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Research Article

Solid Waste Generation, Composition and Potentiality of Waste-to-Resource Recovery in Sylhet City Corporation, Bangladesh

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Abstract: The very fast economic and population growth of Bangladesh, along with its high urbanization rate, have been seen since its independence in 1971. Sylhet City Corporation (SCC) has also experienced high population growth as well as rapid urbanization since 2002. The solid waste generation rate is also increasing along with the high economic and population growth in SCC. SCC and its extended areas are now producing more solid waste than ever before because of accelerated unplanned urbanization, ever-growing tourist pressure, and an overgrowing urban population. Sooner than later, resource recovery and capacity development in existing solid waste management systems are required to allow the sustainable and resilient growth of SCC. This study aimed to explore the total amount of solid waste generation per day as well as the waste composition and potentiality for resource recovery from the generated solid waste in SCC and its extended areas. This study has found that SCC is now generating a total of 375.68 tons of solid waste daily from households, daily kitchen markets, medical institutes, resident hotels, commercial shops, and restaurants. This study has also found that about 90% of daily-generated solid waste is perishable and has a high moisture content. This study has found that the generated waste in SCC has the potential to produce compost fertilizer, solid recovered fuel (SRF), and electricity. On the other hand, this study can directly help the conservancy department of SCC to have a brief idea about the existing solid waste generation rate, composition, categories, and potentialities of resource recovery from the generated solid waste. It can also succor other conservancy departments of other city corporations or urban areas of Bangladesh as well as other researchers in a similar way.

***Keywords*:** solid waste, waste composition, resource recovery from solid waste

1. Introduction

Sylhet City Corporation (SCC) has seen significant improvements in health, education and quality of life of city dwellers. However, SCC is still facing severe development challenges in other areas like solid waste management and waste-to-resource recovery. It is also seen that the existing solid waste management system is not at the level that SCC and its extended areas demand. Despite unplanned solid waste management, SCC is now facing environmental pollution, road and drainage blockages, and odor problems [1]. Sources of solid waste generation, per capita waste generation rate, total amount, composition, categories, recycling practices, and waste-to-resource recovery processes are different in many ways in the different cities and urban areas of Bangladesh [2].

Waste is an unavoidable consequence of human activities and natural processes. Accelerated urbanization and a rise in living standards in urban areas have increased the volume and changed the composition of solid waste generated.

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Bangladesh is now producing more than 8,000 tons of solid waste per day from the six major divisional cities [2]. We should be more careful about solid waste management, as by 2025 the amount of per capita waste generation will be 0.75 kg per day and about 21.07 million tons per year in Bangladesh [3]. On the other hand, municipal solid waste (MSW) management is a challenging piece of work as the urban population is increasing and the composition of waste is changing. Solid waste generation in urban areas differs because of economic factors, social factors, demography, lifestyle, seasonal variation, a lack of public awareness, and inadequate management capacity. With rapid urbanization, the waste generation rate is also rising in urban areas where a well-equipped waste management system is necessary. The existing waste management system is not at a satisfactory level and requires adequate and effective policies and strategies [4]. Another research stated that due to a lack of inducement, public awareness, proper selection of technology and enough financial support, a significant amount of solid waste (40 to 60%) is not appropriately segregated, stored, collected, transported, and disposed of in the designated locations for final disposal [5]. In Bangladesh, nonperishable solid waste (such as scarp, paper, polythene, plastic, rubber, leather, glass, etc.) is partly reused and reprocessed in an informal way, while different nongovernmental organizations (NGOs) are engaged in the production of compost fertilizer from the perishable waste on 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 perishable portion of solid waste consistently accounts for more than 50% of the total produced solid waste and needs expensive disposal methods [6]. On the other hand, the concerned authorities in urban areas of Bangladesh are becoming aware of the consequences of improper solid waste management and reprocessing. However, they are facing difficulties managing the growing amount of solid waste linked to the 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 undertaken to ensure the availability of sustainable energy in Bangladesh through efficient waste management. Bangladesh can earn a total profit of USD 791 million per year only from Dhaka and Chittagong, including carbon credit revenue by 2050 [7].

Daily solid waste generation in SCC had reached 260 tons in 2017, which was about 2.5 times that of 2004. 52% of the generated waste was collected from door-to-door systems and 22% from community bins. The rest of the generated waste was dumped in open places, drains, and water bodies [8]. It was also observed that about 79% of the solid waste generated in SCC is residential or kitchen waste [9]. This study aimed to examine the current daily solid waste generation rate, per capita waste generation, waste composition, and the potentiality of waste-to-resource or energy recovery in SCC.

2. Study area

Sylhet is one of the most popular tourist and pilgrim cities in the eastern part of Bangladesh, on the bank of the Surma River. It was established as a municipality in 1878 and became a city corporation on 28 July 2002 with a 26.50 km^2 area. Sylhet Sadar Upazila is on the north, while Dakshin Surma and Sylhet Sadar Upazilas are on the south and east, respectively. Dakshin Surma and Sylhet Sadar Upazilas are on the west. On 31 August 2021, in Bangladesh Gazette S, R, and No-288-Law/2021 [10], two upazilas were newly included in SCC (four unions of Sylhet Sadar Upazila, namely Tukerbazar, Karimnagar, Khadimpara, and Tultikor Union, and three of South Surma Upazila, namely Kuchai, Barikandi, and Tetli Union). Now the area of SCC is 79.50 km^2 (the extended area is 53.00 km^2, and the old area is 26.50 km^2). The total population of SCC is now about 1 million, along with the population of the extended areas [10].

The whole city corporation area with its proposed extended areas was considered the study area. Figure 1 shows the study area location on the Bangladesh map, and Figure 2 shows the details of SCC and its proposed extended areas, as well as the proposed Sylhet Metropolitan Area.

Figure 1. Map of the study area [11]

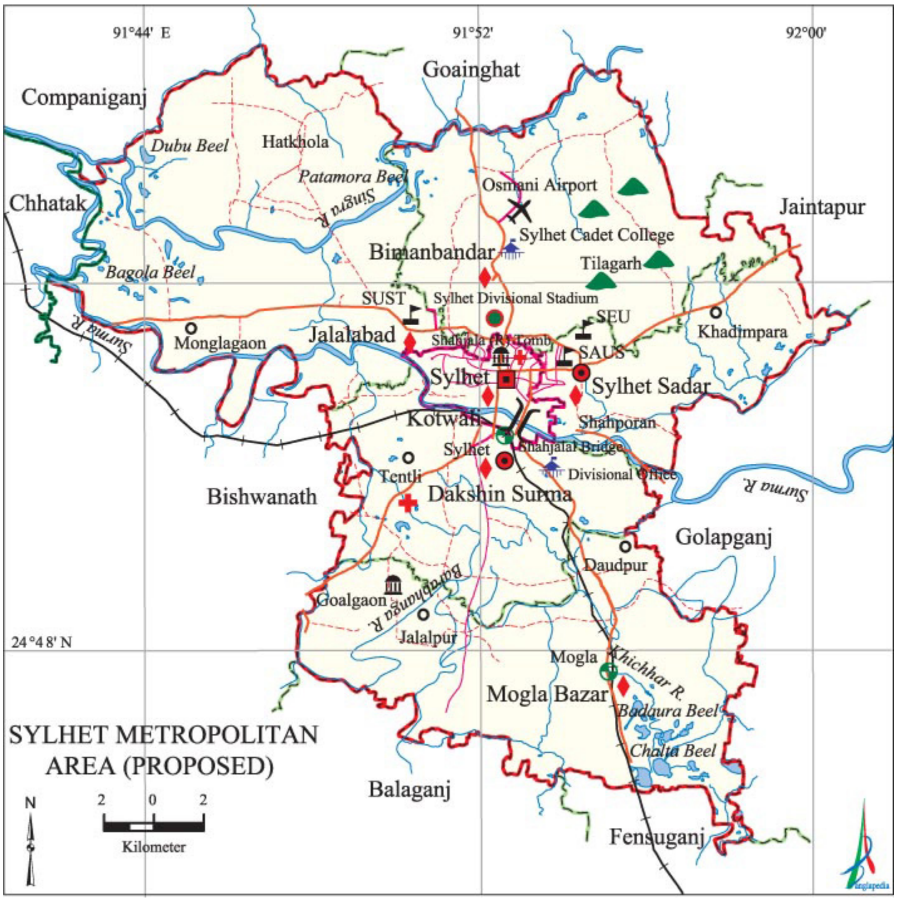

Figure 2. Map of the proposed Sylhet Metropolitan Area [12]

3. Literature review

Solid waste refers to futile, unwanted, and discarded non-liquid waste materials produced from household, trade, commercial, industrial, agricultural, and institutional services [13].

Solid waste generation is influenced by socioeconomic characteristics, demography, seasonal variation, a lack of public awareness, and weak waste management capacity. As a result, the uncollected wastes are thrown away in surrounding water bodies, open spaces, and roadsides, which obstruct the drainage system, creating serious hazards, environmental degradation and health threats in urban areas [4].

Waste management is a demanding piece of work as the urban population is rising and the category of municipal waste is changing. Proper solid or municipal waste management exercises require concern not only for their growing generation but also for their inadequate management. Improper waste management and a 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 [14]. It is also seen that the public health of urban people in developing countries has deteriorated because of improper waste management. A modern and well-equipped waste management plant is required for accurate assumption of solid waste production and collection by the concerned authorities, as well as transportation to the dumpsites for final disposal and other renewable energy plants [15]. The urban areas of Bangladesh are together producing about 23,688 tons per day of MSW, and about 70% of it 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 efficiency rate is about 56% in the urban areas of Bangladesh. Open burning and dumping are widely practiced waste management and disposal systems 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 recycling plants with the generated recyclable solid waste. More or less 0.5 million people are engaged in waste recycling businesses for their daily livelihoods and save around USD 15.29 million per year in disposal costs [16].

Per capita waste production and composition of waste components are the two most important features for governing an effective waste management system. This information assists in identifying the waste components to target for waste-to-energy production. Waste generation in urban areas is usually proportional to the total population and the income level of the residents. Other characteristics, such as seasonal changes, occupation, education, and social and public status, can also affect the production and composition of solid waste [17]. Table 1 shows the daily solid waste generation rate and per capita waste generation rate with the respective city corporation areas and demographics of the six major cities of Bangladesh. Table 2 shows the per capita waste generation rate in different income groups of the six major cities of Bangladesh.

Table 1. Solid waste generation scenario in the major urban areas of Bangladesh [18]

Name of city corporation	City area (km^2)	Population (millions)	Waste generation rate (kg/capita/day)	Total waste generation (ton/day)
Dhaka City Corporation (DCC)	360	110.00	0.40 to 0.55	5,000 to 5,500
Chittagong City Corporation (CCC)	156	3.65	0.30 to 0.45	1,200 to 1,400
Khulna City Corporation (KCC)	47	1.50	0.30 to 0.40	420 to 520
Rajshahi City Corporation (RCC)	48	0.45	0.25 to 0.35	160 to 210
Barisal City Corporation (BCC)	45	0.40	0.20 to 0.25	100 to 140
SCC	26.5	0.50	0.35 to 0.45	200 to 250

Table 2. Per capita generation of waste in six major cities of Bangladesh [5]

	Per capita waste generation (kg/day)						
Income level	DCC	CCC	KCC	RCC	BCC	SCC	Average
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
Average	0.368	0.030	0.297	0.291	0.259	0.334	0.309

Dhaka, Chittagong, Khulna, Rajshahi, Barisal, and Sylhet generate about 7,690 tons of MSW per day [5]. Another study stated that Bangladesh is now producing about 8,000 tons of solid waste per day from the six major cities [2]. A recent study shows that only Dhaka is now generating more than 7,000 metric tons of solid waste per day [19].

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 [2]. Table 3 shows the details of waste composition in the major six cities of Bangladesh.

Table 3. Production of different categories of solid waste in the six major cities of Bangladesh [5]

Waste category	DCC	CCC	KCC	RCC	BCC	SCC	All waste streams
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 and wood	118	28	7	3	2	5	163
Leather and 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	1,315	520	170	130	215	7,690
Per capita (kg/day)	0.485	0.360	0.347	0.378	0.325	0.430	0.387

Alamgir and Ahsan [5] mention that the key characteristics of solid wastes, including 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 the chemical composition of organic fertilizers including all wastes was identified in Bangladesh in 2007. Table 4 shows some of the standard parameters of compost fertilizer production.

Table 4. Standards of quality compost fertilizer in Bangladesh [20]

Parameter	Characteristics	Parameter	Characteristics
Organic carbon	10 to 25%	P	0.5 to 1.5%
pH	6 to 8.5	K	1.0 to 3.0%
C:N ratio	Maximum of 20:1	Zn	Maximum of 0.1%
S	Maximum of 0.1 to 0.5%	Cu	Maximum of 0.05%

A small portion of perishable waste is used for composting before being transported to the designated landfills. This sector is not flourishing up to the expected level due to a lack of effective initiatives by municipalities, finance, technology, suitable land, proper location, enough supply of waste, quality of waste and marketing facilities [18]. Till now, NGOs and some private organizations have been trying on their own accord to promote the sector. Waste Concern, a social business enterprise, is playing a role in developing different community-based and small-scale composting models in Bangladesh.

Direct landfill is the most common old way of waste management, which is no longer applicable due to the scarcity of available and suitable land in the urban areas of Bangladesh [21]. Sylhet City is situated in the north-eastern zone of Bangladesh and generated about 250 tons of waste per day in 2016 [16]. 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 and dumping in SCC. The land is mainly formed with alluvial silt and clay, which is inundated with flash floods almost every year [22]. This type of dumping practice is very common in the urban areas of developing countries. It is observed that the soil, air, and water (surface and ground) qualities near the landfill sites are alarming to the local biodiversity and residents in Bangladesh [23].

Most 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. The advantages of AD are that it produces both biogas (CH_4 and CO_2) and digestate (non-toxic liquid and solid remnants) at the same time [24]. It can reduce landfill waste as well as meet the high electricity demand. Biogas is used to generate power like electricity, and the digestate produces compost fertilizer. It is possible to produce 150 m^3 of biogas from 1 ton of MSW and 250 tons of compost fertilizer from 1,000 tons of MSW through AD [25]. Rana [25] conducted a feasibility study in 2016 on the 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 most of the generated waste is perishable and organic. This study also found that the required initial investment was BDT 50 million with a payback period of 7.1 years for a large-scale composting plant in Dhaka City [25]. It is also found that about 38,850 m^3 of biogas and about 65 tons of compost fertilizer can be produced per day from the generated waste in RCC [21].

Incineration is commonly practiced in waste-to-energy plants in the Asian regions [26]. However, it has high carbon emissions and unhealthy flue gas emissions [27]. 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-size particles for fluidized bed reactors [21]. However, wastes that are non-recyclable and non-biodegradable are recommended for incineration and direct disposal at landfills. Recyclable waste should be recycled as much as possible. Plastics, paper, and paper products should be reduced through a pyrolysis process by encouraging recycling in industries or enterprises.

Recycling in Bangladesh involves many stakeholders. At the generation phase, some households separate recyclables that they sell to recyclable buyers (Feriwallas). In most cases, waste collectors collect the mixed waste and separate some recyclables that they can then sell in recyclable shops (Vangari Dokans or Vangaris). Waste scavengers (Tokai) also separate some recyclables from the mixed waste near secondary collection points, transfer stations, or landfills. The separated recyclables are then sold to recyclable shops (Vangaris), and from there, the waste is sold to the recycling industry and finally to product manufacturers [28]. On the other hand, the circular economy is partly practiced in many similar sectors, where recycling is one of the most commonly followed practices in many industries in Bangladesh [29]. Figure 3 shows the typical waste flow picture of Dhaka City.

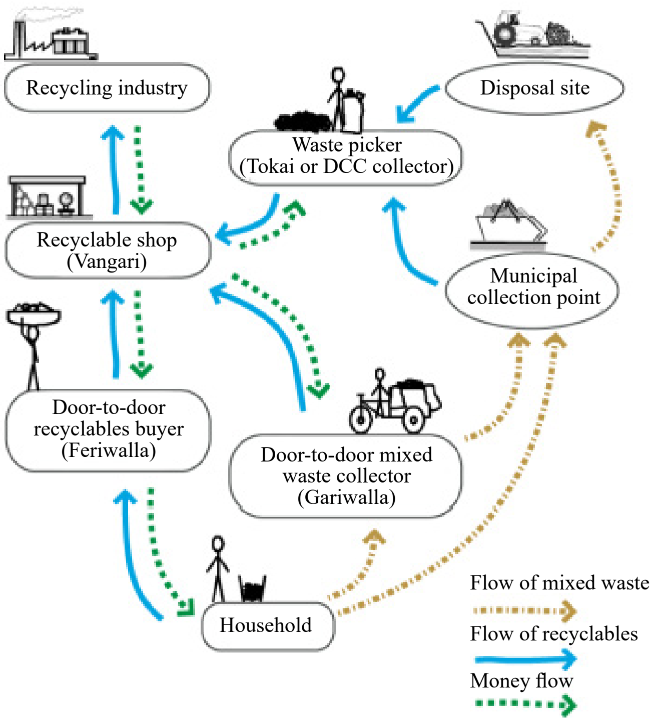

Figure 3. Typical waste flow chain in Dhaka [28]

Till now, the whole waste management system cannot be identified as a modern, effective, sustainable, and comprehensive 3R strategy such as waste reduction, waste recycling, and waste reuse, as well as an environmentally friendly disposal system compared to global standards. There is no systematic monitoring and coordination among the available policy-implementing authorities in Bangladesh. The 3R strategy, 85-year plan (FY2021-2025), Bangladesh Vision 2041, and Sustainable Development Goals (SDGs) have adequate provisions for solid waste management. There are very few action plans in operation, with a lack of capacity to support both government and private sector initiatives. Hence, waste management needs to be included in the priority concerns for sustainable energy supply as well as sustainable development, along with formulating efficient, viable, and contextualized strategies for Bangladesh [30].

4. Methodology

This study is conducted based on primary data. The authors were involved as a team to study solid waste management at SCC from 2021 to 2022. A household survey using Kobo Toolbox, a polythene bag distribution and collection survey, surveys of hotels, restaurants, medical institutes, and commercial shops, key informant interviews (KIIs), and focus group discussions (FGDs) were conducted to collect 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 potentiality of resource recovery from the generated solid waste in SCC and its extended areas was assessed. In the following sections, a brief summary of all surveys and lab tests is discussed.

4.1 *Structured questionnaire survey using Kobo Toolbox for measuring household-level waste generation*

A structured questionnaire was developed for household surveys 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, behavioral pattern of waste generators and waste collectors, informal waste dumping system, waste reuse or recycling plan, etc. Kobo Toolbox and Kobo Collect App were used to conduct the questionnaire survey. The study did not find the total population and household numbers of the extended and slum areas after 2011. There is also no specific data about the current population or household number of SCC. This study found the population and household data of 2011 [31] and projected the data to 2022. However, the study did not find the current number of households in the SCC and its slums and extended areas. For an infinite sample population, the sample size is 384 [32]. Hence, 384 households were selected after discussion with the SCC authority as the sample size for the questionnaire survey in the study areas. The 384 samples had been distributed proportionally among all the study areas. The sample households were selected randomly. This study also classified the households into different income groups. The authors have modified the national income group classification after discussing it with the SCC authority. 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 or family income (BDT)	Broder classification for SCC
Extremely low income	< 10,000	Low income
Low income	10,000 to 20,000	
Low middle income	20,001 to 40,000	Low income
Middle income	40,001 to 80,000	
Upper middle income	80,001 to 120,000	High income
High income	> 120,000	

4.2 *Structured questionnaire survey for measuring the generated solids and their composition from the Katcha Bazars, residential hotels, commercial shops, restaurants, and medical institutes*

Five separate structured questionnaires were developed to examine the solid waste generation rate and composition in residential hotels, commercial restaurants, commercial shops, medical institutes and Katcha Bazars of SCC. The main focuses of those surveys were to examine the daily solid waste generation, waste category, waste management system, and potentiality of waste recycling or resource recovery.

4.3 *Polythene bag distribution and collection survey*

A special type of survey was conducted to identify the quantity and composition of the generated solid waste from 80 households in SCC. The residents of SCC are conservative and accessibilities for households were difficult. The SCC authority helped by managing 80 households for the polythene bag distribution and collection survey. Polythene bags were distributed among 80 households, including 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 (weekends and weekdays) from 1st January 2022 to 4th January 2022. Two different colored bags were distributed to each household, one for perishable waste (like kitchen waste, food waste, etc.) and the other for nonperishable 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 for 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 the final disposal site [18]. The findings from this survey helped to estimate the total amount of daily solid waste generation from households in SCC areas as well as the per capita waste generation rate. Figure 4 shows the fieldwork during the polythene bag distribution and collection survey in the Shahi Eidgah STS of SCC.

Figure 4. Fieldwork conducted (polythene bag distribution and collection survey)

4.4 *KIIs*

Five KIIs were conducted with the chief engineer and superintending engineers, SCC; medical officer, SCC; ex-chairman of the higher income group society; ward councilor, SCC; and program coordinator, 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, behavioral change of waste generators and waste collectors, willingness to promote recycling of waste, and encouraging the use of recycled products.

4.5 *FGDs*

Six FGDs were conducted with waste collectors, community-based organizations (CBOs), brokers of solid waste trade, recycling industry (plastic industry) representatives, slum residents, and kitchen market owners' association representatives. In the FGDs, the focus was on the quantity and composition of solid waste generated.

4.6 *Solid waste sample collection and transport to BUET for lab testing*

A waste sample was collected from Shahi Eidgah STS on 26 January 2022 and transported to the Bureau of Research, Testing, and Consultation Department (BRTC) of the Bangladesh University of Engineering and Technology (BUET) for a calorific value test, a moisture content test, and a chemical composition test. Shahi Eidgah STS was selected for waste sample collection because it received all kinds of generated solid waste from all possible sources in SCC. A 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, and vegetables), 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, and plastic medical waste), polythene bag (polythene, chips packet, and polythene packet), leather, electronic waste (cable and accessories), rubber (hand gloves, rubber product, and medical waste), cloth (rags, masks, and diapers), 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 analyzed using the statistical software Microsoft 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, which were collected through FGDs and KIIs, had been processed and analyzed following the content analysis approach. The data from lab tests such as chemical composition test, moisture content test, and calorific value test were analyzed 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 its accessibility to households for the questionnaire survey and polythene bag distribution and collection survey. The conservancy department of SCC has managed the accessibility of the surveyed households. On the other hand, the data collection could be different based on the season of the year. There were also some limitations to conducting the required lab tests at BRTC. They have to customize their lab test methods to conduct the chemical composition test and calorific value test for mixed waste as per study requirements.

4.9 *Originality or value of the study*

Though some research has been conducted on solid waste management, waste composition, waste generation, and waste to resource recovery in different cities of Bangladesh, no detailed research has yet been investigated on the potentiality of waste to energy production in SCC. This study will contribute to looking differently at waste management and waste-to-resource recovery in the urban areas of Bangladesh. More research on waste-to-resource recovery can make the urban areas of Bangladesh more resilient and environmentally friendly.

5. Results 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 at 375.68 tons, with about 306.82 g per capita waste generation. For the estimation, data collected from households through questionnaire surveys, polythene bag surveys of households, and structured questionnaire surveys of commercial establishments were considered. The basis of the estimate for domestic waste is presented in Table 6. The average per capita waste generation by households across income groups was multiplied by the estimated population to arrive at the total domestic waste generation figure mentioned. It is assumed that the proportion of samples 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 generated 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% of waste is non-perishable. Table 6 shows the per capita waste generation from different income groups in SCC. Table 7 shows the details of solid waste generation from different sources in SCC, which amounts to 375.75 tons in total daily. The majority of solid waste generated comes from households. Residences produce about 87.85% (330.08 tons) of generated solid waste in SCC.

Table 6. Estimated per capita residential waste generation per day

Income group	Average household 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 households	1,075,824	0.31	330.08
Hotels	237	14.90	3.53
Restaurants	477	25.00	11.93
Shops	9,500	1.40	13.30
Medical	138	22.50	3.11
Katcha Bazar	30	460.00	13.80
		Total	375.75
Waste generated in SCC		Perishable (90%)	338.18
		Non-perishable (10%)	37.58

5.2 *Key findings from the lab tests*

A polythene bag survey was mainly considered to identify the physical composition of the generated solid waste in SCC. On the other hand, waste samples were collected from the Shahi Eidgah STS and transported to the BRTC department of BUET for lab tests. The key findings from the lab tests are the following:

5.2.1 *Results of the moisture content test*

Moisture content means how much water is in the waste. High moisture content in solid waste can influence the physical characteristics of the waste, including weight, density, viscosity, and conductivity. This study found that the moisture content of the 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 a moisture content of 57%. 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 SCC. Table 8 shows the details of moisture content in different types of solid waste produced in SCC.

Table 8. Waste categories and moisture content of each waste category in SCC (lab test method: ASTM D 3173)

Waste category	Moisture content (%)
Fruit and vegetable peels	80.75
Bread and rice	57
Curry (fish, meat, and vegetables)	48.13
Meat bones, fish bones, and egg shells	39.54
Paper (newspaper, book, note paper, pad, diary, and tissue paper)	27.39
Plastic (plastic bottle, plastic cosmetic bottle, plastic medicine bottle, and plastic medical waste)	1.56
Polythene bag (polythene, chip packet, and polythene packet)	4.16
Leather	36.84
Electronic waste (cables and accessories)	1.03
Rubber (hand gloves, rubber products, and medical waste)	3.24
Cloth (rags, masks, and diapers)	28.08
Mixed waste	23.65

5.2.2 *Results of the calorific value test*

Here, the calorific value of the waste sample means the amount of heat energy produced from the sample solid waste, which is mainly found by the complete combustion of a specified quantity at standard temperature and pressure. This study has found that the calorific value of tested solid waste samples varies according to waste types and the 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 waste produced is more than 4,000 kcal/kg in SCC, whereas it is less than 4,000 kcal/kg for perishable solid waste. Table 9 shows the details of the calorific values of different types of solid waste generated in SCC.

Table 9. Waste categories and moisture content of each waste category in SCC (lab test method: ASTM D 3173)

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

5.2.3 *Results of the 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 vapor. Volatile materials can easily come off as a gas in the environment after incineration. Solid waste with a high volatile material composition can be a potential source of environmental pollutants. Uncontrolled incineration of solid waste with a high volatile content can pollute our living environment. It is evident from the lab test that perishable waste, which constitutes the bulk of waste in SCC, is high in volatile content. Bread and rice contain 95.35% volatile matter in their chemical composition, while curry, fruit, and vegetable peels contain around 90% volatile matter in their chemical composition. Table 10 shows the details of the 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 SCC (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, and egg shells	68.47

5.3 *Potentiality of waste-to-resource recovery in SCC*

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.

5.3.1 *Compatibility of waste to biogas and compost fertilizer production in SCC*

SCC is now producing about 375 tons of solid waste per day, of which 90% (338.1 tons) is perishable waste. Perishable waste has a high potential to produce biogas and compost fertilizer. The chemical composition standards of the 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 with high potential for biogas and compost fertilizer production. The study has found that the existing waste compositions of SCC have high potential to produce biogas and compost fertilizer.

5.3.2 *Potentiality of waste-to-electricity production in SCC*

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. A city like SCC must need 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 is composed of potential energy-rich compounds such as plastic, paper, yard waste, electronic waste, kitchen waste, etc. It is evident that the typical range of electrical energy production through the incineration method is about 500 to 600 kWh (kilowatt-hour) per ton of solid waste [33]. 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 for energy production plants otherwise feasible [34]. 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 favorable to 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. The 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 can also be used as a raw material for waste-to-electricity production, but its compatibility is not too high. However, there are some disadvantages to waste-to-electricity production. They include the pollutants and particulates released into the air.

5.3.3 *Potentiality of waste to SRF production in SCC*

Solid recovered fuel is another high-potential raw material for electricity production and a worthy replacement for typical non-renewable coal or fuel. SRF is mainly manufactured through the drying, filtering, and shredding of solid waste. SRF can be manufactured from 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 the complete burning of SRF, to replace natural assemblage in the cement production process. SRF can typically be characterized by an energy content in the range of 10 to 25 MJ/kg (2,380.95 to 5,952.38 kcal/kg) [35]. SCC can also go up with SRF by using their generated solid waste.

5.4 *Key findings from the KIIs and FGDs*

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

a. Key informants suggested conducting a detailed waste survey to identify waste characteristics, waste production trends, and future projections. They also suggested that 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 experienced professionals in the private sector to conduct an assessment of 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 sites without pre-treatment or re-proposes. The program coordinator, Islamic Relief Bangladesh, suggested that SCC conduct an evidence-based feasibility study on waste to resource recovery methods and technologies that includes cost-benefit analysis, circular economic perspectives, economic viability, and environmental benefits to keep 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 a 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. The superintending engineer of SCC emphasized a 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 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 arranging periodic meetings among all levels of stakeholders, such as the executives and elected wing of the city corporation's solid waste management board. The key informants also suggested that SCC should comply with the National Environment Conservation Act, Rules, and Preservation Act to select a place for landfilling and waste management.
b. This study also had several findings from the FGDs. The participants of the FGDs suggested that SCC needs to take initiatives by stimulating the establishment of micro-enterprises in waste-to-resource recovery and recycling sectors. They emphasized source-segregated waste collection at the household level through the anticipation of all levels of city dwellers. The suggested regular anticipated waste collection system would be associated with the ward councilors and community-based organizations by using separate waste vehicles according to the nature of the waste.

6. Recommendations on solid waste management in SCC

Based on data analysis, results and discussions, and 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. It is high time for SCC to come up with time-specific plans, strategies, and policies to manage its rapidly growing solid waste generation.
b. The SCC authority has no solid waste management plant but rather has a landfill site or dump yard named Lalmatia Dumpsite or Landfill Site. 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 sites without pre-treatment or re-proposes.
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 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 products, such as recycled and reusable products, compost fertilizer, bio-gas, crude oil, electricity, ashes, SRF, etc., instead of direct dumping at landfill sites.
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 the privatization of some aspects like waste collection, waste recycling, and resource recovery from solid waste.

7. Conclusion

Urbanization and tourist attention, accompanied by 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 the level that SCC authorities and modern cities demand. Every day, 375.67 tons of solid waste are generated and directly dumped at the existing landfill site without any kind of pre-treatment. The current solid waste management system at SCC creates health risks for the residents and leads to environmental pollution such as air pollution, soil pollution, and water pollution. Efforts need to be made to improve the existing system of waste collection, storage, transportation, recycling, incineration, and land filling. SCC needs to take immediate steps to prepare a resource recovery plant to produce green products such as compost fertilizer, biogas, SRF, and electricity from the currently generated solid waste. The potential of waste to compost fertilizer and biogas can be the best initiative to manage the currently generated solid waste in SCC. On the other hand, SRF, or electricity production from solid waste can also make SCC more resilient and environmentally friendly. More research and lab tests are required to identify the in-depth potential of waste-to-resource recovery, especially SRF and electricity production from the generated solid waste in SCC.

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Conflict of interest

The authors declare no conflict of interest in this study.

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