CHARACTERIZATION AND ENERGY POTENTIAL OF MUNICIPAL SOLID WASTE FROM OPEN DUMP SITE IN KHULNA CITY

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ABSTRACT

The management and disposal of municipal solid waste (MSW) are critical environmental challenges faced by urban areas worldwide. In many areas, open dump sites are still a common practice to dispose of waste, raising worries about environmental degradation and public health dangers. This study focuses on the characterization and composition analysis of MSW from an open dump site at Rajbandh in Khulna city, aiming to provide insights into the types of waste deposited. In this study, the characterization has been done on the physical composition of solid waste, and proximate analysis parameters in terms of moisture content, fixed carbon, volatile compound, and ash percentage. The results of this study revealed organic matter contributes 64.5% of waste, with paper, cardboard 11.87%, plastic 12.38%, textile and wood 1.25%, leather and rubber 0.5%, glass and ceramic 6.5%, metal and aluminum foil 2.03%, and cork and other materials accounting for the remaining 0.97%. These statistics showed the differences in solid waste composition with other dump sites from different regions of Bangladesh. For determining the energy potential an equation was used which was proposed by Liu et al., 1996 which contains the percentage of plastic, paper, garbage/food, and moisture content of the waste. Furthermore, the study highlights that MSW from Khulna, Rajshahi, and Barisal has higher energy potential which can be used to produce energy from waste compared to the other cities of Bangladesh. The energy potential of Khulna, Rajshahi, and Barisal is 2455.98 Kj/kg, 3379.29 Kj/kg, and 2741.97 Kj/kg, respectively. A comprehensive characterization and composition analysis of MSW in an open dump site reveals the complexity of waste materials present and their implications for the environment. This study contributes valuable information for policymakers, waste management authorities, and researchers working towards more effective and environmentally friendly solutions for urban waste challenges.

Keywords: *Municipal solid waste, characterization, composition, energy potential*

1. INTRODUCTION

Rapid global economic development and urbanization have led to a substantial increase in the generation of municipal solid waste (MSW), accompanied by significant shifts in its composition (K. D. Sharma & Jain, 2020). These transformations impose additional pressures on the environment, human health, and the existing MSW management systems. The heightened production of waste worldwide is primarily attributed to population growth and increased consumer choices. MSW sources are typically categorized into residential, institutional, and commercial waste, with the characteristics and composition influenced by factors such as topography, seasons, food habits, and the commercial status of the city (Cheela et al., 2021). Characterization of solid waste in terms of its sources, generation rates, types, and composition becomes essential to effectively monitor, control, and enhance prevailing waste management systems (Gidarakos et al., 2006; Palanivel & Sulaiman, 2014).

It is observed that a decreasing rate of growth in total waste as economic development progresses. The global waste generation has risen from 635 million metric tons (Mt) in 1965 to 1999 Mt in 2015, projecting an increase to 3539 Mt by 2050 (median values, middle-of-the-road scenario). In the period from 2015 to 2050, the global proportion of organic waste diminished from 47% to 39%, while the shares of all other waste types rose, with a notable increase observed in paper waste (Chen et al., 2020). The remarkable increase in population and the improvement of living standards in lower and middle income countries pose a considerable challenge in managing vast amounts of municipal solid waste (MSW) produced daily (Peter et al., 2019). The practice of disposing of MSW through open dumping remains prevalent in numerous countries worldwide including Bangladesh. Open dumpsites are areas of open land where MSW is discarded in an unregulated and disorganized manner. The waste found in the existing dumpsites comprises a mix of both organic and inorganic materials, highlighting the inadequacy of segregated collection and transportation at the source. The characterization of Municipal Solid Waste (MSW) is vital information necessary for the implementation of a sustainable waste management system (Al-Khatib et al., 2010). The approaches to Municipal Solid Waste (MSW) management need to be not only environmentally sustainable but also economically viable and socially acceptable (Malinauskaite et al., 2017).

Fossil fuels serve as the most dependable energy sources at present, fulfilling nearly 84% of the worldwide energy requirements (Holechek et al., 2022; Shafiee & Topal, 2009). It is crucial to recognize the capabilities of waste-to-energy (WTE) as a viable choice for sustainable management of solid waste. Moreover, it stands out as a prominent forthcoming renewable energy source, offering economic viability and environmental sustainability (Bajić et al., 2015; Kalyani & Pandey, 2014; Stehlík, 2009). The global population has undergone remarkable expansion, escalating from 3.1 billion in 1960 to nearly 7 billion in 2010. Scientists anticipate this figure to further increase to 9.3 billion by 2050. This substantial population growth significantly contributes to the generation of a vast volume of Municipal Solid Waste (MSW), which amounted to 2.01 billion tonnes per year in 2016. Projections indicate that this annual MSW generation is expected to reach 3.40 billion tonnes by the year 2050 (Chand Malav et al., 2020). The utilization of energy from Municipal Solid Waste (MSW) is gaining traction in highly populated countries globally, including Indonesia, Brazil, Pakistan, Nigeria, Bangladesh, and Russia, as part of sustainable waste management solutions. Japan is at the forefront of global efforts, leading with an impressive 78% conversion of waste to energy (WTE), while the remaining 22% is directed towards recycling and composting (Mukherjee et al., 2020). The commitment of the Bangladesh government extends to the reduction of significant greenhouse gas emissions from open dumpsites by 2030. Strategic planning holds the promise of mitigating this issue, concurrently opening avenues for revenue generation (Setu et al., 2023).

In this study, the characterization of fresh municipal solid waste from the open dump site of Khulna city is done, and a comparison between the MSW of other cities of Bangladesh is done. The study also evaluates the potential energy of waste from different parts of the country and compares them which have not been much evaluated in the past. The objective of this research is to determine which city holds more significant potential in addressing Bangladesh's energy challenges in the form of electricity, biogas, etc. through the application of waste-to-energy principles.

2. MATERIALS AND METHODS

2.1 Study Area

Khulna City, regarded as the third largest among Bangladesh's ten major cities, is located in the district's northern section. Geographically, Khulna is located between 89°31´36´´ and 89°34´35´´ east longitude and between 22°47´16´´ and 22°52´0´´ north latitude. This city is located along the banks of the Rupsha and Bhairab rivers. Currently, the city has 1.5 million residents and a 45.65 km^2 area (Rafizul & Fahmida, 2019)

Figure 1: Map of Rajbandh open dump site

The Khulna City Corporation (KCC) uses the Rajbadh open dump site to dispose of all Municipal Solid Waste (MSW). The open disposal site is located outside of KCC, on the north side of the Khulna-Satkhira highway, and it is roughly 8 kilometers from the city center (Pangkaj et al., 2023a). The coordinates of Rajbandh are 22°47’43.17” N and 89°29’58.35” E. As it is the only site where all of Khulna city's MSW is disposed of, it is taken as the study area. Khulna City Corporation (KCC)has secured a total area of around 20 acres (80937 m2) for waste disposal. The landfill site is encircled by permeable soil, encompassing a barrier that is both low and thick. During the monsoon season, the open dump site's perimeter becomes vulnerable to leachate breaches. The site's surroundings primarily consist of water bodies, with only a few small patches of vegetation (Pangkaj et al., 2023b). The area of Rajbandh is shown in Figure 1 which was developed using ArcGIS. Rajbandh is situated far from residential areas so that peoples’ daily routines don’t get hampered.

2.2 MSW Collection and Sampling

Random truck sampling of municipal solid waste (MSW) is a systematic methodology used to gather representative samples from waste disposal sites or landfills. In order to initiate this process, it is crucial to clearly define the objectives and scope of the sampling project. This helps determine the specific area within the landfill or waste disposal site to be sampled. The procedure aids in determining the characteristics of fresh waste. As Rajbandh is an open dump, during the rainy season it becomes more complicated to gather samples. So, the collection and sampling were done from the 19th to the 21st of March, 2023 during the dry summertime.

The Random Truck Sampling Method was used to gather the typical municipal solid waste from the waste stream. This process starts by picking up garbage at random from arriving waste loads (compactor trucks). This method was also followed in (Kalantarifard & Su Yang, n.d.) for waste characterization and determining the energy potential of MSW. A total of 400 kg of solid waste was collected from 40 trucks. Only MSW compactor vehicles were considered when collecting samples. From the 400 kg, using the quartering and conning technique, 100 kg of waste was separated, and again, through quartering and conning, 25 kg sample was taken. According to the chosen classification of the solid waste components, the garbage was separated. 2 kg of waste was taken for the laboratory test and analysis. A flow chart is given in Figure 2.

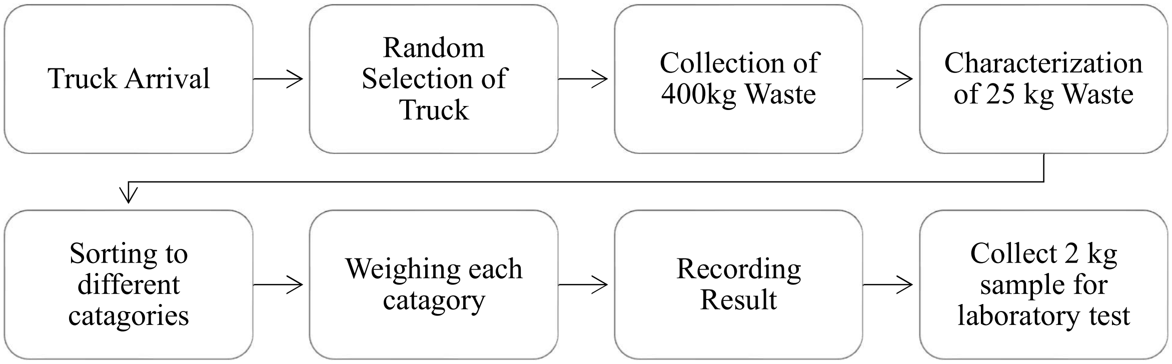

Figure 2: Flow of random truck sampling method

Quartering was used to divide a large bulk sample into smaller, more manageable portions while preserving the overall composition of the original sample. 400 kg of collected MSW was mixed well together and then divided into four equal portions by marking and collecting one of the quarters as a subsample. This process was repeated with the subsample for further size reduction to 25 kg. In the coning method, a conical pile of granular material is created, and samples are collected incrementally while moving from the apex of the cone down the sides, ensuring that material from all parts of the pile is included.

Municipal Solid Waste (MSW) can be sorted into various categories based on the types of materials it contains. These categories help in efficient waste management. The waste collected from the Rajbandh open dump site was categorized as food waste, paper, plastic textile and wood, leather and rubber, metal, glass, and others.

2.3 Proximate Analysis

Proximate analysis is a set of laboratory techniques used to determine the basic composition of a sample. It gives the value of fixed carbon, volatile matter, ash content, and moisture. The percentages of the total sample weight are used to measure these components.

2.3.1 Moisture Content

This measures the amount of water or moisture present in the sample. It is expressed as a percentage of the sample's weight. For determining moisture content, a representative sample of the solid waste was collected and placed into a crucible, and its combined weight was recorded. The drying oven was preheated to 105°C (221°F) ± 5°C (9°F), and the was dried at 105°C for 1 hour. Until a steady sample weight was reached, the weight and drying procedures were repeated. After drying, the container was removed and cooled in a desiccator to prevent moisture absorption from the surrounding air.

$$\boldsymbol{Moisture\ Content} = \frac{\boldsymbol{wet\ weight - dry\ weight}}{\boldsymbol{wet\ weight}} \times \mathbf{100}\% \qquad (1)$$

(de Jong, 2014)

The container with the dried waste sample was then weighed, and this weight was recorded. The moisture content (MC) was calculated using Equation 1. The obtained MC value represents the percentage of the solid waste sample's weight attributed to moisture. ASTM D 3173 was followed for moisture content determination.

2.3.2 Ash Content

Ash content measures the inorganic, non-combustible mineral matter that remains after the sample is heated to high temperatures. Ash is typically composed of minerals like silica, alumina, iron, calcium, and other elements. To determine ash content, the dried sample from the MC was placed into a crucible, and the combined weight was recorded. The open crucible with the sample was heated in a muffle furnace at 950°C (1,742°F) ± 25°C (45°F) until the material was completely ashed. After cooling in a desiccator, the crucible with the ash sample was weighed and recorded.

$$\boldsymbol{Ash\ Content} = \frac{\boldsymbol{Dry\ weight - Residue\ weight}}{\boldsymbol{Dry\ weight}} \times \mathbf{100}\% \qquad (2)$$

(de Jong, 2014)

The ash content (AC) is calculated using the Equation 2. The resulting AC value represents the percentage of the sample's weight that is composed of inorganic ash material. Procedures were followed as per ASTM D 3174.

2.3.3 Volatile Matter

Volatile matter represents the portion of the sample that evaporates when the sample is heated in a controlled environment. It includes substances like volatile hydrocarbons and other organic compounds. This measurement is often significant in fuel analysis and helps determine the combustibility of a material. For determining the volatile matter (VC) the same procedure as AC was followed but while heating the sample in a muffle furnace closed crucible was used.

$$\boldsymbol{Volatie\ Matter} = \frac{\boldsymbol{Weight\ Loss\ during\ ignition}}{\boldsymbol{Initial\ dry\ weight}} \times \mathbf{100}\% \qquad (3)$$

(de Jong, 2014)

All the procedures were followed according to ASTM D 3175.

2.3.4 Fixed Carbon

Fixed carbon is the portion of the sample that remains after the volatile matter is driven off during heating. It consists primarily of carbon, with some residual inorganic materials. In waste-to-energy facilities, the fixed carbon content is an important parameter to consider when determining the energy potential of MSW. Higher fixed carbon content indicates a greater potential for energy recovery through combustion or incineration. Equation 3 was used to determine the fixed carbon of the waste.

$$\boldsymbol{Fixed\ Carbon = 100\% - Volatile\ matter} \qquad (4)$$

2.4 Calorific Value

The calorific value of Municipal Solid Waste (MSW) refers to the amount of energy that can be released when the waste is burned or incinerated. It is a crucial parameter for assessing the energy potential of MSW and is often used in waste-to-energy processes. The calorific value of MSW varies widely depending on its composition, as MSW is a heterogeneous mixture of organic and inorganic materials.

The calorific value of MSW can be determined either through experiments or using mathematical models. The experimental determination includes the use of a bomb calorimeter which requires a specific size of the sample being 1g pellets, which can be difficult to achieve as MSW waste consists of various sized particles (Ledford et al., 1982). Mathematical models are based on the physical composition of the material and can provide reasonably accurate results quickly and at a lower cost. In this study, the energy content will be evaluated using the mathematical model based on Liu et al., 1996 and Kathiravale, 2003 which give the Net Calorific Value (NCV) of MSW.

$$\boldsymbol{NCV = 2229.91 + 28.16Pl + 7.90P + 4.87Ga - 37.28} \qquad (5)$$

This equation is obtained from Liu et al., 1996.

$$\boldsymbol{NCV = 112.815Ga + 184.366P + 298.343Pl - 1.920M + 5130.380} \qquad (6)$$

This equation is obtained from Kathiravale, 2003.

Here, Ga= garbage/food; M= moisture; P= paper; Pl= plastic.

The value of calorific value from Equation 5 will be obtained in the unit of kcal kg^{-1} which later is converted in kJ kg^{-1} and from Equation 6 the calorific value will be obtained in kJ kg^{-1}.

3. RESULT AND DISCUSSION

The amount, type, and attributes of waste can vary depending on factors like time, location, and local conditions. In our study, we observed significant diversity in the composition of solid waste, reflecting the wide variations in waste characteristics. The chemical and physical properties of waste differ based on its source and category, illustrating the direct influence of the type of waste origin.

3.1 Physical Composition of Fresh Waste

Khulna, ranking as the third-largest city corporation in Bangladesh, generates 450 tons of Municipal Solid Waste (MSW) daily, which is disposed of at the Rajbandh open dump site (Pangkaj et al., 2023b). All of the waste is brought through trucks. A total of 400 kg sample was collected from 40 different trucks which were taken randomly. Afterward, the samples were brought to 100 kg through the quartering and conning technique and further ahead it was brought to 25 kg. Table 1 shows the physical waste categorization of the sample.

Table 1: Fresh waste sample composition

Fraction No	Waste Category	120 mm retained (kg)	40 mm retained (kg)	10 mm retained (kg)	pan (10 mm passed) (kg)	Total (kg)	Percentage (%)
1	Organic	0.14	2.98	9.3	3.41	15.83	64.48

2	Paper, and Cardboard	1.23	1.95	0.16	0	3.34	11.87
3	Textile and Wood	0.15	0.11	0.05	0	0.31	1.25
4	Leather and Rubber	0.072	0.02	0.028	0	0.12	0.50
5	Plastic, PET	0.45	2.37	0.22	0	3.04	12.38
6	Glass, Ceramics	1	0.4	0.2	0	1.6	6.51
7	Metal, Aluminum Foil	0	0.45	0.05	0	0.5	2.04
8	Other	0.1	0.1	0.04	0	0.24	0.97
	Total	2.92	8.25	9.97	3.41	24.55	100

The obtained physical composition of the waste via the sorting process is shown in Figure 3 which reveals that the main constituent of the waste is organic matter such as food , garden waste, jute, bones, etc. at 64.48%. There is a good amount of paper and plastic present in the waste composition which are 11.87% and 12.38% which contributes greatly towards calorific value. Textile and wood, leather and rubber, and glass, ceramics was found to be 1.25%, 0.50%, and 6.51% of the total waste. The composition was comprised of 2.04% of metal, aluminium foil and 0.97% of other wastes.

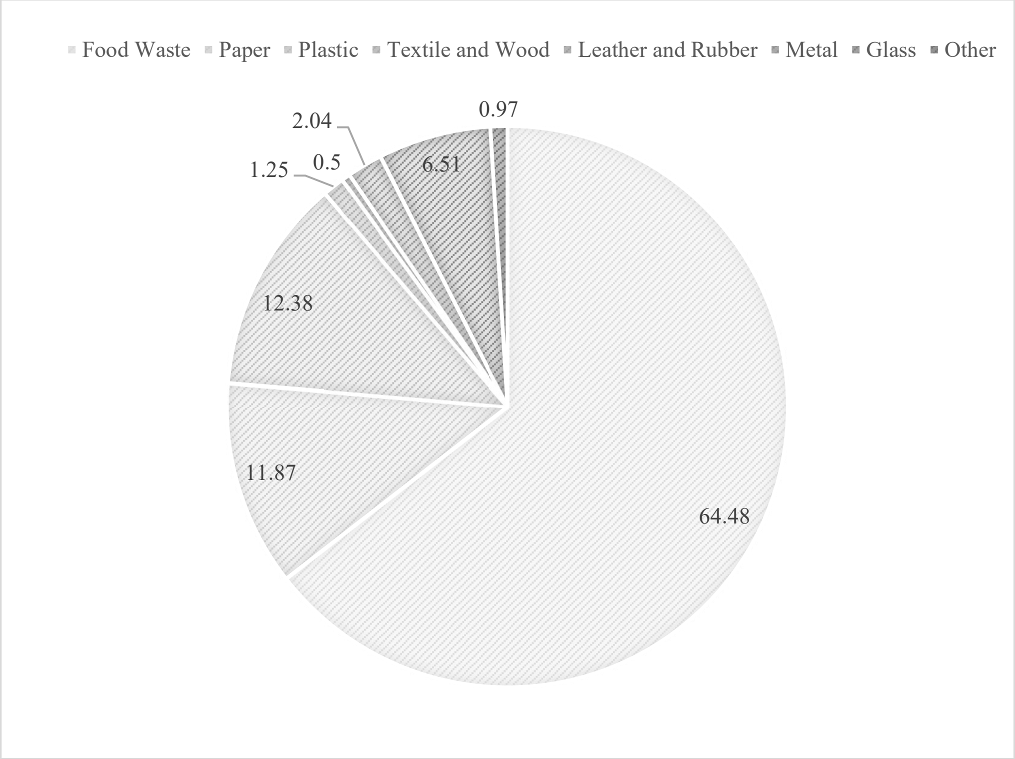

Figure 3: MSW physical composition of Khulna City

3.2 Waste Composition Comparison

Dhaka, being the capital and more densely populated, generates a larger volume of waste than other cities. Same goes for Chittagong for being the largest port in Bangladesh.

Table 2: Waste composition of different cities

City	Organic	Paper	Plastic	Textile and Wood	Leather and Rubber	Metal	Glass	Other
Khulna	64.48	11.87	12.38	1.25	0.5	2.04	6.51	0.97
Dhaka	68.3	10.7	4.3	2.2	1.4	2	0.7	10.4
Chittagong	70.5	4.63	8.7	2.4	5.8	2.65	1	7.4
Rajshahi	70	9	9	6	1.1	3	1.1	0.8
Barisal	81.1	7.2	3.5	1.9	0.1	1.2	0.55	4.5
Sylhet	73.5	8.6	3.5	2.1	0.6	1.1	0.7	9.9

N.B.**:** MSW for Khulna region was determined by the authors and other compositions were taken from (Shams et al., 2017)

This higher population and greater industrial and commercial activities result in a higher proportion of commercial and industrial waste, including packaging materials and manufacturing by-products. All the cities produce residential waste, including food waste, paper, cardboard, and plastics which are given in Table 2. Organic waste, particularly from households and markets, is a significant component in all the cities. It can be observed that the presence of recyclables like paper, cardboard, glass, and plastics are in a greater proportion in Khulna than other cities in their MSW composition from Figure 4. One of the draw backs of this table is due to lack of recent information of the current composition of the MSW of the other cities could not be found, the MSW composition data was obtained from (Shams et al., 2017) which was done in 2017, whereas the Khulna's MSW composition is done in 2023.

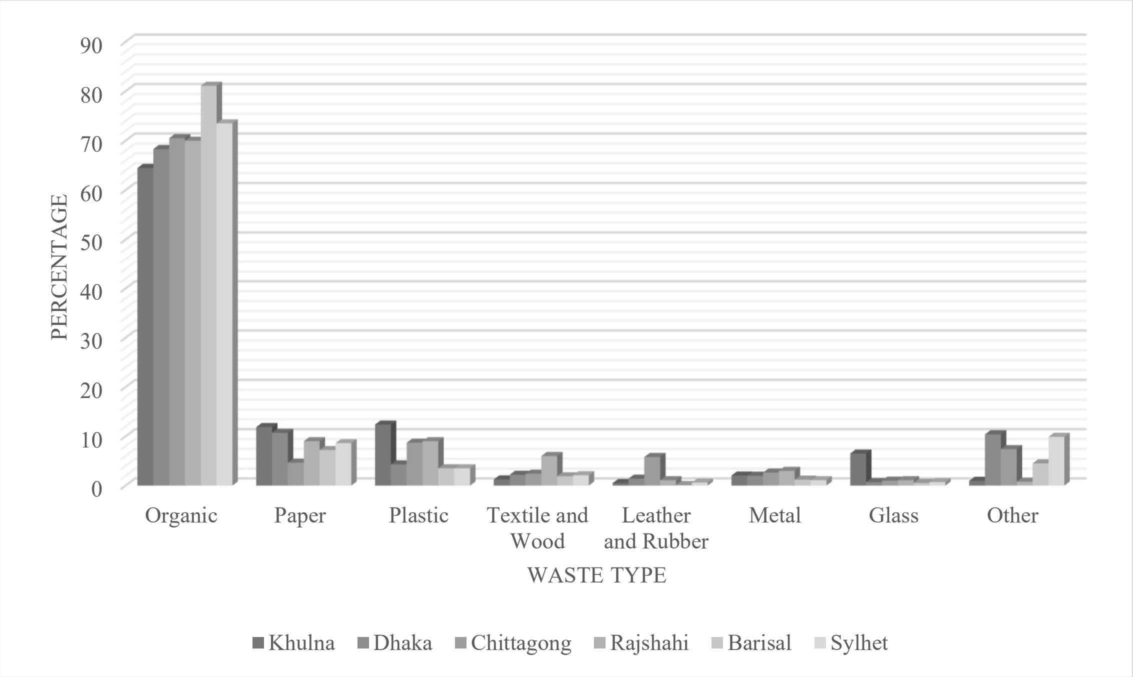

Figure 4: Waste component comparison of different cities

3.3 Proximate Analysis

Proximate analysis is a comprehensive laboratory technique employed to assess the fundamental composition of a sample, particularly applied to substances like coal, biomass, and food products. The analysis involves the meticulous separation of a sample into distinct components, providing insights into its key constituents. Proximate analysis, as formally outlined in a set of ASTM test methods, involves assessing the moisture, volatile matter, fixed carbon, and ash content present in a sample (de Jong, 2014; Donahue & Rais, 2009).

Proximate analysis was carried out for the MSW of Khulna city. The sample was gathered from the random truck sampling method and was taken to laboratory for determining moisture, volatile content and ash content. The proximate analysis result of Khulna city is shown in table 3. Using Equation (4) the fixed carbon was determined.

Table 3: Proximate analysis of municipal solid waste of Khulna city

Parameters	Moisture	Volatile Content	Fixed Carbon	Ash Content
Plastic	58.09	91.39	8.61	16.92
Mixed	63.20	78.15	21.85	21.14
Paper & Textile	61.57	85.22	14.78	13.57
Organic	70.65	68.67	31.33	16.72

The proximate analysis parameters of other cities were obtained from (Shams et al., 2017) and was modified the values of Khulna city. The proximate analysis data are show in table 4. The table shows that the moisture content is highest in Dhaka at 70% and the lowest is in Rajshahi which is 56%. Higher value of moisture content contributes towards the reduction of the calorific value of waste (A. Sharma et al., 2019). This reduction contributes to an increased calorific value, as the absence of water means a higher proportion of the waste's weight is composed of combustible materials, resulting in greater energy yield during processes like incineration or waste-to-energy conversion. Improved combustion efficiency is another notable benefit, as wet waste requires more energy to reach ignition temperatures, while lower moisture levels facilitate easier and more effective combustion.

Table 4: Proximate analysis of MSW of different cities in Bangladesh

City	Khulna	Dhaka	Chittagong	Rajshahi	Barisal	Sylhet
Moisture (%)	63	70	62	56	57	69
Volatile Content (%)	81	71	54	48	43	65
Ash Content (%)	17	29	46	52	57	35

Source: Modified after (Shams et al., 2017)

Sitting at a lower range of around 63% of moisture content in the waste of Khulna region indicates that a higher energy potential can be obtained from it.

3.4 Energy Potential

Municipal Solid Waste (MSW) possesses significant energy potential that can be harnessed through various waste-to-energy technologies. MSW is a diverse mixture of organic and inorganic materials, including paper, plastic, food waste, textiles, and more. The energy potential of MSW lies primarily in its combustible components. In this paper the energy potential measured are not for ash-free-dry basis and are determined using mathematical equations which are Equation 5 and 6. These equations are sourced from Liu et al., 1996 and Kathiravale, 2003.

Table 5 upholds the mathematically derived calorific value of MSW from different cities of Bangladesh. The calorific values of Khulna, Rajshahi and Barisal stood out on top for both equations. The calorific value for MSW of Rajshahi is highest being 3379.29 kj kg^{-1} according to Equation 5 and according to Equation 6 the highest value is 17628.62 kj kg^{-1} which is of Khulna city's MSW.

Table 5: Measured NCV of MSW for different cities

City	Pl	Ga	P	M	Net Calorific Value		
					NCV for Equation 5 (kcal kg^{-1})	NCV for Equation 5 (kj kg^{-1})	NCV for Equation 6 (kj kg^{-1})
Khulna	10.58	64.48	11.87	63	586.9934	2455.98	17628.62
Dhaka	4.3	68.3	10.7	70	158.549	663.37	15956.84
Chittagong	8.7	70.5	4.63	62	543.454	2273.81	16414
Rajshahi	9	70	9	56	807.67	3379.29	17264.29
Barisal	3.5	81.1	7.2	57	655.347	2741.97	16541.87
Sylhet	3.5	73.5	8.6	69	182.035	761.63	15919.55

Here, Ga= garbage/food; M= moisture; P= paper; Pl= plastic.

The proportion of plastic in MSW of Khulna and Rajshahi is greater than other cities where as the moisture content of the waste is lower which elevates the energy potential of the waste of these cities. On the contrary having a considerably higher moisture content in MSW of Dhaka and Sylhet lowered their energy potential significantly. The figure 5 shows more clearly how much higher the potential energy of Khulna, Rajshahi and Barisal is, compared to other cities which gives the opportunity to harness this energy.

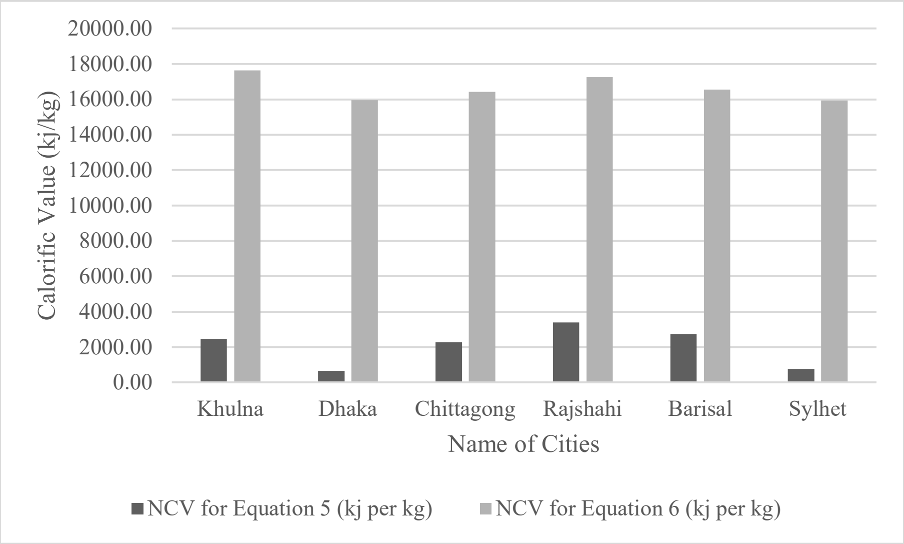

Figure 5: NCV of MSW of different cities

From (Habib et al., 2021) the calorific value of MSW of Rajshahi was found to be 14.9 MJ kg^{-1} which was measured using Dulong formula (Habib et al., 2021) and here the result from Equation 6 shows the value to be 17.26 MJ kg^{-1} which are very close. So, it is justifiable to use the Equation 6 in context of Bangladesh.

4. CONCLUSION

Comparing the energy potential of MSW among different cities is a critical aspect of sustainable waste management and energy planning. It allows cities to assess the feasibility of harnessing the energy locked within their waste streams. By understanding the composition and volume of MSW, cities can determine how much energy can be generated. In this study it is seen that according to Equation 5 Rajshahi has the most NCV of 3379.29 kj kg^{-1} whereas Equation 6 shows the highest NCV being 17628.62 kj kg^{-1} of the MSW from Khulna. Both waste from Khulna and Rajshahi have higher values because of their high volatile matter and lower moisture content. Dhaka having a very moisture content of 70% have less calorific value of 663.37 kj kg^{-1} according to Equation 5 and 15956.84 kj kg^{-1} according to Equation 6 compared to other cities. From random truck sampling method higher percentage of organic waste of 64.48% and 12.38% of plastic was found in the MSW of Khulna which greatly contributes towards potential energy. Also, moisture content from proximate analysis shows MSW of Khulna city is 63% which is comparatively low, further increasing the energy potential. Cities with high energy potential such as Khulna, Rajshahi, and Barisal in their MSW can reduce landfilling, lowering greenhouse gas emissions while generating renewable energy which can be obtained in the form of electricity, biogas, etc. This can greatly play important role in diminishing the energy scarcity of Bangladesh. Also, city-specific waste characterization studies are important as these details are essential for optimizing waste management strategies. Additionally, it informs policy development and community engagement efforts, promoting sustainable waste-to-energy practices and a greener, more efficient waste management system. This study can further be expanded and more accurate results can be obtained by undertaking more methods such as Ultimate Analysis, Heating Value, Pilot Projects, etc.

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