SOLID WASTE GENERATION, COMPOSITION AND POTENTIALITY OF WASTE TO RESOURCE RECOVERY IN NARAYANGANJ CITY CORPORATION

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ABSTRACT

Narayanganj City Corporation (NCC) is growing fast as an urban and industrial center in Bangladesh. The city is now facing serious challenges in managing municipal solid waste (MSW). This study assesses current solid waste generation, composition, and the potential for resource recovery. The study used a mixed-method approach. Primary data were collected between 2019 and 2020. Data sources included 384 household surveys (using Kobo Toolbox), three-stream polythene bag segregation trials, Key Informant Interviews (KIIs), and Focus Group Discussions (FGDs). Physicochemical tests were carried out at the Department of Chemical Engineering, Bangladesh University of Engineering and Technology (BUET). Moisture Content was tested using ASTM D 3302. Calorific Value was tested using ASTM D 2015. The findings show that NCC produces 922 tons of waste per day (TPD) dominated by organic waste (58.2%) and recyclables (31.3%). The per capita waste generation rate is 463 grams per day (g/day). NCC collects only around 50% of the total waste generated. The waste stream is dominated by biodegradable materials. About 536.84 TPD of the waste is perishable or fermentable. Food waste has a high moisture content of 69.89% w/w. Plastic and polythene waste has a high calorific value of 8649 Kcal/kg. These characteristics indicate strong potential for resource recovery. Organic waste is suitable for anaerobic digestion and composting. The high-energy plastic fraction supports Waste-to-Energy (WtE) options. The study highlights the need for source segregation, improved collection, and development of an integrated SWM facility to enhance resource recovery. These actions can help the city convert its waste challenge into a valuable resource opportunity. This study provides one of the most detailed assessments of waste generation and composition for NCC. It combines household surveys, segregation trials, stakeholder consultations, and laboratory analysis within a single framework. The findings offer clear evidence to support Waste-to-Energy investment. The study also provides practical guidance for policy makers by identifying priority actions such as source-level segregation and integrated facility development for waste to resource recovery.

Key Words: Municipal Solid Waste, Waste Composition, Waste Management, and Resource Recovery.

1. INTRODUCTION

1.1 Global and National Context of Solid Waste Management Deficiencies

Solid waste generation is becoming a major environmental concern worldwide, and every society is struggling to manage it effectively. In developing countries like Bangladesh, waste is often handled through simple but harmful practices such as open dumping, uncontrolled burning, and careless disposal into water bodies or along roadsides. These practices lead to serious problems, including air pollution, soil and water contamination, and frequent clogging of urban drainage systems. As a result, overall urban living conditions continue to decline. The scale of the issue is significant: the six major metropolitan cities—Dhaka, Rajshahi, Chittagong, Barisal, Khulna, and Sylhet—were already generating around 8000 tons of solid waste per day (Abedin & Jahiruddin, 2015). Future projections show that per capita waste generation may reach 0.75 kg per day, contributing to an estimated 21.07 million tons of waste annually by 2025 (Ashikuzzaman & Howlade, 2020). Managing this growing volume of municipal solid waste (MSW) is becoming increasingly difficult due to rapid urban population growth and shifting waste characteristics. Although city authorities are more aware of the consequences of poor SWM, the pace of urbanization continues to exceed their capacity to keep up with rising waste volumes (Yasmin & Rahman, 2017). Therefore, improving solid waste management through appropriate technical solutions and strong policy support is essential for protecting public health and safeguarding the environment.

1.2 Profile of Narayanganj City Corporation (NCC) and the SWM Imperative

Narayanganj City Corporation (NCC) is one of Bangladesh's fastest-growing cities and a major industrial hub, historically recognized as the "Dundee of the East" for its strong textile and jute industries. The city took its current form in 2011 after the merger of three municipalities—Narayanganj Paurashava, Siddhirganj Paurashava, and Kadam Rasul Municipality. This administrative shift accelerated development and led to rising per-capita waste generation. NCC's strong economic growth has been both a benefit and a burden. Industrial expansion has created jobs and boosted the local economy, but it has also driven rapid population growth, dense urbanization, and high levels of in-migration. These pressures have resulted in large volumes of solid waste that the young city corporation often struggles to manage due to financial and institutional limitations (Noman et al., 2016). As a result, an estimated 40–60% of the waste produced in NCC is not properly stored, collected, or transported to disposal sites (Alamgir & Ahsan, 2007). This gap in collection and disposal exposes residents to significant environmental and public health risks. The situation in NCC highlights a common challenge in many developing cities, where economic and industrial growth move quickly, but solid waste management systems and institutional capacity fail to keep pace.

1.3 Research Objectives

Against this background, this study was undertaken to achieve the following specific objectives:

(i). To estimate the daily waste generation in NCC.
(ii). To analyze the composition of generated solid waste stream.
(iii). To assess the potential for resource recovery through composting, biogas, and Waste-to-Energy technologies.

1.4 Literature Review

1.4.1 Socioeconomic Determinants of MSW Generation

Usually, the amount of municipal solid waste (MSW) generated is determined by a combination of socioeconomic factors, population trends, lifestyle habits, and the effectiveness of waste management systems (Pattnaik & Reddy, 2010). In large cities, waste generation tends to increase with population size and residents' disposable income. Differences in income levels are a key factor influencing how much waste is produced. Analysis of major cities in Bangladesh supports this pattern, as summarized in Table 1.

Table 1. Per capita generation of waste in six major cities of Bangladesh (Alamgir & Ahsan, 2007)

Income level	DCC (kg/day)	CCC (kg/day)	KCC (kg/day)	RCC (kg/day)	BCC (kg/day)	SCC (kg/day)	Average (kg/day)
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	0.300	0.297	0.291	0.259	0.334	0.309

1.4.2 Comparative Benchmarking of MSW Generation in Bangladeshi Cities

Together, Bangladesh's major metropolitan areas have historically generated around 7,690 to 8,000 tons of municipal solid waste (MSW) each day (Alamgir & Ahsan, 2007; Abedin & Jahiruddin, 2015). In these cities, the waste is largely composed of perishable or organic materials, accounting for 70% to 74.4% of the total, and it typically has a high moisture content, often above 50% (Abedin & Jahiruddin, 2015). Understanding these characteristics is important for planning effective resource recovery strategies. Table 2 provides a summary of the different categories of solid waste produced in the six major cities of Bangladesh.

Table 2. Production of different categories of solid waste in the six major cities of Bangladesh (Alamgir & Ahsan, 2007)

Waste category	DCC (Tons)	CCC (Tons)	KCC (Tons)	RCC (Tons)	BCC (Tons)	SCC (Tons)	All waste streams (Tons)
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

1.4.3 Policy and Technological Context for Resource Recovery

Effective solid waste management (SWM) is increasingly being linked to strategies that turn waste into useful resources (Roy et al., 2022). One widely recognized approach is anaerobic digestion (AD), which can convert the large organic portion of waste into energy. This process produces biogas, mainly methane and carbon dioxide, and digestate, which can be further processed into compost fertilizer (Mudhoo, 2012). Research indicates that 1,000 tons of municipal solid waste can generate around 150 m^3 of biogas per ton and 250 tons of compost (Sohel Rana, 2016). For non-biodegradable waste, thermal treatment such as incineration is commonly used worldwide, especially in Asia (Yuan et al., 2008). While incineration effectively reduces waste volume, it also produces hazardous flue gases and high carbon emissions (Purnomo et al., 2021).

In Bangladesh, the government has introduced policy frameworks like the National 3R (Reduce, Reuse, Recycle) Strategy and the Solid Waste Management Rules 2021 to improve SWM. However, the implementation of these policies remains limited, with insufficient active plans and support for public and private sector initiatives. This highlights the need for practical, context-specific strategies tailored to the waste streams of industrial cities such as Narayanganj (Jerin et al., 2022).

1.5 Study Area Profile: Narayanganj City Corporation

1.5.1 Geographic and Institutional Overview

Narayanganj City Corporation (NCC) is located in central Bangladesh, close to the capital, Dhaka, and covers an area of 72.43 sq. km. The city is strategically situated near the confluence of the Shitalakhya and Buriganga rivers and is home to one of the country's oldest and busiest river ports. NCC was formed in 2011 by merging three smaller municipalities, creating a large industrial and commercial hub. According to the 2022 census, the population was 967,951 (BBS, 2022), and it is projected to exceed 1.4 million by 2035, reflecting an annual urban growth rate of around 3%. This rapid population increase, driven largely by industrial employment, adds significant pressure on the city's solid waste management system.

1.5.2 Current SWM Practices and Infrastructure Gaps

The main facility for managing and disposing of solid waste in Narayanganj City Corporation (NCC) is the dumpsite in Ward 15 (Alamin Nogor). The current system relies heavily on direct dumping, a practice that is becoming increasingly unsustainable due to limited land availability and its significant impact on the environment. A study has highlighted concerns about soil, air, and water pollution around the dumpsite, a problem common in many developing cities (Parvin & Tareq, 2021). NCC's ability to manage waste effectively is also limited by financial instability (Noman et al., 2016), which reduces funding for essential SWM operations and contributes to low collection efficiency. The situation in NCC, where financial and institutional capacity has not kept pace with economic growth and population increase, underscores the need for a comprehensive overhaul of the waste management system rather than small, incremental changes. Figure 1 shows the study area map as well as the ward map showing the tentative location of Alamin Nogor dumpsite in ward 15 of the Narayanganj City Corporation.

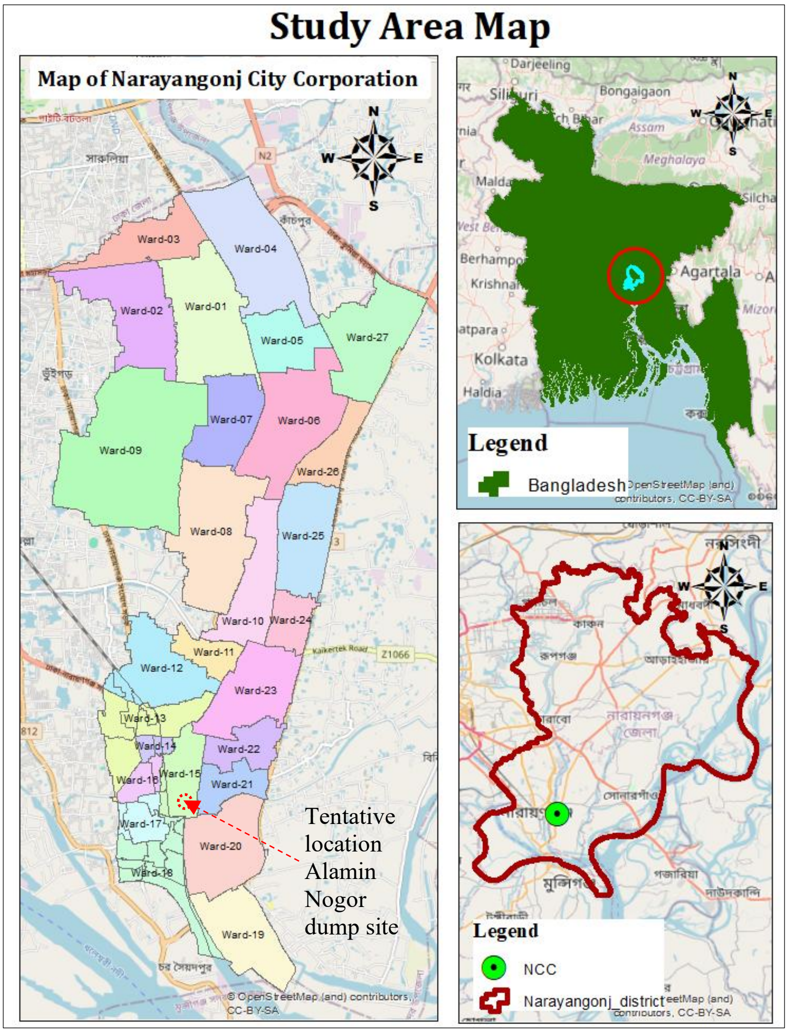

Figure 1: Study area map depicting Alamin Nogor dump site located in ward 15 of NCC

2 METHODOLOGY

This study is based on primary data collected by the authors between 2019 and 2020 under a formal government project titled "Solid Waste Collection and Disposal Management in Narayanganj City Corporation in 2019-2020". The study covered all 27 wards of Narayanganj City Corporation, including slum areas, to ensure that the data captured a representative picture of waste generation across the Narayanganj city.

2.1 Sampling and Survey Instruments

A rigorous mixed-methods approach was employed to gather comprehensive data on waste generation dynamics and composition.

2.1.1 Quantitative Sampling

(i). **Household Questionnaire Survey:** A standardized questionnaire was deployed using Kobo Toolbox and the Kobo Collect App to acquire detailed information on family size, waste generation source, waste typology, storage system, collection methods, and recycling behavior. Based on standard principles for an unlimited sample size (Das et al., 2016), a sample size of N=384 households was randomly selected and proportionally distributed across the 27 wards, following consultation with NCC authorities. The households were initially stratified into six income groups, subsequently consolidated into low, middle, and high income classifications for analytical purposes. Table 3 shows the details of household classification based on income level in NCC.

Table 3. Household classification based on income level in NCC

Income group	Income range or family income (BDT)	Broder classification for NCC
Extremely low income	< 10000	Low income
Low income	10000 to 20000	
Low middle income	20001 to 40000	Middle income
Middle income	40001 to 80000	
Upper middle income	80001 to 120000	High income
High income	> 120000	

(ii). **Polythene Bag Segregation Survey:** To get a detailed picture of what kind of waste households produce, this study carried out a simple segregation exercise. This study selected 100 households from different income groups—20 from high-income areas, 50 from middle-income, and 30 from low-income. Each family was given three color-coded bags: one for perishable items like kitchen waste, one for non-perishable items such as plastic, lather, and paper, etc. and one for hazardous waste. Households used these bags for three days—covering 2 workdays and one weekend day to observe their waste patterns more accurately.

(iii). **Commercial and Industrial Surveys:** This study designed simple, structured questionnaires and used them to collect information from commercial shops, hotels, restaurants, medical facilities, and major industries. This helped to understand how much waste these places produce and what types of waste they generate.

2.1.2 Qualitative Sampling

The authors also spoke directly with people who play key roles in waste management. This included senior NCC officials such as the supervising engineer, medical officer, ward councilors, and conservancy officers to understand the challenges they face, how waste is currently collected, and their plans for improving resource recovery from waste.

In addition, they held group discussions with community members who are closely involved in day to day waste activities. These included waste collectors, residents of informal settlements, local community organizations, owners of scrap warehouses (*Bazar Malik Somity*), and people working in the informal recycling sector. Their insights helped for better understand how waste moves through the city and how the community views the overall system.

2.2 Laboratory Analysis and Quality Control

Waste samples were collected from the primary dumping site at Alamin Nogor landfill. These samples were then taken to the Chemical Engineering Department at BUET for detailed testing. The laboratory team carried out key physicochemical tests such as moisture content (ASTM D 3302) and calorific value (ASTM D 2015) to understand the potential for resource recovery. However, the process was challenging. Because the city's waste is highly mixed and not sorted at the source. Due to lab limitations, the laboratory had to adjust its usual testing procedures. Lab technicians modified their standard methods so they could properly analyze the mixed waste samples. They initially segregated the waste before going to lab test. The authors prepared a list for waste typology. Following the waste typology, lab technicians completed the physicochemical tests. After physicochemical tests, they dried the waste samples to prepare them for the calorific value test, which was conducted using the ASTM D 2015 method for dry waste.

2.3 Data Analysis Techniques

The quantitative data collected from households and the polythene bag surveys were processed and analyzed in microsoft excel to assess the waste generation rates, composition percentages, and category-wise breakdowns. On the other hand, the qualitative information gathered from the KIIs and FGDs was reviewed through content analysis, helping the authors understand the views of institutions and community members on solid waste management and opportunities for resource recovery from municipal waste.

Figure 2: Picture of authors field works, Source: author

3 RESULT AND DISCUSSION

3.1 Solid Waste Generation Rates and Projections

According to the 2025 projections, Narayanganj City Corporation generates around 922 tons of waste per day from households (about 492 tons), commercial enterprises and industries (about 340 tons), and scrap warehouses (about 90 tons). On the other hand, per capita waste generation is estimated about 463 grams per day. The household survey shows a strong link between income level and how much waste people produce similar to national other cities patterns. High-income households generate the most waste at 601.27 g/day, followed by middle-income households at 421.22 g/day, and low-income households at 365.21 g/day. These differences highlight the need for more tailored waste management approaches, such as specialized collection systems and income-sensitive fee structures, to address the varying levels of waste generation across groups.

High income households generate more waste because they consume more packaged and manufactured goods. Much of this waste is non-perishable and often has high energy content, meaning it needs specialized recycling or energy recovery methods unlike the mostly organic waste from middle and low income households.

Looking to the future, household waste is expected to rise to about 1,480 tons per day by 2040 in NCC. To keep up, the city's waste management system would need to nearly double its current capacity, just to maintain the present, already limited level of service. This makes it clear that careful long-term planning is essential. Table 4 summarizes the total and per person daily waste generation from different sources in Narayanganj City Corporation.

Table 4. Details of total and per capita solid waste generation per day in NCC (2025)

Household Income Group	**Average Household Size**	**Average Solid Waste Generation per Person (gm)**	**Per Capita Solid Waste Generation (kg/day)**
High Income Group	5.44	601.272	0.463 (Overall)
Middle Income Group	4.964	421.224	
Low Income Group	4.416	365.206	
Total Population in NCC (2025 Projection)	1,063,576 *(Based on BBS, 2022 data: Projected with exponential growth methods* including floating people		
Total solid waste generation in NCC from the households in 2025	491.975 tons		

3.2 Waste Composition Analysis and Source Heterogeneity

Households are the largest source of solid waste in Narayanganj City Corporation, contributing 53.4% of the total. Commercial and industrial activities account for 36.9%, while warehouses storing scrap or broken materials contribute 9.7%. Analysis of the waste composition shows that a large portion consists of resource recoverable materials. Table 5 presents the key findings on waste generation and composition across different sources in the city.

Table 5. Summary of the key finding regarding solid waste generation and their composition in Narayanganj City Corporation

Source of SW Generation in NCC	**Amount (tons/day)**	**Perishable/Fermentable SW (tons/day)**	**Non-Perishable SW (tons/day)**
Composition		Fermentable	Recyclable
Household	492	366.84 (74.56 %)	89.99 (18.29 %)
Commercial and Industrial	340	170 (50 %)	136 (40 %)
Scrap Warehouses	90	0 (0 %)	63 (70 %)
Total	922	536.84	288.99

The data (table 5) show that of the total 922 tons of daily waste, 536.84 tons (58.2%) are perishable or fermentable, 288.99 tons (31.3%) are recyclable, and 96.18 tons (10.4%) are non-recyclable or hazardous. The large share of perishable waste is typical of municipal waste in Bangladesh and highlights the need for biological treatment processes as a key part of the municipal waste management strategy.

Another important finding is the composition of waste from scrap material warehouses, which contributes 90 tons per day. About 70% of this is recyclable, while 30% is hazardous. This emphasizes the need for specialized regulations and separate collection systems for industrial and scrap waste, keeping it apart from regular municipal waste to safely manage the highly concentrated hazardous components.

3.3 Physicochemical Characterization and Resource Potential

Laboratory tests were essential to understand how different types of waste could be reused or converted to resources. By measuring their physical and chemical properties, the authors were able to assess the potential for recovering resources from the waste.

3.3.1 Moisture Content Analysis (ASTM D 3302)

The amount of moisture in waste strongly affects its potential for energy recovery. The lab tests found that food and kitchen waste contained the most moisture at 69.89%, paper and rags had 42.77%, and plastic and polythene were much drier at 10.25%. Table 6 shows the summary result of moisture content test of the collected waste samples.

Table 6. Waste categories and moisture content of each waste category in Narayanganj City Corporation

Test Item	Unit	Food/Kitchen Waste	Plastic/Polythene	Leather/Rubber	Paper/Rag	Methods
Moisture Content	w/w%	69.89	10.25	15.49	42.77	ASTM D 3302

The high moisture content of organic waste makes it well suited for biological treatments, such as anaerobic digestion because water supports the microbial activity needed for these processes (Mudhoo, 2012). On the other hand, this same high moisture makes the raw mixed waste less suitable for direct thermal treatment, since a lot of extra energy would be needed to dry it first.

3.3.2 Calorific Value Analysis (ASTM D 2015)

Calorific value (CV) measures the amount of energy released when waste is fully burned, making it a key factor in assessing waste-to-energy potential. The lab tests showed that non-perishable wastes have high energy content: plastic and polythene recorded 8,649 Kcal/kg, and leather/rubber had 5,245 Kcal/kg. On the other hand, food and kitchen waste had a much lower CV of 2,986 Kcal/kg. Table 7 summarizes the calorific values of the waste samples the authors analyzed.

Table 7. Waste categories and calorific value of each waste category in Narayanganj City Corporation

Test Item	Unit	Food/ Kitchen Waste	Plastic/ Polythene	Leather/ Rubber	Paper/ Rag	Methods
Calorific Value	Kcal/Kg	2986	8649	5245	3607	ASTM D 2015

Non-perishable waste, especially plastics, contains much higher energy, making it suitable for waste-to-energy solutions. Yet, about half of the city's waste is not collected, causing serious pollution and wasted economic value. When 461 tons (NCC, 2025) of waste are dumped each day, the wet organic material breaks down without oxygen, releasing uncontrolled methane a potent greenhouse gas. At the same time, high-energy materials are lost, missing the chance to recover energy and generate revenue. Establishing an Integrated Solid Waste Management (ISWM) system is therefore essential, offering both environmental benefits and economic gains.

3.4 Potentiality for Sustainable Resource Recovery

The analysis of Narayanganj City Corporation's waste shows that it is well-suited for a combined approach to resource recovery, using both biological treatment for organic waste and thermal processes for non-perishable, high-energy materials.

3.4.1 Biological Conversion: Anaerobic Digestion and Composting

The largest portion of Narayanganj's waste 536.84 tons per day of perishable material provides a reliable feedstock for biological treatment. With its high moisture content (69.89% in food waste), anaerobic digestion (AD) is more suitable than simple composting. AD not only produces biogas that can be used to generate electricity but also creates digestate that can be refined into compost fertilizer (Sohel Rana, 2016). This approach maximizes resource recovery and is consistent with experiences in other cities where organic waste dominates (Das et al., 2019). To ensure environmental safety and agricultural efficacy, any compost produced must strictly comply with national standards for quality fertilizers. Additionally, using the biogas to power machinery at the waste management plant can improve the plant's energy self-sufficiency. This integrated approach demonstrates how organic waste can be transformed from a disposal challenge into a valuable resource, contributing to both environmental protection and local economic benefit.

3.4.2 Thermal Conversion: Waste-to-Electricity (WtE)

For waste-to-energy (WtE) facilities to operate efficiently, the waste needs an average lower calorific value of at least 1,500 kcal/kg (around 6 to 7 MJ/kg) (Rand et al., 2000). In Narayanganj, thermal conversion through incineration or other WtE technologies is technically feasible because the non-perishable components of the waste, particularly plastics, have very high energy content. Plastics, for example, have a calorific value of 8,649 Kcal/kg (around 36 MJ/kg), making them a suitable feedstock compared to typical mixed municipal waste. Using this waste in WtE facilities, it is estimated that each ton of combusted material could generate between 500 and 600 KWH of net electricity (Ofori-Boateng et al., 2013), highlighting the significant energy potential of the city's non-organic waste stream.

The economic viability and long-term operation of waste-to-energy (WtE) in Narayanganj mainly depend on proper source segregation and collection. Even though certain waste fractions have a high calorific value, mixing them with high amounts of moisture, organic waste dilutes the overall energy content. High moisture in the mixed waste reduces net energy output and increases operating costs, such as the extra energy needed for pre-drying, which can threaten the financial sustainability of WtE operations.

Therefore, the successful operation of the planned WtE plant at Jalkuri, Siddirganj, depends on effective upstream source segregation programs that separate and prepare high-calorific refuse derived fuel (RDF). Beyond energy generation, WtE provides systemic environmental benefits, including drastic reduction of landfill volume, avoidance of future methane emissions from disposal, and displacement of carbon dioxide emissions from fossil fuel-based generation.

3.4.3 Integration with the Informal Recycling Sector

Bangladesh has a strong and active informal recycling sector. It includes *Feriwallas* (waste buyers), *Vangari Dokans* (recycling shops), and *Tokai* (scavengers). Together, they collect and sort a large share of the city's recyclable materials. This work reduces pressure on the municipal system and saves the city millions in disposal costs every year. If NCC formally recognizes and partners with this sector, recycling can improve even further. Supporting households and businesses to segregate waste at the source will make their work easier and more effective. With these steps, NCC can increase its recycling rates and move toward a more circular and resource-efficient economy (Ahmed et al., 2022).

4 CONCLUSION AND RECOMMENDATIONS

4.1 Summary of Key Findings

Narayanganj City Corporation is facing a severe solid waste management challenge. The city generates about 922 tons of waste per day, but only half of it is collected. Rapid population growth and industrial activities have increased waste production faster than the city's waste management systems can handle. More than half of the waste (58.2%) is perishable and contains high moisture. This type of waste is well suited for biological treatment such as biogas production and composting. On the other hand, the non-perishable portion especially plastics with a calorific value of 8649 Kcal/kg can support thermal Waste-to-Energy technologies. Additionally, non-segregated storage and collection practices are putting increasing pressure on public health and the environment. Without urgent improvements, the situation will continue to worsen to public health and the environment.

4.2 Strategic and Policy Recommendations for NCC

To support Narayanganj City Corporation in building a cleaner, safer, and more resilient city, the following key strategic and technical actions are recommended:

(i). **Mandatory Source-Level Segregation:** The most important step moving forward is to introduce a simple three-stream waste collection system. Households, commercial shops and activities, and industries should separate their waste into three categories: perishable, recyclable, and hazardous. This separation is essential. Waste-to-Energy plants can only work well if wet organic waste is kept apart from high-calorific dry materials. Without proper segregation, the energy potential of the waste becomes too weak to be useful.

(ii). **Integrated Facility Development:** NCC needs more Integrated Solid Waste Management plants at least two more like the one planned in Jalkuri, Siddirganj. These new facilities must be able to manage both major types of waste. The large amount of organic waste (536.84 TPD) should go to anaerobic digestion or composting. The dry and high-energy materials, once properly sorted and prepared, should be used in a Waste-to-Energy unit. With this combined system, the city can manage its waste more efficiently and recover more value from it.

(iii). **Collection and Logistics Upgrade:** Introduction of regular, reliable waste collection using dedicated fuel-efficient vehicles. Each vehicle should handle only one specific type of waste so that the segregated streams stay separate and clean.

(iv). **Institutional Capacity Building and Compliance:** Arrangement of focused technical training for all staff involved in solid waste management in NCC. This should cover every step of waste generation, storage, segregation, collection, and the operation of advanced facilities like composting, biogas, and Waste-to-Energy plants. NCC must also strictly follow the Solid Waste Management Rules 2021 and all relevant environmental laws, especially those related to landfill site selection and final disposal.

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6 DECLARATION OF USE OF AI

The authors declare that Artificial Intelligence (AI) tool (ChatGPT, OpenAI)) was used only to support language refinement, grammar correction, and improvement of clarity in selected sections of this manuscript. All data analysis, interpretation of results, fieldwork, laboratory testing, methodological design, and formulation of conclusions were fully conducted and critically reviewed by the authors. The authors maintained full oversight and responsibility for the conceptual development, scientific accuracy, and integrity of the manuscript. No AI tools were used to generate, analyze, or interpret research data, nor to draw scientific conclusions.

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