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ROLE OF SCIP PLASTICS PROJECT TO MITIGATE PLASTIC POLLUTION IN KHULNA REGION OF BANGLADESH

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ABSTRACT: As a heavily populated and rapidly developing country, Bangladesh has experienced significant environmental issues in recent years, particularly with pollution and plastic usage due to rapid urbanization. Despite being classified as a low-middle-income country in 2015, Bangladesh is expected to continue generating waste at the same rate as poorer nations until 2050. In urban Bangladesh, plastic consumption has risen from 3 kg/cap/a in 2005 to 9 kg/cap/a in 2020. Khulna, a fast-growing city situated alongside the Rupsha and Bhairav Rivers, is also facing an increasing amount of municipal solid waste (MSW) production. The use of plastic has become a global environmental concern due to its harmful effects on marine and wildlife, as well as human health, making the Khulna region particularly vulnerable to marine plastic pollution due to its proximity to the Bay of Bengal. The study investigates the sources and proportion of plastic waste in mixed and source-separated waste and assesses the role of waste collectors and recycling shops in managing plastic waste. Recycling shops in Bangladesh play a significant role in recycling about 850 tons of plastic waste every month. The study finds that waste collectors only recover a small proportion of recyclable plastics, missing a potential recovery of plastics of 4.04% of uncaptured recyclable plastics. Also in this paper, the assessment of the landfill highlighted the need for improved embankment and daily cover measures to prevent waste movement by air and water. The findings of this study can inform the development of strategies to mitigate plastic pollution in Khulna.

Keywords: plastics, pollution, waste management, waste generation, recycling shop, landfill

1. INTRODUCTION

Bangladesh, a populous and rapidly rising nation, has faced a serious environmental crisis throughout the years. As a result of its rapid urbanization and expansion, the nation experienced a significant increase in pollution and plastic use. According to the World Bank report, Bangladesh generates around 22,000 tons of plastic waste every day, and only 35% of it is collected and disposed of properly (Kaza et al., 2018). Bangladesh is ranked tenth in mismanaging plastic waste on the list in plastics pollution despite being the first nation to restrict the use of poly shopping bags in 2002 (Tembon, 2021). This is due to the widespread usage of single-use plastics, their inefficient handling in some places, and poorly run landfills without waste separation techniques (Nadiruzzaman et al., 2022). The rate of waste generation per person in poor nations ranged from 0.12 to 5.1 kg/cap/day, as per World Bank statistics. Despite its classification as a low-middle-income country in 2015, Bangladesh will remain in the range of waste generation of poor nations until 2050 (Table 1).

Table 1. MSW generation in Bangladesh per capita per day in 2012, 2016 as well as projections for 2030 and 2050 (Kaza et al., 2018)

Particulars	2012	2016	2030	2050
MSW generation [kg/cap/day]	0.26	0.28	0.33	0.42

The rural average MSW generation is significantly lower than those of the urban population, which reflects disparities in the country. A report by World Bank revealed that in Bangladesh's metropolitan areas, annual plastic consumption per person tripled in 15 years' time, from 3.0 kg in 2005 to 9.0 kg in 2020. For instance, the number of plastic bags used in 2020 compared to 2005 was more than five times higher. 977,000 tons of plastic were consumed in 2020, yet only 31% of that was recycled. Plastics make up about 8% of all waste generated in Bangladesh, of which 0.79 MMT goes to landfills without further treatment, and 0.12-0.31 MMT of plastic enters the ocean annually (Jambeck et al., 2015; Gayer et al., 2017). Khulna, as one of the biggest cities in the highly populated Ganges Delta, receives about 500 tons of trash daily and is thus a particularly sensitive contributor to marine pollution.

Plastics are one of the most used materials nowadays, but their fame is also a reason for the environmental downfall of their mismanagement. Plastics are being utilized more and more frequently in daily life today, including packaging for items made by different food and beverage, pharmaceutical, cosmetics, and other manufacturing businesses to deliver products to the consumer more effectively and safely (Evode et al., 2021). The biochemical process of polymerization or polycondensation is used to make plastics of various types like high-density polyethylene (HDPE), polyvinyl chloride (PVC-U), polystyrene (PS), polyethylene terephthalate (PETE), polypropylene (PP) and others (Guo, 2017).

At the same time, the development of disposal and treatment pathways is not keeping pace with the rapid development on the product side. Mishandled plastic debris is contaminating the countryside, cities, rivers, and canals. They cause floods in cities by clogging sewers (Hossain et al., 2021). The already overloaded landfills for MSW are additionally under pressure through the production of more plastics. Once deposited, plastics occupy about 25% of a landfill's space. If solid wastes are not recycled, landfill sites would quickly run out and new ones would need to be established (Alabi et al., 2019; Pires et al., 2019). Moreover, microplastics which consists plastics slowly disintegrating into smaller particles, pose a serious threat to ecosystems, marine life, and humans. Ineffective management of plastic waste, in particular in the context of city landscapes, constitutes the maximum urgent hassle that contributes to the systematic deterioration of the environment (Amobonye et al., 2021).

Khulna City, a symbol of a quickly expanding city region of the nation, is significantly exhausted by this problem. This study mainly depicted the application of the concept of the SCIP plastics project to reduce plastic pollution in the context of Khulna, Bangladesh. In addition, this study also focused on the assessment of secondary disposal points, recycling shops and landfill to know the present scenario of plastic waste in the Khulna region.

2. PLASTICS WASTE SCENARIO IN KHULNA AND SCIP PLASTICS PROJECT

2.1 Brief discussion of the SCIP plastics project

The project "Sustainable Capacity building to reduce Irreversible Pollution by Plastics" (SCIP Plastics) is collaborative research between Bauhaus-Universität Weimar (BUW), Germany, and Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh. Besides, other partners are involved like the

Institute for Social-Ecological Research (ISOE); Chittagong University of Engineering & Technology (CUET); The Government of the People's Republic of Bangladesh (GoB); The Ministry of Environment, Forest, and Climate Change; the University Grants Commission (UGC); the Mayor's Office of Khulna City Corporation (KCC); the Mayor's Office of Mongla Pourashava; and Nirala Janokallan Samity at Ward No. 24.

This study is part of the SCIP Plastic Project, which aims to prevent marine plastics from entering the oceans. The fields of work include secondary disposal points, recycling shops and landfill assessment and even further investigate the impact of direct plastic pollution in ports and the potential substitution of plastic with jute products. However, the main concern is the formation of a knowledge transfer hub that builds up, bundles and connects competencies in the region and puts them into practice. The knowledge transfer hub tends to conduct studies, consult laws and regulations and contribute to a broader public education in professional but also general fields in its own Awareness Centre operated by KCC. Figure 1 represents the six outputs of the project.

Figure 1. Outputs of the SCIP plastics project

2.2 Study area

The city of Khulna is situated in the southwest part of the country, close to the world's largest mangrove forest Sundarbans (Alamgir et al., 2005). It is located near the intersection of latitude 22.49º north and longitude 89.34º east. It is located along the Bhairab River hosting a significant river port on the bank of the Rupsha. It has access to the major cities of the southern Gangetic delta through rivers, roads, and trains. It is a city with a linear development pattern that runs beside the Bhairab-Rupsha River and Khulna-Dhaka Road (Figure 2).

Khulna City Corporation (KCC) has a total size of 64.78 sq. km., which includes 31 wards (BBS 2013). Figure 2 shows the location map of KCC area. The current metro area population of Khulna in 2022 is 955,000 (UN, 2022).

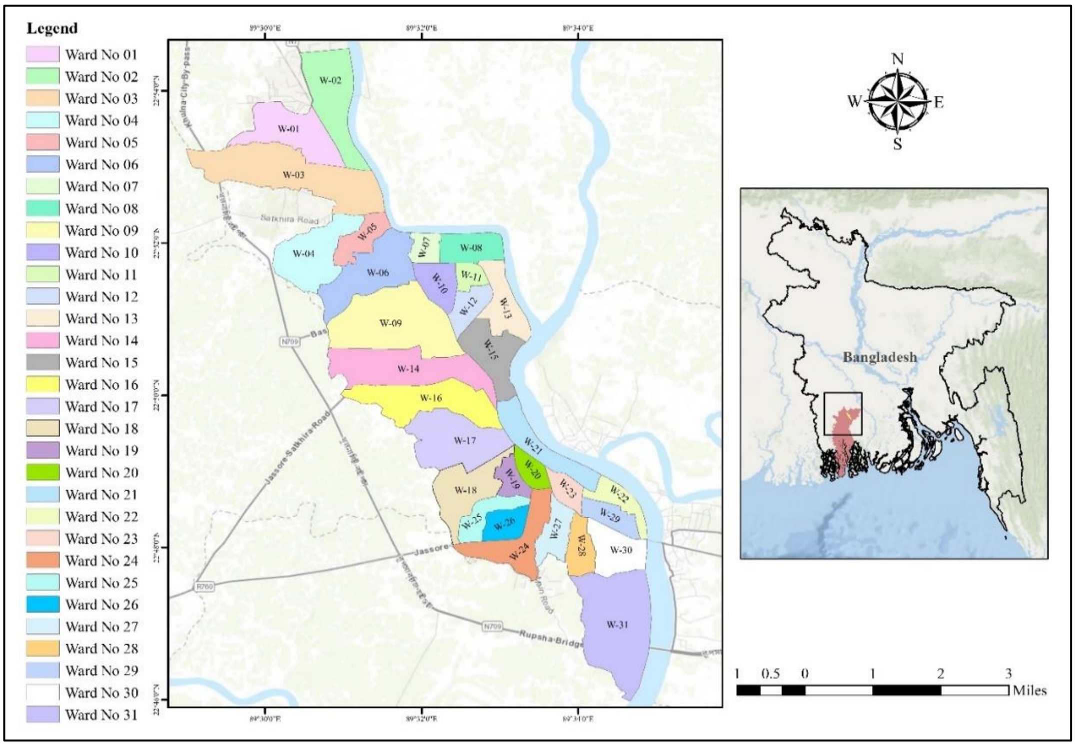

Figure 2. Location map of Khulna City Corporation area (by Swadhin Das 2023)

2.3 Present scenario of plastic waste

2.3.1 Overview of plastics

Municipal Solid Waste (MSW) consists of many varieties of different components, such as metals, plastics, glass, residues from manufacturing, medical or other waste, etc. MSW is the unwanted or useless solid materials generated from human activities in residential, industrial, or commercial areas (Alamgir & Ahsan 2007). Around the world, one million plastic bottles are purchased every minute, while up to five trillion plastic bags are used worldwide every year (UNEP, 2017). It has been found that globally about 400 million tons of plastic waste are produced every year (UNEP, 2017).

The actual activities and consumption of plastics however strongly depend on the wealth of nations. While average consumption in the USA (68 kg/year) and Europe (50 kg/year) are very high, the per capita usage in Bangladesh (3.7 kg/year) is comparably low (Mourshed et al., 2017). The picture gets even stronger, looking at the underlying growth numbers of plastic usage per person between 2005 and 2014, to be at +25% worldwide; but only +16.2% in Bangladesh (Moazzem, 2016). Similar findings were achieved by another author, investigating the use of plastic per capita in cities continuing to rise from 2.07 kg in 2005 to 3.5 kg in 2014 (Hossain et al., 2020).

However, Bangladesh with comparably low plastic consumption is already experiencing difficulties in accruing volumes of plastic waste. there are various categories of plastics like High-density polyethylene (HDPE), Polyvinyl chloride (PVC-U), Polystyrene (PS), Polyethylene terephthalate (PETE), Polypropylene (PP), etc. Total plastic marine debris input from coastal areas of Bangladesh is estimated at 0.12–0.31 million metric tons/per year (Jambeck et al., 2015). Despite the challenges Bangladesh wants to curb its plastic waste by 30% in a decade, according to the country's national action plan. This paper will provide an overview of the major challenges and potentials that might contribute to achieving the goal of reducing mismanaged plastic waste in the city of Khulna.

2.3.2 Technical waste management in Khulna

In order to understand the waste management chain starting from households, collection, transfer stations to final disposal access to information is limited. In an investigation of 67 collection points including distinct collection routes (20%), small- (4%) and large- (27%) hauled container points and secondary disposal points (49%), it was found that the majority of MSW is collected from secondary disposal points (SDP) (Islam et al., 2019).

The physical characteristics of solid waste have been investigated in a study by Islam et al., 2017. The results in the physical composition of solid waste in Khulna City are depicted in Table 2. In these compositions, food and vegetable wastes are maximum of 78.9% (Islam et al. 2017). Among them, polythene and plastics waste is in a noticeable amount of 3.1%.

Table 2. Khulna city's solid waste composition (Islam et al. 2017)

Compositions of waste	**Percentage of weight**
Vegetables and food wastes	78.90
Paper products and paper	9.50
Plastics and polythene	3.10
Wood and textile	1.14
Leather and rubber	0.50
Tin and metal	1.10
Ceramics and glass	0.50
Concrete, stones, and brick	0.10
Dust, mud, ash	3.70
Others	1.46
Total	100

a) Waste in open space (by Abdullah All Noman 2022)

b) Drainage waste (by Abdullah All Noman 2022)

c) Street waste (by Shyamol Kumar Sarkar 2022)

d) Waste in open dump site (by Pangkaj Kumar Mahanta 2022)

Figure 3. Mismanagement scenarios of plastic waste in Khulna city

Domestic plastic wastes such as foams and containers for food packaging, plates, and cutlery, disposable cups, vending cups, CD and container cases, electronic equipment cases, icebox liners, carbonated drink bottles, drainage pipes, flooring, and plumbing pipes and guttering are just a few examples of the numerous plastic sources of MSW (Özsin & Pütün, 2018). The waste from the agriculture sector includes feed bags, mulch films, fertilizer bags, coverings for fodder, wire, and cable, automobile wreckages, silage, etc. Therefore, major elements of plastic wastes like PE, PP, PVC, PET, PS, and others were collected from the auspices of MSW area unit (Adejumo & Adebiyi, 2020).

According to KCC, average solid waste generation rate is at 0.50 kg/cap/day (Ahasan, 2020). It appears that Khulna City Corporation (KCC), the sole public sector organization charged with handling the city's solid waste, has reached the pinnacle of its capacity. It receives about 500 tons of waste daily (Halim, 2021). Large quantities of plastic are included in this waste each day—more than 3400 kg (Ahmed & Moniruzzaman, 2018). It can be estimated that major sources of plastic pollution are households, institutes, schools, colleges, universities, offices, parks/tourist spots, marketplaces, hospitals, bus stands, rail-station, and ports. Publicly visible is mismanagement or unplanned waste dumping in open spaces, parks, streets, vacant plots, drains, water bodies, and sewerage systems (Figure 3).

According to completed USAID-sponsored research (Rahman & Murtaza, 2002), KCC does not have enough waste cans and those cans did not distribute evenly around the city as well as a significant amount of waste is dumped haphazardly in the open area throughout the city. Besides, the apathy of many household members who are unaware of applying the systematic procedure of waste management is the cause of the growth in plastic garbage in Khulna city. Since home waste is dumped in the open street without being properly disposed of, the problem is growing and getting severe. Recently, a study has categorized the limitations and key problems of solid waste management in the Khulna city area which is depicted in table 3 (Halim, 2021).

Table 3. Khulna city’s solid waste management limitations and problems (Halim, 2021)

Problems at the policy level	**Operational level problems**
Organizational constraints.	Inefficient collection & disposal practices
Lack of community-based participation	Absence of resource recovery component
Non-integration of informal sector's activities	Lack of human resources and vehicles

2.3.4 Organizational waste management in Khulna

Waste management is an essential part of KCC in the city areas of Khulna. The KCC takes the main responsibility in this regard and also plays a lead role in overall waste management. Besides KCC, some other actors like Non-Governmental Organizations (NGOs), Community-Based Organizations (CBOs), small entrepreneurs, etc. have been engaged with Khulna city’s waste management system. MSW itself and its management may be a valuable societal good if resources can be recovered and is properly handled. The activities associated with this MSW management comprise six sections roughly. The sections area unit storage & collection; use & reuse; waste evacuation; waste treatment; waste transport and lowland disposal. The garbage from homes is collected by the waste collector, who then stores it in secondary disposal points (SDPs) for eventual disposal. For the purpose, of collecting rubbish from primary sources, KCC offers vans, mini trucks, trolleys, and other necessary vehicles (Idumah & Nwuzor, 2019). Figure 4 shows the activities related to MSW management. The initial stage of MSW management activities starts with household collection. Then the second step is transportation via van or hand to hand. The next stage is to dump in open space or in dustbin containers. Thereafter, MSW is transferred to secondary transfer station and with the support of motorised vechicle, the MSW’s final disposal is to dumping site/landfill.

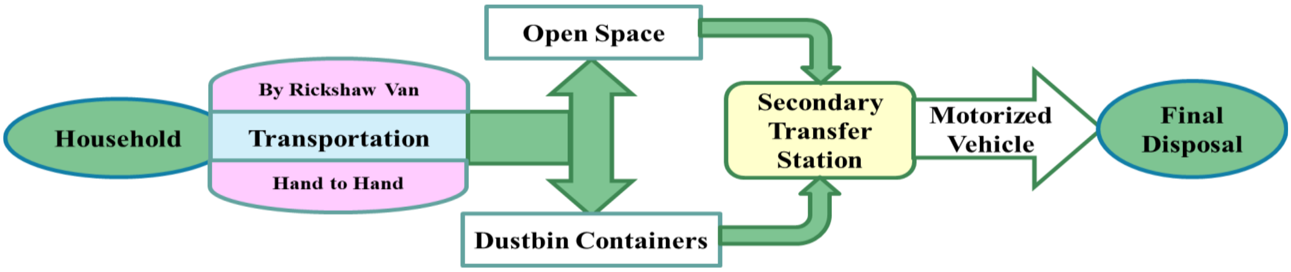

Figure 4. MSW management activities (Mourshed et al., 2017)

The duties and practices of solid waste management are decided by several KCC departments. The KCC Conservancy Division plays a vital role in the collection, disposal, and removal of waste from Khulna City (Halim, 2021). Some other labor-intensive aspect of MSW management is the collecting of plastic garbage, which can be done in a variety of locations including private residences, trash bins, plastic waste disposal, and garbage collection trucks (Cointreau et al. 2010). Figure 5 shows the conventional trend of plastic waste disposal practices in Khulna city. More than 356 employees and more than 50 officials are working in the KCC conservancy department for addressing the solid waste crisis in Khulna City

a) Household waste collection (by Abdullah All Noman 2022)

b) Waste transfer to SDP (by Abdullah All Noman 2022)

c) Waste collection from SDP (by Abdullah All Noman 2022)

d) Waste disposal to landfill (by Pangkaj Kumar Mahanta 2022)

Figure 5. Traditional plastic waste disposal practices in Khulna city

Recycling is a major part of plastic waste management. In Khulna City, there are some recycling industries of different scales. The Small-Scale Recycling Dealers (SSRD) buy recyclable material from waste collectors in order to recycle just under 250 kg of waste each day. They classify, wash, and sell the recycled garbage to Medium Scale Recycling Dealers (MSRD), who are only capable of recycling up to 600 kg of waste every day. The MSRD buys waste plastic from various SSRD, collects the processed trash, and sells it to Large Scale Recycling Dealers (LSRD) with recycling waste production rates of more than 600 kg per day. The LSRD collects waste from all MSRD, accumulates and sells it to recycling industries (Moniruzzaman et al., 2011).

Both formal and informal sectors are engaged in the process. Besides, individual/independent people collected waste from households, markets, institutions, and many other places. After collection, the first duty is to sort the plastic items. Then, the sorted plastic materials are sold to medium-scale recycling shops. The next phase is to process the materials for large-scale recycling shops or factories. These factories produce new products to sell in marketplaces or export to foreign countries. Figure 6 depicts the overall plastic waste management cycle in Khulna**.**

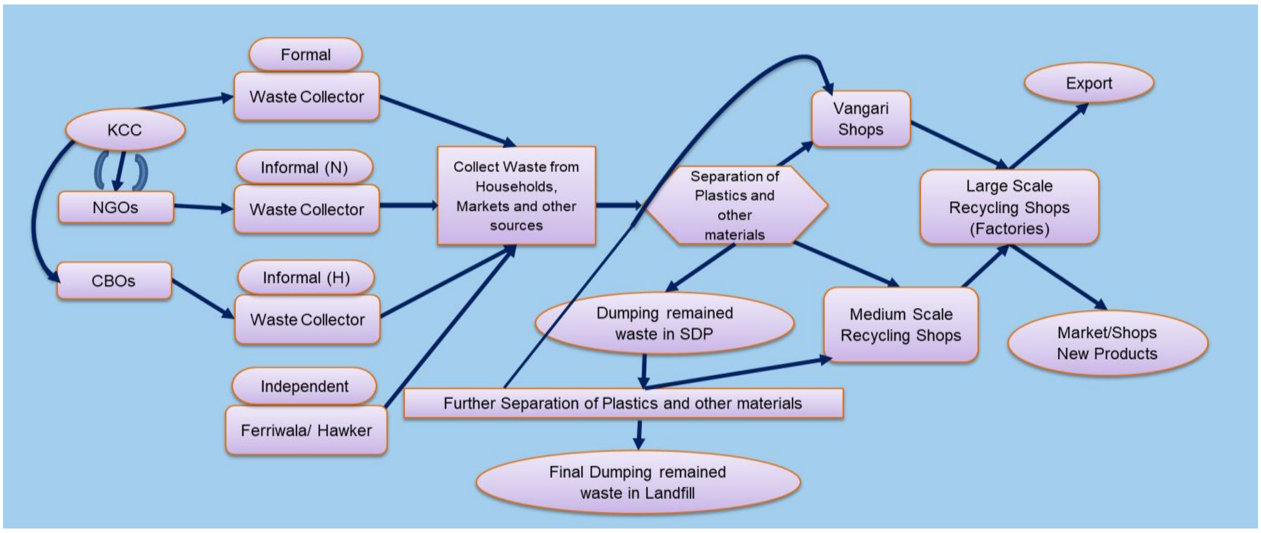

Figure 6. Overall plastic waste management cycle in Khulna

3. METHODOLOGY

3.1 Assessment of household solid waste in Khulna

3.1.1 Selected wards for waste characterization

For waste characterization, 9 wards (1, 2, 5, 9, 11, 16, 17, 21 and 24) were selected which is shown in Figure 7. In this study, for the selection of these 9 wards among 31, Natural Breaks (Jenks) method through ArchGIS has been implemented.

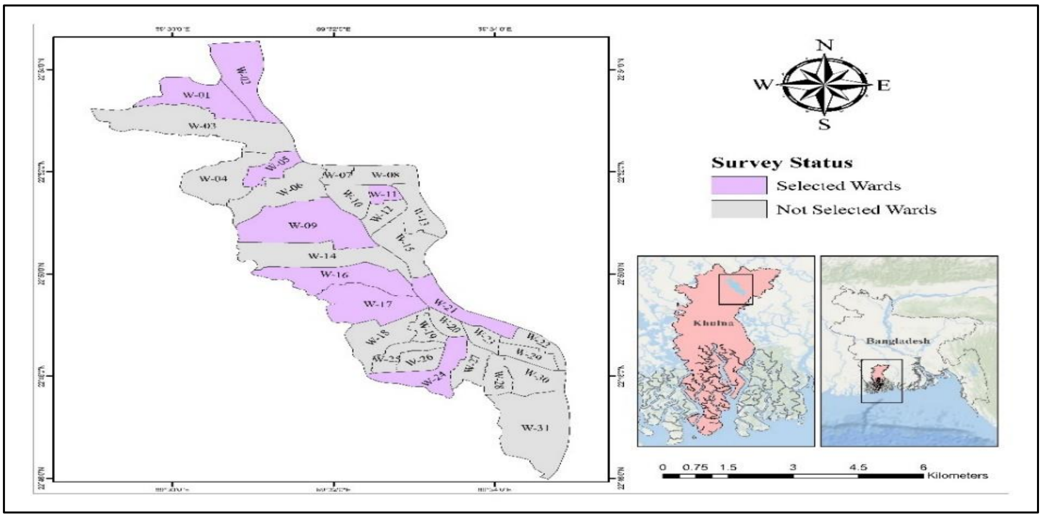

Figure 7. Map of KCC showing different selective wards for this study

3.1.2 Selection of household

The goal of selecting households is to obtain a dataset that accurately represents the nine chosen wards in Khulna City. Based on an estimated waste generation rate of 15 tons per day, each ward would generate about 105 tons of waste per week. To obtain a reasonably representative sample, practitioner guidelines for household waste analysis, such as Bidlingmeier and Müsken (2017), suggest a 1% sample of the weekly waste generated. Therefore, this study would require a sample of around 1050 kg. Assuming an average household size of five, this amount of waste could be produced by 75 households. Therefore, 75 households with 15 households from each socioeconomic group were randomly chosen to collect waste. The socioeconomic characteristics of the selected households are presented in Table 4.

Table 4. Categorization of income group for selected wards

Socio-economic condition	Income (BDT)	Household
Low-income families	<10000	15
Lower-middle-income families	10000-20000	15
Middle income-families	20000-30000	15
Higher-middle-income families	30000-40000	15
Higher-income-families	>40000	15
Total		75

At the beginning of the study, households that were chosen through a survey were given two types of waste bins: one for biodegradable waste and one for non-biodegradable waste. Waste was collected from each household at one-day intervals for a period of seven days. The waste collected from each household was weighed and the information was recorded. The waste samples were then packed and transported to the laboratory, where the physical characteristics of the municipal waste were determined. On the other hand, for evaluating the potential of source separation, 15 households (3 households from each income group) were selected. Two types of waste (e.g., source separated waste and mixed waste) were collected from the selected household. After collecting waste from the selected households, the waste collector of the selected area was advised to separate and take the wastes which are generally separated by themselves during waste collection from households. Then the remaining waste was collected and sent to the laboratory and measured the composition of both wastes (source-separated waste and mixed waste).

3.2 Identification of recycling shops

This research conducted a baseline survey with the aim of identifying Recycling Shops (RS) in Khulna City, where no such information was available with either government or non-governmental authorities. A comprehensive structured survey was used to collect detailed information on waste collection rates, operations, workmanship, and monthly turnover. The survey was carried out to ascertain the current number of recycling shops, classify them into different categories, and proceed with an in-depth analysis of each category. Shop owners, managers, waste collectors, and other individuals involved in the activities were cooperative in providing all necessary data and information.

3.3 Point source identification of waste discharge in landfill

Rajbandh open dump site is the only operational dump site in Khulna city. Khulna is the 3rd largest metropolitan city in Bangladesh producing a considerable MSW and other types of waste. The latitude and longitude of the site are 22° 47' 47.87" N and 89° 29' 57.68" E respectively. Khulna City Corporation (KCC) collects waste from all over the city and dumps here. A total of 20 acres of municipality-owned land is used on this site as a dumping area.

Identifying specific points from where waste discharges to the surroundings from the open dump site is regarded as the point source in this study. To identify point source locations, a reconnaissance survey was done along the periphery of the site. By visual observation, all the waste outlet points were identified and GPS coordinates were collected. A map of the site was prepared using Esri QGIS 3.28.0 software to show all the point source locations. The red dots in Figure 8 represents point source locations. Also, the waste composition was done in on-site and off-site locations and the plastic percentage was compared. Moreover, the waste flow driver was identified and a new boundary strategy was addressed.

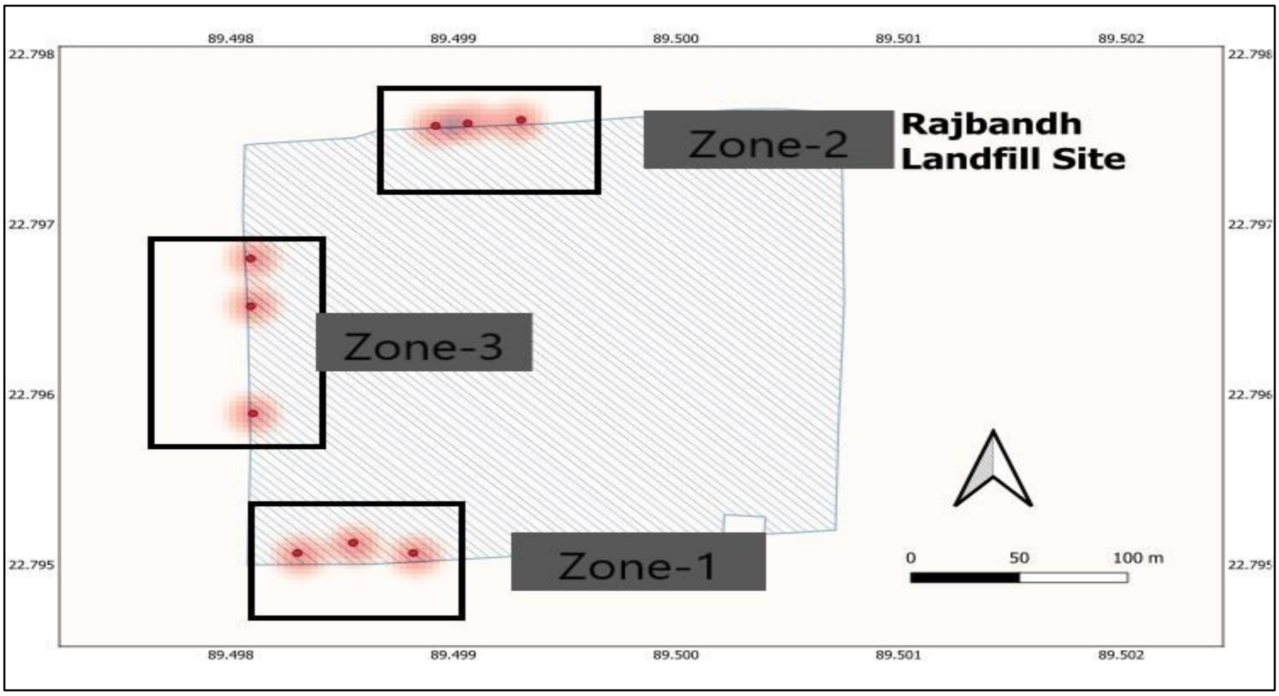

Figure 8. Most vulnerable zones of the open dump site in the case of plastic discharge (Esri QGIS 3.28.0, 2023)

4. RESULTS AND DISCUSSION

4.1 Waste characterization

4.1.1 Waste generation rate

Table 5 presents data on the waste generation rate for the selected nine wards, which were categorized by income level. The highest average waste generation rate was found to be 0.55 kg/capita/day in Ward No. 16, while the lowest average rate was 0.41 kg/capita/day in Ward No. 1.

Table 5. Waste generation rate of different socio-economic households

	Waste generation Rate (kg/cap/Day)									
	Ward 1	Ward 2	Ward 5	Ward 9	Ward 11	Ward 16	Ward 17	Ward 21	Ward 24	Average
Low	0.27	0.30	0.29	0.34	0.33	0.33	0.32	0.31	0.32	0.31
Lower Middle	0.33	0.35	0.36	0.39	0.40	0.44	0.38	0.39	0.38	0.38
Middle	0.39	0.43	0.41	0.55	0.53	0.52	0.45	0.49	0.45	0.47
Higher Middle	0.49	0.52	0.50	0.67	0.63	0.68	0.57	0.55	0.51	0.57
Higher	0.56	0.64	0.55	0.74	0.71	0.76	0.62	0.69	0.60	0.65
Average	0.41	0.45	0.42	0.54	0.52	0.55	0.47	0.49	0.45	0.48

The waste generation rates for Wards No. 2, 5, 9, 11, 17, 21, and 24 were estimated to be 0.45, 0.42, 0.54, 0.52, 0.47, 0.49, and 0.45 kg/capita/day, respectively. These rates were assigned to their respective income groups and are presented in Table 4. The amount of waste generated by a family is influenced by their income level. Higher-income families tend to generate more waste because they have more money to spend on necessities and have a greater consumption rate. In contrast, lower-income families tend to produce less waste because they have lower earning potential and tend to use necessities for longer periods. As a result, middle and lower-income family groups generally generate less garbage. Low-income households have a waste generation rate of 0.31 kg/capita/day, whereas high-income households have a waste generation rate that is more than double this amount at 0.64 kg/capita/day. The average waste generation rate was estimated for the selected wards was 0.48kg/cap/day (Table 5).

4.1.2 Waste composition

The average composition of municipal solid waste generated in various wards of Khulna City, as collected during the investigation is shown in Figure 9. Understanding the composition of the waste is crucial for developing effective strategies for reusing, recycling, storing, processing, transporting, and disposing of it. The result reveals that the largest portion of waste in the total waste stream is biodegradable waste, accounting for 81.62% of the overall waste. The next most substantial waste categories include plastics, paper and cardboard, and dust and other materials, comprising 4.49%, 6.37%, and 3.67% of the total waste, respectively. The other categories of waste such as glass, textiles, wood, electrical goods, ceramics, metals, and medical waste, make up relatively small percentages of the total waste stream, ranging from 0.21% to 1.55% (Figure 9).

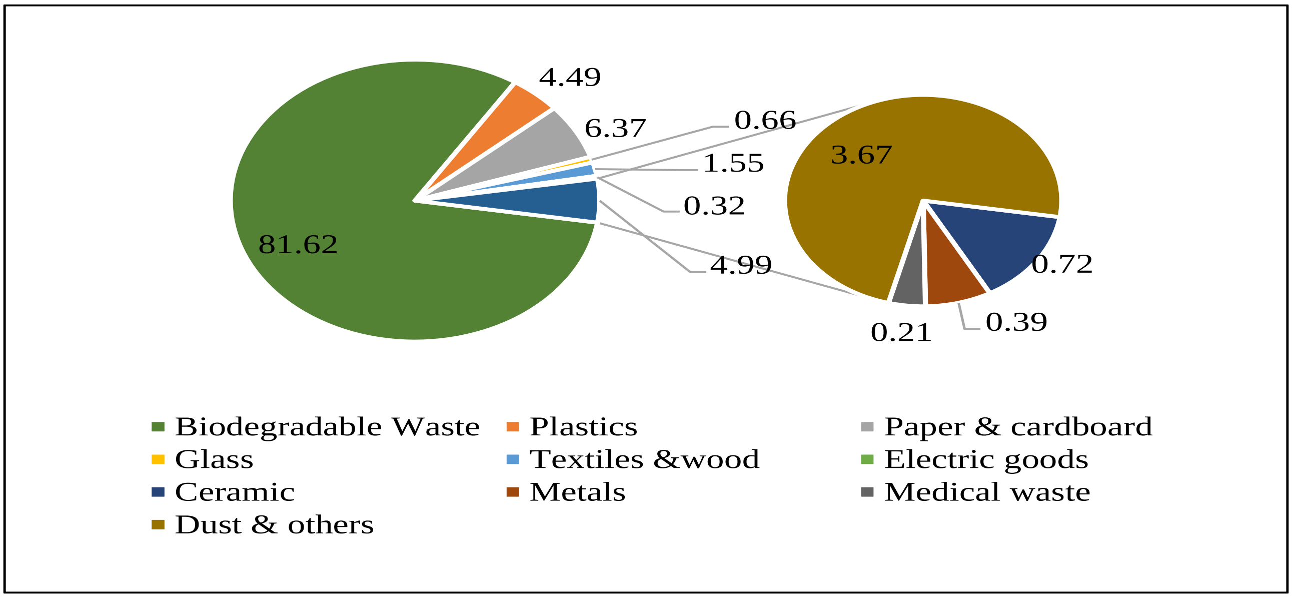

Figure 9. Composition of household municipal solid waste

4.1.2.1 Potential of source separation for recyclable waste

Figure 10 presents a comparison between the waste composition of source-separated waste and mixed waste that was sorted by waste collectors. Generally, waste that is generated in the household is carried by waste collectors. The waste collector is assigned by KCC or NGOs of CBOs. The waste collector carried the waste from the household to Secondary Disposal Points (SDP). The current waste collection system in Khulna City involves the collection of mixed waste from households, which limits the potential for recovering recyclable materials. This study aimed to determine the differences in recoverable materials between source-separated waste and mixed waste. The results indicate that the proportions of plastic, paper, and metals in the mixed waste were 4.04%, 5.48%, and 0.24%, respectively. However, these proportions could be reduced by implementing a source-separated waste collection system. In mixed waste, the organic portion gets mixed up with valuable materials such as paper, plastic, textiles, etc., which reduces the potential for recovering recyclable materials. Therefore, the proportions of plastics, paper, and metals in source-separated waste were found to be lower than in mixed waste, at 2.99%, 3.92%, and 0%, respectively (Figure 10).

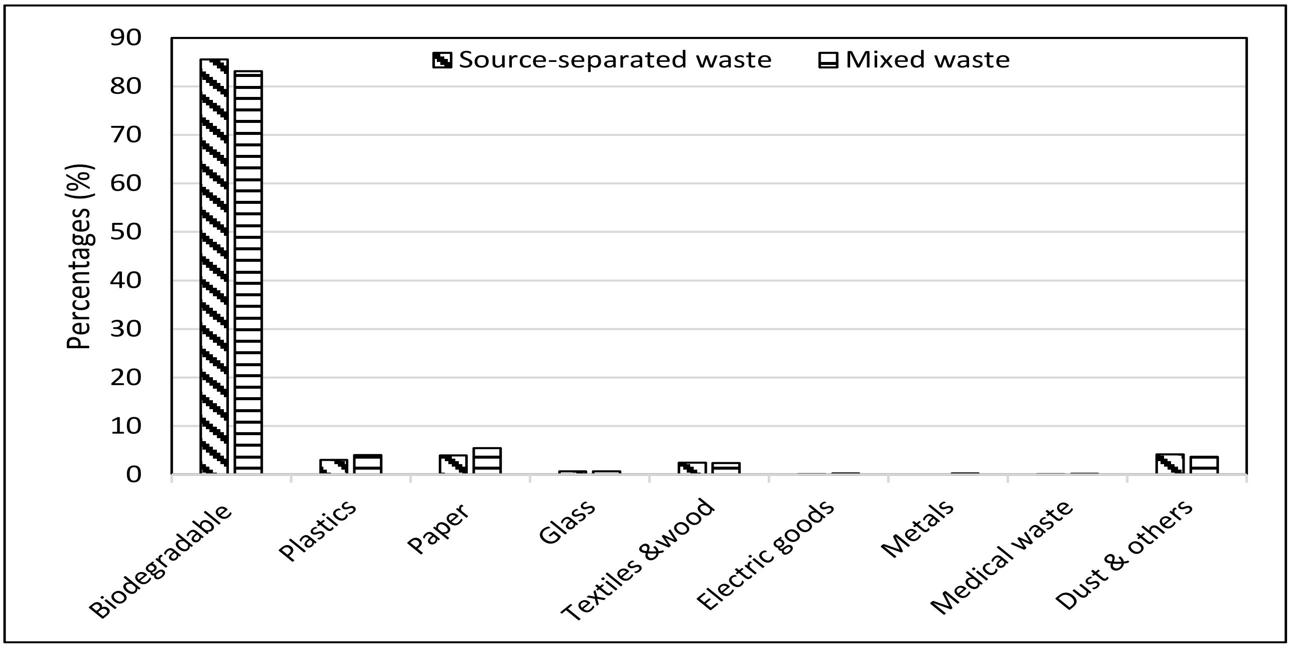

Figure 10. Comparison of waste composition between source-separated waste and mixed waste after sorting by the waste collector

4.2 Existing recycling shops and their activities

Recycling shops in the Khulna City Corporation (KCC) area have a long history dating back to the 1990s, with some establishments dealing exclusively with PETE being established more recently. These shops have formed a strong network connecting informal waste collectors, recycling waste traders, recycling shops, and industries (Bari et al., 2012). Most of these shops are concentrated in the Khalishpur and Shonadanga areas, with only a few located in Lobonchora and Zero Point areas. The workforce of these areas primarily consists of individuals who have been displaced from the growing economy of educated individuals. The preliminary field survey identified a total of 35 recycling shops, with the majority of them dealing with mixed plastics. Some shops traded with PETE exclusively, and very few were dedicated to hard plastic recycling. Based on the types of recycling activities being carried out, the identified recycling shops were categorized into five categories, as presented in Table 6. PETE flakes manufacturing shops distinctly deal with wasted PETE bottles to produce recycled PETE flakes, with three recycling shops found in this category. PETE and mixed flakes manufacturing shops utilize both PETE bottles and other mixed plastic waste to produce PETE and mixed plastic flakes. This is the largest category, with 23 recycling shops dealing with both PETE bottles and mixed plastics. Additionally, the survey identified six new end-product manufacturing shops in Khulna City producing various new products from recycled grains. Two Mixed Plastic Flakes producing shops and one hard plastic flakes manufacturing shop were also identified.

Table 6. Category of existing recycling shops in Khulna city

Component	Category	Utilized Waste	Output Material
Recycling Shop	PETE Flakes Manufacturing Shop	PETE Bottles	PETE Flakes
	PETE and Mixed Flakes Manufacturing Shop	PETE Bottles and Mixed Plastics	PETE and Mixed Plastic Flakes
	Mixed Flakes Manufacturing Shop	Mixed Plastic	Mixed Plastic Flakes
	New End Product Manufacturing Shop	PETE Bottles and Mixed	New End Products

		Plastics	
	Hard Plastic Flakes Manufacturing Shop	Mixed Plastics	Hard Plastic Flakes

4.3 Plastic waste material flow pattern

Solid waste recycling practice has been influencing the solid waste management system of Khulna City with a great contribution. This study identified plastic waste material flow patterns in light of solid waste recycling practices to evaluate the contribution of recycling shops in reducing plastic waste pollution. The plastic waste flow starts from the generated sources i.e., households, public places, institutions, etc. (Moniruzzaman et al., 2011). The waste collectors used to collect valuable plastic waste from various sources and sell it to recycling waste traders. The recycling waste traders sort the received waste from waste collectors into different categories based on the price of variant waste. Afterward, the recycling shops buy their input waste material from recycling waste traders as displayed in Figure 11. This plastic waste material flow chain clearly dignified the specific contribution of each stakeholder involved in the plastic waste recycling section of Khulna City. Based on the field survey conducted in this study, around 850 tons of plastic waste is being recycled through 35 recycling shops in the city area.

Figure 11. Plastic waste flow pattern in Khulna City

Table 7 shows the estimated amount of recycled plastic waste in different areas of the city.

Table 7. Measurement of recycled plastic waste by RS of Khulna city

Area	Existing Shops	Recycled Plastic (Kg/ Month)
Labanchora	4	32000
Khalispur	10	240000
Zeropoint	6	200000
Sonadanga	6	310000
Daulatpur	4	50000
Total		832500

Total, Ton	832

The recycling shop (RS) assessment group has been conducting field surveys, laboratory analysis, stakeholder assessment, etc., to evaluate the existing recycling pattern of plastic RS of Khulna City. All the research activities of this group are related to patronizing the recycling practice in Khulna City and developing guidelines for a better environment-friendly approach. A discussion meeting has already been conducted by the working group members with the recycling shop owners to discuss the current challenges of plastic recycling activities. Figure 12 exhibits a photograph of the discussion meeting. Moreover, the other activities of this group are shown in Figure 13.

Figure 12. Discussion meeting with recycling shop owners at the awareness center of the SCIP Plastics Project (by Abdullah Al Hasan 2023)

(a) (b)

Figure 13. a) Field Survey at Recycling Shop and b) Discussion with waste collector (by Md. Sheikh Shadi Razu 2023)

4.4 Point source identification of waste discharge in landfill

Figure 8 identifies three separate waste outflow zones using a heatmap created with Esri QGIS 3.28.0 utilizing point source coordinates. The waste composition was done on-site and off-site in zone-1 and zone-2 and the result is shown in Figure 14.

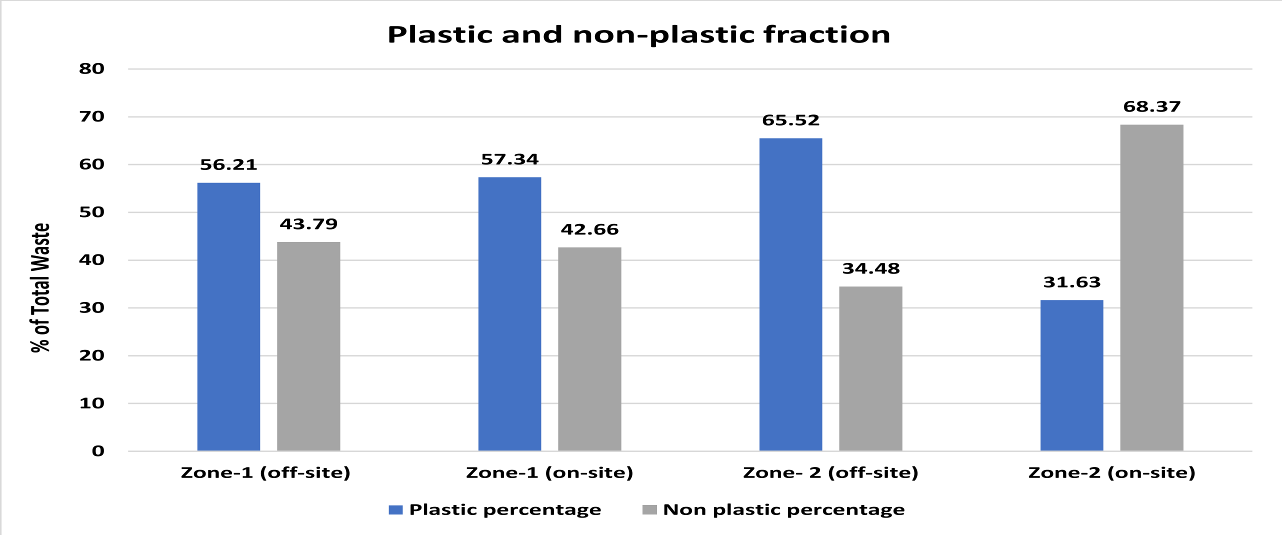

Figure 14. Percentage of plastic in total waste in zone-1 and zone-2 (on-site and off-site)

In the Zone-1 off-site condition, the plastic and non-plastic fractions were 56.21% and 43.79%, and on-site, it was 57.34% and 42.66% respectively. In the Zone-2 off-site condition, the plastic and non-plastic fractions were 65.52% and 34.48%, and on-site, it was 31.63% and 68.37% respectively. Observations confirm that plastic percentages in these waste discharging areas are greater than non-plastic fractions except in Zone-2 on-site condition. It reveals unequivocally that plastic discharges from the site and continuously pollutes the surrounding environment. Figure 15 shows the surrounding land use pattern of the site where it was seen that a total of 16 waterbodies are adjacent to the site and susceptible to plastic pollution.

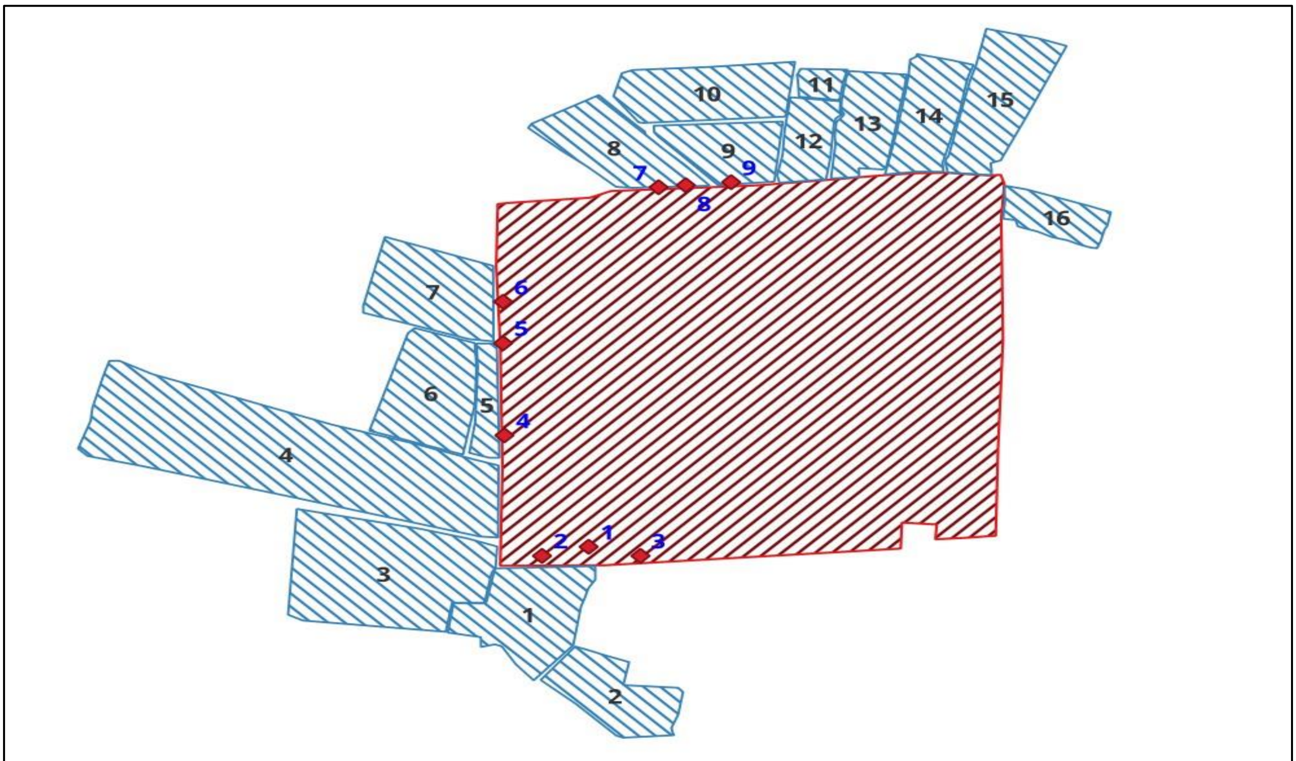

Figure 15. Point source locations (red dot), site area (red hatched area), and surrounding water bodies (blue hatched area) (Esri QGIS 3.28.0, 2023)

Additionally, the site's elevation observation by Google Earth Pro revealed that the elevation of the center of the site is much higher than the surrounding portions, demonstrating that water is the main force behind the waste flow as water flows from the center to the outside of the site and carries wastes with it. Observations also supported the hypothesis that air is a further driver of waste flow.

5. CONCLUSIONS

For a very long time, plastic pollution has been an inevitable part of human society. The number of plastic items is increasing significantly, and micro- and nanoscale plastics are having a significant detrimental influence on our ecology. Despite the fact that the effects of plastic pollution are already known, there is poor management of plastic trash, particularly in developing nations. For instance, a number of lifeforms face health risks from open burning, illogical landfilling, and disposal in the environment, including cremation. A thorough summary of Khulna city's current solid waste management is provided by our review, including its mismanagement. This study describes the partial research outcome of the three working groups' i.e., secondary disposal points and recycling shops, and assessment of landfill.

A thorough waste analysis revealed that 81.62% of the waste is biodegradable, emphasizing the need for proper disposal and composting. Paper and plastic comprise 6.37% and 4.49%, respectively. Source separation is crucial to reduce plastic leakage to the secondary disposal sites. Sorting by waste collectors reduced plastic in mixed waste from 4.49% to 4.04%. Source-separated waste had 2.99% plastic after sorting.

Khulna has a network of mixed plastic recycling shops dating back to the 1990s, with five categories of recycling activities identified. Among those recycling shops, 23 recycling shops have been found dealing with both PETE bottles and mixed plastics. Solid waste recycling practices have positively impacted the solid waste management system in Khulna City by reducing plastic waste pollution. It is also identified that the plastic waste material flow patterns and stakeholders involved in the recycling process, estimated around 850 tons of plastic waste recycled by 35 recycling shops.

As per the assessment of the landfill, the embankment of the site should be reviewed, and a new earth boundary plan should be implemented, to avoid waste movement by air and water. Fencing might be a good solution against the waste flow by air. It is important to prevent airborne waste flow to save the surrounding waterbodies of the site. Also, the daily cover with proper sloping should be implemented to prevent waste flow to the environment.

Finally, it can be concluded that the SCIP Plastics project is playing a significant role in managing plastic pollution reduction. After the successful implementation of the project, it will foster a stimulating environment where the technical, economic, social, and ecological aspects of sustainable waste management are emphasized. With time, it will be possible to accept the difficulties of the KCC's waste management system and help and empower local communities, municipal bodies, and companies with the long-term objective of establishing a more secure, wholesome, and appealing environment.

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