycling, and landfill systems. A comprehensive management plan for the systems is also necessary. The KCC officials could manage and perform the duty with assistance from experts in the field, aiming for completion during the second year. The concerned authority should also provide specific attention to source separation to ensure the completion of the composting process. Although the step is already underway, it should be a continuous effort. The present study suggests that KCC officials should assume responsibility.

The KCC has the opportunity to develop a skilled workforce in composting, recycling, and landfill management. The staff could attend short courses in countries such as Japan and Vietnam. The present study recommends achieving the objective during the second year. Compost fertilizers are less effective than their chemical counterparts. The KCC could also offer compost fertilizers obtained from the composting plant to farmers at a low cost or for free, providing a subsidy. The process would begin immediately post-compost fertilizer production.

Beginning in the project's second year, government banks could offer loans to NGOs and private organizations at a minimum interest for composting and recycling. Furthermore, KCC could incorporate informal recycling industries into its management framework to establish a connection with the formal sector. The effort, which could begin immediately, would be performed continuously.

Currently, the KCC requires additional funds for an effective SWM system. Consequently, the present study proposes constructing a landfill as a solution. Subsequently, the KCC could consider implementing incineration as an alternative to landfilling before reaching the landfill's lifespan due to the limited land availability in Bangladesh. The program could commence in five years.

The KCC could determine appropriate landfill locations with GPS by considering the factors outlined in the sludge treatment guideline. An aspect stated in the protocol involves ensuring that the flooding level is higher than 2 m above the maximum anticipated water level of nearby water bodies. A minimum distance of 500 m from populated areas should also be maintained when constructing the sites. Construction activities within protected areas should be avoided, and potential landfills should not be constructed in flood plains and areas prone to natural disasters. The underground infrastructure of the landfill must possess the ability to withstand mechanical stresses and prevent leachate leakage and pollutants. Water impermeability and buoyancy in safety are also key characteristics of landfills outlined in the treatment guideline. The present study suggests completing this step during the second year with KCC staff members or a consultant in the field assuming responsibility.

Upon reaching the end of its lifespan, KCC could rehabilitate the landfill area through activities such as gardening and plantation or constructing a park. Leachate treatment plants could be operated for up to 30 years in line with the 30-year decomposition period. The project would begin simultaneously with the completion of the landfill construction. The KCC officials could perform the task. The KCC could also conduct a feasibility investigation on gas production in landfills with assistance from a specialized consultant. The gas might possess potential as an energy source if enough is discovered. The current study recommends finishing the task a year before the expiration of the landfill's lifespan.

4.4 Operation, Monitoring and Evaluation

The municipal waste management systems among various entities and stakeholders in the focused area under the KCC demonstrated noticeable disparity. The differences are also apparent within the KCC itself, the Khulna Development Authority (KDA), Khulna Water and Sewerage Authority (KWASA), NGOs, the civil administration, the Department of Public Health Organization (DPHE), commercial institutions, and CBOs (R. Ahsan et al., 2009; Islam et al., 2019). The KCC could reduce the gap by implementing an effective management policy. The current study recommends initiating the process immediately with continuous and gradual progress. This study suggests that the KCC officials, the Ministry of Local Government Rural Development and Cooperatives, and the Ministry of Environment, Forest and Climate should assume the responsibility.

There is minimal scientific evidence of public health issues caused by MSW in the focused area. Consequently, further research on the matter could be beneficial. The investigation could start immediately and would be performed regularly. The KCC and the Department of Environment could be responsible for executing the task.

A planning and implementation body should include representatives from relevant authorities and stakeholders. The current study proposes beginning the process promptly and progressing gradually. The KCC official, the Ministry of Local Government, and Environment, Forest, and Climate could be involved in the duty. Every Bangladesh authority responsible for managing MSW should also establish a specific SWM department to ensure an effective system. The study suggests that the KCC and Ministry of Local Government Rural Development and Cooperatives initiate the step immediately.

The present study recommends that the KCC possesses the authority to supervise and monitor the system proposed closely, including the collection, transportation, disposal, and treatment processes. The corporation could also penalize parties or individuals failing to comply with the regulations. This study suggests that the KCC official and the Ministry of Environment, Forest, and Climate could start the task immediately.

The central government and KCC should allocate adequate funds for MSW management as the budget could initiate the subsequent activities. Consequently, the KCC and Ministry of Finance could be responsible for completing the task. The KCC should also consider improving its environmental monitoring efforts to assess the impact of MSW management activities, including collection, transportation, disposal, and treatment processes. This study recommends that the KCC and the Department of Environment perform the task.

4.5 Policy or Regulation Construction

The current study suggests that the Bangladeshi government should establish a comprehensive policy, law, regulation, and strategy for managing waste generated from various sources in urban areas of the country, considering the absence of specific laws and regulations for MSW management. Furthermore, the government could connect current environmental rules and regulations with new policies, statutes, regulations, and strategies that would be developed. The objectives should be achieved during the second year of the proposed project. The KCC, Ministry of Local Government Rural Development and Cooperatives, Ministry of Environment, Forest and Climate, and Members of the Parliament could assume the responsibility of performing the tasks.

Waste minimization and source separation policies should be constructed and completed during the second year. The present study recommends the KCC, Ministry of Local Government Rural Development and Cooperatives, Ministry of Environment, Forest and Climate, and Member of Parliament as the authoritative bodies in charge of the duty. The government can also establish laws and regulations encompassing waste treatment processes. The current study suggests achieving the objective during the second year, where the KCC would collaborate with the Ministry of Local Government Rural Development and Cooperatives, Ministry of Environment, Forest and Climate, and Members of Parliament.

The government could consider incorporating essential solid waste management into school-level educational curricula as a segment of its awareness policy. This study recommends that KCC and the Ministries of Local Government Rural Development and Cooperatives, Environment, Forest and Climate, and Education should complete the task in the second year.

ACKNOWLEDGEMENTS

The authors would like to gratefully acknowledges the Local Government Engineering Department, Bangladesh.

REFERENCES

Abedin, M. A., & Jahiruddin, M. (2015). Waste generation and management in Bangladesh: An overview. *Asian Journal of Medical and Biological Research, 1*(1), 114-120.

Ahsan, A., Alamgir, M., Imteaz, M., Shams, S., Rowshon, M., Aziz, M. G., & Idrus, S. (2015). Municipal solid waste generation, composition and management: Issues and challenges. A case study. *Environment Protection Engineering, 41*(3).

Ahsan, R., Islam, A., & Shams, S. (2009). *Municipal waste management mechanism for Khulna city: a practice for better environment.* Khulna University of Engineering and Technology,

Alam, O., & Qiao, X. (2020). An in-depth review on municipal solid waste management, treatment and disposal in Bangladesh. *Sustainable Cities and Society, 52*, 101775.

Alamgir, M., Bidlingmaier, W., Glawe, U., Martens, J., Sharif, L., Visvanathan, C., & Stepniewski, W. (2007). *Safe and sustainable management of municipalsolid waste in Khulna City of Bangladesh.* Paper presented at the Eleventh International Waste Management and Landfill Symposium, Cagliari, Italy.

Ashikuzzaman, M., & Howlader, M. H. (2020). Sustainable solid waste management in Bangladesh: issues and challenges. *Sustainable waste management challenges in developing countries*, 35-55.

Ayilara, M. S., Olanrewaju, O. S., Babalola, O. O., & Odeyemi, O. (2020). Waste management through composting: Challenges and potentials. *Sustainability, 12*(11), 4456.

BBS.Report. (2011). *Bangladesh Bureau of Statistics (BBS), Statistics and Informatics Division (Sid) Ministry of Planning, Government of the People's Republic of Bangladesh, Parishankhan Bhaban*. Retrieved from

Catriona Bogan, I. C., Chris Deed. (2002). *Guidance on Landfill Gas Flaring*. Retrieved from Environment Agency Scottish Environment, Almondsbury, The Castle Business Park, Bristol: https://www.sepa.org.uk/media/28988/guidance-on-landfill-gas-flaring.pdf

Ding, Y., Zhao, J., Liu, J.-W., Zhou, J., Cheng, L., Zhao, J., . . . Li, X. (2021). A review of China's municipal solid waste (MSW) and comparison with international regions: Management and technologies in treatment and resource utilization. *Journal of cleaner production, 293*, 126144.

Ghosh, S. K. (2016). Waste Management and Resource Efficiency Proceedings of 6th IconSWM 2016. *Proceedings of 6th IconSWM*, 1.

Islam, M. S., Moniruzzaman, S., & Mondal, S. (2019). Municipal solid waste quantification, transportation and management in Khulna city. *Journal of Engineering, 10*(2), 61-68.

KCC. (2023). Khulna City Corporation (KCC). Retrieved from http://www.khulnacity.org/Content/index.php?page=About_KCC&ZGU&pid=30

Khan, S., Anjum, R., Raza, S. T., Bazai, N. A., & Ihtisham, M. (2022). Technologies for municipal solid waste management: Current status, challenges, and future perspectives. *Chemosphere, 288*, 132403.

Khanam, M. (2012). National Encyclopedia of Bangladesh. Retrieved from https://en.banglapedia.org

Lee, B. H., & Khor, S. M. (2023). Biodegradation Versus Composting. In G. A. M. Ali & A. S. H. Makhlouf (Eds.), *Handbook of Biodegradable Materials* (pp. 1275-1306). Cham: Springer International Publishing.

McAllister, J. (2015). Factors influencing solid-waste management in the developing world.

Savage, G. (2020). Calculating Capacity At Composting Sites. Retrieved from https://www.biocycle.net/calculating-capacity-at-composting-sites/

Serutla, B. T. V. (2016). *Potential for energy recovery and its economic evaluation from a municipal solid wastes landfill in Cape Town.* Cape Peninsula University of Technology,

Wikipedia(Recycling). (2023). Recycling. Retrieved from https://en.wikipedia.org/wiki/Recycling

WorldData.info. (2023). Climate in Khulna (Bangladesh). Retrieved from https://www.worlddata.info/asia/bangladesh/climate-khulna.php

Yang, M., Chen, L., Wang, J., Msigwa, G., Osman, A. I., Fawzy, S., . . . Yap, P.-S. (2023). Circular economy strategies for combating climate change and other environmental issues. *Environmental Chemistry Letters, 21*(1), 55-80.