

PLASTIC WASTE MANAGEMENT THROUGH MATERIALS FLOW ANALYSIS: A CASE STUDY IN CHATTOGRAM

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ABSTRACT

Usages of plastic materials for daily activities have increased due to their advantages of being cost-effective, lightweight, and resistant to chemicals and corrosion. Hence, there is a continual increase in their proportion within domestic solid waste, raising concerns about its environmental impact. The improper processing and management of post-consumer plastic waste can have numerous adverse environmental impacts. Managing large amounts of plastic waste is challenging, especially for developing nations like Bangladesh. Enhancing the comprehension of plastic flows is vital for pinpointing inefficiencies and potential environmental leaks. This study presents an analysis of plastic flows in one densely populated ward (Ward No. 39: The South Haliashahar ward) in Chattogram City to enhance the efficiency of resource utilization and minimize waste in the environment. The study identified that high-income people produce the highest solid waste of 359.64 gm/cap/day, middle-income people produce 349.32 gm/cap/day and low-income people produce 237.06 gm/cap/day. Monthly, 383.4 tons of plastic waste are generated, and about 27.49 % is recycled or recovered by formal and informal recyclers. Approximately total 188 tons (49.03 %) per month of plastic materials are presently being discarded at landfills and the remaining 90 tons (23.48%) per month are uncollected and polluted the environment. However, this study helps decision-makers create policies for the improvement of solid waste and plastic waste management systems for sustainable solutions.

Keywords: *Materials flow analysis(MFA), Sankey diagrams, flow and stocks, mass-balance principle, waste management.*

1. INTRODUCTION

The widespread use of plastics in the modern economy is so ubiquitous that it's hard to believe that their substantial utilization only began in the 1950s (Bai & Li, 2020). Plastic has become an essential and vital element of society worldwide since it can be used for a variety of purposes, including packaging, agriculture, car parts, electronics, medical equipment, etc. (Mehta et al., 2022). Plastics are artificial organic polymers, primarily sourced from petrochemical raw materials. Plastics are easily moldable, and their properties can be tailored to specific requirements (Andrady, 2003). Due to the properties of plastic, such as its inertness, longevity, flexibility, and versatility, people are depending on it progressively every day (Lee et al., 2021). The global production of plastics has witnessed a significant rise, surging from 1.7 million tons in the 1950s to surpassing 322 million tons by 2016 (Vingwe et al., 2020). Though plastic usage offers numerous advantages, it simultaneously gives rise to various environmental concerns throughout its life cycle.

Currently, plastic waste is widely acknowledged as a major source of environmental pollution. (Bureecam et al., 2018; Kawecki et al., 2021; Lombardi et al., 2021; Vujić et al., 2010). The effects of plastics extend beyond the pollution phase at the end of their life cycle. The increasing production and application of conventional plastics endanger not only human health but also the major living elements such as air, water, and land (Hossain et al., 2023). The effect of plastics on the environment is presented in **Figure 1**.

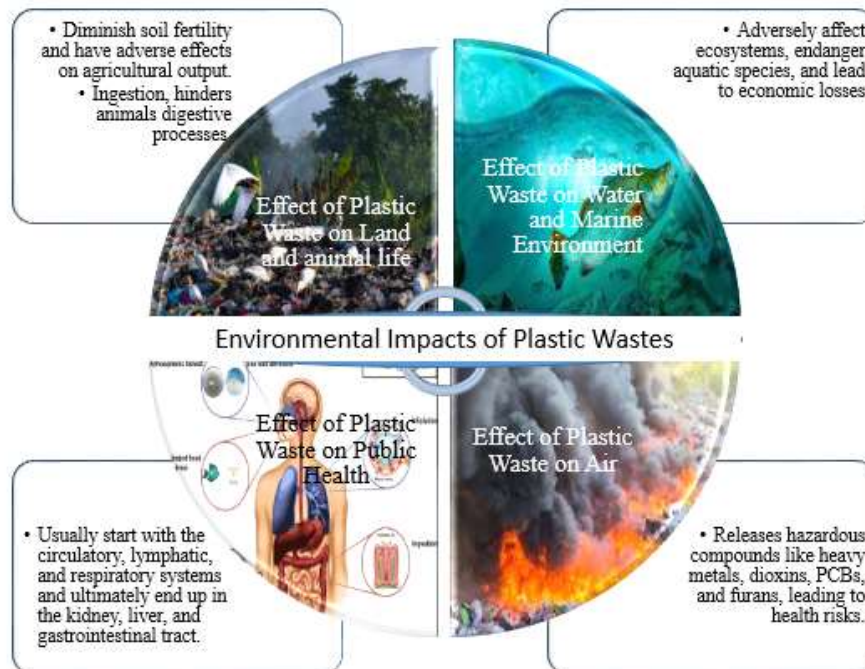


Figure 1: Environmental Impacts of Plastic Wastes.

Every year, around 500 billion plastic bags are utilized, and an estimated 13 million metric tons of them find their way into the ocean, resulting in the loss of approximately 100,000 marine lives (Widyarsana et al., 2020). Between 1950 and 2015, approximately 6.30 billion tons of plastic waste were produced, with a mere 9% undergoing recycling, resulting in over 80% accumulating in landfills or the natural environment (Geyer et al., 2017). The Pacific Ocean is expected to become a massive waste dump due to the rapid expansion (33 billion tons of plastic are expected to be generated by 2050) in the use of plastic items (Kibria et al., 2023).

Nowadays, there are two primary approaches to handling plastic waste: burning them in landfills (although being cautious to reduce the harmful gases and chemicals that occur) and recycling (Evode et al., 2021). It is strongly discouraged to burn plastics due to the emission of harmful gases, including furans, mercury, dioxins, and polychlorinated biphenyls, into the atmosphere (Pathak et al., 2023). The necessity for the scientific dumping of waste plastics has been acknowledged since the 1980s, and many efforts have been made to find appropriate techniques for managing plastic waste since then.

The circulation of resources within environmental and economic systems stands as a critical need for the sustenance and prosperity of human society (Amin et al., 2022). Presently, the whole environment, especially the natural environment, is significantly damaged by human activity (Lombardi et al., 2021). This environmental damage contributes to resource depletion, subsequently exerting pressure on the economic system (Cochran & Townsend, 2010). Material flow analysis (MFA), as articulated by Fischer-kowalski (1998), provides a dynamic illustration of the interplay between environmental conservation and economic progress. MFA is a commonly utilized evaluation tool for finding sustainable resource management (Makarichi et al., 2018).

Analyzing the stock and flow of materials through MFA is needed to effectively regulate and manage material flow, thereby enhancing resource utilization efficiency (Nakamura et al., 2007). Despite ongoing efforts to enhance handling and management practices, the effective management of plastic waste remains a significant challenge in Bangladesh. So, this study focuses on enhancing plastic waste management systems for the 39 no. South Haliashahar ward of Chattogram City through the utilization of MFA techniques.

2. METHODOLOGY

2.1 Study Area

Chattogram, the largest port city in Bangladesh, is characterized by its notably second-largest population. Such densely populated areas are consistently at risk of environmental challenges. Chattogram City is facing notable disruptions in both its environmental conditions and public health. These disruptions are primarily attributable to the piling up of uncollected waste in streets and other public areas. The congestion of drainage systems results from the careless disposal of waste (**Figure 3(b)**).

For the betterment of the sustainable environment, a proper waste management system needs to be developed with proper planning. 39 no. South Haliashahar ward in Chattogram City Corporation (the most populated area) is selected as a study area to both assess the current state of plastic pollution and establish a material flow analysis to pave the way for a circular economy. For the total population of 256206, this ward only contains 5 container spots. The most commonly available dumping scenario is open-spot dumping. Due to this open spot dumping, during heavy rainfall, the waste takes its place in the existing drainage system and creates water logging. Figure 3(a) shows the blockage of the existing drain due to the waste. A summary of the waste collection points in the study area is given in **Table 1**.

Table 1: Summary of the waste collection points.

Ward	Concrete Bin	Open Spot	Container	Plastic Bin Spot	STS	Total Population
Ward-39	5 [#]	25 [#]	5 [#]	7 [#]	0 [#]	256206*

*Population and Housing Census 2022, Bangladesh Bureau of statistics (BBS)

[#]CCC, according to Feasibility Study funded by Ministry of Environment, Japan.

STS (Secondary Transfer Station)

The two industrially significant zones included in the study region are the New Mooring Container Terminal (NCT) and the first of Bangladesh's eight export processing zones, the Chittagong Export Processing Zone (CEPZ). **Figure 2** shows the data collection points and locations of municipal dumping sites.

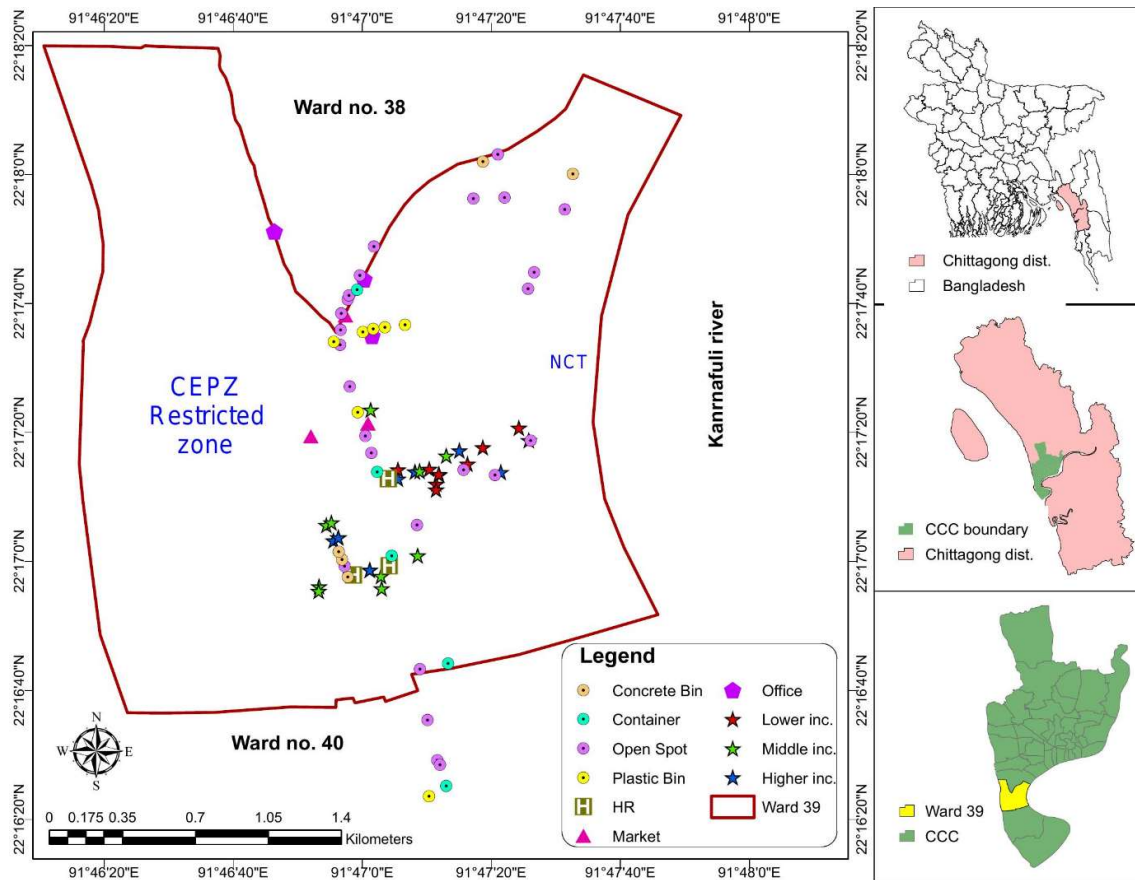


Figure 2: Study area, Data Collection point and dumping sites.

2.2 Data Collection Methods

The datasets were gathered, extracted, and analyzed using data obtained from both primary and secondary sources. Primary data were acquired through on-site investigations, observations, surveys, and interviews with key participants involved in the waste plastic management chains. The **UNHabitat Waste Wise Cities Tool (WaCT)** is used for primary data collection. Samples from selected locations are collected daily for 0–7 days within a fixed time (UN-Habitat, 2020). Waste samples from landfills (**Figure 3(e)**) and municipal dumping sites (**Figure 3(c)**) were collected as well for composition analysis, followed by the collection of waste from the various waste-producing sources indicated in **Table 2**. Additionally, recycling operations are monitored while data is gathered from those recyclers (**Figure 3(d), 3(f)**).

Table 2: Data collection facilities name and sample size.

Facilities Name	Sampling Size
House hold	30nos. (10 high Income, 10 middle Income and 10 low Income group)
Market	03 nos.
Hotel and Restaurant	03 nos.
Office	03 nos.
Street	03 nos.



(a) Blockage of the drain due to waste dumping.



(b) Blocking activity of drains putting waste through water passing bore by human awareness.



(c) Sample collection at the dumping site.



(d) Recyclers activities in municipal dumping site.



(e) Present situation of final landfill site (LFS)



(f) Recycling of PET from LFS.

Figure 3: Different stages of data collection from various source.

After waste has been gathered from various sources, it is divided into two major categories: organic and other waste and plastic waste. As per **Table 3**, the plastic waste is then reclassified into several groups.

Table 3: Classification basis of plastic waste

Scientific Name	Examples of Application
Polyethylene terephthalate (PET)	Water bottles, Soft drink bottles, Food jars, Coking oil containers
High-density polyethylene (HDPE)	Bottles, Water and Sewer pipe, Bucket (pails), Chairs, Detergent bottles
Polyvinyl Chloride (PVC)	Food trays, plumbing products, electrical cable insulation, outdoor furniture
Low-density polyethylene (LDPE)	Carrier bags, Single use plastics (SUP), bread bags, food tubs
Polypropylene (PP)	Disposable cups, bottle caps, straws, auto parts and industrial fibre
Polystyrene (PS)	Boxes and various foam, disposable glasses, plates, spoon, trays
Others (O)	Thermosets plastics, multilayer and laminates, Nylon, fibre-reinforced plastic, CD, melamine plates, helmets and shoe soles

Source: Central Pollution Control Board (CPCB)

2.3 Material Flow Analysis

Material Flow Analysis (MFA) was performed following the computation of various stage data using the STAN2.7.101 (substance flow analysis) tool, which is freely available software for investigating material flows developed by the Vienna University of Technology. A comprehensive explanation of the software is provided by Brunner and Rechberger (2005) and Cencic and Rechberger (2008). Details of the process description for the MFA are given in **Table 6**.

Table 4: Data evaluation process for Materials flow diagram.

Process Name	Process Description
System Boundary Definition	39 no ward, South Haliashahar in Chattogram city corporation
Plastic Inflow data Collection	Suppliers and manufacturers and BPGMEA
Flow and stocks data Collection	Waste from Household, Market, Hotel and Restaurant, Office, Street, Dumping sites or secondary stations, final dumping sites.
Composition analysis of solid waste	Sorting and analyze the composition of various waste content using mass-volume measurements.
Composition analysis of Plastic Waste	Detailed composition analysis of plastic waste, differentiating between LDPE, HDPE, PP, PVC, PS, PET, and other types of plastics.
Collection efficiency & flow and stocks calculation	Using the Mass balance principle
Creation of Sankey diagram for plastic waste management	Using STAN2.7.101

3. RESULTS AND DISCUSSION

3.1 Solid Waste and Plastic Waste Generation and Composition

In this study, data was collected and analyzed for high, middle, and low-income people. The findings indicate that individuals with higher incomes generate the highest amount of waste, surpassing that of low-income individuals by 1.5 times. Specifically, high-income individuals produce plastic waste at a rate 2.15 times higher than low-income people. According to the source, the market generates the highest percentage of plastic waste in solid waste. The breakdown of the estimated waste composition is outlined in **Table 5**.

Table 5: Estimated waste proportion from different waste source.

Waste Type	Hosehold (HH)			Market	Hotel & Restaurant (RH)	Office	Street
	High Income	Middle Income	Low Income				
Total wastes (gm/cap/day)	359.64	349.32	237.06	N/M	N/M	N/M	N/M
No. population	208	218	184	N/M	190 seats	70	N/M
Organic & Other Wastes* (%)	88.81	89.49	92.1	87.33	92.25	90.13	92.92
Plastics (gm/cap/day)	40.36	40.32	18.53	N/M	N/M	N/M	N/M
Plastics (%)	11.19	10.51	7.90	12.67	7.75	9.87	7.08

*Other Wastes (paper, dust, stones, wood, textiles, metals, leather and rubber).

N/M (Not Measured)

According to Chattogram City Corporation (CCC), household waste is approximately 61% of the total waste. UNDP's "Politics, Governance, and Middle-Income Aspirations: Realities and Challenges (2016)" computed the entire population and divided it into three income levels: high income (10%), middle income (50%), and low income (40%). An individual or household's income is categorized as high if it surpasses Tk. 80,000, as middle-income is over Tk. 10,000 but less than Tk. 80,000, and as low income is Tk. 10,000 or less (UNDP, 2016). Utilizing the population distribution ratio from UNDP, this study's survey results estimate household waste generation, as presented in **Table 6**.

Table 6: Estimated waste generation by waste type

HH Waste (ton/day)	Street & Construction Waste	Business waste (ton/day)			Total Waste (ton/day)
		Market Waste	Restaurant & Hotel Waste	Office Waste	
*61%	*17%	*10%	*9%	*3%	*100%
81.73	22.78	13.40	12.06	4.03	134

*CCC, according to Feasibility Study funded by Ministry of Environment, Japan.

Table 7 provides an overview of the plastic waste compositions sourced from different outlets. LDPE predominates in households, markets, and streets, while PET is the dominant plastic in offices, hotels, and restaurants. In household waste, the major contributor to LDPE is single-use plastic bags utilized for shopping, while in market waste, packaging waste is the primary source of LDPE. Hotels and restaurants predominantly contribute PET bottles used for water and cold drinks.

Table 7: Plastic waste composition in different waste sources

Facilities Type	PET (%)	HDPE (%)	PVC (%)	LDPE (%)	PP (%)	PS (%)	Others (%)
HH	14.83	9.72	5.28	48.63	14.14	5.26	2.14
Market	33.48	1.54	3.26	55.42	3.36	1.98	0.96
HR	80.40	0.20	0.20	3.98	7.95	6.68	0.60
Office	79.52	1.20	0.78	3.68	10.15	4.19	0.48
Street	22.74	0.50	1.06	58.9	7.97	8.24	0.60

Note: Field data collected from September, 2023 to December, 2023.

3.3 Materials Flow analysis

3.3.1 Municipal Solid Wastes flow

Figure 4 shows that approximately 4020 tons of solid waste are generated per month in South Haliashahar ward. Flows 1 to 5 represent the consumption and production of waste from HH, markets, hotels, offices, and streets. Flows 7 and 9 show the movement of generated solid waste to LFS via the municipal collection point. Flows 6, 10, and 11 show the recycled amount from various parts of this flow, and the recycled amount is approximately 165.47 tons per month. The rest of the 879.74 tons (21.89%) of monthly waste are mismanaged and moved to the environment and water bodies, creating water logging during heavy rainfall.

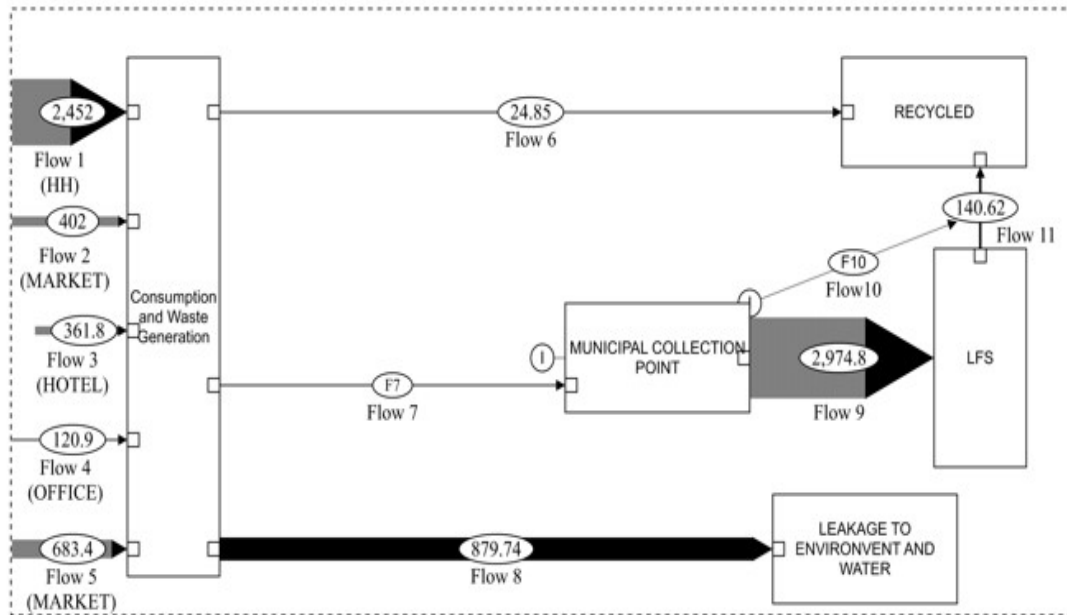


Figure 4: Solid waste flow of 39 no. South Haliashahar ward.

3.3.2 Plastic Wastes Flow

Figure 5 illustrates that the 39th South Haliashahar ward receives around 400 tons of final plastic products each month, following the mass balance principle. The usage of plastic products results in the generation of waste, with LDPE being a significant contributor. The substantial amount of LDPE waste is primarily attributed to the prevalence of single-use plastics, as items such as fruits, groceries, and various commodities are routinely transported using single-use plastic. PET, the second most utilized material, finds application in the production of items such as bottles for oil, water, and cold drinks.

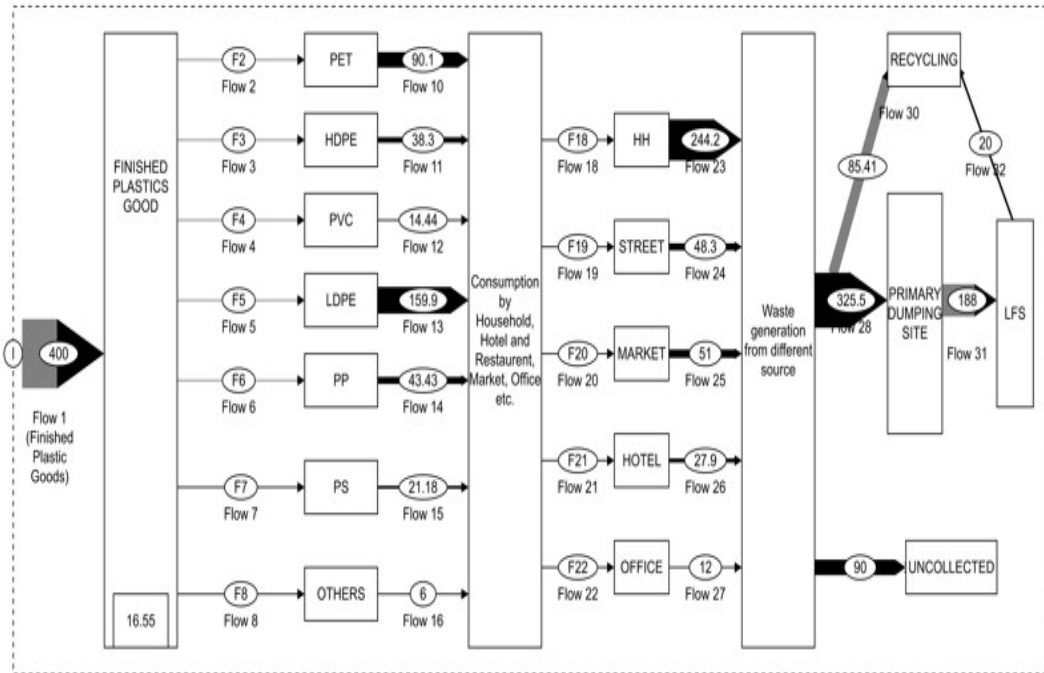


Figure 5: Flow of different plastic wastes of 39 no. South Haliashahar ward, Chattogram.

The recycling process comprises three distinct stages: initially from households to scrap collectors, then from dumping sites managed by Tokai, and finally from the Landfill Site (LFS). Historically, LDPE was not collected by recyclers due to its low recycling value. However, thanks to the financial incentives program implemented by Young Power in Social Action (YPSA), recyclers now collect LDPE, as depicted in figures 6(a) and 6(b). In total, 105.4 tons (27.49%) of various plastic types undergo recycling at different stages, from the point of generation to the landfill. Unfortunately, due to inadequate management, an estimated 90 tons of plastic waste each month end up in the environment and water bodies.



Figure 6: (a) Collection of LDPE by the recyclers from LFS, (b) Dumped LDPE at LFS.

4. CONCLUSIONS

In this study, solid waste composition from various waste sources, especially plastic waste, is analyzed within the South Haliashahar ward, Chattogram. From the composition data, high-income people generate approximately 40.36 gm/cap/day of plastic waste, 2.15 times higher than low-income people (18.53 gm/cap/day). Which is not collected appropriately at every stage causes environmental pollution. MFA has been applied to graphically represent the flows of solid waste and plastic waste. The collection

efficiency of solid waste is 74%, and plastic waste recycling efficiency is 27.49 %. In addition to detailing the amount and types of waste, it highlights the significant role played by informal recyclers in the material recovery process, often driven by financial incentives to meet their basic needs. Integrating informal recyclers into the initial waste collection phase could enhance current recycling rates, decrease the energy-intensive transportation of waste to landfills, and temporarily reduce landfill disposal. A more comprehensive investigation is required to analyze the scenario of various waste management approaches compared to the existing method to quantify not only waste quantity but also energy potential and intensity, process efficiency, inherent byproducts, and the environmental impact associated with applicable waste management technologies.

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