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Research Paper

Solid waste generation, composition and potentiality of waste-to-resource recovery in Sylhet City Corporation

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Abstract

Solid waste generation is increasing with high economic and population growths in Sylhet City Corporation (SCC). Characteristics of solid waste generation are different in many ways in the different cities/urban areas of Bangladesh. SCC is facing severe development challenges in areas like solid waste management and waste-to-resource recovery. SCC and its extended areas are now producing more solid waste than ever before because of accelerated unplanned urbanization, ever-growing tourist pressure and growing urban population. Sooner than later, resources recovery and capacity development in existing solid waste management systems will be required to allow sustainable and resilient growth of SCC. This study was aimed to explore the amount of solid waste generation per day in SCC and its extended areas. It also aimed to examine the current waste composition and the potential for resource recovery from solid waste in SCC. The study found that SCC is now generating a total 375.75 tons of solid waste every day from the households, kitchen markets, medical establishments, hotels, restaurants, and shops. This study has also found that about 90% of solid waste is perishable with high moisture content. The study identified some weaknesses of the existing solid waste management system. Recommendations were made for initiatives to convert waste into resources such as compost fertilizer, solid recovered fuel, and electricity production. This study can directly help the conservancy department of SCC, and possibly of other municipalities in Bangladesh, to formulate their policies and plans.

Keywords: Solid waste, waste composition, resource recovery from solid waste.

1. Introduction

Waste is an unavoidable consequence of human activities, and natural processes. Accelerated urbanization and rise in living standards in urban areas have increased the volume and changed the composition of generated solid waste. Bangladesh is now producing more than 8,000 tons of solid waste per day from the six major divisional cities (Abedin & Jahiruddin, 2015). We should be more careful about solid waste management as by 2025 the amount of per capita waste generation will be 0.75 kg/day and about 21.07 million tons per year in Bangladesh (Ashikuzzaman & Howlader, 2020). Municipal solid waste management is challenging work as urban population is increasing and composition of waste is changing. Solid waste generation in urban areas varies because of economic factors, social factors, demography, lifestyle, seasonal variation, lack of public awareness and inadequate management capacity. With rapid urbanization, the

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waste generation rate is also rising in urban areas where a well-equipped waste management system is necessary to be built. The existing waste management system is not at a satisfactory level and requires adequate and effective policies and strategies (Yasmin & Rahman, 2017).

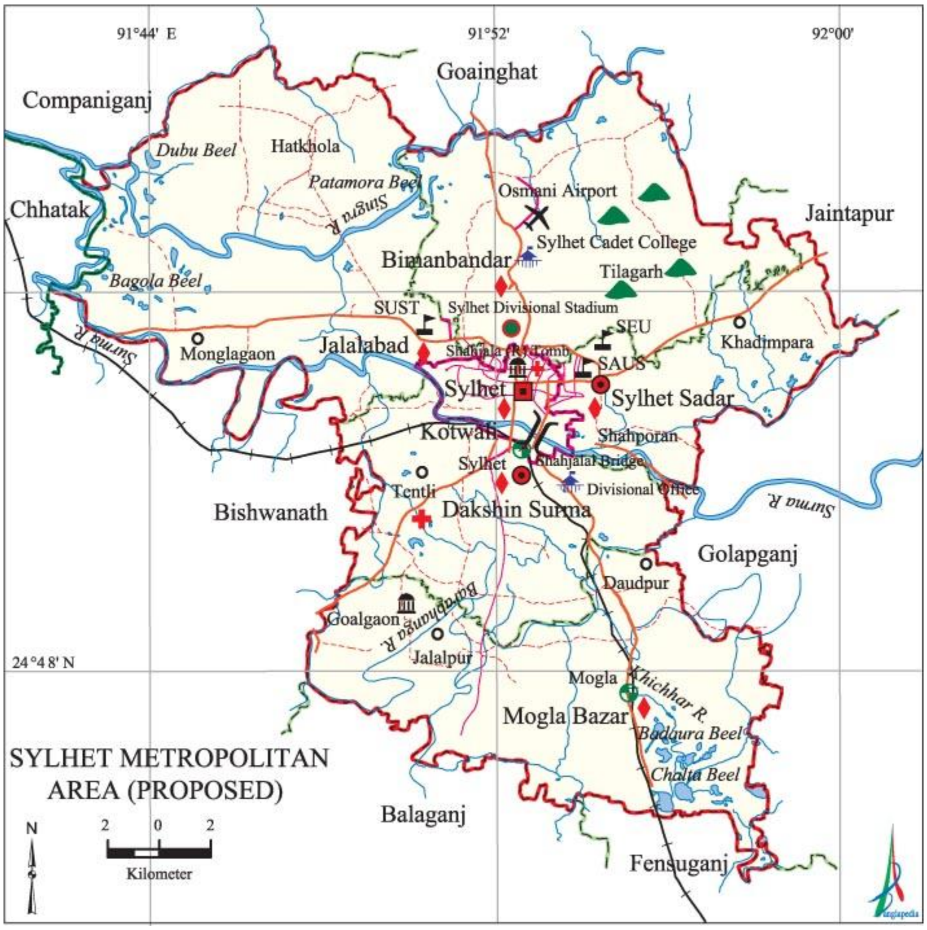
According to one study, due to lack of inducement, public awareness, proper selection of technology and enough financial support, a significant amount of solid waste (40-60%) is not appropriately segregated, stored, collected, transported, and disposed of in designated locations for final disposal (Alamgir & Ahsan, 2007). In Bangladesh, non-perishable solid waste (such as metal scrap, paper, polythene, plastic, rubber, leather, glass, etc.) is partly reused and reprocessed in an informal way, while different NGOs are engaged in production of compost fertilizer from the perishable waste in a small scale. A modern reprocessing sector has not developed yet. Consequently, much of the perishable part of solid waste, which has no economic value, is left untreated and creates an unhealthy environment in cities. The share of perishable portion of solid waste is consistently more than 50% in volume of the total solid waste produced and needs expensive methods for disposal (Ali & Rouse, 2004). On the other hand, the concerned authorities of urban areas of Bangladesh are becoming aware of the consequences of improper solid waste management and reprocessing. However, they are facing difficulties to manage the growing amount of solid waste linked to rapid urbanization rate. Therefore, improper solid waste management results in waste dumping on roads as well as along open drains and water bodies, which creates an unhealthy living environment for city dwellers. On the other hand, waste-to-energy projects need to be taken to ensure the availability of sustainable energy in Bangladesh through efficient waste management. Bangladesh can earn a total of US $ 791 million per year, including carbon credit revenue, from only Dhaka and Chittagong by 2050 (Roy, et al., 2022).

Sylhet city is situated in the north-eastern zone of Bangladesh and generates about 250 tons/day waste in 2016 (Alam and Qiao 2020). Daily solid waste generation in Sylhet City Corporation (SCC) area amounted to about 260 tons in 2017 which was about 2.5 times that of 2004. Door-to-door collection accounted for 52% of waste and 22% were collected in community bins. The rest was dumped in open places, drains and water bodies (Al Mamun et al., 2018). It was also observed that about 79% of generated solid waste in SCC is residential/kitchen waste (Rahman et al., 2011). This study is aimed to examine the current daily solid waste generation rate, per capita waste generation, waste composition and the potential for waste-to-resource or energy conversion in Sylhet City Corporation.

2. Study area

Sylhet is one of the most popular tourist and pilgrimage cities on the bank of the River Surma in the eastern part of Bangladesh. It was established as a municipality in 1878 and became a City Corporation on 28 July 2002 with 26.50 km^2 of area. Sylhet Sadar *upazila* is on the north of the corporation area while Dakshin Surma and Sylhet Sadar *upazilas* are on the south and east respectively. Dakshin Surma and Sylhet Sadar *upazilas* are on the west. In August 2021, according to a notification in *Bangladesh Gazette* (Government of Bangladesh, 2021), two *upazilas* were added to SCC. The added area included four unions of Sylhet Sadar *upazila*, namely Tukerbazar, Karimnagar, Khadimpara and Tultikor, and three of South Surma *upazila*, namely Kuchai, Boroikandi and Tetli (Bangladesh Gazette, 2021). Now the area of Sylhet City Corporation is 79.50 km^2, including 53 km^2 in the newly acquired region. The total population of SCC is now about 10 lakhs including the population of the extended areas (Bangladesh National Portal, 2023).

The whole city corporation area with its proposed extended areas were considered as the study area. Figure 1 shows the details of SCC area and its proposed extended areas, as well as the Sylhet metropolitan area.



Source: Sylhet City Corporation (2021).

Figure 1. Map of proposed Sylhet Metropolitan area (area: about 80 km^2).

3. Literature review

Solid waste refers to unwanted and discarded non-liquid waste materials producing from household, trade, commercial, industrial, agricultural and institutional services (Bhuiyan, 2010). Solid waste generation is influenced by socio economic characteristics, demography, seasonal variation, lack of public awareness and weak waste management capacity. When waste management is weak, which is often the case in developing countries like Bangladesh, uncollected waste may be thrown in water bodies, open spaces, and on roadsides which clog drains creating serious hazards, environmental debasement, and health threats in the urban areas (Yasmin & Rahman, 2017).

Waste management is a demanding piece of work for municipalities as urban population is rising and the composition of municipal waste is changing. Proper municipal solid waste management requires concern not only for its growing volume but also for its sustainable disposal. Improper waste management and lack of knowledge about modern and sustainable waste management are the main reasons for different types of environmental and human health hazards in the urban areas of Bangladesh (Habib et al., 2021). A modern and well-equipped waste management plant is required for accurate estimation of the solid waste production and collection by the concerned authorities as well as transportation to the dumpsites for final disposal and to energy conversion plants (Hoque & Rahman, 2020).

The urban areas of Bangladesh are together producing about 23,688 tons/day of municipal solid waste and about 70% of them is perishable and organic waste. It is also seen that the generated waste contains on average more than 50% moisture. On the other hand, the collection rate is about only 56% in the urban areas of Bangladesh. Open burning and dumping of waste are widely practised in Bangladesh. Some NGOs are running some small-scale pilot projects to produce compost fertilizer from the perishable or organic portion of the generated waste. Private informal entrepreneurs are also operating some recycling plants with the generated recyclable solid waste. Around half a million people are engaged in waste recycling businesses for their daily livelihoods and they save approximately US $15.29 million/year in disposal costs.

Per capita waste production and composition of waste are the two most important features for governing an effective waste management system. This information assists to find out the waste components to target for waste-to-energy production. Waste generation in urban area is usually proportional to the total population and the income level of the residents. Other characteristics such as seasonal changes, occupation, education, social and public status of residents can also affect the production and composition of solid waste (Pattnaik & Reddy, 2010). Table 1 and 2 show the relationship among waste generation, demography, and the income level of residents in the urban areas of Bangladesh.

Table 1. Solid waste generation scenario in the major urban areas of Bangladesh.

City corporation	Area in km^2	Population in millions	Waste generation rate in kg/cap/day	Total waste generation in tons/day
Dhaka	360	110.00	0.40–0.55	5000–5500
Chittagong	156	3.65	0.30–0.45	1200–1400
Khulna	47	1.50	0.30–0.40	420–520
Rajshahi	48	0.45	0.25–0.35	160–210
Barisal	45	0.40	0.20–025	100–140
Sylhet	26.5	0.50	0.35–0.45	200–250

Source: Ahsan et al. (2014).

Table 2. Per capita generation of waste by income level in six major cities of Bangladesh.

Income level	Per capita waste generation (kg/day)						
	Dhaka	C'gong	Khulna	Rajshahi	Barisal	Sylhet	Mean
High	0.504	0.378	0.368	0.343	0.327	0.429	0.392
Upper middle	0.389	0.343	0.333	0.320	0.278	0.395	0.343
Middle	0.371	0.350	0.319	0.242	0.247	0.340	0.312
Lower middle	0.305	0.253	0.264	0.309	0.269	0.248	0.275
Low	0.270	0.189	0.203	0.239	0.172	0.260	0.222
Mean	0.368	0.030	0.297	0.291	0.259	0.334	0.309

Source: Alamgir & Ahsan (2007).

Dhaka, Chittagong, Khulna, Rajshahi, Barisal and Sylhet generate about 7,690 tons of municipal solid waste (MSW) per day (Alamgir & Ahsan, 2007). Another study stated that Bangladesh is now producing about 8,000 tons of solid waste per day from the six major cities (Abedin & Anwarul, 2015). Recent study shows that Dhaka alone is now generating more than 7,000 metric tons of solid waste per day (Ahmed et al., 2022).

The physical composition of the generated waste in Bangladesh was about 74.4% perishable waste or organic matter, 9.1% paper, 3.5% plastic, 1.9% textile and wood, 0.8% leather and rubber, 1.5% metal, 0.8% glass and 8% other wastes (Abedin & Anwarul, 2015). Table 3 shows the details of waste generation in the major six cities of Bangladesh.

Table 3. Volume of different categories of solid waste in six major cities (in tons).

Waste category	Dhaka	C'gong	Khulna	Rajshahi	Barisal	Sylhet	Total
Organic matter	3,647	968	410	121	105	158	5,409
Paper	571	130	49	15	9	18	792
Plastic	230	37	16	7	5	8	303
Textile & wood	118	28	7	3	2	5	163
Leather & rubber	75	13	3	2	1	1	95
Metal	107	29	6	2	2	2	148
Glass	37	13	3	2	1	2	58
Others	555	97	26	18	5	21	722
Total	5,340	1315	520	170	130	215	7,690

Source: Alamgir & Ahsan (2007).

Alamgir and Ahsan (2007) mentions that as key characteristics of solid wastes, the following parameters should be explored,

- Moisture content
- Compressibility
- Chemical characteristics

a) Calorific Value
b) Existence of volatile matter
c) Lipids
d) Carbohydrates
e) Proteins
f) Synthetic organic material (Plastics)
g) Non-combustibles
h) Heating value

The standard for chemical composition of organic fertilizers including all wastes had been identified in Bangladesh in 2007. Table 4 shows some of the standard parameters of compost fertilizer production.

Table 4. Characteristics of compost fertilizer in Bangladesh.

Parameter	Measure	Parameter	Measure
Organic carbon	10 – 25%	P	0.5-1.5%
pH	5.5 - 8.5	K	1.0-3.0%
C: N ratio	Max. 20:1	Zn	Max. 0.1%
S	Max. 1%	Cu	Max. 0.05%

Source: BARC (2007).

A small portion of perishable waste is used for composting before being transported to the designated landfills. This sector is not flourishing up to expected level due to lack of effective initiatives of municipalities, finance, technology, suitable land, proper location, enough supply of wastes, quality of wastes and marketing facilities (Ahsan et al., 2014). Till now NGOs and some private organizations are trying on their own accord to promote the sector. Waste Concern, a social business enterprise, is playing the key role in developing different community based and small-scale composting model in Bangladesh.

Direct landfill is the most common and conventional way of waste management which is not desirable due to scarcity of suitable land in the urban areas of Bangladesh (Das et al., 2019). Mogla Bazar waste dumpsite (24°51′16.8"N, 91°53′23.4″E), also known as Lalmatia dumpsite, is the main dumpsite with an area of about 10.25 acres for solid waste management in SCC. The land is mainly formed with alluvial silt and clay, which is inundated by flash floods almost every year (Alam et al., 2020). This type of dumping practice is very common in the urban areas of the developing countries. It is observed that the soil, air and water (surface and ground) qualities near the landfill sites are threats to local biodiversity and residents in Bangladesh (Fahmida & Tareq, 2021).

The greater portion of the generated waste is perishable and biodegradable. To produce electricity from the generated solid waste, anaerobic digestion (AD) could be an effective and attractive waste-to-energy recovery process. One advantage of AD is both biogas (CH_4 and CO_2) and digestate (non-toxic liquid and solid remnants) are produced at the same time (Melville et al., 2014). It can reduce landfill waste as well as providing electricity. Biogas is used to generate power like electricity, while the digestate produces compost fertilizer. It is possible to produce 150 m3 of biogas from one ton of MSW and 250 tons of compost fertilizer from 1000 tons of MSW through anaerobic digestion (Rana, 2016). Rana conducted a feasibility study in 2016 on potentiality of waste-to-resource recovery in Dhaka city, Bangladesh. He recommends that waste-to-resource recovery can be a solution for the severe waste management problem in Dhaka. Among a number of waste-to-resource recovery methods, composting was identified as the most feasible method for Dhaka, as much of the generated waste is perishable and organic. This study also found that the required initial investment was Tk. 50 million with a payback period of 7.1 years for a large-scale composting plant in Dhaka city (Rana, 2016). It is also found that about 38,850 m3 of biogas and about 65 tons of compost fertilizer can be produced per day from the generated waste in Rajshahi City Corporation (Das et al., 2019).

Incineration is commonly practiced in the waste-to-energy plants in the Asian region (Yuan et al., 2008). However, it has high carbon and unhealthy flue gas emissions (Purnomo, et al., 2021). On the other hand, pyrolysis is a widely used method for waste-to-energy conversion where the major challenge is the development of the required technology for small-sized particles for fluidized bed reactors (Das et al., 2019). However, the waste that is non-recyclable and non-biodegradable is recommended for incineration and disposal at landfill. Recyclable wastes should be recycled as much as possible. Plastics, paper, and paper products should be reduced through a pyrolysis process through encouraging recycle industries or enterprises.

Recycling in Bangladesh involves many stakeholders. At the generation point, some households separate recyclables and sell them to traders dealing with them. In most of cases, waste collectors collect the mixed waste and separate some recyclables that they can then sell to recycling shops (*vangari dokans*, or *vangaris*). Waste scavengers (known as *tokais*) also separate some recyclables from the mixed waste near secondary collection points, transfer stations or on the landfills. The separated recyclables are then sold to recycling shops and from there, the waste is sold to the recycling industry and finally to product manufacturers (Matter et al., 2012). The circular economy is partly practised in many similar sectors where recycling is one of the commonly followed practices in many industries in Bangladesh (Ahmed et al., 2022).

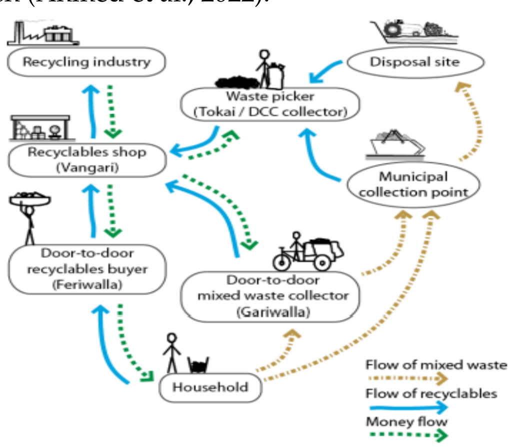


Figure 2. Waste Flow Chain in Dhaka. Source: Matter et al. (2012).

Till now, the waste management system cannot be characterized as modern, effective, sustainable, and comprehensive with 3R strategies such as waste reduction, waste recycling and waste reuse as well as environment friendly disposal system compared to global standards. There is no systematic monitoring and coordination among the policy implementing authorities in Bangladesh. The 3R strategy, eighth five-year plan (FY 2021–2025), Bangladesh vision 2041, and SDG have adequate provisions for solid waste management. There are very few action plans in operation to support government and private sector initiatives. Hence waste management needs to be considered as a priority for sustainable energy supply as well as sustainable development with efficient, viable, and contextualized strategies for Bangladesh (Jerin, et al., 2022).

4. Methodology

This study was conducted based on primary data. The authors were involved in a team to study solid waste management in SCC in 2021–22 which facilitated the collection of data. Household survey using Kobo Toolbox, polythene bag distribution and collection, surveys of hotels, restaurants, medical institutes and commercial shops, Key Informant Interviews (KIIs), and Focus Group Discussions (FGDs) were conducted to collect the primary data about current waste generation and composition in SCC and its extended areas. Waste samples were also collected for lab tests. Based on surveys, KIIs, FGDs and lab test reports, the potential for resource recovery from the generated solid waste in SCC was assessed. In the following sections, a summary of all surveys and lab tests are discussed.

4.1. Structured questionnaire survey of households using Kobo Toolbox

A structured questionnaire was developed for household survey in 27 wards, and extended areas of SCC including slum areas. The questionnaire had a focus on quantity and composition of generated waste along with family size, solid waste generators, sources of solid waste generation, waste category, waste storage mechanism at source, waste collection process, behavioural pattern of waste generators and waste collectors, informal waste dumping system, waste reuse or recycle plan etc. Kobo Toolbox and Kobo Collect App were used to conduct the questionnaire survey. The study did not find the total population and number of households in the extended and slum areas after 2011. There is also no data about current population and number of households in SCC as well. So, the population and household data of 2011 (BBS, 2011) were projected to 2022. For a very large population, 384 is an adequate sample size at the 90% confidence level (Creative Research System, 2012). Hence, 384 households were taken as the sample size for the questionnaire survey in the study areas. Samples were selected proportionately from all the wards and slums of the study area. In the absence of a sampling frame, a convenience sampling approach was taken to select households in the sample. This study had also classified the households into different income groups. Table 5 shows the details of the household classification based on income level in SCC.

Table 5. Household classification based on income level in SCC.

Income group	Income range (family income) in BDT unit	Broader classification for SCC
Extreme low income	<10000	Low Income
Low income	10000-20000	
Low middle income	20001-40000	Middle Income
Middle Income	40001-80000	
Upper middle income	80001-120000	High Income
High Income	>120000	

Source: (Author and SCC authority, 2021)

4.2. Structured questionnaire survey of commercial establishments

Five separate structured questionnaires were developed to examine the solid waste generation rate and composition in the residential hotels, commercial restaurants, commercial shops, medical institutes and *katcha* bazars (kitchen markets) of SCC. The main focuses of these surveys were to examine the daily solid waste generation, waste category, waste management system and potentiality of waste recycling or resources recovery. Table 6 shows the details of waste generation from these origins with number of sources in SCC.

4.3. Polythene bag distribution and collection survey

The authors had conducted a special type of survey to find out the quantity and composition of the generated solid waste from 80 households in SCC. The residents of SCC are conservative and access to the households was constrained. The SCC authority helped the authors and managed 80 households for polythene bag distribution and collection survey. Polythene bags were distributed among 20 high-income households, 30 middle-income households, 10 low-income households, and 20 households in slums. The survey was conducted for four consecutive days (weekend and weekdays) from 1st January 2022 to 4th January 2022. Two bags of different colours were distributed to each household, one for perishable waste (like kitchen waste, food waste etc.) and the other for non-perishable waste (like plastic, rubber, leather, paper etc.). All bags were distributed among the different income group households at noon in wards 5, 19, and 20 and a slum (Shahin Master Colony) in ward 19 and collected on the next day at noon. This was repeated on the next three days. After collecting the polythene bags with waste, they were transported to Shahi Eidgah Secondary Transfer Station (STS) for further analysis. An STS is a temporary intermediate waste storage station between the sources and final disposal site (Ahsan et al., 2014). The findings from this survey helped estimate the total amount of daily solid waste generated from the households of SCC areas as well as the per capita waste generation rate.

Figure 3. Collection of waste in polythene bags.

4.4. Key Informant Interviews (KIIs)

The authors conducted interviews with five key informants, namely, the chief engineer and superintending engineers, SCC; medical officer, SCC; ex-chairman of higher income group society; a ward councillor of SCC; and program coordinator of the NGO Islamic Relief Bangladesh. In the KIIs, the focus was on waste quantity and composition in SCC as well as environment friendly waste collection and disposal processes, behavioural change of waste generators and waste collectors, willingness to promote recycling of waste and encouraging the use of recycled products.

4.5. Focus Group Discussions (FGDs)

The authors also conducted six focus group discussions (FGDs) with waste collectors, community-based organizations (CBOs), brokers of solid waste trade, recycling industries (plastic industries) representatives, slum residents and kitchen market owners' association representatives. In the FGDs, the focus was on quantity and composition of generated solid waste.

4.6. Solid waste sample collection and transport to BUET for lab test

Waste sample was collected from Shahi Eidgah STS on 26 January 2022 and transported to the Bureau of Research, Testing and Consultation (BRTC) of Bangladesh University of Engineering and Technology (BUET) for calorific value test, moisture content test and chemical composition test. Shahi Eidgah STS was selected for waste sample collection because it receives all kinds of generated solid waste from all possible sources in SCC. Waste sample was randomly collected from the STS and separated into different categories such as fruit and vegetable peels, bread and rice, curry (fish, meat, vegetables), bones and shells (meat bones, fish bones, egg shells), paper (newspaper, book, note paper, pad, diary and tissue paper), plastic (plastic bottle, plastic cosmetic bottle, plastic medicine bottle, plastic medical waste), polythene (polythene bags, chips packet, polythene packet), leather, electronic waste (cable and accessories), rubber (hand gloves, rubber products, medical waste), cloth (rags/masks/ pampers) and mixed waste.

4.7. Data processing and analysis

All the data collected from the questionnaire survey and polythene bag distribution and collection survey have been processed and analysed using MS Excel. Based on the respondent responses and waste sample analysis, the waste generation rate, composition and waste category were determined. On the other hand, the qualitative primary data collected through FGDs and KIIs had been processed and analysed following the content analysis approach. The data from lab tests such as chemical composition test, moisture content test, and calorific value test were analysed by following their respective standards.

4.8. Limitations and challenges of the study

This study has a few limitations that need to be recognized. One of the most challenging limitations of this study was access to the households for the questionnaire survey and polythene bag distribution and collection survey. The conservancy department of SCC facilitated the accessibility to the surveyed households. There were also some limitations on conducting the required lab tests from BRTC. They had to customize their lab test methods to conduct the chemical composition test and calorific value test for mixed waste as per study requirements.

5. Result and discussion

5.1. Total amount of solid waste generation per day

Based on the collected data, this study estimated the total amount of solid waste generation from different sources in SCC as 375.68 tons with about 306 gm per capita waste generation. For the estimation, data collected from both polythene bag surveys (of households) and questionnaire survey (of commercial establishments) were considered. The basis of estimate for domestic waste is presented in Table 6. The average per capita waste generation by households (HHs) across income groups was multiplied by the estimated population to arrive at the total domestic waste generation figure mentioned above. It is assumed that the proportion of sample from different income groups is representative of the income group distribution in the population. *Katcha* bazars (kitchen markets), residential hotels, commercial shops and restaurants also have significant contributions to the total amount of waste generation in SCC. Most of the residential hotels and medical establishments in SCC have attached restaurants. They mainly produce perishable waste (about 90%) from those restaurants. The production of perishable solid waste in the *katcha* bazars of SCC is also comparatively high (more than 90%). On the other hand, in the shops, the amount of non-perishable waste is high. Perishable solid waste constitutes 90% of the total, while only 10% waste is non-perishable. Table 7 shows the details of solid waste generation from different sources in SCC, which amounts to 375.75 tons in total. Residences produce 87.85% of generated solid waste.

Table 6. Estimated per capita residential waste generation per day.

Income group	Average HH size	Per capita waste generation (kg/day)
High	6.06	0.37399
Middle	4.85	0.33407
Low	4.80	0.23793
Slum	3.64	0.28130
Mean of all groups	4.84	0.30682

Table 7. Estimated waste generation by all establishments.

Source	Number of establishments	Mean waste generation (kg/day)	Total amount of solid waste generation (ton/day)
Residents in HHs*	1,075,824	0.31	330.08
Hotels	237	14.90	3.53
Restaurants	477	25.00	11.93
Shops	9500	1.40	13.30
Medical	138	22.50	3.11
Katcha bazar	30	460.00	13.80
Waste generated in SCC		Total	375.75
		Perishable (90%)	338.18
		Non-perishable (10%)	37.58

*Population projected with exponential growth model with 2011 base data from BBS (2011).

5.2. Waste Projection

The solid waste generation in SCC was projected up to 2040. Total amount of generated solid waste in SCC in 2022 was considered as base data for the projection. Table 7 shows the summary of waste projection.

Table 7. Solid waste generation in Sylhet City Corporation up to 2040.

Year	Population of SCC and its extended area	Total amount of generated waste in SCC (in tons)	Amount of perishable waste (90%) (in tons)	Amount of non-perishable waste (10%) (in tons)
2022	1,075,824	375.67	338.10	37.57
2025	1,246,559	433.77	390.39	43.38
2030	1,593,427	551.24	496.12	55.12
2035	2,036,813	700.53	630.48	70.05
2040	2,603,577	890.25	801.22	89.03

5.3. Key findings from the laboratory tests

Polythene bag survey samples were used to find out the physical composition of solid waste generated in SCC. On the other hand, waste samples were collected from the Shahi Eidgah STS and transported to BRTC department of BUET for laboratory tests. The key findings from the tests are described below.

A. Results of moisture content test

Moisture content means how much water is in the waste. High moisture composition in solid waste can influence the physical characteristics of the solid waste including weight, density, viscosity, and conductivity. This study found that the moisture content of collected waste sample from SCC varies according to waste categories. The study has revealed that perishable solid waste contains more moisture compared to non-perishable waste. The moisture content of seasonal fruit and vegetable peel is 80.75% whereas bread and rice have 57% moisture content. Other perishable wastes have comparatively less moisture content. On the other hand, the moisture content of plastic, polythene, electronic waste and rubber is less than 5% in SCC. The moisture content of mixed waste is 23.65% in Sylhet City Corporation. Table 8 shows the details of moisture content in different types of solid waste produced in Sylhet City Corporation.

Table 8. Moisture content of different categories of waste (test method: ASTM D 3173).

Waste category	Moisture content (%)
Fruit and vegetable peels	80.75
Bread and rice	57.00
Curry (fish, meat, vegetables)	48.13
Meat bones, fish bones, eggshells	39.54
Paper (newspaper, book, note paper, pad, dairy, and tissue paper)	27.39
Plastic (plastic bottle, plastic cosmetic bottle, plastic medicine bottle, plastic medical waste)	1.56
Polythene (polythene bags, chips packet, polythene packet)	4.16
Leather	36.84
Electronic waste (cable and accessories)	1.03
Rubber (hand gloves, rubber product, medical waste)	3.24
Cloth (rags/masks/pampers)	28.08
Mixed waste	23.65

B. Results of calorific value test

The calorific value of waste sample means the amount of heat energy produced from the solid waste, which is mainly found by the complete combustion of specified quantity at standard temperature and pressure. This study found that the calorific value of tested solid waste samples varies to waste types, and chemical and physical composition of solid waste. It is evident that the calorific value of perishable waste is comparatively low compared to non-perishable solid waste in SCC. The calorific value of non-perishable solid wastes is more than 4,000 kcal/kg in SCC where it is less than 4,000 kcal/kg for perishable solid waste. Table 9 shows the details of calorific values of different types of solid waste generated in SCC.

Table 9. Waste categories and calorific value of each waste category in Sylhet City Corporation (Lab test method: ASTM D 5865).

Waste category	Calorific value (in kcal/kg)
Fruit and vegetable peels	3,588
Bread and rice	3,975
Curry	4,792
Meat bones, fish bones, eggshells	3,175
Paper	3,641
Plastic	4,108
Polythene bags	4,938
Leather	3,870
Electronic Waste (cable and accessories)	7,182
Rubber	7,475
Cloth	7,433
Mixed waste (dry)	5,628

C. **Results of volatile material test**

Volatile material means unstable material. Usually, these materials do not stay in one state and change easily to a different state. Solid or liquid volatile content can be easily converted into gas or vapour. Volatile materials can easily come off as a gas in the environment after incineration. Solid waste with high volatile materials composition can be potential sources of environmental pollutants. Uncontrolled incineration of solid waste with high volatile content can pollute our living environment. It is evident from the lab test that perishable waste that constitute the bulk of waste in SCC is high in volatile content. Bread and rice contain 95.35% of volatile matters in its chemical composition while curry, and fruit and vegetable peels contain around 90% volatile matters in their chemical composition. Table 10 shows the details of volatile matter composition of different types of perishable solid wastes generated in SCC.

Table 10. Waste categories and volatile matter composition of different waste categories in Sylhet City Corporation (Lab test method: ASTM D 3175).

Waste category	Volatile matter (%)
Fruit and vegetable peels	89.16
Bread and rice	95.35
Curry	90.22
Meat bones, fish bones, eggshells	68.47

5.4. Potential for waste-to-resource recovery

Solid waste can be transformed into compost solid recovered fuel (SRF), compost fertilizer, biogas, electricity etc. To have a healthy and pollution free-living environment, integrated solid waste management is mandatory.

A. Compatibility of waste-to-biogas and compost fertilizer production

SCC is now producing about 375 tons solid waste per day of which 90% (338 tons) is perishable waste. Perishable waste has high potentiality to produce biogas and compost fertilizer. The chemical composition standards of generated solid waste are also enough for composting. The moisture content of the generated perishable solid waste in SCC is also high. High moisture content is another parameter of high potentiality for biogas and compost fertilizer production. The study has found that the existing waste compositions of SCC have high potentiality to produce biogas and compost fertilizer.

B. Potentiality of waste-to-electricity production

SCC can generate electricity by burning the generated solid waste. SCC needs a modern, controlled and well-equipped solid waste management plant to produce electricity from the generated solid waste in SCC. A city like SCC needs a waste-to-energy facility that incinerates garbage and converts chemical energy into heat energy. The most common technology for waste-to-energy conversion is incineration. The generated solid waste in SCC consists of potential energy-rich compounds such as plastic, paper, yard waste, electronic waste, kitchen waste etc. The typical range of electrical energy production through incineration method is about 500 to 600 kWh per ton of solid waste (Ofori-Boateng et al., 2013). The required average low calorific value of solid waste needs to be more than 1,500 kcal/kg or 7 MJ/kg to make waste-to-energy production plant feasible (Rand et al., 2000). On the other hand, the United Nations Environment Programme stated that the low calorific value and high moisture content of waste are the major technical challenges for waste-to-electricity production. It also stated that the average calorific value of solid waste needs to be at least 7 MJ/kg, and never less than 6 MJ/kg. The calorific value of the produced solid waste in SCC is also in favour of waste-to-electricity production. The average calorific value of mixed dry solid waste is 5,628 kcal/kg or 23.56 MJ/kg in SCC which is comparatively high. Calorific value of non-perishable waste is higher compared to perishable waste or kitchen waste. Non-perishable waste can be the potential raw material for waste-to-electricity production in SCC. Perishable waste also can be used as raw material for waste-to-electricity production, but its compatibility is not too high. However, there are some disadvantages of waste-to-electricity production. They include the pollutants and particulates released in the air.

C. Potentiality of waste–to–solid recovered fuel (SRF) production

Solid recovered fuel is another high potential raw material for electricity production and worthy replacement of typical non-renewable coal or fuel. SRF is mainly manufactured through drying, filtering, and shredding of solid waste. SRF can be manufactured from the food and kitchen waste, paper, green waste, plastic bottles, toys, fabrics and composite waste. In addition, SRF can be an effective solution to bring off 'zero to landfill' initiatives. Cement manufacturers can also utilize the by-product such as ash produced after complete burning of SRF and replace natural assemblage in the cement production process. SRF can typically be characterized by an energy content in the range of 10–25 MJ/kg (2,380.95 – 5,952.38 kcal/kg) (Nasrullah et al., 2014). SCC can also go for SRF using their generated solid waste.

5.5. Key findings from the KIIs and FGDs

The followings are the key findings from the conducted KIIs and FGDs:

- Key informants suggested conducting a detail waste survey to identify the waste characteristics, waste production trends and future projections. They also suggested that the waste management related infrastructure and city conditions need to be examined to prepare a waste-to-resource recovery plant. SCC can use expert consultants or private sector experienced professionals to assess all potential waste-to-resource recovery methods and technologies. The chief medical officer of SCC suggested that SCC needs to take immediate initiatives to stop direct waste dumping at existing landfill site without pre-treatment or pre-proposes. The program coordinator, Islamic Relief Bangladesh suggested that SCC should conduct an evidence-based feasibility study on waste-to-resource recovery methods and technologies that includes the cost-benefit analysis, circular economic perspectives, economic viability and environmental benefits to keep the city residents informed of any proposed waste management projects and build public support for policy decisions. The chief engineer of SCC suggested that a life-cycle assessment with cost benefit analysis of waste-to-resource recovery and other potential waste-to-energy conversion methods and technologies also need to be considered. He also emphasized the social, economic, and environmental benefits of the waste-to-resource recovery plant throughout its life cycle. Superintending engineer of SCC emphasized comprehensive legal framework before implementing a waste-to-resource recovery plant and technologies. He also suggested preparing a financial model for the life cycle of the plant that includes the investment planning, payback period, operation and management and monitoring and evaluation. On the other hand, the ward councilor of SCC suggested that SCC requires structural changes within administration aimed at decentralizing authority and responsibilities and arrange periodic meetings among all level of stakeholders such as the executives and elected wing of the city corporations' solid waste management board. The key informants also suggested that SCC should comply with national Environment Conservation Act, Rules, and Preservation Act to select a place for landfilling and waste management plant.
- This study also had several findings from the FGDs. The participants of the FGDs suggested that SCC needs to take initiatives through stimulating the establishment of micro-enterprises in waste-to-resource recovery and recycling sectors. They emphasized on source segregated waste collection at household level through anticipation of all levels of city dwellers. They suggested a regular waste collection system associated with the ward councilors and community-based organizations by using separate waste vehicles according to the nature of the wastes.

6. Recommendations and conclusion

6.1. Recommendations for solid waste management

Based on data analysis, results, and discussions as well as key findings from the KIIs and FGDs, the following recommendations are suggested:

A. Solid waste generation is expected to increase in the coming years in SCC and its extended areas. This is high time for SCC to come up with time specific plans or strategies/policies to manage its rapidly growing solid waste generation.

B. SCC authority has no solid waste management plant. Rather, it has a landfill site/dump yard at Lalmatia. They are now directly dumping their generated solid waste in the Lalmatia dumpsite. SCC needs to take immediate initiatives to stop direct waste dumping at existing landfill site without pre-treatment or pre-processes.

C. As the chemical composition standards and moisture content of the generated solid waste are suitable for producing compost fertilizer, SCC should come up with an effective plan with appropriate technology for composting.

D. The calorific value of generated solid waste in SCC is higher than the required or standard value of waste-to-electricity and solid recovered fuel (SRF) production. SCC should take steps to extract energy such as electricity and SRF from the generated solid waste.

E. SCC can take initiatives to prepare a planned, modern and technology based solid waste management plant to convert the generated solid waste into economic product such as recycled and reusable products, compost fertilizer, biogas, crude oil, electricity, ashes, SRF etc. instead of direct dumping at landfill site.

F. As the presence of volatile matter is comparatively high in the generated solid waste in SCC, direct incineration of solid waste could be hazardous for the city's environment. Direct incineration of any type of solid waste should be banned and restricted immediately in SCC.

G. SCC should develop public-private-partnerships and micro-enterprises leading to privatization of some aspects like waste collection, waste recycling, and resource recovery from solid waste.

6.2. Conclusion

Urbanization and tourist attention accompanied with population growth are the stimulating factors for the high rate of solid waste generation in SCC. The existing solid waste management system is not at that level what SCC authorities and modern cities demand. Every day 375 tons of solid waste is being generated and this is likely to go up to 890 tons by 2040. The waste is currently dumped at the existing landfill site without any pre-treatment. The current solid waste management system of SCC creates risks for the residents. Efforts are needed to improve the existing system of waste collection, storage, transportation, recycling, incineration, and land filling. SCC needs to take immediate steps to prepare resource recovery plant to produce green products from the generated solid waste. Potentiality of waste-to-compost fertilizer and biogas can be the best initiatives to manage the generated solid waste in SCC. On the other hand, SRF or electricity production from solid waste also can make Sylhet City Corporation more resilient and sustainable. But more research and lab tests are required to identify the in-depth potentiality of waste-to-resource recovery, especially SRF and electricity production from the generated solid waste in Sylhet City Corporation.

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