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Research Paper

An evaluative scrutiny of the waste separation and collection system in the urban setting of Narayanganj, Bangladesh: A comparative assessment in developed and developing country context

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Abstract

Waste management is a crucial issue that affects the environment, health, and economy of different countries. However, the practices and systems of waste collection and separation vary significantly between developed and developing countries, depending on the availability of resources, infrastructure, regulations, and public awareness. This paper aims to compare the waste management systems in two different urban settings of developed and developing countries i.e., Frankfurt, Germany, and Narayanganj, Bangladesh; with contrasting levels of development and waste generation. Based on secondary data, the paper analyses the current situation, challenges, and opportunities of waste management, mostly focused on waste separation and collection systems in Narayanganj City. The comparative assessment is performed to figure out the divergence between the two cities in waste management practices. The paper also provides some guidelines for improving the waste management system in Bangladesh by shedding light on the best practices of a German City. Finally, it concludes focusing on the waste separation system which requires a rigorous change in multiple tools, policies, organizational arrangements, incorporation of modern systems and technology, and individual awareness.

Keywords Waste separation, waste collection, waste management system

1. Introduction

Waste management system in developing countries can vary depending on the social, economic, and environmental context. However, some common problems are**:** low collection coverage, irregular collection services, open dumping and burning, pollution, and informal waste picking (Ezugwu, 2015 and Ogawa 2005). On the other hand, in developed countries, it depends on the country's policies, regulations, and infrastructure with some common characteristics such as higher collection coverage, more advanced treatment and disposal methods, more recycling and composting, and lower environmental impact(Hossain, 2022)**.** In developing countries, this problem is appearing asmore intense and substantial one because authorities are not well structured to handle this issue while recognition of the problem is the most critical issue (Kaza et al. 2018). Rising population level, economic growth, rapid urbanization, and improvement in community living standards have significantly increased the rate of municipal solid waste generation in developing countries (Minghua et al., 2009). In these regions, particularly among the urban poor, the negative effects of poorly managed waste are rather severe, compared to those in developed countries (World Bank, 2022). In most cities of the developing countries, this massive amount of waste remains untreated while w recycling is ignored. Thus, a sustainable urban waste management system is mostly absent in these

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countries and the urban environment is getting highly polluted gradually (Sujauddin et al., 2008).

Municipal solid waste management is one of the major challenges for authorities in all over the world due to the increased rate of waste, complex system of treatment, maintenance of the waste-related infrastructure, high cost, and lack of understanding over a diversity of factors (Guerrero, 2012). The world will generate 3.4 billion metric tons of solid waste by 2050 (Kaza et al. 2018). According to this estimation, the management of solid waste is going to be one of the biggest burdens while keeping the urban environment sound. Waste collection and segregation are two related but distinct processes of solid waste management. Waste collection is the act of picking up waste from households, businesses, or other sources and transporting it to a disposal or treatment facility. Waste segregation is the act of separating waste into different categories, such as organic, recyclable, hazardous, etc., at the point of generation or after collection. Waste segregation can help reduce the amount of waste that goes to landfills or incineration, increase the recovery of valuable materials, and protect the environment and human health (Climate and Clean Air Coalition, 2013).

The local government body of Narayanganj City Corporation is not capable of carrying more than 40% of the generated waste to the landfill site (NCC, 2020). The remaining waste is typically disposed of in the landfills, often left unmanaged, or dumped locally along riversides and canals. This practice leads to significant environmental degradation and poses serious public health risks to nearby communities. There, the poor management of landfilling sites considering open dumping, no segregation of waste, no special treatment for hazardous waste, no recycling, no reusing after composting or incineration, an old unhygienic method of dumping exists.

2. Pertinent Literature

According to World Bank (2022), "In 2020, the world was estimated to generate 2.24 billion tonnes of solid waste, amounting to a footprint of 0.79 kilograms per person per day. With rapid population growth and urbanization, annual waste generation is expected to increase by 73% from 2020 levels to 3.88 billion tonnes in 2050." According to researchers from the World Bank (2021), the world now produces at least 3.5 million tons of plastic and other solid waste every day, which is ten times more than what was generated a century ago.

In urban areas of Bangladesh, the current annual generation of municipal solid waste (MSW) is about 22.4 million tonnes, which amounts to 150 kg per person including organic/biodegradable waste (e.g., food waste, garden waste), plastic waste (e.g., bottles, bags, wrappers), and other inorganic waste (such as paper, metal, glass, etc.). The estimated per capita greenhouse gas (GHG) emissions from MSW in Bangladesh was 0.06 tonnes of CO_2 equivalent in 2016. By 2030, the MSW generation in Bangladesh is expected to reach 47,064 tonnes per day or 220 kg per person per year. GHG emissions from MSW are projected to produce upto 0.11 tonnes of CO_2 per person by 2030. By 2050, Bangladesh's daily MSW generation is expected to reach 82,000 tonnes, equivalent to 300 kilograms per person per year, with GHG emissions from this waste equivalent to 0.18 tonnes of CO_2 per person. Urban plastic consumption per capita in Bangladesh saw a threefold increase, rising from 3.0 kg in 2005 to 9.0 kg in 2020. Low-density polyethylene (LDPE). While packaging, including plastic bags, also witnessed a fivefold increase in consumption

during the same period. In 2020, Bangladesh consumed 977,000 tons of plastic, but only 31 percent of this was recycled (The World Bank, 2021). In Dhaka, approximately 646 tons of plastic waste is collected daily, making up 10 percent of the total waste generated in the country. However, only 37.2 percent of the plastic waste in the capital is recycled (The World Bank, 2021).

The Sustainable Devleopment Goals (SDG) identifies the global waste management goals for improving sustainability through ensuring access for all to adequate, safe, and affordable solid waste (SW) collection services by 2030, and stopping uncontrolled dumping (Wilson, 2019). On the other hand, the net zero emission targets are the commitments made by countries to reduce their GHG emissions to net zero by a certain date, usually by 2050 or earlier. Bangladesh has committed to achieving the SDGs and aims for net zero emissions by 2050. However, it is also crucial to focus on developing and low-income countries, where solid waste is often poorly managed (Ferronato, 2019). Recycling rates in many developing nations remain significantly lower than those in developed countries. For example, in 2019, only 9% of waste in Indonesia was sorted and reused (Malhotra, 2020).

In many developing countries, over 90% of waste is often disposed of in the unregulated dumping grounds or burned openly, resulting in severe health, safety, and environmental problems (The World Bank, 2022). Poor waste management and uncontrolled disposal lead to heavy metal pollution in water, soil, and plants. Additionally, open burning releases pollutants such as sulfur oxides (SO_2), nitrogen oxides (NO_2), particulate matter (PM_{10}), carbon monoxide (CO), carbon dioxide (CO_2), and other harmful emissions that affect the atmosphere and damage the ozone layer (Vongdala, 2019). Waste picking in open dump sites exposes workers to serious health risks, while the release of solid waste into water bodies increases marine litter and contributes to global environmental contamination (Ferronato, 2019). The improper disposal of garbage in waterways and on land poses significant health and environmental hazards, particularly in rapidly growing urban areas (Climate Policy Watcher, 2022).

The combined efforts of the 3R (Reduce, Reuse, Recycle) strategy aim to promote sustainable solid waste management and align with global environmental goals, particularly in mitigating climate change and reducing greenhouse gas emissions. This approach can lead to sustainable development benefits through the reduction of methane (CH_4), carbon dioxide (CO_2), and other pollutants such as volatile non-methane organic compounds (NMVOCs), NO_x, and CO from landfills. Implementing technologies like organic waste composting, advanced incineration methods, improved sanitation coverage, waste-to-energy solutions, industrial combustion, landfill gas recovery, and thermal processing can help minimize or eliminate greenhouse gas emissions (Recycling, 2019).

Solid waste management is one of the most pressing environmental challenges faced by municipal authorities in the Narayanganj City Corporation (NCC) area. Narayanganj is primarily an industrial zone, producing large amounts of industrial waste daily, including polyethylene, cloth, and paper. In total, the city generates approximately 1,000 tons of solid waste each day, comprising industrial, medical, residential, and commercial waste (NCC, 2022). However, inefficient and disorganized waste collection and disposal practices have made the city highly vulnerable to various forms of pollution, exacerbating severe health risks for its residents.

In contrast, Germany's waste management policy is built on closed cycles and has evolved significantly over the past two decades. For example, Germany's Closed Cycle Management Act aims to shift waste management into resource management, emphasizing the reuse and recycling of materials. In Germany metals, glass, and textiles have long been collected and repurposed, illustrating how waste can serve as a valuable source of energy and raw materials. This approach places the responsibility of proper waste disposal on manufacturers and distributors. As a result, new disposal methods have been developed, recycling capacity has grown, and public awareness about waste separation has increased. Currently, recycled waste accounts for about 14% of the raw materials used in German industry. Furthermore, modern closed-cycle management contributes around 20% to achieving Germany's Kyoto targets for reducing climate-relevant emissions.

3. Research Goal and Methods

This research paper has reviewed the waste management system, and the main practices implemented for waste collection and separation in a developing country, Bangladesh. The system for collecting and separating different types of waste has been identified as involving various waste-generating sectors, such as residential areas, construction and demolition activities, industrial operations, urban agriculture, and healthcare facilities. Among the developed countries, Germany is adopting exemplary practice in waste management system particularly in waste collection and separation. Sustainable practices of waste treatment in different cities of Germany are explored from their official websites, annual reports, summary reports of waste treatment, and reports on waste management system.

Furthermore, to recommend supporting policies for improving the collection and separation system, the evident guidelines from different international organizations' concerning waste management, waste separation; alongside existing effective practices and strategies from different municipalities in developed and developing countries are observed. The Figure 1 shows the enhancement process of the waste management system. Furthermore, the databases of waste generation, collection, treatment, and separation of Narayanganj City are collected from the NCC website, waste management report, waste management master plan and national statistics. To compare the condition of Narayanganj city, other cities of Bangladesh waste database are collected from Bangladesh Waste Database (2014).

Figure 1. Enhancement of Waste Management System (Source: Authors, 2024)

4. Case Study

4.1. Case study city from developing country

Narayanganj is one of the major hubs of the industry and a very prominent city in terms of location and economic activities in Bangladesh. It is a city of 709,381 people with an area of 73.23 sq. km (NCC, 2020). With this huge population and high density in the city core area, the municipality has been facing an acute waste management problem for years. NCC is located to the south of Dhaka city, within Narayanganj district, which is part of the Dhaka division (**Figure 2**). It is the seventh-largest city corporation in Bangladesh and is divided into 27 wards (Water Aid, 2018). Narayanganj is about 17 km southeast of Dhaka, the capital city of Bangladesh. Due to the huge pressure of migration due to industrial growth, the population of Narayanganj is increasing rapidly The horizontal expansion of the city appeared as urban sprawl with unplanned growth which accelerates the lack of proper management and insufficient urban services.

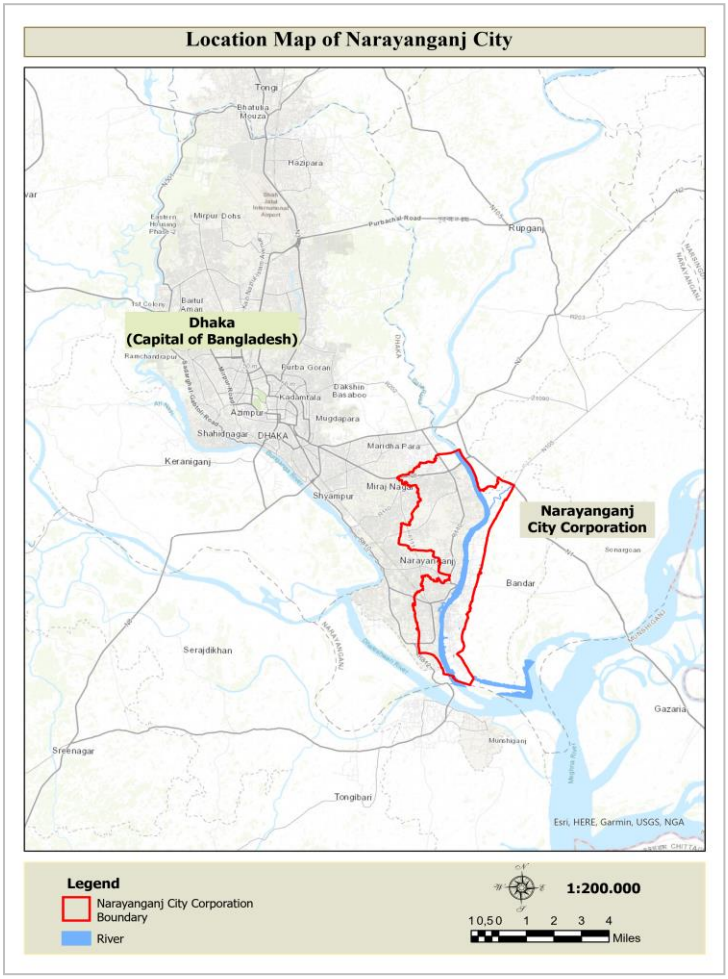

Figure 2. Location Map of Narayanganj City (Source: GIS Database of NCC, 2020)

4.2. Case study city from developed country

As a case study the waste management system of Frankfurt City, Germany is presented here. In the Rhein-Main region, waste collection systems are provided by the FES, Frankfurt waste disposal company. Firstly, the waste was categorized according to different types. After that, a systematic collection system is developed for each category of waste, and the process of recycling or reuse is established afterward. FES offers a variety of colored bins to the residents and gives clear indications of how to separate and treat the waste. Afterwards, they collect the waste in a periodic time or directed way. Besides, they also offer collection from specific points of the city or neighborhood or at pre-scheduled appointment for some kinds of waste (Friedrich-Ebert-Stiftung (FES), 2022). Through the effective operation of the FES and the cooperation of residents and businesses in separating waste, significant progress has been made in reduction and avoidance of waste. Between 2000 and 2010, total per capita waste decreased from 493 kg to 406 kg, representing an 18% decline. Additionally, the collection of reusable materials improved, increasing from 38.3%

in 2000 to 42.1% in 2010, showing a notable rise in sustainable waste practices (Frankfurt Green City, 2016).

5. Existing Waste Management Status in Narayanganj

5.1. Existing waste collection and separation practice in Narayanganj

For waste management, municipalities can either develop own policy or follow the national policy or can introduce a management system that residents of the city need to follow. From the collection stage to recycling and final disposal of waste municipalities are the key actors. They are primarily responsible for managing domestic waste; however, in some cases, these responsibilities are delegated to local waste management companies. These companies oversee key aspects of municipal waste management, such as transportation, landfill operations, composting, incineration facilities, and public waste education. The municipal waste management authority is also responsible for determining waste tariffs and the overall waste treatment system. When multiple municipalities collaborate to form a regional waste management company, they must also establish a joint organizational structure to manage administrative functions.

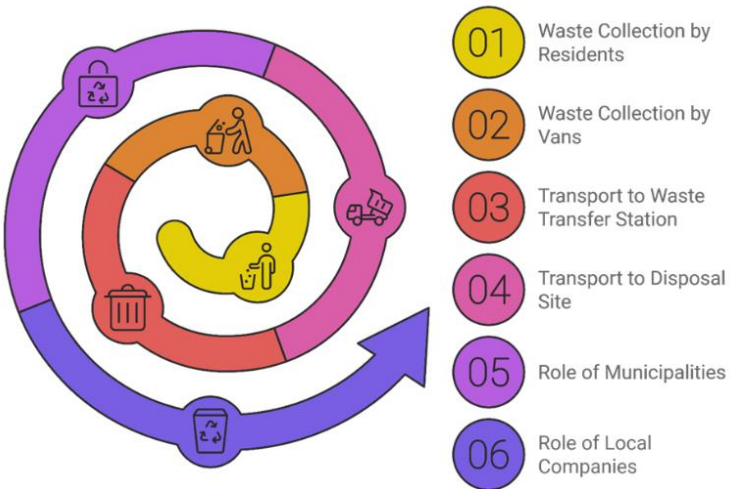

Figure 3. Waste Management Process in arayanganj City (Source: GIS Database of NCC, 2020)

In the Narayanganj City Corporation Area, the general process of the waste collection system is subdivided into two stages. In the first stage, residents need to carry the waste to a certain dustbin or some point (figure 3). Recently, some non-motorized vehicles are visiting every residential area and collecting waste from door to door. They also carry the waste to the waste transfer station (WTS). The residents have to bear the charge of this service. In the second stage, the truck of the city corporation carries the waste to the disposal site from WTS. There is no legal requirement of waste separation at household

level. So, WTSs and waste disposal sites are key sites for waste separation in Narayanganj city. However, the number of WTSs is still not enough according to the city's size, location, land use, and huge number of populations.

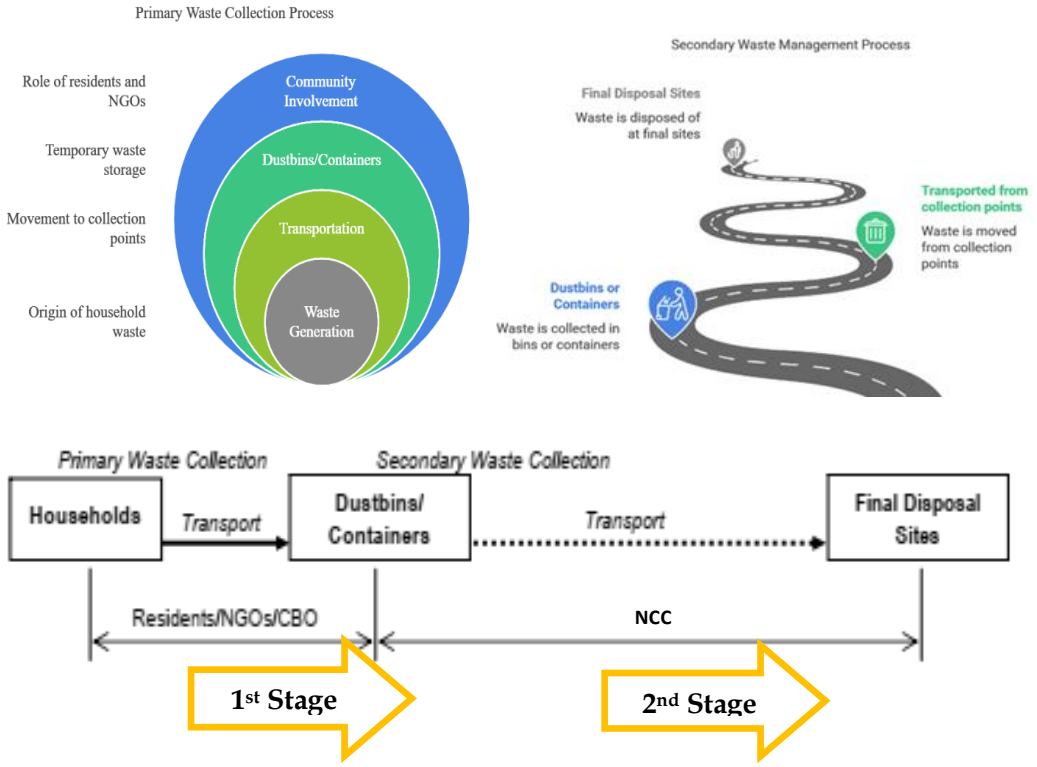

Figure 4. Waste Collection process. (Source: NCC, 2020)

In the NCC, 228 waste pickers collect waste from households, while 1140 street cleaners, and 307 plastic collectors are working in the field. As the number of waste pickers is very low compared to thecity size and household number. Most of the households depend on private waste pickers who collect the waste from door to door with a van for a monthly charge. The overall collection process of waste from collection to disposal shows in the figure 4. Besides this, seven staff of NCC are working in the field and one officer is working in the municipality office. A permanent waste management committee with eight members is responsible for the management of the whole process. The committee is headed by a councillor of the city corporation. The mayor herself is a member of the committee too (NCC, 2017).

5.2. Waste composition in Narayanganj

For an efficient waste separation mechanism, waste composition analysis is very important. In Narayanganj waste management master plan (2020), the waste composition is divided into major three categories: fermentable fraction, recyclable fraction, and non-recyclable (either hazardous or not economic) (shown in the Table 1). The waste contained in the NCC area is household waste, city waste, commercial and non-hazardous industrial

waste, hazardous (toxic) industrial waste, medical waste, human and animal waste, construction waste, underground waste, etc. The main components of the city's solid waste are food, vegetables, fruits, polythene, paper, and jute cloth. The city of Narayanganj is an industrial area that produces almost 340 tons of waste per day. So, large quantities of industrial waste such as polythene, metal, cloth, and paper are produced every day.

Table 1. Waste Composition in Narayanganj City, 2020

MSW generation at NCC		**Waste amount of different type**		
Source of Solid waste	Amounts tons/day	Food and Farm waste	Nonfood waste	
		Fermentable fraction	Recyclable fraction (Metal, plastic, cardboard, etc)	Non-recyclable either hazardous or not economic
Household	492	366.84	89.99	35.18
Commercial and Industrial	340	170	136	34
Warehouse of broken material	90	0	63	27
Total	922	536.84	288.99	96.18

Source: Waste Management Master Plan (2020)

5.3. Waste generation in difference zones of NCC

NCC comprises three municipalities and 27 wards. According to the waste report and GIS database of NCC and the GIS the ward-wise waste generation, population, and land use are presented in figure 5. As the waste pattern in a certain area is highly dependent on the land use pattern and the existing population, the existing waste composition in comparison with land use and population is explored here.

Industrial waste: As Narayanganj is one of the main industrial hubs of Bangladesh. Within the city corporation area almost 30 categories of industries are established. So, management of the industrial waste is one of the major challenges for the authority. According to the municipality GIS database (2020), Ward no 04 has the most industrial units (355) in Narayanganj City. After that, wards no 03, 06, 08, 15, 18, and 27 have more than 170 industrial units. These indicate the importance of industrial waste treatment within this area. Most of these units are garments, textile, and yarn-based industries. Besides bakery, cement industry, cotton processing, cycle and tube industry, cosmetics. Dyeing, Jute, glass, iron, leather, limestone, medicine, newspaper, PVC products, private

warehouses, printing, re-rolling mills, furniture, shipbuilding, handloom, salt crushing, soap-detergent, rice mill exist all over the city.

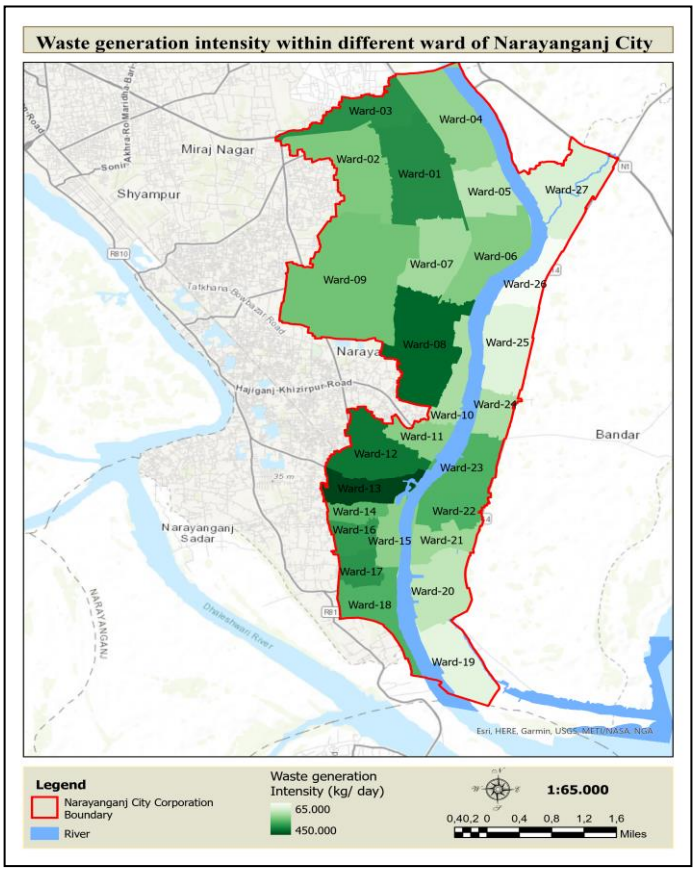

Figure 5. Waste intensity in different zones in Narayanganj City (Source: GIS Database of NCC, 2020)

Medical Waste: Most of the medical facilities and hospitals are located within the city center of Narayanganj. For that reason, most of the hospitals and clinics exist in the ward no 12 and 13. Besides, ward no 04, 06, 09, and 15 have more than 5 healthcare facilities. These wards are the key zones for medical waste generation and would need special focus to separate the waste.

Construction Waste: The city faces a high demand for housing due to significant in-migration driven due to industrial units. This, along with ongoing commercial and industrial development, has led to extensive construction and demolition projects throughout the city. As a result, construction waste has become a new challenge for the municipality. This waste includes various building materials e.g., mortar, sand, ceramics, concrete, wood, paper, metals, plastics, stones, bricks, and paint. Ward no 01, 03, 08, 12, 13, 16, and 17 produce more waste than others which indicates the necessity of spatial treatment and provision in terms of waste management (Figure 5).

5.4. Waste management status in NCC

The cleaning department is responsible for keeping Narayanganj city clean and managing waste. According to the waste management branch, in 2020 approximately 1000 tons of waste was generated daily in Narayanganj city. Organic manure is prepared from 20 tons of waste through the compost plant located at Panchabati (Shows in Table 2). To modernize and improve the waste management of the city, a power generation project has been undertaken in the city's Jalkuri. Under this project, 8 MW of electricity can be generated from 600 tons of waste daily. In addition, plans have been made to build another plant in the Kadmarsul area for efficient waste management (NCC, 2020).

Table 2. Overview of Collected Waste in NCC

Category	Status	Remarks
Amount of waste per day	1000 ton	Approximate data from NCC
Treatment percentage	83%	Approximate data from NCC
Compost plant capacity	20 tons	Operation from 2016
Medical waste treatment	No specific amount, 2 trucks working daily for collection	Pilot project
Plastic waste collection	2 tons daily	Working informal collector

Source: NCC (2022)

The daily rate of waste collection by city corporations is about 83% . The rest is dumped on the banks of local rivers or canals which causes environmental degradation to the locals and serious damage to public health (NCC, 2020). Two trucks with a capacity of three ton are working daily for the transport of medical waste. But still, it's a pilot project and not sufficient to carry hazardous waste. For lack of proper system and capacity, community wastes and commercial and medical wastes are dumped on roadsides, ponds, canals. Solid waste collection and disposal management is so inadequate that it increases pollution and health risks in the city.

5.5. Waste management system of Narayanganj City

The flow chart presented below (Figure 6) shows the proposed waste management model of the new master plan of Narayanganj City.

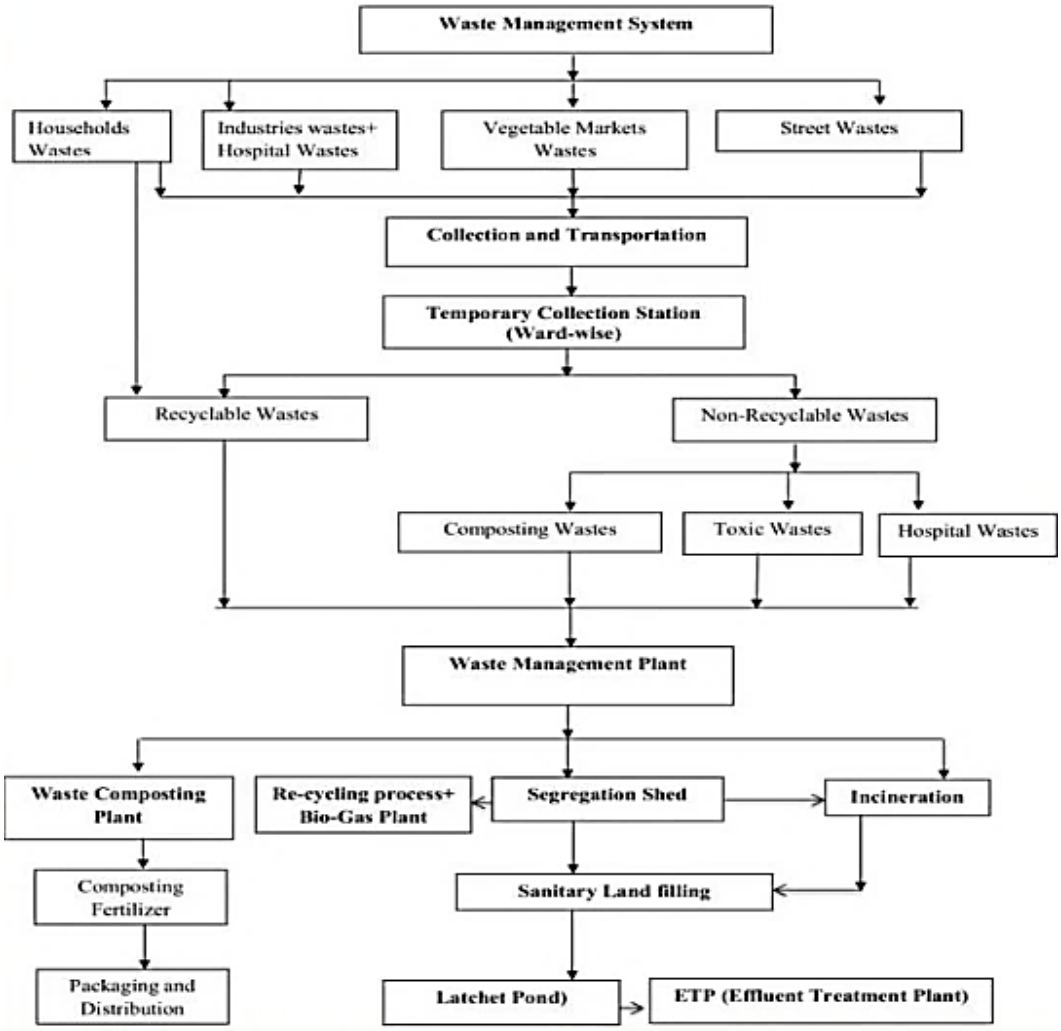

Figure 6. Proposed waste management system in Narayanganj City Corporation Area (Source: Waste Management Plan for NCC, 2021)

5.6. Waste separation practice

5.6.1. Waste separation in compost plant

The compost plant, which began operations in 2016, occupies a 4,046-square-meter area and is equipped with various facilities, including a sorting ground, 49 compost boxes, 10 maturing boxes, a biogas plant, a drying bed, a polythene recycling facility, an office, and other infrastructure. The plant has the capacity to process 22 tons of waste per day and can produce up to 4 tons of compost daily. Waste separation takes place after collection and transport to the composting facility. Figure 7 shows waste separation and compost plant site in NCC. The primary objectives of this project are to reduce greenhouse gas (GHG)

emissions from the waste sector, integrate the 3R (Reduce, Reuse, Recycle) approach into waste management, and enhance soil quality by providing organic fertilizer to farmers.

Figure 7. Waste Separation at Compost plant site in Narayanganj (Source: SACEP, 2016)

5.6.2. Plastic waste collection

According to NCC, 10-11% of total waste is plastic waste which indicates the amount is approximately 100 tons. This is the most recent idea generated for plastic waste separation and collection from NCC, However, the recycling amount of plastic waste is still very low. Only 2 tons of the plastic waste is collected by the city corporation and a recycling plant is working on a pilot basis. But the waste department is working to collect more waste. They have already developed 5 collection models to increase the amount of collection. The authority is contacting one of the leading factories of the country that is working with recycling plastic as a potential client of the Narayanganj recycling plastic. Besides this, some informal factories and collectors exist within the city area. This private informal collector plays a very important role in collecting plastic waste and recycling it. But their interest area is fixed according to their commercial need. Mostly they collect plastic bottles and polythene. Around 74 informal points can be located named "*Vangari Dokan*" within the city with 500 people engaged in the sector. The system of the plastic collection and conventional recycle model is showing below in the figure 8.

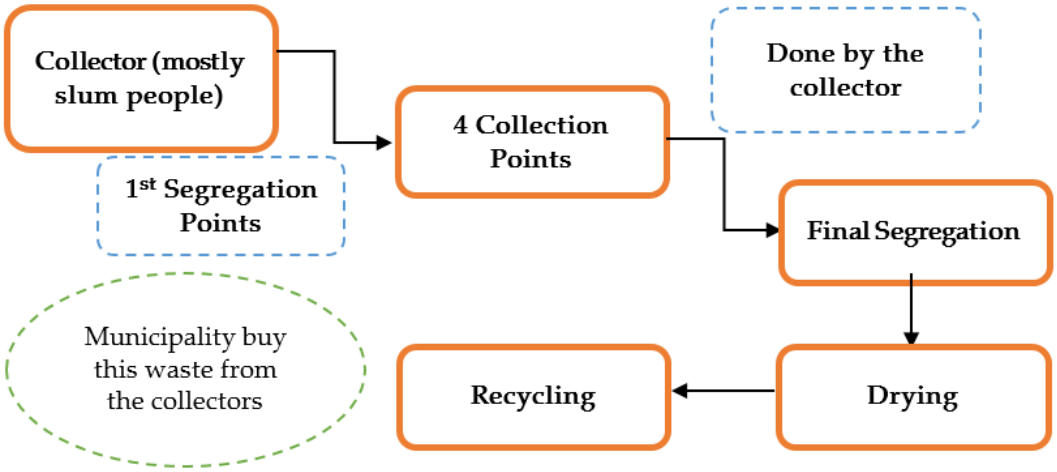

Figure 8. Plastic Recycle Model of NCC (Source: Author, 2022)

5.6.3. Other waste collection and separation

A private electrical waste recycling company exists in Jalkuri, Narayanganj city. The company collects the electric waste and also exports the Plastic and the metal. However, there is no government regulation and authorities have no clear data about their process and recycling amount of waste. And according to NCC, the amount of electrical waste is still so low that it is tough to continue an electrical recycling plant.

At present, there are no legal bindings to manage the waste from industry or commercial establishments including hazardous waste. Also, no provision for waste separation from the household level and no rigid regulations for environmental pollution regarding poorly managed open dumping sites. Though in some policies, some guidelines are mentioned about recycling but there is no clear guideline for specific types of waste. Even no guidelines about waste reduction, or reuse of waste separation at the source.

5.7. New provision for waste separation and collection in Master Plan 2020

In the new waste master plan the major drawbacks of the present practice are addressed. But the implementation of the plan needs some years and authority is on the way of executing the plan. According to "Waste Management Master Plan, 2020" (Narayangang City Corporation, 2020) -

- 8 new secondary waste transfer stations with provision of waste separation are proposed. The typical size of the station is proposed to be 40-50 ft or 50-60 ft. The distribution of these WTS will be in three sub-districts named Siddhirganj, Narayanganj, and Kadam Rasul.
- An area comprising 13.29 acres is developed with the provision of a solid waste disposal site as well as a biogas plant, recycling plant, compost plant, lychee pond, green pond, gray water pond, garage, and many installations including rooms. Waste separation provision in the disposal site subdividing into different wings is also proposed in support of 129 new employees.

- However, still the recycling options, strategies, and waste separation indication are ambiguous. Though some guidelines and provisions of waste separation are mentioned in the report. Nevertheless, how the recycling should be managed or the development of any model for waste separation is absent.
- No particular model for waste separation regarding different categories is absent as well as no particular model of waste separation from the household stage which is the most effective model of waste separation appeared in many municipalities of the developed world.

6. Comparative Scenario in Developed and Developing Countries' WMS

To find out the best solution for sustainable waste management for developing countries based on the apparent practice of collection and separation systems, the case study from a developed country; Frankfurt city of Germany is compared with the study area Narayanganj in terms of waste composition, collection system, waste separation, and policy restriction. A comparative analysis in different dimensions is presented in this section to evaluate the current condition of the study area in terms of waste composition, separation, and collection.

6.1. Difference in waste composition

As the socio-economic condition, daily life patterns, and food consumption patterns are quite different in Bangladesh as well as in Narayanganj compared to Frankfurt, Germany; waste composition is also very different in terms of amount. So, without mentioning the vital component of waste composition, the comparison of waste separation could be an imprecise explanation.

In Narayanganj, People use less processed food and fewer packets and plastic but the use of polythene to carry any goods is high. According to different research and different food consumption, the categorization of waste is different in two cities (Figure 9). Where the major portion of the waste in Narayanganj is food waste (75.64%), the maximum portion of waste in Frankfurt is found in household and light commercial waste comprising 53% of the total. Besides this, paper waste is also found in large quantities which is 14% and bulky waste is 8%. The other categories of waste in Narayanganj are metals, wood, Fabrics or textiles, Paper, Plastic, and others. So, there is a huge difference in the categorization of the waste composition data. So, it is tough to compare these databases and also tough to analyze the data in a common contextual ground regarding the percentage of waste of different categories (NCC waste database, 2014).

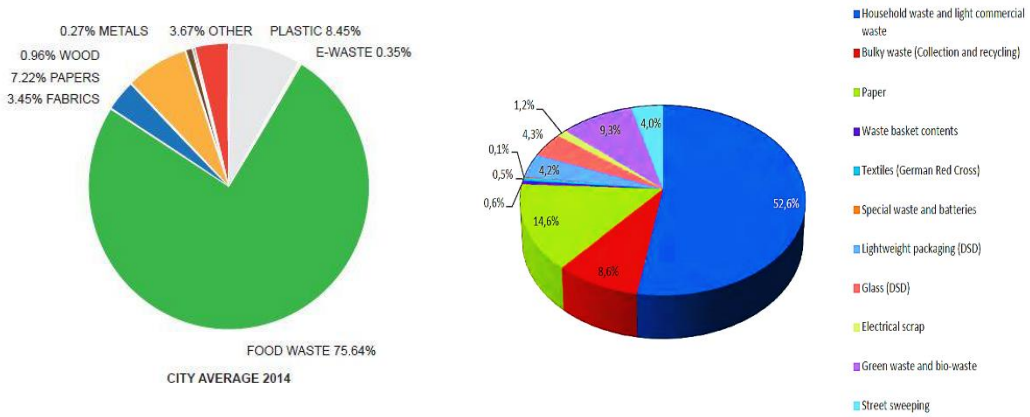

Figure 9. Comparison in Waste Composition of Narayanganj 2014 and Frankfort 2009 (Source: NCC waste database, 2014, City of Frankfurt am Main, 2010 and Peterek, et al, 2013)

6.2. Comparative scenario of waste collection and separation

In most cases, a noticeable difference in every phase of waste management or supportive infrastructure is explored between two management system (Table 3). However, as per the new master plan for waste management 2020, there is a new strategy and provision of waste separation and recycling incorporated in some infrastructure development projects that are already approaching in Narayanganj City.

Table 3. Differences between the collection systems of two cities.

Category	Narayanganj	Frankfurt
Special Governance body for waste management	No special Department. The waste management branch of the city corporation with only 7 officials the management is going on.	The Frankfurter Entsorgungs- und Service GmbH (FES) is the primary company tasked by the city authorities with collecting and recycling waste and reusable materials. FES operates as a public-private enterprise, established from the former Waste Management and City Cleaning Department.

Separation Phase	No clear indication of the separation phase rather it is a complex system of separation, collection, and recycling in different stages.	The waste treatment done by the FES in four levels with clear guideline of waste separation in two phases. Separation from sources and final stage separation is the remarkable stage.

Table 3. Cont.

Category	**Narayanganj**	**Frankfurt**
Separation from the source	There is no provision or no system of waste separation at the household level. And the separation in disposal site is also dissimilar than the Frankfurt city as the provision of landfilling is absent in Frankfurt.	In 1990, Germany launched the "green dot" recycling system to serve as a model for waste recycling. Under this system, household waste is separated into five categories: plastic waste, residual waste, organic waste, glass, and paper and cardboard. Typically, buildings are equipped with bins for plastic, paper and cardboard, residual waste, and often organic waste, which are usually emptied on a weekly basis.
Use of Different Bin for separation	Nowhere in the city, separation bins for the waste is found. Separation recommendation is in the second stage, after collection.	Everywhere, even in commercial and industrial structures waste separation in different bins is mandatory and before collection and transportation of the waste.
Policy Restriction	Environmental conservation policy is the basic law for the country where the landfill should be managed sustainably without environmental degradation.	After the revision of the law in 2005, the operation of the landfill sites has been made tough with certain clauses. The only landfill site in the city area ("Monte Scherbelino") was closed in 1968 and is in aftercare (Peterek, et al, 2013).
Waste avoidance	Waste separation is still not a very significant point of waste management. So, waste avoidance is not a part of the strategy till now.	Waste avoidance is one of the key instruments to reuse the waste that successfully took place in Frankfurt city. In 2010 around 117,561 tons of reusable materials were separated from the total amount of domestic waste which is 42.1% of total waste (Peterek, et al, 2013).

Collection or drop-off points	No option for a drop-off site within the city.	A drop-off point within the designated distance is available which is a big acceleration of waste separation.
Plastic waste, paper, and cardboard	No system to Separate Plastic or glass bottles from the source. The plastic waste is collected by the informal collector from different parts of the city and in the waste transfer station, some plastic bottles are segregated.	Plastic packaging, aluminium, and beverage boxes should be disposed of in the yellow bins. Paper and cardboard go into the green bin, which is emptied every two weeks. Once collected, the paper and cardboard are taken to a wastepaper sorting facility before being sold to paper mills for further processing.

Table 3. Cont.

Category	Narayanganj	Frankfurt
Special waste	Some informal shops and collectors collect the electric waste for repair and resell it. For the socio-economic condition, most of the bulky waste like furniture is recycled within the community. However, no formal strategy or model exists for this kind of waste. The Authorities are not concerned yet about this waste.	For Bulky & electronic waste a collection date needs to be fixed to pick up this waste by FES. Usually, they collect it free of charge. To maintain separation, wood, metal, electrical appliances, and bulky residual waste are typically collected using three different vehicles. Once separated, the wood is processed for use in biomass power plants, while metals are supplied to the metal-processing industry. Electrical waste is collected by Werkstatt Frankfurt e.V. and is recycled whenever feasible.
Toxic waste	Only 10% of the toxic waste is separated from the regular channel. Two vehicles are working to carry toxic waste from the medical center to the incineration point.	For disposal of any kind of toxic waste for example paint or specialized glue, two options are available. Either it needs to take to a "Wertstoffhof" or the "toxic waste mobile". Medical waste treatment is totally separated.
Charges with incentives to separate waste	Till now there is no incentive to promote waste separation in Narayanganj City. Municipal authorities are too reluctant in this area. No policy or strategy formulation in this specific area.	For the violation of the rules for waste separation or problem of collection, the municipal administration can impose extra charges on the residents. The minimal presence of foreign materials in biowaste bins (less than 3%) and waste paper bins (less than 1%) reflects the high level of public adherence and acceptance of proper waste sorting for these categories (Peterek et al., 2013).

Training-Awareness Program and PR work	Though Municipal authorities organize some workshops for the officials and workers related to waste management, still it's an occasional program and awareness program or education for residents is absent in Narayanganj City. Furthermore, there is some guideline to initiate this program in the new master plan but till now it's not in practice within the city.	FES publishes the "Oskar" magazine three times a year and distributes it among all households. The magazine is a guideline for seasonal waste disposal and lists important dates and locations related to waste management. Along with, several brochures published in 13 languages with information on waste type and disposal channels. A central service center and 24-hour call center are active from FES for the support of normal residents. (Frankfurt am main, 2020)

Source: Author (2023)

7. Major Findings and Guideline for Solid Urban Waste System (SUWS)

7.1. Findings and major problems

Major findings after the present scenario analysis and the comparative study with a developed waste management system can be identified as:

- Absence of implementation of national policy to encourage recycling practice and no clear guideline or policy restriction from the city authority to implement the recycling process.
- Insufficient and traditional way of waste collection and dumping in disposal sites.
- Less concern about waste separation and very little practice of source separation.
- Lack of awareness about the environmental problems associated with landfilling and hazardous waste.
- Lack of incorporation of the informal sector, no model is developed for recycling with the existing informal recycling options.
- No specific model or system of recycling for specific kinds of waste and no policy restriction for different types of land use.
- Above all, understanding of the problem by considering waste generation and recycling options.

7.2. Guideline for sustainable urban waste separation system

A sustainable waste separation system involves a complex interplay of various factors to ensure its effectiveness and long-term viability. These factors encompass social, economic, environmental, and technical considerations. Public awareness, policy and municipal strategy, infrastructure, source separation facility, infrastructure, community engagement, economic viability, and recycling opportunity are the dynamic factors that can highly influence the separation system. Some guidelines regarding the context of the case study

area as well as the developing countries' context where the scenarios are similar are anticipated here.

Waste Avoidance: The inclusion of a waste avoidance policy could be a massive blow to the waste separation system. Waste prevention is highlighted as a top prioritized strategy for sustainable development. It is the first step that prevents a substance from becoming waste (Wan et al. 2019). By waste separation, a huge amount of product can be recycled and reused. But without separation, the bulk amount of waste is very tough to reuse and the waste can go only to incineration or disposal sites.

***Introduction of Drop-off sites*:** A sufficient number of drop-off facilities for paper, plastic, and glass need to be installed within the city area. Each glass drop-off station consists of a separate container for different kinds of bottles. Another major problem for the city is the widespread use of plastic bottles which need to be addressed immediately. A refund option with this drop-off site could be one of the most logical solutions for this issue. In Some cities in Germany, the station density is considered one for every 1000 inhabitants and at least one station within 15 minutes (NREL, 2018). The location and number can be fixed later on according to the city standard. Besides this, the strategy of refund should be incorporated with the selling method of different kinds of bottles. These drop-off containers can be installed in supershops, public places, some service areas, marketplaces, etc.

Separation Model: According to the master plan 2020, new waste transfer station construction is ongoing and these WTS are a vital part of the Narayanganj waste collection system. In the present system, the waste is collected privately from households to WTS with non-motorized vehicles privately. So, before the final treatment, two models can be installed within the existing process.

- *Model 1:* After collecting the waste from different households with private support to the waste transfer station (WTS), waste can be kept separately according to type in different containers in WTS. After that, waste can be carried for final disposal or to the compost, energy plant, or incinerator.
- *Model 2*: From the household, waste can be carried separately from the drop-off bin at the initial stage and can be carried to WTS. After that, it can go for final disposal, and for special kinds of waste like bulky waste, hazardous waste, or medical waste, the waste should be transported to the treatment place directly. For this, a well-connected collection point is necessary within the neighborhood (Bilitewski, 2018).

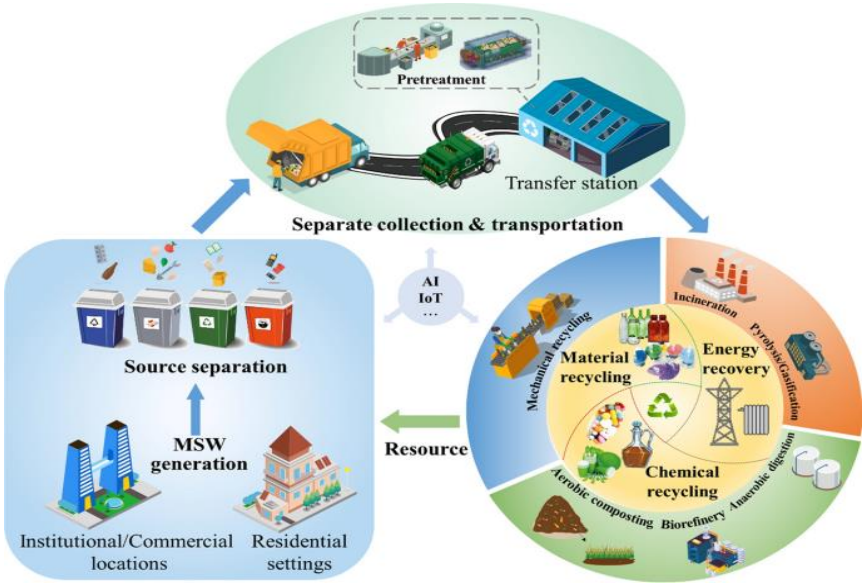

Figure 10. Waste Separation Model (Source: Zhang et al., 2021)

***Waste separation model after collection*:** Source separation of municipal solid waste (MSW) provides ideal conditions for effective recycling (Salah et al., 2020). Following source separation and mixed collection, fine sorting of recyclable materials can proceed in two ways. This involves manually or mechanically removing organic waste, bulky recyclables such as cardboard, plastic and glass bottles, large metals, and hazardous materials. The remaining waste is then sorted using various methods, such as magnetic separation, eddy currents, and optical sorting, to recover valuable feedstock. The cleaning process aims to eliminate contaminants or impurities on the surface, ensuring high-quality recycled materials, particularly for plastics that tend to have high variability (Soto et al., 2020). As Narayanganj waste management now depends on mixed collection the separation could be possible with the method of using a shredder and with a period source separation method needs to be introduced by providing different colored bins.

Category-oriented separation and collection Strategy: In communities that feature a mix of residential, commercial, and industrial areas, relying on a single waste collection system can be challenging. To effectively manage waste, it is often necessary to implement multiple collection systems tailored to local waste patterns and designed to meet specific needs and spatial requirements (Bilitewski, 2018). As the land use pattern is mixed all kinds of land use can be found in every ward. So, a different collection system for different areas and different vehicles for the collection of different types of waste (Shows in table 4) is mandatory.

Table 4. Waste separation for different kinds of waste

Waste Category	Separation Stage	Treatment Options	Remarks
Residual Waste	Source separation with Separation Bin, WTS separation	Household composting, Compost plant, paper recycle plant, plastic recycling plant, Alternative use of goods, Re-sell, Reuse.	Waste separation from source is the key and need to initiate this strategy
Medical Waste	Source separation with a colored bag	Three containers for sharp, infectious, and household waste. Incineration for hazardous waste.	To increase recycle rate separation is important.
Industrial Waste	Source separation, Source treatment plant, Private owned secondary recycler	Combined treatment plant for small scale, Big Effluent Treatment Plant for large scale.	More than 30 categories of industries exist in Narayanganj, and an integrated industrial waste recycling plan for every category is necessary.
Electrical Waste	Separation in private sector workshops or electric plants,	Non-destructive, semi-destructive, or destructive techniques (Ottiger et al., 2019).	Municipality can incorporate the private sector and develop this recycling commercially with an appropriate controlling strategy
Construction Waste	Source, In plant, In private factory	CDW Recycling Plant, Private commercial recycler	Need to incorporate the private sector more under the supervision of authority.

Source: Author (2023)

The Policy Approach needs to incorporate the National Waste Policy: The waste hierarchy is a widely used framework that emphasizes prioritizing waste prevention, followed by reduction, reuse, recycling, recovery, and finally disposal, in descending order of preference. The "polluter pays" principle assigns the responsibility and costs of waste management to those who generate or produce the waste. Extended Producer Responsibility (EPR) is a policy approach that holds producers accountable for their products even after consumer use, requiring them to take back, recycle, or safely dispose of their products and packaging. The circular economy aims to break the link between economic growth and resource consumption or environmental harm by creating products and systems that minimize waste and maximize value retention throughout their lifecycle. Integrated solid waste management (ISWM), is a framework that considers the technical, environmental, social, economic, and institutional aspects of MSWM and applies a mix of appropriate technologies and practices to suit the local conditions.

Formulation of Special Body: Narayanganj City Corporation's waste management wing institutional capacity is still very low with only 7 key personnel. Creating a Sustainable urban solid waste management system focusing on recycling is almost impossible within this structure. Besides this, the infrastructure and the effective legislation are still immature in the city area. So, a special body for waste management with sufficient infrastructure and employees is essential for the implementation of an effective separation system. In comparison, Frankfurt's special body for waste management could be a model that can be followed after necessary appropriation with the local context.

Formulation of Area-Based Specific Policy: Though waste recycling is encouraged in national policy, the waste recycling policy is still not very clear and descriptive for the country. So very transparent policy guidelines for the MSW focusing on waste separation and waste recycling should be developed. Narayanganj Municipality can develop its policy for systemic waste recycling regarding industrial waste management or household waste management considering the land use pattern and socio-economic condition of the city. Some specific provision is needed for some wards (Ward-18, Ward-13, etc.) and special kind of waste like plastic and polythene.

Informal Sector/ Privatization: In developing countries, informal waste recycling is a common source of income for many urban poor. While accurate estimates of the number of individuals involved in waste picking or its overall economic and environmental impact are limited, studies indicate that when waste picking is organized and supported, it can drive community-level investment by low-income groups, generate employment, reduce poverty, cut municipal costs, enhance industrial competitiveness, conserve resources, and protect the environment. Waste pickers have been organized through three main models: microenterprises, cooperatives, and public-private partnerships. These approaches can lead to more efficient recycling processes and contribute to reducing poverty more effectively (The World Bank, 2021).

Special attention to specific kinds of waste: Plastic waste is now one of the key concerns for Narayanganj city. Authority should give special focus to reducing the use of plastic and promote traditional jute bags and alternative polyethylene made from jute. Besides recycling plastic, the pilot project that is already initiated should be developed in a more systematic approach to increase the amount of recycling. Additionally, special attention should be given to glass waste, which is 100% recyclable and retains its purity and quality no matter how often it is recycled. With the amount of glass waste steadily increasing, it poses a growing challenge. Since glass can take approximately one million years to fully decompose, it creates significant strain on already overburdened landfill sites.

8. Conclusion

Waste management is a global challenge that affects the environment, health, and economy of different countries. The paper compared the waste collection and separation systems in developed and developing countries, focusing on the case studies of Germany and Bangladesh. The paper found that Germany has a well-established and efficient system that relies on high public awareness, strict regulations, advanced technologies, and adequate funding. On the other hand, Bangladesh has a poor and ineffective system that

suffers from low public awareness, weak regulations, outdated technologies, and insufficient funding. The paper suggested some recommendations for improving the waste management system in Bangladesh, such as increasing public education and participation, enforcing environmental laws and standards, adopting appropriate technologies and practices, and enhancing financial and institutional support. The paper concluded that waste management is a shared responsibility that requires the cooperation of all stakeholders, including governments, industries, communities, and individuals. Through learning from the best practices of developed countries, developing countries can overcome their challenges and achieve sustainable waste management. To reduce the waste in disposal sites and to preserve nature from pollution it is high time for the Narayanganj city to develop a sustainable waste management system. A great focus on reuse, recycling, and reduction of waste could be the best strategy to decrease the amount of waste and a more effective way to reduce environmental degradation.

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