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Investigation of Solid Waste Generation Rate of Dhaka City and Characterization for Biofuel Conversion

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Abstract

Municipal solid waste generation in urban areas of Bangladesh is a major environmental concern that threatens to achieve sustainable development goals in this country. A detailed study was carried out to investigate the solid waste generation rate of Amin Bazar landfill coming from 36 wards of Dhaka North City Corporation and characterized them using laboratory analysis to determine its potential for biofuel processing. The generation rates were examined using statistical analysis and characterization was performed using proximate, elemental, biochemical, and functional group assessment. It was found that the average waste generation in DNCC varied over a range of 621-10892 tonnes per month for 36 wards depending on geographic area, population density, and economic status with an overall average of 2510 tonnes per month. The proximate analysis suggested that the solid wastes contained lower amount of ash (2.2 - 3.7%) and higher amount of volatile matters (6.0 - 10.3%), indicating desirable properties of thermochemical conversion. FTIR analysis revealed higher proportion of carbohydrate (37.8 - 42.1%) and moderate portion of protein (17.6 - 20.3%) and lipid (15.4 - 17.3%), suggesting a high-quality biofuel material. This is supported by H/C and O/C molar ratio of 1.91 - 1.94 and 0.73 - 0.85 respectively. The heating value of 15.3 - 17.4 MJ/kg indicated the solid wastes an energy-efficient fuel. Elemental analysis represented lower NO_x and SO_x emission during combustion, referring to an environment-friendly fuel. Overall, the studied solid wastes will serve as a potential resource and can be used as an alternative to fossil fuel.

Keywords: Municipal solid waste; Waste generation rate; Waste characterization; Biofuel conversion; Waste-to-energy

1. Introduction

Around 700 million tonnes of solid waste (SW) produced globally is not managed in an environmentally safe manner (Santana *et al.,* 2022). Consequently, SW becomes a significant source of environmental pollution by causing greenhouse gas emissions and public health impacts. The municipal solid waste (MSW) generation rate in urban centers of Bangladesh is approximately 23,688 tonnes/day, which is a primary environmental concern (Alam and Qiao, 2020). MSW management is a significant issue that threatens Bangladesh to meet sustainable development goals (SDGs). Traditional waste management system has still been practiced in Dhaka city that allows indiscriminate and open dumping and disposal of waste into landfill and water bodies.

Dhaka North City Corporation (DNCC) consists of 54 wards that are situated in the northern part of Dhaka city, Bangladesh.

The authorities of both Dhaka North and Dhaka South City Corporation are under tremendous pressure to maintain SW management services due to the increasing volume of waste generated, poor management plan, and lack of resources. The total area of DNCC is 196.22 sq. km and population is 5990723 (Bangladesh Bureau of Statistics, 2023). Although the annual growth rate of population in Dhaka is currently below 2%, an increase in SW was found 8% in 2019 - 20 (Ananno *et al.,* 2021). Amin Bazar landfill is the ultimate disposal site of SW for the DNCC which is situated in the low-lying floodplain areas in Savar upazila, Dhaka (Parvin and Tareq, 2021). It has been operational since 2006 with 53 acres of land (Mahmud, 2021).

The primary sources of MSW are households, industry, hospitals, fresh markets, shopping malls, restaurants, and slaughterhouses. Household wastes contribute to 90 % of the total SW streams, out of which around 80 - 90 is the organic fraction (Pap *et al.,* 2021). Currently, 3075 tonnes of waste per day is dumped in Amin Bazar (Himu *et al.,* 2022). It has been targeted as a dumping ground for all types of waste except tannery and medical waste. The landfill site is expected to be exhausted soon, and expansion of the site has already been initiated. Dhaka's landfills are located distant from the city center due to the lack of sufficient space, ultimately raising the cost of trash disposal (Ahmed *et al.,* 2022). The operating cost of Amin Bazar landfill per tonne of waste is about US$ 2 (Ahmed *et al.,* 2022). Since the region is inundated regularly during monsoon period, surface water contamination from this landfill site poses a risk to the adjacent villages situated within a 1 km radius of the landfill site. Previous study found that the by-products of SW deposited to a landfill site have adverse effects on human health and surrounding environment as they possess higher health risks to the residents living nearby (Njoku *et al.,* 2019).

This unmanaged waste would act as a resource if it could be efficiently converted to renewable energy (Li *et al.,* 2012). Conversion of unmanaged SW to bio-energy would work as an integrated "Solid Waste to Bio-energy" approach, which would play a critical role to overcome this environmental issue, mitigate global warming, and create a sustainable path for energy generation (Cesaro *et al.,* 2020). Sweden and Brazil are working on SW gasification or pyrolysis plants for converting this waste to fuels in commercial-scale plants (Gutberlet *et al.,* 2020). However, wastes having high moisture content are still a major concern in gasification or pyrolysis plants. As a potential solution, Kabir and Khalekuzzaman (2022) proposed co-hydrothermal liquefaction of organic wastes for conversion to biocrude. About 50% of the waste organic fraction was converted to biocrude having a higher heating value of 42 MJ/kg through the co-HTL approach. Besides thermochemical conversion, the biological processes of waste to biohythane and bioethanol conversion have gained much attention in recent years (Mlaik *et al.,* 2019). Industries around the world (Hythane company, Treviso, Sapporo Breweries Limited, etc.) have started to process biohythane and bioethanol using SW and sludge at a commercial scale (Kabir *et al.,* 2022b).

The objective of this study is to evaluate the potential of renewable energy generation and subsequent carbon reduction of MSW management in DNCC using an integrated waste-to-energy approach. The study initially estimated the on-site MSW generation rate of Amin Bazar landfill coming from 36 wards of DNCC and then evaluated the MSW as both potential and environment-friendly biofuel. To achieve this, several laboratory analyses were conducted to characterize the generated SW including proximate, elemental, and functional group assessment. This would facilitate to understand the carbohydrate, protein, and lipid fraction of the MSW for the extent of bioconversion as well as the nature of flue gases containing NO_x and SO_x during combustion.

This study would not only provide a methodical way for determining waste generation scenarios in Dhaka city but also propose the most efficient pathway for waste minimization through biofuel conversion. It is believed that the findings of the investigation would throw light on 'waste-to-energy' approach with special reference to environment-friendly and economically feasible biofuel. The results might conclude the studied MSW as a potential alternative to fossil fuel. Such findings might be applicable to any other region prior to proper calibration of the processes and characterization of SW.

2. Methodology

2.1 Study area

Previously, DNCC was comprised of 36 northern wards of Dhaka city. There are 54 wards that are governed by DNCC at present after it underwent expansion. The DNCC area comprises of 196.22 sq. km having latitude 23044´ - 23054´ N and longitude 90020´ - 90028´ E (Dhaka North City Corporation, 2023). The average population density of DNCC is 30531 per sq. km. A total of 36 out of 54 wards (Ward 1 to Ward 36) of DNCC were considered as the study area of this research as shown in Figure 1.

2.2 Collection of data

The SW generated from 36 wards of DNCC was considered as the raw data for this investigation. The SW generation data of wards 1 to 36 were collected from DNCC. With the support of their staff, data has been received at twenty-four-hour intervals. Monthly data of seven months from March to September in 2019 were collected which included various information such as serial numbers, date and time of entries, ward numbers, gross weight, tare weight, and net weight of garbage trucks. The SW of interest was eventually transferred to Amin Bazar landfill.

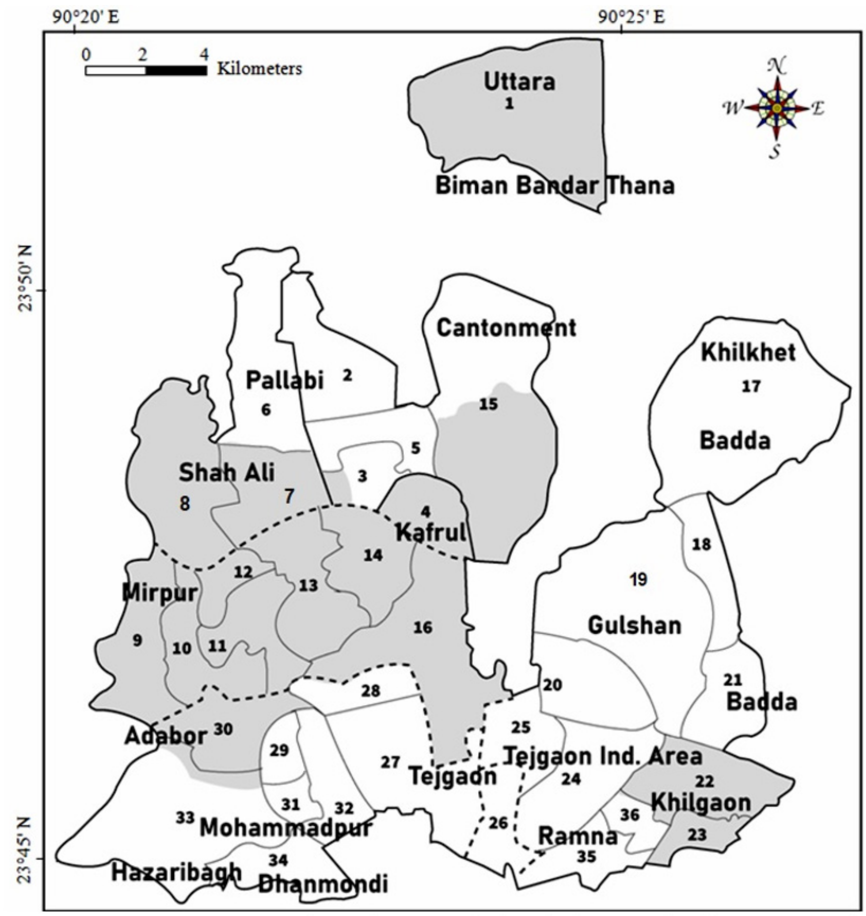

Figure 1. Location of 36 wards in Dhaka North City Corporation

2.3 Data analysis of waste collection

Participants in the research relied on computer applications such as Microsoft Office and IBM SPSS Statistics to conduct statistical data analysis (Rowston *et al.,* 2021). The six data types that were considered for extensive analysis were serial numbers, timestamps, ward numbers, gross weight, tare weight, and net weight. It was therefore possible to observe how much waste was generated in each ward on any given day, which is an important parameter for tracking waste volume. The primary focus of the study was on the weight of MSW in each ward for a particular month and the weight per month for each ward (Adib and Mahapatro, 2022). Knowing the MSW generation from one ward to the next is very effective to understand and follow the pattern. Since dry and wet climatic circumstances cause volume fluctuations in SW (Rafew and Rafizul, 2021), a long-term or at least a year-round study would improve the precision of the analysis. It was not possible to compare seasonal variations in this study as the data was available for seven months during the monsoon period only.

2.4 Waste characterization

In order to characterize the waste material, several analyses have been carried out including proximate analysis, elemental analysis, and Fourier-transform infrared spectroscopy (FTIR) analysis (Islam *et al.,* 2021). Oven-dried triplicate samples have been selected to conduct laboratory analysis. Proximate analysis is a process of measuring moisture content (MC), ash content (AC), volatile matter (VM), and fixed carbon (FC) of any substance. According to the ASTM approach, this study calculated the proximate analysis of SW biomass to quickly assess the percentage of elements necessary for thermochemical conversion of biomass (ASTM D3172).

2.4.1 Elemental analysis

Elemental compositions of MSW samples were determined through Vario MICRO cube elemental analyzer (Elementar, Germany) calibrated by acetanilide standard. The hydrogen-to-carbon effective ratio (H/C_{eff}) was calculated using Eq. (1) to determine the feedstock potentiality for biocrude conversion (Parthasarathy *et al.,* 2022). The atomic symbols H, C, and O represent the molar percentage of hydrogen, carbon, and oxygen content respectively.

$$H/C_{eff} = (H - 2O)/C \quad (1)$$

2.4.2 FTIR analysis

The mode of vibrations, functional groups, and range area of biochemical composition (lipid, protein, and carbohydrate) present in the MSW was determined by dry FTIR analysis. At room temperature, a Shimadzu (IRTracer-100) model FTIR spectrophotometer was employed with potassium bromide (KBr) carrier window material. With a resolution of 2 cm^{-1}, the IR spectra ranged from 400 cm^{-1} to 4000 cm^{-1}. MS Excel, irAnalyze-RAMalyze, and OriginPro 2018 software were applied to evaluate the data.

3. Results and Discussion

3.1 Generation of solid waste

Figure 2 (a) presents the monthly SW generation data from March to September in 2019 for wards 1 to 36. The SW generation in DNCC varied over a range of 621 tonnes to 10892 tonnes, average being 2510 tonnes per month. This variation depends on population density, size of area, and economic activities. Ward 1 (Uttara Model Town and surrounding area) produced the highest amount of SW (10892 tonnes/month) which is nearly 10 times that of most of the wards. It also had the highest geographic area compared to other wards, which justified the huge amount of SW generation.

The average SW generation per holding was calculated by dividing the average monthly SW to the number of holdings in that ward and displayed in Figure 2 (b). The mean SW per holding in 36 wards was mostly below 1 tonne with a few exceptions. Ward 19 (Gulshan and Banani) showed the highest SW generation per holding (4.45 tonnes/holding) which is a commercial center and residential place for elite and upper-class people.

The average SW generation per area of most wards was below or around 1500 tonnes/km^2 as represented in Figure 2 (c). Ward 26 showed the highest SW generation per area (4268 tonnes/km^2) among the wards. Kawran Bazar is situated in this ward which is one of the largest commodity marketplaces in Dhaka city. This could be the reason that such a large amount of SW was generated in this ward.

3.2 Solid waste characterization

3.2.1 Proximate analysis

The proximate analysis suggested that the SW biomass was in wet conditions having 84 - 90% moisture, representing optimum feedstock condition for hydrothermal liquefaction conversion to biocrude.

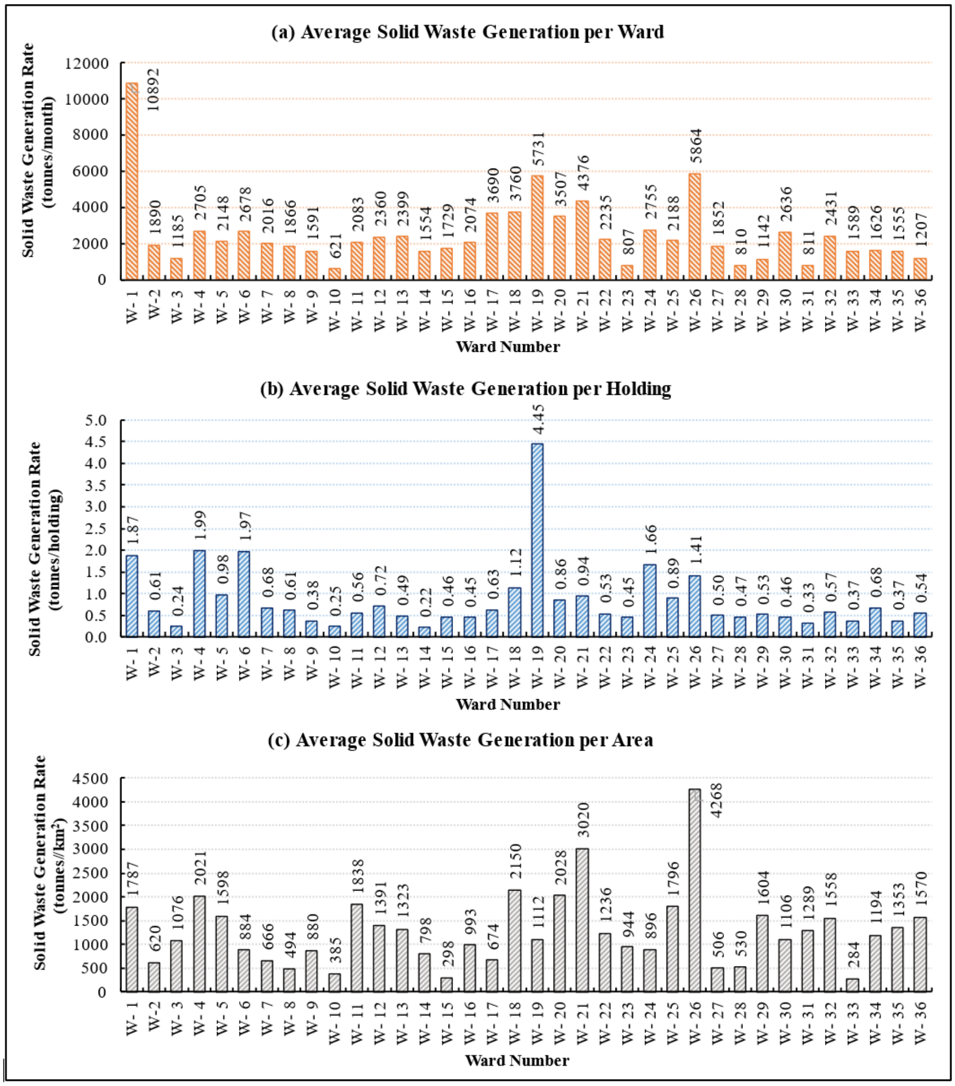

Figure 2. (a) Average solid waste generation per ward (b) Average solid waste generation per holding (c) Average solid waste generation per area

However, moisture contents were observed to be lower (12 - 76 %) in three other countries of the world including a neighbouring country, perhaps due to seasonal variations during waste collection (Table 1). The total solids of the feedstock were 9 - 15 %, out of which 6 - 10 % was the volatile matter, representing good characteristics for fuel production. The higher volatile fraction in wastes suggested that the waste has good combustion properties. Similarly, MSW generated from India, Ghana and Bhutan had higher proportion of volatile fraction and ash content as compared to Dhaka suggesting its potentiality for biochemical conversion (Cesaro *et al.,* 2020). On the contrary, the amount of fixed carbon was lower than ash content, suggesting char formation during hydrothermal conversion. Kabir *et al.* (2022b) reported similar characteristics for organic SW, such as 16 % total solids, 12 % volatiles, 3 % ash, and 0.9 % fixed carbon, and recommended that one of the best feedstocks for hydrothermal liquefaction. Since this study's findings had similar waste characteristics, it represents a higher proportion of organics in waste composition and its suitability for thermochemical conversion.

3.2.2 Biochemical and elemental composition analysis

The biochemical composition such as lipid, protein, and carbohydrate of SW was quantitatively determined by FTIR spectrum analysis, as presented in Table 2. The lipid proportion of SW (15.3 - 17.4 %) could be converted to biodiesel using a transesterification conversion process (Khalekuzzaman *et al.,* 2020). The SW contained a high proportion of carbohydrates (37.8 - 42.1%), suggesting a high potential feedstock for the pyrolysis/gasification process (Dong *et al.,* 2016). The protein fraction of SW(17 - 20%) indicated that catalytical hydrothermal conversion of SW would be economical (Bitonto *et al.,* 2018). The results indicated higher carbohydrate and moderate protein-lipid content in SW biomass suggesting it a high-quality biofuel raw material (Kabir *et al.,* 2022a).

The elemental analysis of SW biomass was determined to identify its potentiality for biofuel conversion, as shown in Table 2. The elemental analysis suggested that the biomass contained higher carbon and hydrogen content, representing high potentiality for thermochemical conversion to biofuels. The biomass also contained lower nitrogen and sulphur content which represented lower NO_x and SO_x emission while combustion. The heating value of SW biomass was 15 - 17 MJ/kg, representing similar properties of an economical liquid hydrocarbon raw material. Mahesh *et al.* (2021) reported SW biomass having 50.4 % C, 5.5 % H, 7.1 % N, 0.5 % S, and 28.7 % O could be hydrothermally converted to liquid biocrude fuel. The elemental properties of this study suggested its appropriateness for hydrothermal conversion.

Table 1. Proximate analysis of solid wastes of Dhaka in comparison with other countries

Proximate composition (wt.%)	Dhaka, Bangladesh		India	Bhutan	Ghana
	Ward 11 (DNCC)	Ward 26 (DNCC)			
Moisture	90.98 ± 0.41	84.61 ± 0.24	42.05	12	25-76
Total solids	9.02 ± 0.34	15.39 ± 0.42	58.36	-	-
Volatile matter	6.04 ± 0.47	10.32 ± 0.62	19.63	68	31-88
Ash content	3.78 ± 0.31	2.20 ± 0.24	-	12	2.2-19
Fixed carbon	0.78 ± 0.13	1.29 ± 0.15	-	6	-
Reference	This study	This study	(Kumar and Goel, 2009)	(Choden *et al.*, 2021)	(Miezah *et al.*, 2015)

Table 2. Biochemical and Elemental composition of solid wastes

Biochemical composition (wt. %)	Ward 11	Ward 26
Lipid	17.31	15.43
Protein	20.32	17.67
Carbohydrate	37.83	42.19
Elemental composition (dry basis, wt.%)		
C	44.64	41.81
H	7.12	6.78
N	4.23	3.53
O	43.93	47.71
S	0.08	0.16
Elemental molar ratio		
H/C	1.91	1.94
O/C	0.73	0.85
N/C	0.08	0.07
C/N	12.31	13.81
H/C_{eff}	0.43	0.23
Chemical formula	$CH_{1.91}O_{0.74}N_{0.08}$	$CH_{1.94}O_{0.85}N_{0.07}$
HHV ($MJ\ kg^{-1}$)	17.41	15.31

The H/C and O/C molar ratios of SW were 1.91-1.94 and 0.73-0.85 which indicated high potentiality of SW as a suitable biomass for biofuel conversion, as shown in Figure 3. The van Krevelen diagram illustrates that SW could be converted to biocrude by deoxygenation and decarboxylation reaction mechanism of the hydrothermal liquefaction process (Kabir *et al.,* 2022a). Whereas, the gasification process would involve dehydration, demethanation and decarboxylation reaction mechanisms to convert biomass to biofuel. The chemical conversion of biomass lipids to biodiesel would involve the dehydrogenation reaction mechanism of transesterification process. Thus, SW biomass could be converted to biofuel using thermochemical/chemical conversion processes.

However, the C/N molar ratio of SW was in the range of 12.3 - 13.8, which showed its inappropriateness for biological conversion routes, since anaerobic digestion/ dark fermentation requires a C/N ratio in the range of 20 - 30 for biohythane production (Kabir *et al.,* 2022b) and composting requires C/N ratio of 25 - 35 (Patwa *et al.,* 2020). The H/C_{eff} was found to be 0.43 - 0.23, which was larger than 0.2, suggesting no coke formation in thermochemical conversion process (Hossain *et al.,* 2022). The heating value of SW biomass was 15 - 17 MJ/kg, representing similar properties of an economical liquid hydrocarbon raw material. The results suggested that SW biomass could be effectively converted to biofuel using thermochemical/chemical conversion rather than biological conversion.

3.2.3 Functional group assessment

The functional group assessment based on FTIR analysis of SW biomass was presented in Figure 4. The FTIR spectrum detected the presence of C = C, C – O, N - H, C = O, C – N, and C – H stretch. The long-chain aliphatic hydrocarbon (C - H stretching) was detected by a sharp peak in the range of 2800 - 3000 cm^{-1}. Islam *et al.* (2022) also observed the similar peak of C - H stretching at the range and representing the lipid fraction of SW. The spectra peaks of the 1400 - 1700 cm^{-1} range indicated the amide I (C = O stretching), amide II (N - H bending), and amide III components of protein fraction. Hossain *et al.* (2022) investigated the FTIR spectrum of microalgae and peat biomass and suggested that these peak ranges represent the protein fraction of biomass. The carbohydrate content in SW biomass could be identified by C - O stretching (850 - 1200 cm^{-1}). The medium peak in the range of 1400 - 1450 cm^{-1} indicated the presence of lignin fraction in SW biomass. Figure 4 suggested that SW biomass had the necessary spectra bands for thermochemical conversion to biofuel.

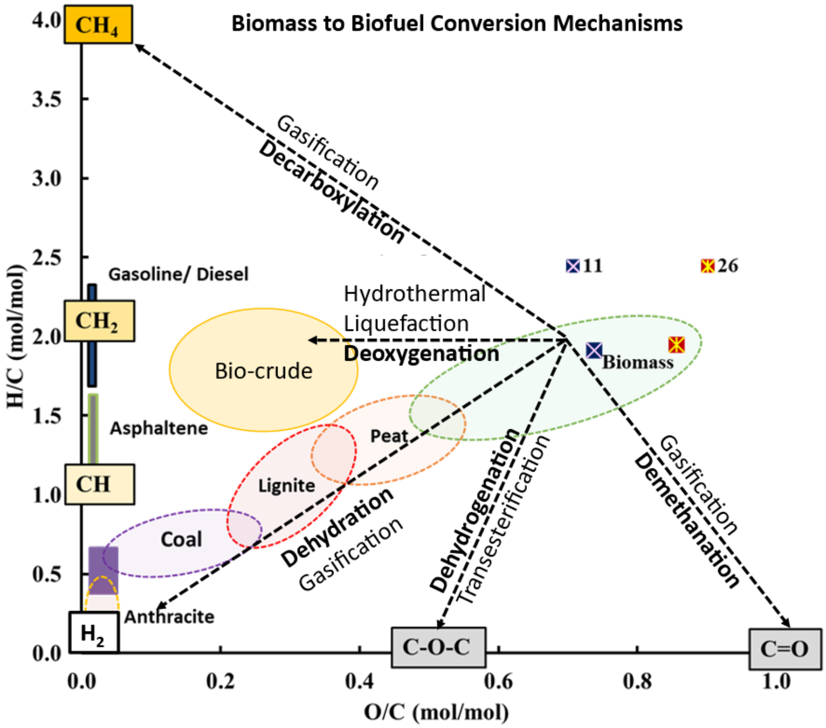

Figure 3. van Krevelen diagram of solid wastes to biofuel

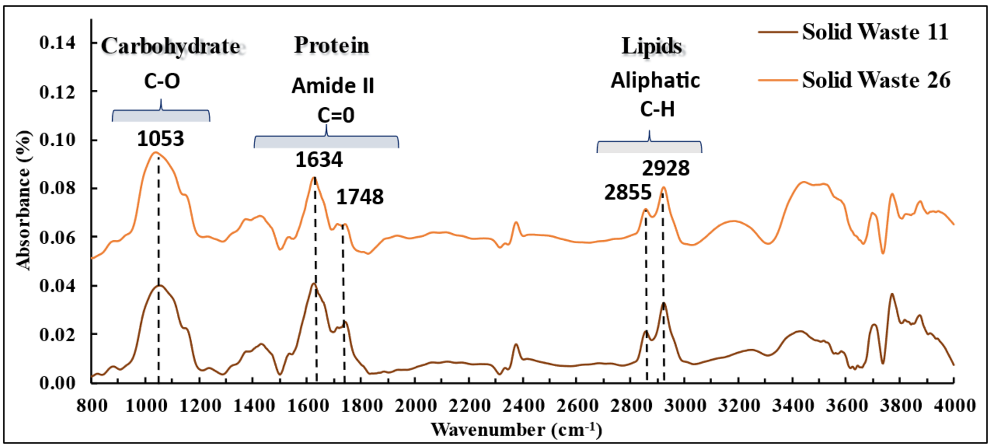

Figure 4. FTIR analysis of solid waste biomass

4. Conclusion

Mounting land scarcity issue around the world including Bangladesh highlights the waste-to-energy strategy for MSW management in urban areas as a promising option, not only for the minimization of land pressure but also for the generation of energy and green jobs. Comprehensive data of waste generation and detailed waste characterization creates awareness among the stakeholders including policy makers and organizations responsible for waste management. The MSW management in Dhaka North City Corporation is in a crisis due to an enormous average waste generation rate of around 1500 tonnes/km^2. This organic feedstock might be utilized as a resource by biofuel conversion. The findings of SW's higher carbohydrate and moderate protein-lipid content as well as the H/C (1.91 - 1.94) and O/C (0.73 - 0.85) molar ratios indicated high potentiality of SW as a suitable biomass for biofuel conversion. The SW biomass demonstrated lower NO_x and SO_x emission during combustion due to low nitrogen and sulphur content and the heating value represented desirable properties for thermochemical conversion.

The traditional waste disposal system is failing to provide a cleaner city to the citizens of Dhaka. The challenge to achieve SDGs is to make the existing system smarter and more efficient with economic returns. Thus, the integrated approach of combining thermochemical conversion of MSW could be the optimum strategy of a double-edge solution for both waste reduction and renewable bioenergy production in Bangladesh. A long-term or year-round data would have been ideal as generation of MSW depends on seasonal variation, geographical location, population density, socio-economic conditions, cultural practices and waste management systems. Even though solid waste generation rates and properties vary both spatially and temporally, the results of this study would be beneficial for future research to understand the nature of MSW generation at densely populated urban region (Dhaka city) with distinctive seasons. Such an approach might be applicable to any other landfill in the world prior to proper characterization of the solid wastes and calibration of the maturity assessment of kerogen and petroleum products through van Krevelen diagram.

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