Characterization of Metropolitan Solid Waste for Nepal's Waste to Energy

Sudikshya Karki[1], Priyanka Mehta[2]

[1]M.Tech 4th Semester, Parul Institute of Engineering & Technology, P.O.Limda-391760, Gujarat, India

[2]Assistant professor, Parul Institute of Engineering &Technology P.O.Limda-391760, Gujarat, India

Email: [1]karkisudikshya7@gmail.com, [2]priyanka.mehta21539@paruluniversity.ac.in

Abstract

The current Metropolitan Solid Waste Management system (MSWM) in Biratnagar Metropolitan city is outmoded and too conventional. Biratnagar's MSWM is restricted to trash collection, transportation, and disposal in dump sites, all of which have a detrimental effect on the environment and the community at large. Additionally, garbage that was produced was improperly categorized, causing all of the recyclable, reusable, and organic waste to be mixed with other hazardous material before being dumped. Given that organic waste makes up a sizable chunk of MSW, there is a tremendous potential for energy generation with WtE technology. Therefore, the goal of this study is to characterize MSW in order to assess the Waste to Energy (WtE) production potential of BMC, aid BMC in choosing appropriate WtE technologies, and help BMC create proper and successful SSWM plans. The average amount of garbage produced per person in BMC is 316.74 grams, with a total MSW creation of 110 tons per day. Furthermore, it was discovered that the majority of Biratnagar's MSW, or 62.133% of the total, was organic trash, which has a high potential for energy recovery. Plastic waste came next, at 15.20%, followed by paper waste at 14.39% and other waste at 8.24%. According to the calculations, each ton of BMC MSW has the capacity to produce 16.24 million Btu of heat, or theoretically 4.75 MWh of energy every day. Similar to how paper waste has a theoretical capacity of 553.18 KWh whereas plastic garbage currently has a potential of 1017.913 KWh. In a similar vein, the BMC's biodegradable garbage has the ability to annually produce $13*10^3$ m^3 of biogas, which contains about $11*10^5$ m^3 of methane (CH_4). Additionally, the methane gas produced daily by the anaerobic digestion of organic waste perhaps utilized to create around 1.06MWh of power each day. The study's conclusions include that for organic waste, AD is the most effective and environmentally friendly WtE method, while BMC incineration is the best choice for plastic and paper trash. This study also created a brand-new MSWM framework for BMC that incorporates WtE technology for energy recovery. This component is anticipated to greatly lessen environmental and public health problems in addition to lowering garbage and its GHG emissions from landfills. It will also produce renewable energy at the same time, which will help BMC meet its energy needs.

Keywords: Metropolitan Solid Waste, SSWM, Characterization, Biratnagar, WtE technology, Anaerobic Digestion, Incineration, GHG emission

1. Introduction

One of the most significant environmental challenges in cities of many developing nations, including Nepal, is solid waste management (SWM). The amount and sophisticated composition of municipal solid garbage have increased as a result of economic development, urbanization, and rising living standards in cities of developing nations. (MSW). In the majority of developing countries, the management of municipal solid waste brought on by fast urbanization has become a major concern for governmental departments, pollution control agencies, regulatory authorities, as well as the general population. (Das & Bhattacharyya, 2014).Thus SWM has grown to be a major issue for Nepal's municipalities. The MSWM has also never been regarded as a significant issue in Nepal due to the huge demand for other public services like food, roads, energy, and healthcare overall, which are prioritized by the nation's municipalities. (ADB, 2013). The population of the BMC has increased tremendously as a result of various factors like urbanization, business, and trade center for Koshi Province, industrialization, a rise in immigration rate, etc. The city's rate of waste output has also risen sharply in response to the population growth. This city has not been prepared to develop efficient plans to manage the collection, transportation, and disposal of MSW due to the lack of information and assessments on trash generation and composition. Within the dumping sites, the gathered waste is thrown into the trash carelessly. The handling of solid waste in a sustainable manner is lacking in BMC as most recyclable, reusable waste is additionally mixed with other waste and dumped within the dumping sites leading to GHGs emissions, soil, air, land pollution causing serious environmental and health hazards. Furthermore, as cities grow and develop, waste management becomes more crucial and difficult, especially for developing nations like Nepal. This is because landfill selection, operation, labor costs, fuel and transportation costs, and urban expansion all need to be taken into account. The estimation of two third of the total budget is consumed by the collection and disposal process in the SWM and transportation is the major component in its collection and disposal process.

Waste-to-energy (WtE) technology may be a renewable method of recovering energy for use as heat, electricity, or other alternative fuels like biogas from MSW. (GIZ, 2017). It is an environmentally superior method of waste disposal compared to landfills since it reduces the harmful emissions of greenhouse gases (GHG) from dumping grounds and landfills, replaces fossil fuels used for power generation by producing energy from the combustion of MSW, and reduces the amount of energy used for fossil fuels. (GIZ, 2017). In addition to the rest of the garbage being able to be recycled and repurposed, the created organic waste has a large potential for generating electricity via WtE technology. This can significantly help to solve the MSW issue in BMC. As a result, the MSWM in BMC may benefit from the deployment of appropriate WtE technology, and the energy produced may help to meet both the present and future energy needs. Before choosing an appropriate WtE technology, it is essential to evaluate the waste's properties and volume. (Idris et al., 2004). Therefore, characterization and quantification of solid waste generated are crucial steps in determining the possibility for converting trash into energy and, ultimately, recovering energy from the waste produced. It also results in the creation of sound strategies and regulations for the sustainable management of solid waste in this metropolis.

2. AIMS AND OBJECTIVES

The primary aims are:

- Biratnagar Metropolitan City Municipal Solid Waste Quantitative and Qualitative Analysis
- To evaluate the effects of the existing MSWM
- To determine the potential for energy production from generated MSW using several effective WtE strategies.
- Creation of the WtE system framework (model) for the BMC's effective MSWM system.

3. RESEARCH METHODOLOGY

3.1. Study area

The capital of Koshi Province in Nepal, Biratnagar Metropolitan City, is one of the biggest and densestly populated cities in the world. It is located in the Koshi zone's Morang district. Recently, in 2074/2/17 BS, BMC was promoted to Metropolitan city status. BMC has 19 wards, which together cover an area of 76.9 km2. The city's population is 305529, and it is growing at a pace of 2.25 per year. (CBS, 2014). It is bordered by India in the south, Budhiganga and Gramthan VDC in the north, Sunsari district in the west, and Kathari and Jahada VDC in the east. BMC is renowned for having many different industries. Figure 1 is a map of the BMC that displays the locations of each of the 19 wards.

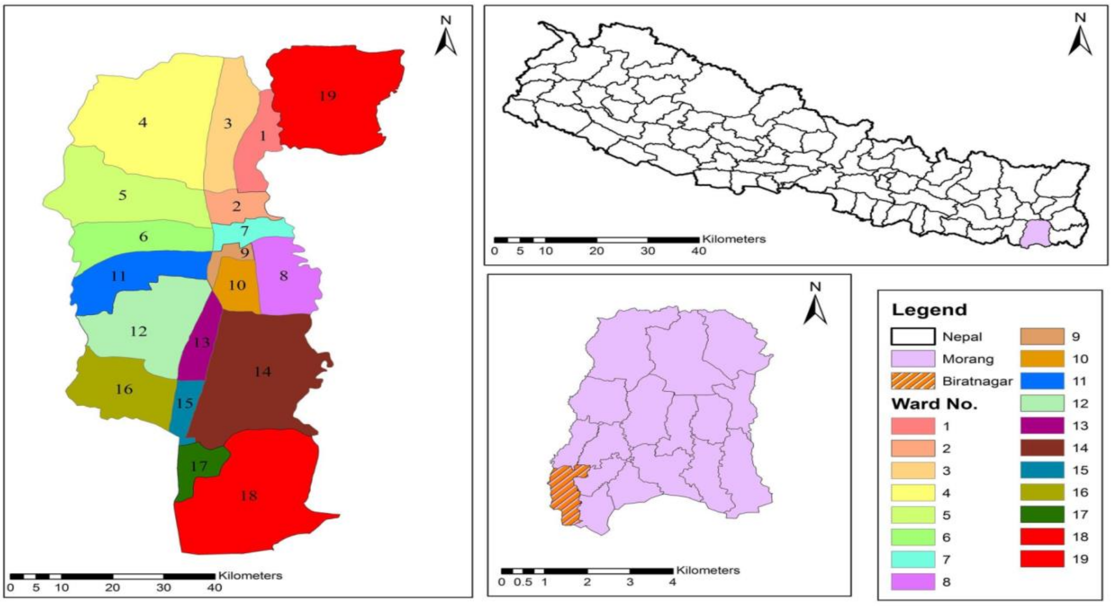

Figure 1: Map of Biratnagar Metropolitan city (source:http://biratnagarmun.gov.np/)

3.2. Current Situation

The collected MSW in BMC is haphazardly dumped in the dumping sites. There is a lack of proper characterization of waste generated resulting all the recyclable, reusable, organic waste being mixed with other hazardous waste and ended up in dumping site that has resulted in soil, air, land pollution causing serious environmental and health hazards. This city has not been able to create efficient strategies to effectively manage, collect, transport, and dispose of

MSW due to the absence of updated data on trash generation and composition. The present state of MSWM in BMC is depicted in Figure 2.

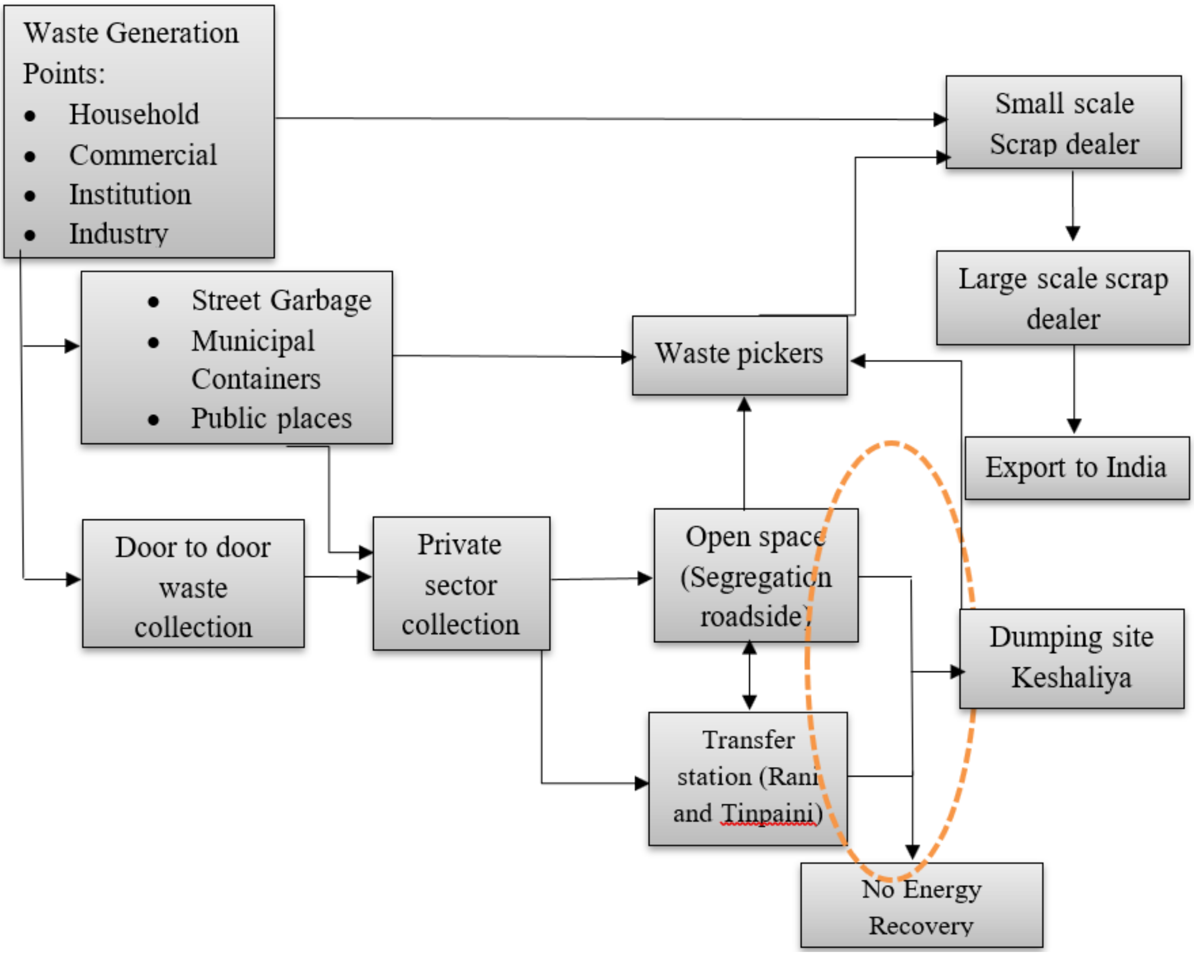

Figure 2: Present waste management practices in BMC

3.3. Data Collection:

One of the most accurate methods for describing garbage is to directly sort it at the generation sites, and this kind of study should be carried out for at least one week during each season of the year. (Gu et al., 2015). A draft comprehensive questionnaire survey was prepared and then feedback and comments was taken. The survey was conducted to the municipal staff and the project chief and field officer of the Waste Management Group of Biratnagar. The purpose of the questionnaire's design was to:

- find out the amount of garbage produced by the BMC per day
- know the composition of the garbage produced by BMC
- know the the amount of waste produced per person
- Know the average annual growth rate of waste productio

3.4. Field Activities

Step 1: Household and Institute Sample identification and distribution

Table 1: Data collection of three different Regions

Regions	Wards	Total Houses	Sample size	Sample households with WCF	Sample Households w/o WCF
Northern R1	1,2,3,4,5,19	13000	114	31	83
Central R2	6,7,8,9,10,11	17000	148	61	87
Southern R3	12,13,14,15,16,17, 18	18000	157	48	109
Total				140	279
				419	

Table 2: Sample size from Commercial and Institutional Sectors

S.n	Commercial and Institutional Sector	Total	Sample
1.	Health Care Facilities	128	16
2.	Schools and Colleges	202	21
3.	Agriculture Market and Haat Bazar	41	4
4.	Hotel and Restaurants	566	57
5.	Bank and Cooperatives	245	24

ii) Step 2: Household survey(Brief HHs for Assessment and plastic bag distribution for waste collection.

iii) Step 3: Municipal waste characterization from vehicle

Figure 3: Municipal waste characterization from vehicle

iv) Step 4: Waste Collection (waste weighing-dry and wet waste separately)

Table 3: Dry and wet trash categorization

S.n	Sectors	Dry trash(kg/day)	Wet trash(kg/day)
1.	Commercial and Institutional sector		
i.	Bank and cooperatives	3.8	0.6
ii.	Hotel	16.1	67
iii.	Restaurant	5.2	34.5
iv.	Schools and colleges	9.8	23.8
2.	Households	261.23	347
	Total	296.13	472.9

v) Step 5: Waste Transfer to Waste Segregation Station (Dumping site is proposed)

Figure 4: Waste Transfer to Dumping site for Segregation

vi) Step 6: Waste Characterization and calculation.

3.5. Solid waste's energy content:

The energy content of dominant inorganic wastes will be calculated after knowing its %composition and corresponding heat value and the obtained energy will be one of the alternative sources of energy for BMC. The energy content will be calculated through this formula:

$$\textbf{Total Energy content (HC)} = \sum \mathbf{f_i} * \mathbf{hvi}$$

Note: E= Theoretical heat content per ton (million Btu)

f_i= fraction of waste component i in the composition of all MSW

hv_i = Waste component i's heat value (million Btu/ton)

It's done by the Dulong formula

Gross Calorific Value (HCV) = 1/100 [8080C + 34500(H-O/8) + 2240S] kcal/kg

Where C, H, O, and S, respectively, stand for carbon, hydrogen, oxygen, and sulfur.

In this manner, Biratnagar's solid waste's energy content is calculated. (Shrestha, Junun, Ridwan, & Hizbaron, 2014).

Table 4: The percentages of various elements in municipal trash components

Waste material	%carbon	%hydrogen	%oxygen	%sulpur
Organic	48	6.4	37.6	0.4
Plastic	60	7.2	22.8	
Paper	43.5	5.9	44.3	0.2
Glass	0.5	0.1	0.4	
Textile	55	6.4	40	0.2
Leather and Rubber	69	8.35	11.6	1
Metal	4.5	0.6	4.3	0
Others	26.3	3	2	0.2

3.6. Potentiality of biogas generation from organic waste

The BMC's organic wastes will be managed utilizing the biogas yield from organic wastes, which will be determined using the formula below. The TS and VS will also be taken (AEPC, 2014).

$$\textbf{Biogas yield}\left(\frac{\mathbf{m^3}}{\mathbf{kg}}\textbf{of waste}\right) = \textbf{Biogas yield}\left(\frac{\mathbf{m^3}}{\mathbf{kg}}\textbf{of VS}\right) * \mathbf{TS}(\%) * \mathbf{VS}(\%)$$

Note: m^3= meter cube

TS= Total organic waste or TS

VS= Volatile solid or VS

3.7. Calculation of biogas-based electricity production

When using a gas motor as a combustion engine, biogas has an energy generation potential of 6 KWh/m3, with an average calorific value of 21-23.5 MJ/m3. (Agency of Renewable Resources, 2005, AQPER, 2019). Methane gas produced from organic MSW accounts for 75% of biogas. (AEPC, 2014).

The formula to determine the amount of electricity generated from methane gas (Adhikari, Khanal & Miyan, 2015) is:

Electricity Production from methane (MW/day)

= [methane yield daily * generation of energy per m^3)/ (1000*0.75)*average calorific value]

4. RESULTS AND DISCUSSIONS

4.1. Metropolitan solid waste generation and composition

Although waste volume and its composition are reliant on various factors, including urbanization, the level of living of the population, population growth, and economic activities, they are the crucial elements that must to be taken into account while creating a strategy and system for MSWM. (ADB, 2013). In BMC, household waste and non-residential waste from businesses and institutions together make up the municipal rubbish. (ADB, 2013). There are 110 tons of garbage generated daily in BMC, of which 86.99 tons are generated from household waste, commercial waste at 19.305 tons/day, and institutional waste at 5.97 tons/day as shown in Table 5, which lists the total waste produced by the various sectors of the city. In BMC, 0.317 kilograms of garbage are produced per person annually. As BMC's population has continued to rise, the amount of waste generated there has increased, and the city now produces roughly 110 tons of rubbish daily.

Table 5: Total garbage generated from different sectors of BMC

Average household waste (kg/day)	1.45
Average per person HH waste (kg/capita/day)	0.317
Total waste from household (tons/day)	86.99
Total waste from commercial (tons/day)	19.305
Total waste from institutional (tons/day)	5.97
Total metropolitan solid waste generation(tons/day)	110
Average per capita metropolitan solid waste(kg/capita/day)	0.317
Average waste collection (tons/day)	95
Collection efficiency	86.36%

4.2. Household waste Composition:

Figure 5 represents the percentage composition of household waste of BMC. It amply demonstrates that organic trash, which makes up 70% of total garbage, is distributed among a variety of materials, including plastic (12%), paper and paper products (7%), glass (3%), textiles (3%), metal (2%), rubber and leather (2.50%), and miscellaneous inert waste (approximately 2% of total waste).

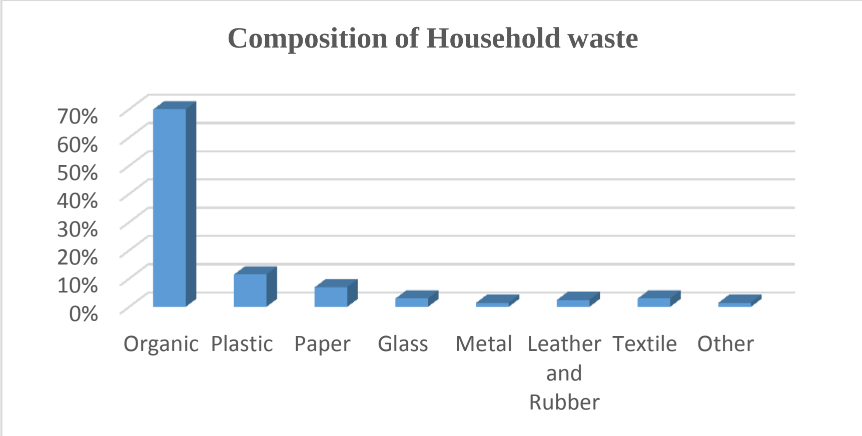

Figure 5: Graph showing the household waste composition

4.3. Institutional Waste Composition:

Figure 6 represents the Institutional Waste Composition of BMC. Institutional waste from schools, colleges, and office consists of the highest percentage of paper and paper products (21.49%) which is followed by plastic (19.63%) and organic waste (62.50%). Other waste such as glass, metal, textiles, rubber, leather, and other waste covers about 1.52%. It can be noticed that the amount of plastic and paper is very high which can be reused, recycled and potential energy can be recovered.

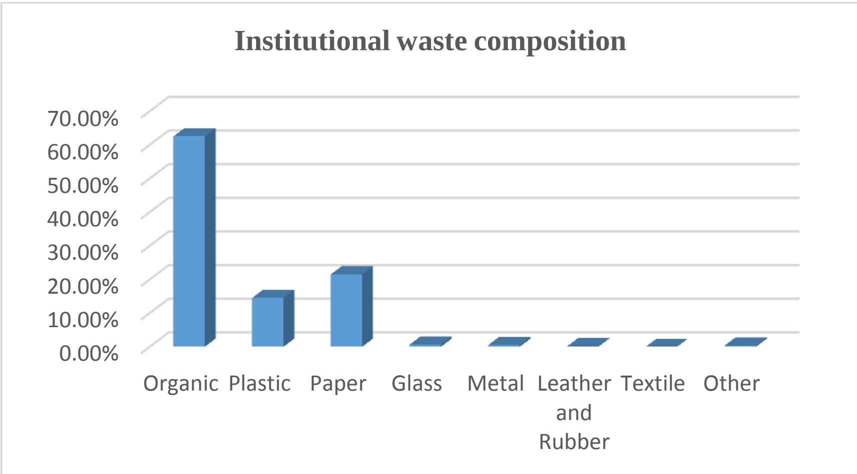

Figure 6: Graph showing the institutional waste composition

4.4. Commercial Waste Composition:

Figure 7 represents the Commercial waste composition of BMC. It demonstrates unequivocally that even in commercial waste BMC, the proportion of organic waste is larger than that of other inorganic waste. Although Organic waste shares a higher fraction (53.90%) than inorganic waste Paper and plastic share a good fraction in total waste i.e. Plastics account up 19.63% of garbage, followed by paper and paper products (14.70%), and other waste (11.77%) including glass, metal, textiles, rubber, and leather. This also means that organic waste has a good chance of being converted into energy and compost, whilst other garbage, such paper and plastic, which account for around 34.33% of total waste, can be recycled, reused, and transformed into energy utilizing WtE technologies.

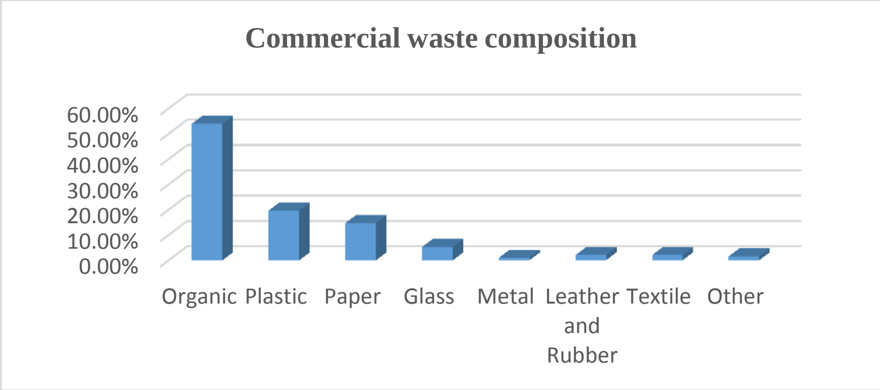

Figure 7: Graph showing the commercial waste composition

4.5. Total MSW composition in Average in BMC

Figure 8 shows the average percentage composition of MSW in BMC. It is obvious from the graph that the volume of organic trash is the biggest (62.13%), followed by plastic (15.20%), paper (14.4%), textiles (1.6%), glass (2.95%), metals (1%), rubber & leather (1.53%), and other waste (approximately) (1.11%).The highest proportion of organic trash in MSW suggests that it has a lot of potential for energy recovery and composting. Most organic garbage requires frequent collection and rubbish removal from the source due to its quick decomposition. (ADB, 2013). According to the data, inorganic waste makes up roughly 36.72% of all MSW and includes items like paper, plastic, glass, textiles, rubber, and leather that may mostly be recycled and reused in the waste recovery process. The remaining inert waste material (only around 1.11%) must be disposed of in landfills.

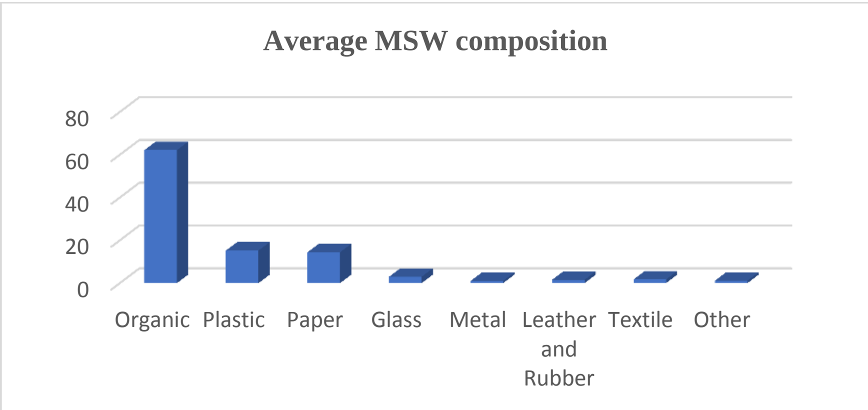

Figure 8: Graph showing the average composition of MSW

4.6. Waste Generation of BMC

The primary source of data for this project is the data obtained from the survey.

Waste generated = per capita waste generation * total population at present

The values of per capita generation of waste is 317.31 g/day and present population is 346661.30 are obtained. Substituting these values in the above equation and found that the total MSW generated per day in BMC is 109.89 tons. The questionnaire survey at the household levels, the commercial, and institutional level was conducted. Also, the questionnaire survey was conducted with the Environmental and Sanitation Head of the Environmental Section, Biratnagar Metropolitan Office, and the Project Chief of all three private sectors, Biratnagar. Some of the major findings of the questionnaire survey are discussed below:

- The daily collected waste according to a survey is 90 to 95 tons per day.
- The approximate waste generation per capita of BMC is 317.3g/day.

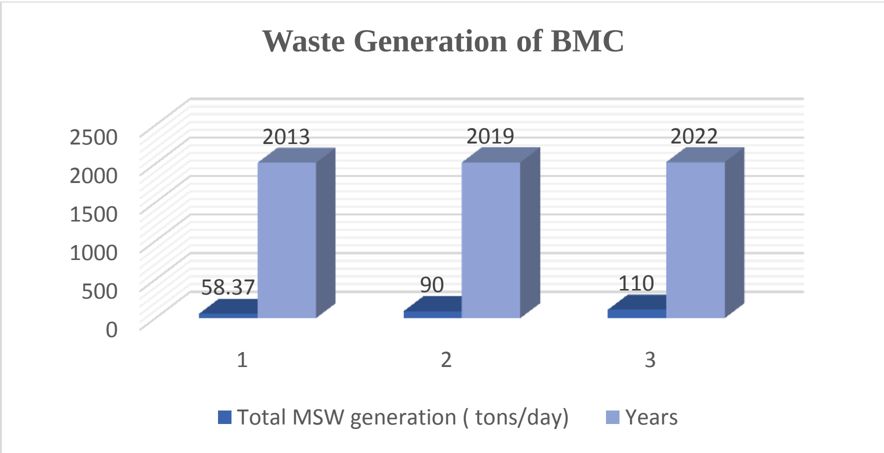

Figure 9: Illustrates the waste generation of BMC in the present period.

Table 6: Data of MSW generation

Total MSW generation	110 tons per day
Average Per capita MSW	317 grams

Table 7: Characterization of Municipal Solid Waste

Type of Waste Material	% Composition
Organic waste	62.133%
Plastics	15.20%
Paper and paper products	14.39%
Textile	1.66%
Leather and rubber	1.53%
Glass	2.95%
Metal	0.99%
Others	1.11%

4.7. The Wastes' Moisture Content

Moisture content was determined with the use of the oven at a constant temperature of 105^0C for pre-defined categories and the weight of dry waste was extrapolated to get the moisture content in the total metropolitan solid waste.

Table 8: MSW moisture content Percentage

Type of waste	Total municipal waste(kilogram)	Moisture content	Moisture wt (kilogram)	Dry wt(kilogram)
Organic	68346.3	0.7	47842.41	20503.89
Plastic	16727.26	0.025	418.18	16309.08
Paper	15835.6	0.07	1108.49	14727.11
Glass	3251.6	0.025	81.29	3170.31
Textile	1095.6	0.03	54.98	1777.62

Leather and Rubber	1686.3	0.125	210.79	1475.513
Metal	1832.6	0.1	109.56	986.04
Others	1221	0.09	109.89	1111.11
Total	109996.26		49935.59	60060.67

The typical moisture content of MSW

Moisture Content = (Total moisture weight/ Total municipal weight)*100

Average MC= 45.39%

4.8. MSW Energy content of BMC

The MSW heat content of each waste of BMC is theoretically calculated by the equation discussed

Total Heat Content (E) = $\sum (f_i * HV_i)$

Table 9 illustrates the calculation of total heat content of each type of MSW of BMC.

Table 9: Solid waste composition heat value under dry conditions in (kcal/kg) and in MWh unit, as well as the fractional percentage of BMC in the MSW composition

S.n	MSW Types	MSW composition in percentage	MSW Fraction Content	MSW Heat Value(kcal/kg)	MSW Heat Content(million Btu/ton)	MSW Energy Content (MWh)
1.	Organic	62.13	0.62	4473.86	10.00047041	2.930847863
2.	Paper and Paper Products	14.39	0.14	3644.34	1.887542988	0.553184111
3.	Plastic	15.21	0.15	6348.75	3.473265386	1.01791336
4.	Glass	2.95	0.0295	57.65	0.006131524	0.001796972
5.	Metal	1	0.010	385.16	0.013810508	0.004047459
6.	Textiles	1.66	0.017	4931.48	0.295693475	0.086659183
7.	Rubber and Leather	1.53	0.015	7978.1	0.440100405	0.128980666
8.	Others	1.11	0.011	3078.27	0.123037213	0.036058639
Total					16.24005191	4.759488252

Note: 1 million Btu/ton= 0.293071MWh

1 kcal = $3.965*10^{-6}$ million Btu

It is observed from the calculation that every ton of MSW of BMC has the potential to generate 16.24 million Btu of heat which is 4.75 MWh/day of energy that can be produced theoretically. Likewise, if organic waste is used to generate energy where other components of MSW can be recycled and reused, nearly 10.00047 million Btu of heat is 2.93 MWh/day of electricity can be generated. Furthermore, the moisture content of solid waste is the most essential factor which is very significant to understand the total energy contained in the MSW for selecting and implementing appropriate WtE technology (Shrestha et al., 2014 Sodari & Nakarmi, 2018). The average value of moisture content for MSW as discussed in section 4.6 is found to be 45.39% for BMC. 70 percent of MSW's organic trash is moist, compared to 7 percent for paper and 2.5 percent for plastic. Although it appears that organic, paper, and plastic wastes, which have high moisture contents, make up the majority of BMC's MSW, Table 9 demonstrates that these wastes also have significant energy contents. This shows that using WtE technology, particularly AD for organic waste and incineration, gasification, or pyrolysis for plastic and paper trash, the MSW of BMC has a rather good potential to produce electricity.

4.9. Potential for incineration of plastic and paper trash in BMC to produce electricity

In BMC, which accounts for one-fourth of all garbage, plastic and paper together are the second most common source of MSW. Plastic waste has a high heat content, so it can be burned to produce electricity, however recyclable paper and plastic garbage are now thrown out carelessly in landfills. We estimated the potential electricity generation from plastic and paper trash in BMC from incineration because it is one of the most popular and simple technologies for garbage burning. Calculating the energy potential of plastic and paper using incineration technology uses the information covered in section 4.9. According to Table 10, paper trash has a theoretical capacity of 553.184 KWh, whereas plastic garbage currently has a potential of 1017.91 kWh. Even if the amount of electricity is not great, it can help during times of energy shortage and be utilized to power the WtE plant directly. However, energy recovery from garbage through incineration was not given priority under Nepal's 2011 Solid garbage Management Act. Even while the current output of plastic and paper trash in BMC is not as large as that of organic waste, WtE technology as incineration is a promising alternative for managing this trend's potential upward trajectory. But burning plastic garbage can release toxic pollutants like dioxin and furans. (Verma et al., 2016). As a result, incineration technology should be utilized in conjunction with pollution prevention techniques.

Table 10: Paper and plastic waste fractional content, heat value, and power production in million Btu/ton and MWh.

MSW Type	MSW composition %	MSW Fraction Content	Heat Value (kcal/kg)	MSW Heat Content in (Million Btu/ton)	MSW Energy Content (MWh)	MSW Energy Content (KWh)
Plastic	15.21	0.152	6348.75	3.47326	1.0179	1017.91
Paper	14.39	0.143	3644.34	1.8875	0.5531	553.184

4.10. Potential for the production of biogas from organic waste in BMC

In BMC, where families are the primary source and account for 70% of organic waste production, it is discovered that the proportion of organic waste is significantly higher than other inorganic garbage. Analyzing this circumstance, it can be seen that the organic portion of BMC's MSW is a fantastic resource for producing renewable energy. Therefore, AD as WtE technology is a viable option for turning this organic MSW into biogas (methane), which can then be used to generate energy, thereby reducing the amount of MSW that is disposed carelessly.

When complex organic material is biochemically broken down by various microorganisms without the presence of air, the process is known as biomethanization (Vogeli et al., 2014). The result is biogas, which is an inflammable, stable, and non-toxic gas with a heat value of 4500–5000 kcal/m3 and a methane content range of between 60–70%. (Igoni et al., 2008). Temperature, pH level, carbon to nitrogen ratio (C:N), features of the feedstock, digester design, hydraulic retention time, and operating conditions are a few critical factors that must be satisfied for a decent generation of biogas from organic waste. Anaerobic bacteria are thought to work best at two different temperatures, with mesophilic bacteria doing best at 30-40^{0}C (average: 27^{0}C) and thermophilic bacteria performing best at 45-60^{0}C (maximum: 55^{0}C). (Vogeli et al., 2014). For high amounts of biogas production, a pH range of 6.5 to 7.5 is ideal. (Khalid et al., 2011). The C: N ratio, another important component of the AD process, has an impact on biogas generation (which will be decreased) if its concentration in solid waste is high. 16 to 25 is the optimal range for this parameter. (Vogeli et al., 2014). The lower retention time actually corresponds to higher thermophilic range temperatures due to the speedier process. The reactor volume also has an impact. It takes more retention time for a large number of reactors to digest organic material, but it also generates a lot of biogas. (Vogeli et al., 2014). All these many issues, which are all listed as technical considerations, must be taken into account before implementing AD technology for controlling BMC's organic waste. Using the following formula, one may determine the biogas yield from BMC's organic MSW:

Biogas yield ($\frac{\mathrm{m}^3}{\mathrm{kg}}$ of waste) = Biogas Yield$\left(\frac{\mathrm{m}^3}{\mathrm{kg}}\text{ of VS}\right)$*TS*VS

Where m^3= Cubic meter

TS= Total organic waste (%)

VS= Volatile solid (%)

Based on the aforementioned data and calculation, the yield of biogas and methane gas is computed and shown in Table 11.

Table 11: Production of biogas and methane from BMC's organic waste

Quantity of organic waste collected for AD	percent Total solid (TS)	Volatile Solid Percentage (VS)	Biogas production(m3/kg of VS)	Biogas yield (m3/kg of trash)	Total organic waste biogas production (m^3/year)	Potential methane gas (m^3/year)	Potential methane gas (m^3/day)
68.34	20	80	0.35	0.056	1396998.372	1117598.7	3061.914

Table 11 demonstrates the potential annual production of 13*10^5 m^3 of biogas, which contains about 11*10^5 m^3 of methane (CH4), from BMC's organic waste. This translates to roughly 3827.4 m^3 of biogas and 3061.9 m^3 of methane gas being produced daily from BMC's organic waste. In the same way, the methane that is created can be used to run the waste-to-energy recovery plant's own electricity generator. This clearly demonstrates that organic waste can significantly impact energy consumption, minimize landfill waste, and provide nutrient-rich organic fertilizer as digested material, which can enhance the quality of soil for optimal crop production and vegetation. (US, EPA, 2018).

4.11. Estimation of biogas-based electricity production

When employing a gas motor as a combustion engine, biogas has an average calorific value of 21-23.5 MJ/m^3 and has the capacity to produce 6 KWh/m^3 of energy. (Agency of Renewable Resources, 2005, AQPER, 2019). Methane gas produced from organic MSW accounts for 75% of biogas. (AEPC, 2014). The calculation of the quantity of electricity generated from methane uses the formula from section 4.11.

Table 12: Electricity generation from the AD process

Estimated methane (m^3/day)	Energy production per cubic meter (KWh)	Average methane percentage in biogas	Generated Electricity (MWh/day)
3061.91	6	75	1.06

The electricity produced by the AD process is depicted in Table 12. Methane gas created by the anaerobic digestion of organic waste can be used by BMC to produce around 1.06 MWh/day of energy per day. Thus, AD may be a potential solution for controlling BMC's organic waste, aiding in the recovery from the energy crisis, and reducing reliance on the importation of foreign fuel for cooking. Additionally, less massive amounts of organic waste will be dumped at the BMC landfill, which also reduces the release of other gases like carbon dioxide and methane that contribute to climate change and leachate that contaminates water from landfill waste.

4.12. Integration of WtE technology with the MSWM framework for BMC

After carefully analyzing the current MSWM system, which is recommended for the sustainable MSWM system in BMC, the framework was established as shown in Figure 10. This framework was created using the planning and ideas provided by the Metropolitan authorities, accounting for a wide range of different aspects with an emphasis on the BMC. This framework is made up of a number of MSWM components that follow the waste hierarchy idea and sustainable integrated MSWM, a more organized and responsible way to manage MSW. The WtE technique is also highlighted in particular since it is the best way to cut down on the amount of garbage transferred to landfills or other disposal locations and it generates a significant amount of relevant data. The WtE method is additionally targeted since it is the most effective approach to limit the quantity of rubbish taken to landfills or dumping sites and produces a significant amount of useful energy. As a result, the WtE strategy can address the problem of energy consumption and aid the BMC's sustainable MSWM.

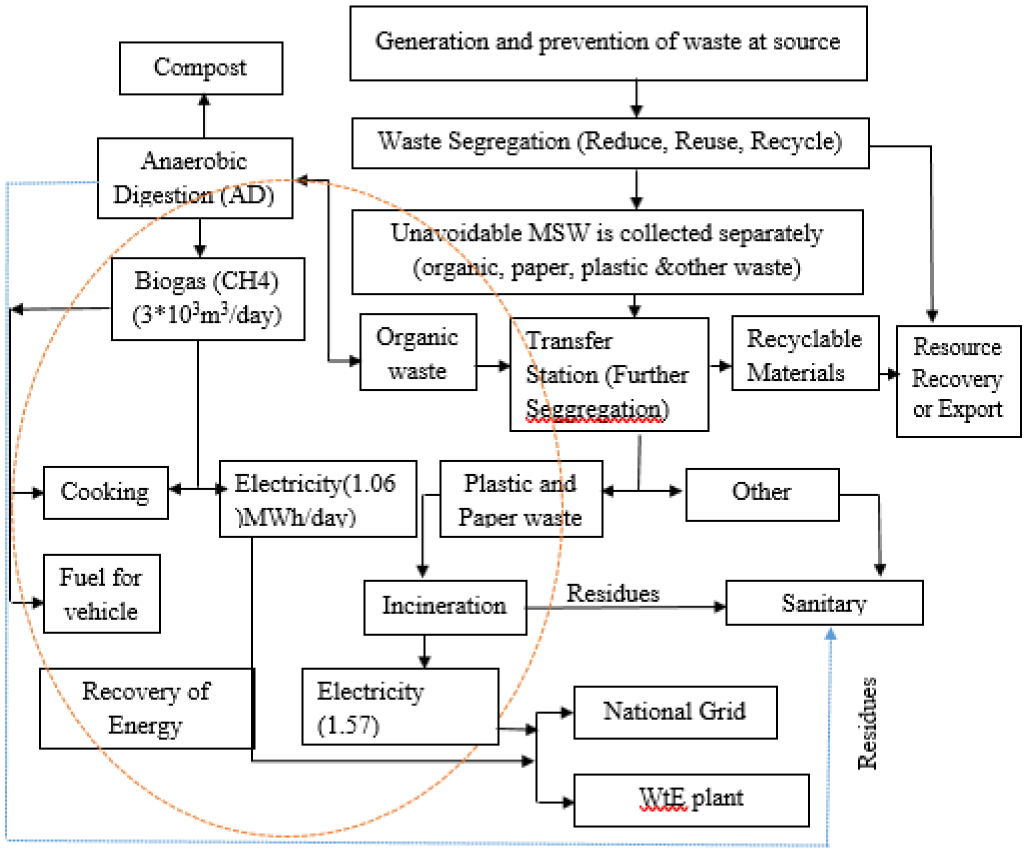

Figure 10: Framework of WtE for BMC

5. CONCLUSION AND RECOMMENDATION

One of the main issues in the cities of emerging nations like Nepal is MSWM. Similar to what was stated earlier in the section above, MSWM is also a serious issue for BMC. The quick population expansion, industrialization, and economic expansion required to satisfy their aspirations are some of the key causes. The environment's quality and public health are at stake because BMC lacks an appropriate and efficient MSWM system. Therefore, an accurate assessment of MSW generation is necessary, and an accurate characterization and quantification of the generated MSW is a crucial component of SSWM. Additionally, integrating WtE technology into the MSWM system may be the best way to address the MSWM issue. The production of electricity from waste minimizes the production of dangerous GHGs.

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