ASSESSING WASTE COMPOSITION AND RECYCLING POTENTIAL OF MATERIALS IN THE WASTE STREAM: A CASE STUDY IN A WARD IN KHULNA CITY

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ABSTRACT

The worldwide solid waste generation rates have brought the issue of solid waste management to the forefront. Addressing this challenge is crucial for safeguarding public health, preserving the environment, and fostering sustainable development. Mismanagement and inadequate source separation often result in the oversight of significant amounts of recyclable materials. This study aims to determine the readily recyclable quantity and potential recyclable waste in the waste stream in Ward 24 of Khulna City. To achieve this, a preliminary questionnaire survey was conducted among waste collectors, followed by the selection of three out of thirteen waste collection vans for detailed analysis. The weight of various items was measured to determine the waste composition and the readily recyclable quantity. The study revealed that approximately 14.22% of the daily waste generated was recyclable. Moreover, waste that had been successfully separated at the source as readily recyclable wastes accounted for 44.22% of all recyclable waste. Among the recyclable materials, plastic had the highest capture rate at 2.36%, followed by glass (0.35%), metal (1.09%), and paper (2.59%). On average, each household contributed 54.55 grams of recyclable waste per day. However, the modest diversion rate of 16.58% indicates that the waste management system needs improvement. Interestingly, approximately 55.78% of the recyclable waste still has the potential to be recycled effectively. In December 2022, the income generated from selling readily recyclable waste amounted to a total of 42,690 BDT. Consequently, this study underscores the importance of raising awareness and implementing education programs to educate communities about the benefits of waste reduction and the detrimental impact of waste on the environment. By employing effective waste management practices, the capture of recyclable materials can be enhanced, and a sustainable and healthier future could be built.

Keywords: *Solid Waste Management, Recyclable Waste, Readily Recyclable Waste, Potential Recyclable Waste, Source Separation of Waste.*

1. INTRODUCTION

Solid waste, consisting of discarded materials from human and animal production and consumption, poses a significant challenge in many urban centres, especially in developing countries experiencing rapid urbanisation. The surge in solid waste generation is driven by factors such as rapid urbanisation, industrialisation, and population growth. This has led to environmental impacts, including pollution, greenhouse gas emissions, and habitat destruction, all associated with the volume of waste produced (Ahmed, 2000). Solid waste management is critical for safeguarding public health, protecting the environment, and fostering sustainable development. According to Alamgir et al. (2007), among the cities in Bangladesh, Dhaka has the highest Municipal Solid Waste (MSW) generation rate of 0.485 kg per capita per day, followed by Sylhet (0.430 kg), Rajshahi (0.378 kg), Barisal (0.325 kg), Chittagong (0.360 kg), and Khulna with the lowest rate at 0.346 kg per capita per day.

Recycling plays a vital role in reducing the environmental impact of waste. By diverting waste from landfills and incinerators, recycling conserves natural resources, minimises energy consumption, and reduces greenhouse gas emissions (Wilson et al., 2001). However, not all materials are equally recyclable, and specific waste streams are better suited for recycling than others. Readily recyclable solid waste refers to materials readily recycled and reused sustainably, such as paper, cardboard, aluminium cans, plastic containers and bottles, glass jars and bottles, and scrap metal. Recycling these materials is crucial for minimising landfill waste, which can have detrimental environmental and health effects. Furthermore, recycling these materials helps by utilising them to create new products rather than producing them from raw materials. Properly recycling these materials reduces waste, conserves resources, and builds a more sustainable future (Haan et al., 1998).

In Khulna City, 520 tons of solid waste are generated daily, and the Khulna City Corporation (KCC) is responsible for waste management (Roy et al., 2022). A study conducted in three wards of Khulna found that average domestic solid waste production ranged from 0.421 to 5.81 kg per day, or 1.917 kg per person daily. Kitchen waste accounted for the majority (87.37%) of the total waste, with smaller contributions from paper, plastic, composite, wood, textile, and metal. The study also examined factors influencing waste formation rates and observed slight variations in municipal solid waste composition across Bangladesh's six largest cities (Jodder et al., 2022).

In Khulna City, a significant amount of solid waste, approximately 70 tons per day, is generated, comprising various materials such as paper, plastic, metal, bone, and glass. Among these, 26% of waste paper and 69% of waste plastic are currently being recycled. Notably, recycling paper and plastic offer attractive profit margins, 40-80% and 23-100%, respectively (Sinha & Enayetullah, 2000). The informal sector is crucial in solid waste management, saving around 8,600,000 BDT/year by recycling 23.85 tons of paper and plastic daily. Implementing improved recycling practices in the area could yield a net profit of 54,676,222 BDT annually (Moniruzzaman et al., 2007).

Emphasising the importance of reusing solid waste materials that are readily recyclable, this practice serves to diminish pollution and preserve valuable resources, benefiting both society and the environment. Recycling reduces emissions during production processes, given the significantly lower energy requirements for manufacturing products from recycled materials compared to producing them from scratch. Materials such as paper, plastic, metal, bone, and glass can be recycled to create new products, reducing waste accumulation in landfills and conserving precious natural resources. Ultimately, incorporating recycling practices is vital in building a more sustainable society, as it contributes to waste reduction and resource conservation (Wei et al., 2017).

The study's objectives include determining the quantities of readily recyclable solid waste, assessing recycling potential, evaluating economic benefits, and examining recycling performance. The study aims to evaluate the recycling potential of the waste stream in Khulna City, a major urban centre in Bangladesh. It will identify types and quantities of recyclable materials, analyse existing recycling practices, and assess economic benefits. The findings will contribute to effective solid waste management strategies, fostering sustainable development in Khulna and similar urban areas.

2. METHODOLOGY

2.1 General

Khulna, the third-largest city in Bangladesh, is positioned on the banks of the Rupsha and Bhairab rivers, covering an area of approximately 59 square kilometres with a population of around 1.30 million (Rahman & Kabir, 2019). Geographically located at 22°49'N and 89°34'E in southwestern Bangladesh, Khulna experiences a tropical climate characterised by hot and humid summers and mild winters, with the monsoon season lasting from June to September. Renowned as a major industrial and commercial centre, Khulna is home to a thriving jute industry and various other manufacturing sectors, including textiles, chemicals, and pharmaceuticals. The city is divided into 31 wards, as depicted in Figure 1.

2.2 Study Area

The study is conducted in the Nirala residential area, ward no. 24, where almost 2568 people reside. This residential area, situated in the northern part of Khulna city, is known for its calm and serene environment. Comprising a mix of apartments, duplexes, and single-family homes, it is also home to local businesses, shops, and restaurants, making it a relatively well-known and developed residential area in the city. The map of the study area is shown in Figure 2.

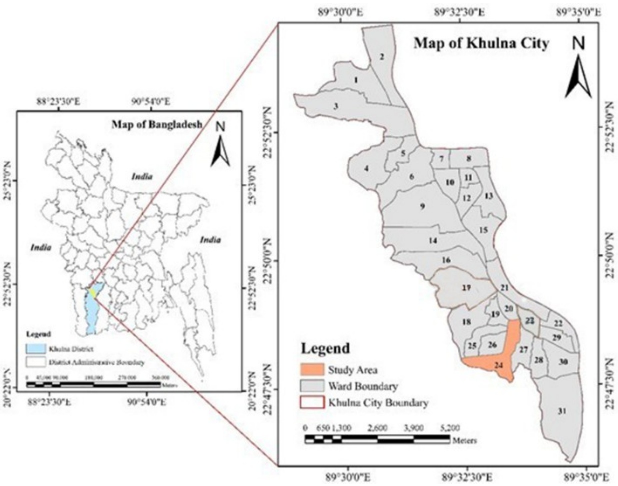

Figure 1: Map of Khulna City

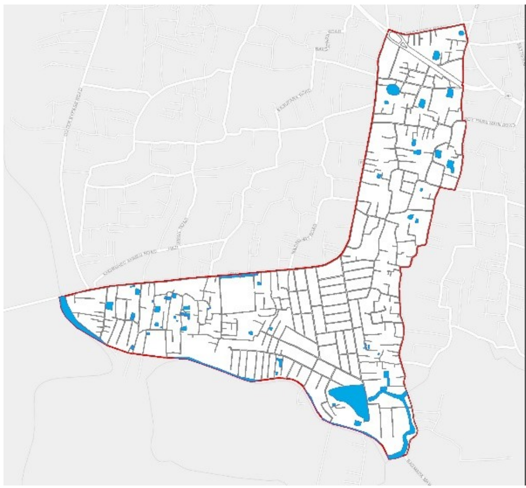

Figure 2: Map of the Study Area

2.3 Data Collection

Data collection took place from November 2022 to February 2023, utilising both primary and secondary sources. Primary information was gathered through in-depth interviews, including the perspectives of waste collectors, recyclers, business people, and Nirala Jonokollan Somite officials. Secondary data, encompassing statistics and reports on solid waste production, composition, and management practices in Khulna, were sourced from earlier research, books, and journals.

2.3.1 Primary Data Collection

A field survey was conducted to understand the current waste collection conditions and challenges related to solid waste recycling. Information on ongoing waste recycling patterns was gathered through questionnaires administered to waste collectors, recyclable dealers, and workers in the recycling industry. The waste composition was analysed by selecting three waste collector vans and weighing different items in the field. The solid waste composition was measured at the secondary disposal site by weighing the different components of solid waste using a weighing machine. The percentages of various components in the total solid waste were calculated based on weight. The weight of readily recyclable items separated at the source by waste collectors was also measured.

2.3.2 Secondary Data Collection

Data on recyclable waste generation in the selected area were collected using secondary sources such as previous study reports and journals. These sources provided information on various aspects of waste, including the total amount generated, per-person generation, composition, and the proportion of recyclable and non-recyclable waste. Additionally, the sources provided information on the percentage of waste with resale value, aiding in determining the percentage of recyclable materials in the overall waste stream. These studies relied on previously published data to analyse the amount and nature of waste generated in some selected areas in Khulna city.

2.4 Data Analysis

The data analysis process employed a straightforward approach, involving a meticulous review of the collected data to discern crucial points. Information obtained from observations and interviews underwent systematic sorting and classification to identify key themes and patterns.

2.4.1 Determination of Solid Waste Composition

Analysing the types and quantities of waste in a specific area or community comprises the process of determining solid waste composition. This involves collecting representative waste samples from diverse sources, categorising them based on material type, and recording their weight and proportion in the waste stream. Factors such as hazardous or electronic waste may also be identified and quantified. The information gathered aids in developing effective waste management strategies, including recycling and disposal, to reduce landfill waste and promote the recovery and recycling of valuable materials.

$$\%\,Component = \frac{Component\ Weight}{Total\ Waste\ Weight} \times 100\,\% \tag{1}$$

2.4.2 Estimation of Recycling Quantity

Estimating recycling quantity involves predicting the recoverable amount of recyclable materials from the waste stream, considering factors like waste composition, existing recycling infrastructure, and market demand for recycled materials. A waste characterisation study is conducted to determine the current disposal and potential recovery of recyclable materials. This information is crucial for designing and implementing recycling programs, promoting sustainable waste management by enhancing material recovery and reducing landfill waste.

$$Recyclable\ Quantity = \frac{Recyclable\ Items\ Weight}{Total\ Waste\ Weight} \times 100\,\% \tag{2}$$

2.4.3 Estimation of Readily Recyclable Quantity

Estimating readily recyclable quantity entails identifying and quantifying easily and economically recyclable materials from the waste stream. This process involves a waste characterisation study to understand the waste composition and evaluate existing recycling infrastructure capabilities for material recovery. The gathered information guides the design and implementation of effective recycling programs, prioritising the recovery of these materials and reducing landfill waste, aligning with sustainable waste management practices.

$$Readily\ Recyclable\ Quantity = \frac{Readily\ Recyclable\ Items\ Weight}{Recyclable\ Waste\ Weight} \times 100 \tag{3}$$

2.4.4 Estimation of Potential Recyclable Quantity

Estimating potential recyclable quantity involves predicting the total volume of materials from the waste stream, encompassing both readily recyclable and hard-to-recycle materials. This is achieved through a waste characterisation study to identify types and quantities of potentially recyclable materials, followed by an evaluation of the existing recycling infrastructure to determine its recovery capacity. The resulting projection informs the design and implementation of effective recycling programs.

$$Potential\,Recyclable\,Quantity = \frac{Recyclable\,Items\,Weight\,Mixed\,with\,Waste}{Total\,Recyclable\,Waste\,Weight} \times 100 \tag{4}$$

2.4.5 Estimation of Economic Benefits

Assessing the economic benefits of selling readily recyclable waste involves evaluating the potential revenue generated from selling easily and economically recyclable materials, such as paper, cardboard, glass, aluminium, and specific plastics.

$$Economic\,Benefits = Total\,Readily\,Recyclable\,Waste\,(kg) \times Unit\,Price\,(Tk) \tag{5}$$

2.4.6 Calculation of Recycling Performance

Calculating recycling performance guides the success of a recycling program in recovering materials from the waste stream and diverting them from landfills, typically expressed as a recycling rate. Various performance metrics are computed, including diversion, participation, recycling, and capture rates. The diversion rate is determined by dividing the weight of recyclable and compostable solid trash by the weight of all other solid waste, expressed as a percentage (Tchobanoglous, 2009).

$$Capture\,Rate = \frac{Material\,Weight\,Percentage \in Entire\,Waste\,Stream}{Weight\,Percentage\,of\,Recyclables \in Entire\,Waste\,Stream} \times 100\,\% \tag{6}$$

$$Recycling\,Rate = \frac{Weight\,of\,Recyclables\,Collected\,per\,Person}{Total\,Weight\,of\,Recyclable \wedge Compostable\,Solid\,Waste} \times 100\,\% \tag{7}$$

$$Diversion\,Rate = \frac{Weight\,of\,Recyclable\,Solid\,Waste}{Weight\,of\,All\,Other\,Solid\,Waste} \times 100\,\% \tag{8}$$

2.4.7 Mass Balance

Mass balance is a quantitative analysis that tracks the inputs and outputs of a system or process, facilitating the understanding of material and energy flow (Tchobanoglous et al., 1993). In waste management, mass balance analysis assesses the efficiency and effectiveness of the system, identifying opportunities for improvement in waste reduction, recycling, and recovery. Data on waste quantities, characteristics, and management methods are collected and analysed to perform this evaluation, offering insights into the overall performance of the waste management system.

3. RESULTS

3.1 Composition of MSW

Table 1: Solid Waste Composition of Three Vans

Compositions	Van 1		Van 2		Van 3		Total	
	Weight (kg)	**%**	**Weight (kg)**	**%**	**Weight (kg)**	**%**	**Wight (kg)**	**%**
Food & Vegetables	58.69	80.65	48.10	81.10	55.70	83.11	162.49	81.61
Plastics	3.59	4.93	3.10	5.23	3.05	4.55	9.74	4.89
Paper	5.58	7.67	4.26	7.18	4.45	6.64	14.29	7.18
Glass	0.49	0.67	0.34	0.57	0.32	0.48	1.15	0.58
Textiles & Wood	0.90	1.24	0.81	1.37	0.49	0.73	2.20	1.10
Metals	1.30	1.79	0.85	1.43	0.98	1.46	3.13	1.57
Medical Waste	0.08	0.11	0.10	0.17	0.06	0.09	0.24	0.12
Dust & Ashes	2.14	2.94	1.75	2.95	1.97	2.94	5.86	2.94
Total	**72.77**	**100.00**	**59.31**	**100.00**	**67.02**	**100.00**	**199.10**	**100.00**
Total Recyclable Solid Waste (Plastics+ Paper+ Glass+ Metals)	10.96	15.06	8.55	14.42	8.80	13.13	28.31	14.22
Non-Recyclable Solid Waste	61.81	84.09	50.76	85.58	58.22	86.87	170.79	85.78

The physical composition of solid waste is contingent upon factors such as geographic location, socio-economic status, and industrialisation levels. In the study area, 13 three-wheeler waste collection vans were employed, each collecting waste 2-3 times daily.

Dimensions of MSW for three different vans:
a. Van 1: Dimensions of $1.22\,m \times 0.815\,m \times 0.685\,m$
b. Van 2: Dimensions of $1.065\,m \times 0.815\,m \times 0.735\,m$
c. Van 3: Dimensions of $1.065\,m \times 0.815\,m \times 0.735\,m$

According to Table 1, food and vegetable waste comprises 80.65% to 83.11%. Paper, a biodegradable component, ranks second, ranging from 6.64% to 7.18%. Plastic waste constitutes between 4.55% and 5.23%, slightly higher than typical compositions. Glass ranges from 0.48% to 0.67%, and metals such as tin and electric weirs vary from 1.43% to 1.79%. Medical and textile items are also present, and dust and ashes account for 2.94% to 2.95%.

3.2 Average Composition of MSW

The data in Table 1 offers a comprehensive overview of waste types in the selected area, indicating the proportional contribution of each category, which is presented in Figure 3. Food and vegetable waste dominates at 81.61%, emphasising the need for effective waste management to minimise organic waste and its environmental impact, including methane production. At 4.89%, plastics pose an environmental hazard, highlighting the necessity of reducing plastic consumption and improving waste management. Paper, cardboard, and recyclable materials make up 7.18%, with room for improvement in recycling practices. Glass and metals contribute 0.58% and 1.57%, respectively, both recyclable. Textiles and wood (1.10%) can also be recycled, but there is room for improvement. Medical waste, dust, and ashes account for 0.12% and 2.94%, requiring specific human and environmental safety disposal methods. The relatively small percentages of recyclable waste suggest promoting recycling and enhancing waste management practices. Figure 4 compares Recyclable and non-recyclable proportions of the total waste.

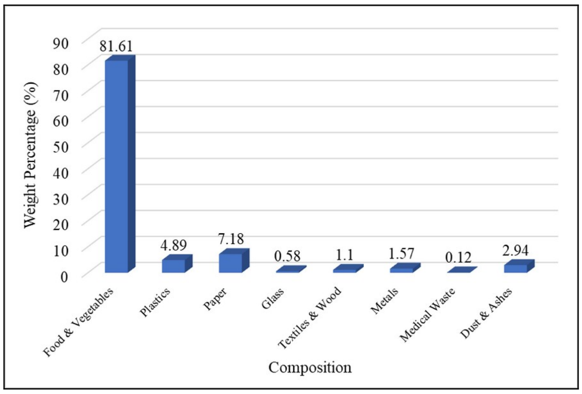

Figure 3: Solid Waste Composition

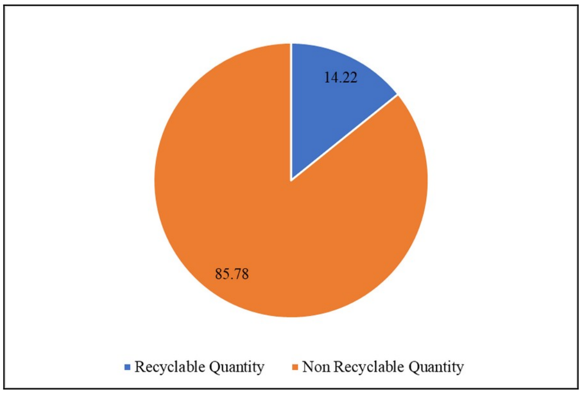

Figure 4: Comparison of Recyclable and Non-Recyclable Quantities

3.3 Waste Generation Rate

Table 2: Waste Generation Rate per Van

	Persons	Total Waste Generation (kg/day)	Waste Generation Rate (kg per capita per day)
Van 1	205	72.77	0.355
Van 2	142	59.31	0.418
Van 3	172	67.02	0.390
Total	**519**	**199.10**	**0.384**

Using the average waste generation rate, the total waste generation from the Nirala residential area is determined to be 985 kg per day, as the total number of people is 2568. From Table 2, the calculated waste generation rate is 0.384 kg per capita per day, closely aligned with values found in the literature. Jodder et al. (2022) reported a waste generation rate of 0.45 kg per capita per day, and Alamgir (2005) found an average of 0.346 kg per capita per day for Khulna city. These results indicate consistency with other studies. Waste generation rates can vary due to factors such as population size, density, economic development, cultural practices, and consumption patterns.

3.4 Recyclable Waste Analysis

From Table 1, the recyclable quantities for vans 1, 2, and 3 stand at 15.06%, 14.42%, and 13.13%, respectively, resulting in an average recyclable quantity of 14.22% across all three vans. The notably low average underscores the imperative for heightened efforts to foster recycling and enhance waste management practices. This necessitates comprehensive initiatives, including educational campaigns, awareness programs, implementation of recycling infrastructure, and encouragement for individuals and businesses to reduce waste and increase recycling actively.

3.5 Recyclable Material Comparison

Table 3: Individual Recyclable Items and Percentages

Recyclable Items	Van 1		Van 2		Van 3		Total	
	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%	Weight (kg)	%
Plastics	3.59	32.76	3.10	36.26	3.05	34.66	9.74	**34.56**
Paper	5.58	50.91	4.26	49.82	4.45	50.57	14.29	**50.44**

Glass	0.49	4.47	0.34	3.98	0.32	3.64	1.15	**4.03**
Metals	1.30	11.86	0.85	9.94	0.98	11.14	3.13	**10.98**
Total	10.96	100.00	8.55	100.00	8.80	100.00	28.31	**100.00**

Table 3, examining the percentages of recyclable items in the waste composition, reveals plastics at 34.56%, paper at 50.44%, glass at 4.03%, and metals at 10.98%, also presented in Figure 5. These percentages represent the proportion of each material in the total waste stream, indicating their potential for recycling. Notably, paper constitutes the highest proportion, emphasising their significant potential for recycling. Reducing paper waste can substantially impact waste reduction efforts. Plastics at 34.56% also represent a substantial recyclable material, with the caveat that different plastics exhibit varying degrees of recyclability. While glass and metals have a relatively smaller proportion in the waste stream, their recycling is crucial due to environmental impact and resource requirements for production.

3.6 Readily Recyclable Solid Waste Quantity

Table 4 represents the amount and percentage of Readily Recyclable Quantities of different types of solid waste, including plastics, paper, glass, and metals.

Table 4: Readily Recyclable Solid Waste Quantity

Recyclable Items	Van 1			Van 2			Van 3			Total		
	Weight (kg)	Readily Recyclable Items (kg)	%	Weight (kg)	Readily Recyclable Items (kg)	%	Weight (kg)	Readily Recyclable Items (kg)	%	Weight (kg)	Readily Recyclable Items (kg)	%
Plastics	3.59	1.75	48.75	3.10	1.62	52.26	3.05	1.29	42.30	9.74	4.66	**47.84**
Paper	5.58	1.79	32.08	4.26	1.56	36.62	4.45	1.74	39.10	14.29	5.09	**35.62**
Glass	0.49	0.30	61.22	0.34	0.15	44.12	0.32	0.19	59.38	1.15	0.64	**55.65**
Metals	1.30	0.92	70.77	0.85	0.62	72.94	0.98	0.59	60.20	3.13	2.13	**68.05**
Total	10.96	4.76	43.43	8.55	3.95	46.20	8.80	3.81	43.30	28.31	12.52	**44.22**

3.6.1 Readily Recyclable Quantity for Plastic

The data in Table 4 indicates that waste collectors have separated 47.84% of the total plastic waste, designating this portion as the "readily recyclable amount." However, this amount represents only 2.34% of the total solid waste composition. This underscores that while a notable portion of plastic waste is collectable for recycling, only a small fraction of the overall waste is readily recyclable.

3.6.2 Readily Recyclable Quantity of Paper

According to the data, 35.62% of generated paper waste is separated at the source for recycling. Yet, merely 2.56% of the total solid waste composition is separated paper waste, which is considered readily recyclable. This indicates that a significant proportion of paper waste remains uncollected, emphasising the need for improved collection processes.

3.6.3 Readily Recyclable Quantity for Glass

The table outlines data on glass waste composition, indicating that 55.65% of generated glass waste is separated for recycling. However, only 0.32% of the total solid waste composition is the separated glass waste, which is readily recyclable. This points to challenges in glass recycling, potentially due to contamination, mixed materials, or subpar glass quality.

3.6.4 Readily Recyclable Quantity for Metals

The data highlights that 68.05% of generated metal waste is separated for recycling. Yet, only 1.57% of the total solid waste composition is the separated metal waste, which is considered readily recyclable. Similar to other materials, this suggests that a considerable portion of collected metal waste may face recycling challenges.

3.7 Potential Recyclable Waste

Table 5: Potential Recyclable Waste Quantity

Recyclable Items	**Van 1**			**Van 2**			**Van 3**			**Total**		
	Weight (kg)	**Potential Recyclable**	**%**	**Weight (kg)**	**Potential Recyclable**	**%**	**Weight (kg)**	**Potential Recyclable**	**%**	**Weight (kg)**	**Potential Recyclable**	**%**
Plastics	3.59	1.84	51.25	3.10	1.48	47.74	3.05	1.76	57.70	9.74	5.08	**52.16**
Paper	5.58	3.79	67.92	4.26	2.7	63.38	4.45	2.71	60.90	14.29	9.2	**64.38**
Glass	0.49	0.19	38.78	0.34	0.19	55.88	0.32	0.13	40.63	1.15	0.51	**44.35**
Metals	1.30	0.38	29.23	0.85	0.23	27.06	0.98	0.39	39.80	3.13	1.00	**31.95**
Total	10.96	6.20	56.57	8.55	4.60	53.80	8.80	4.99	56.70	28.31	15.79	**55.78**

Table 5 reveals a potential recyclable waste amount of 55.78% and a readily recyclable amount of 44.22%, as represented in Figure 6. The potential amount directly goes to secondary transfer stations (STS) and landfilling. Potential recyclable waste represents a significant economic opportunity. It refers to the percentage of waste that could be recycled but requires processing or treatment. This includes materials like plastic, metal, paper, and glass, which may need specialised recycling processes. The figure showcases that the potential recyclable amount requires some processing or treatment, whereas the readily recyclable amount can be recycled without additional steps. Commonly recycled materials like aluminium, glass, and paper have established recycling processes, leading to the disparity in percentages between potential and readily recyclable amounts. Some materials, such as plastics or food waste, may necessitate more specialised recycling processes or facilities, making them less readily recyclable.

3.8 Comparison of Different Readily Recyclable Items and Potential Recyclable Items

Figure 6 compares readily recyclable waste versus potential recyclable items mixed with waste. Among the four waste types, metal exhibits the highest percentage of readily recyclable waste (68.05%), followed by glass (55.65%), plastic (47.84%), and paper (35.62%). The lower percentage of readily recyclable paper is attributed to its biodegradability when mixed with vegetable waste. Notably, the figure indicates that glass and metal waste are more likely to be recycled than plastic and paper waste. Examining the percentage of potentially recyclable items mixed with waste reveals higher rates for paper (64.38%) and plastic (52.16%) compared to glass (44.35%) and metal (31.95%). This suggests that paper and plastic waste are more prone to contamination or improper sorting, potentially complicating recycling processes and reducing efficiency.

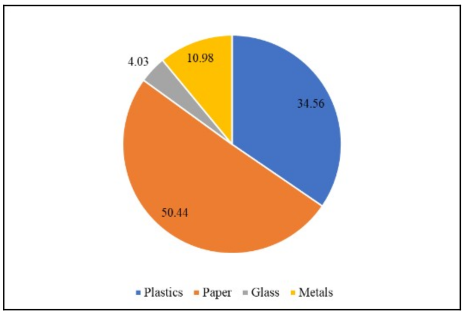

Figure 5: Recyclable Material Comparison

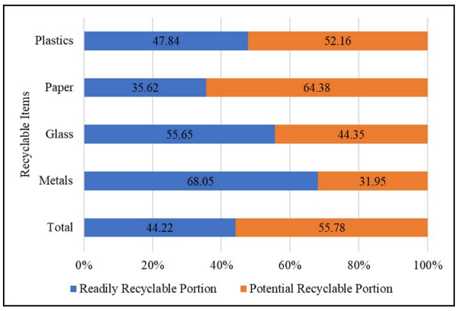

Figure 6: Comparison of Potential and Readily Recyclable Wastes

3.9 Economic Benefits Through Selling Readily Recyclable Waste

Table 6: Economic Benefit of Selling Readily Recyclable Waste

		Plastic items (Kg)						Paper items						Glass			
Waste Collector	**Age**	**Bottle (Soft)**	**Selling Price (Unit Price 25)**	**Other**	**Selling Price (Unit Price 32)**	**Monthly total (kg)**	**Selling Price**	**Fresh**	**Selling Price (Unit Price 11)**	**Scrap**	**Selling Price (Unit Price 6)**	**Monthly total (kg)**	**Selling Price**	**Bottle**	**Selling Price (Unit Price 19)**	**Broken**	**Selling Price (Unit Price 6)**
1	62	52	1300	33	1056	85	2356	45	495	50	300	95	795	6	114	5	30
2	36	47	1175	32	1024	79	2199	53	583	44	264	97	847	6	114	5	30
3	38	48	1200	34	1088	82	2288	41	451	32	192	73	643	6	114	5	30
4	37	40	1000	39	1248	79	2248	42	462	46	276	88	738	4	76	7	42
5	45	45	1125	30	960	75	2085	45	495	51	306	96	801	5	95	5	30
6	34	42	1050	41	1312	83	2362	49	539	40	240	89	779	8	152	6	36
7	47	51	1275	29	928	80	2203	48	528	33	198	81	726	5	95	5	30
8	34	46	1150	35	1120	81	2270	46	506	39	234	85	740	6	114	4	24
9	35	37	925	39	1248	76	2173	41	451	29	174	70	625	4	76	7	42
10	39	42	1050	31	992	73	2042	50	550	35	210	85	760	6	114	5	30
11	36	50	1250	28	896	78	2146	48	528	39	234	87	762	6	114	5	30
12	40	44	1100	33	1056	77	2156	44	484	49	294	93	778	5	95	6	36
13	31	45	1125	35	1120	80	2245	46	506	40	240	86	746	6	114	5	30
Total		589	1472	439	1404	102	**2877**	59	6578	527	3162	112	**974**	73	1387	70	420
Averag		45	1133	34	1081	79.1	**2213**	46	506	41	243	86.5	**749**	5.6	107	5.4	32

Monthly total (kg)	Selling Price (Unit Price 6)	Metal: Monthly total(kg)	Metal: Selling Price (Unit Price 30)	Total (kg)	Total Selling Price
11	144	6	180	197	3475
11	144	6	180	193	3370
11	144	3	90	169	3165
11	118	7	210	185	3314
10	125	7	210	188	3221
14	188	7	210	193	3539
10	125	4	120	175	3174
10	138	6	180	182	3328
11	118	6	180	163	3096
11	144	8	240	177	3186
11	144	7	210	183	3262
11	131	6	180	187	3245
11	144	6	180	183	3315
14	**1807**	79	**2370**	237	**42690**
11	**139**	6.1	**182**	183	**3284**

Table 6 shows that the income earned by 13 waste collectors from selling various recyclable items was 42,690 Taka. Plastic items yielded the highest income at 28,773 Taka, likely due to their widespread use and high demand for recycled plastic products, as shown in Figure 7. Paper items generated the second-highest income at 9,740 Taka, driven by the demand for recycled paper products. The income from selling glass bottles was relatively low at 1,807 Taka, possibly due to the challenges of transporting heavy glass and the limited demand for recycled glass products. Metal items, including tin and aluminium, earned 2,370 Taka, reflecting the high scrap value and extensive demand for recycled metal products.

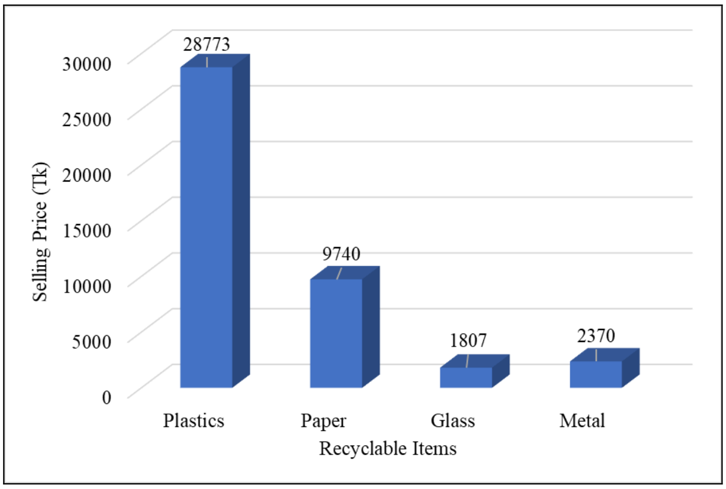

Figure 7: Monthly Total Income by Selling Readily Recyclable Items (December 2022)

3.10 Measures of Recycling Performance

3.10.1 Capture Rate

Table 7: Capture Rate of Different Recyclable Solid Wastes

Recyclable Solid Wastes	Capture Rate (%)
Plastic	2.36
Paper	2.59
Glass	0.35
Metal	1.09
Total	**6.38**

The capture rate, also known as the source recovery factor, refers to the weight percentage of an eligible material successfully separated for recycling. Table 7 details the capture rates for various Recyclable Solid Waste (RSW), with an overall capture rate of 6.38%. The capture rates provided signify the proportion, as a percentage of the total amount generated, of four material types successfully collected and diverted from the waste stream for recycling. Plastic exhibits a capture rate of 2.36%, suggesting room for improvement in the recycling program. Paper has a slightly higher capture rate of 2.59%, indicating a somewhat more effective recycling program. Glass, with a capture rate of 0.35%, faces significant challenges in recycling. Metal shows a capture rate of 1.09%, indicating moderate effectiveness in recycling, though there's room for improvement.

3.10.2 Recycling Rate

The recycling rate refers to the amount of recyclable waste collected per household per unit of time. From Table 8, the average daily generation of 54.55 grams of recyclable waste per residence results in a recycling rate of 54.55 grams per residence per day. Recycling rates can vary due to factors such as recycling infrastructure, consumer behaviour, and types of products and packaging materials used.

Table 8: Average Waste Generation Rate

Recyclable Items	Van 1			Van 2			Van 3			Total		
	Weight	Person	Recycling Rate (%)	Weight	Person	Recycling Rate (%)	Weight	Person	Recycling Rate (%)	Weight	Person	Recycling Rate (%)
Plastic	3.59	205	17.51	3.10	142	21.83	3.05	172	17.73	9.74	519	**18.77**
Paper	5.58	205	27.22	4.26	142	30.00	4.45	172	25.87	14.29	519	**27.53**
Glass	0.49	205	2.39	0.34	142	2.39	0.32	172	1.86	1.15	519	**2.22**
Metal	1.30	205	6.34	0.85	142	5.99	0.98	172	5.70	3.13	519	**6.03**
Total	10.96	205	53.46	8.55	142	60.21	8.80	172	51.16	28.31	519	**54.55**

3.10.3 Diversion Rate

Table 9: Diversion Rate

Total Weight of Solid Waste in Three Vans (kg)	Weight of Recyclable and Compostable Solid Waste (kg)	Weight of All Other Solid Waste (kg)	Diversion Rate (%)
199.10	28.31	170.79	16.58%

Table 9 shows that a diversion rate of 16.58% indicates the waste management system's recycling performance. It represents the percentage of total waste diverted from the landfill or incinerator for recycling, composting, or other recovery methods. This diversion rate signals significant room for improvement. Enhancing the diversion rate involves strategies like waste reduction promotion, efficient recovery processes, and policies incentivising or mandating waste reduction and recovery.

3.10.4 Mass Balance

Based on the mass balance analysis, approximately 985 kg of solid waste is generated daily in the Nirala Residential area. The waste collector initially separated 54.25 kg of readily recyclable waste, generating revenue. However, 930.75 kg was sent to a solid waste transfer station (STS). Informal waste collectors collected some recyclables, but the rest, almost 68.42 kg of potentially recyclable materials, were sent to the landfill. This underscores the need for improved waste separation and collection practices to capture more recyclable materials and reduce landfill waste. The mass balance of the waste stream is shown in Figure 8.

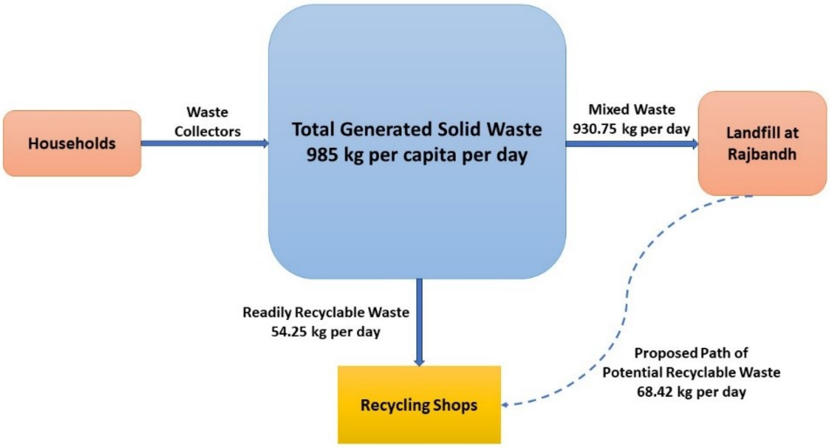

Figure 8: Mass Balance

4. CONCLUSIONS

In summary, analysing computed data and graph representations can draw several important conclusions. The region produces 14.22% of recyclable solid waste daily, underscoring the need for more recycling initiatives. Specifically, source-separated waste contributes to 44.22% of total recyclable waste, equivalent to 54.25 kilograms per day, highlighting the substantial availability of readily recyclable materials. However, 55.78% of solid waste remains unutilised, often combined with other waste and disposed of in landfills. The revenue generated by selling easily recyclable waste products in December 2022 amounted to 42,690 Taka, demonstrating the economic benefit. Diverse material capture rates, including those for plastic (2.36%), paper (2.59%), glass (0.35%), and metal (1.09%), illustrate the varying degrees of success that recycling initiatives have achieved. The recycling rate, which is 54.55 grams per family per day, indicates the need for awareness of waste separation at the household level. However, the diversion rate of 16.58% underscores the necessity for significant improvement in the waste management system, emphasising the importance of implementing strategies to enhance recycling awareness, improve recovery processes, and incentivise waste reduction and recovery.

Recommendations are suggested to increase the source separation of recyclable waste through education and awareness campaigns, provide separate bins, and enhance waste management systems and technologies to improve recycling and waste management. Recycling rates can be boosted by offering convenient recycling services, promoting recycling through education, and developing incentives. It is essential to generate a market for recycled materials and offer higher pricing for recyclables to increase revenue for waste collectors. A cleaner environment can also be achieved by promoting decreased waste production through eco-friendly products and awareness programs.

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