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Quantification and Characterization of Municipal Solid Waste as a Measure Towards Effective Waste Management in Metu Town, South-West Ethiopia

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Abstract

For effective planning and development of waste management systems for cities, proper quantification and characterization of the municipal solid waste are essential. The objective of this study was to determine the composition and generation rate of household, commercials and institutions solid waste in Metu town as a measure towards effective waste management. Total daily municipal solid waste generated from the town was estimated to be 35,649 kg, among it more than 83% of the waste generated from households, 16% from commercials area and the rest from institutions. The per capita daily solid waste generation for households was 0.378 ± 0.05 kg/cap/day, commercials area and institutions were found to be 0.024 ± 0.01 kg/floor area/day and 0.14 ± 0.05 kg/employee/day, respectively. The Physical characterization showed that biodegradable waste, plastic, paper and cardboard, textile, leather, rubber, wood scrap, sanitary product and metal waste were the constituents of all waste samples in the study area, but in varying proportions. The composition analysis of municipal solid waste showed that more than 50% by weight was biodegradable/organic waste which is valuable resource for recycling in the form of organic fertilizer. Whereas, 25% of waste generated from the town can be recycled at generation level. The calorific/energy value of municipal solid waste revealed that 3,305 kcal/kg for paper and cardboard waste, and 3,819.33 kcal/kg for wood scrap waste which revealed the suitability of the Metu town municipal solid waste as energy recovery option. From the result of this study it can be concluded that, higher biodegradable solid waste and good calorific value of the solid wastes generated in the town the town municipality can recover this waste by introducing an integrated urban agriculture that might convert this waste to organic fertilizer through composting and waste to energy conversion can be an attractive urban waste management option and source of energy as an alternative to fossil-based fuels.

Keywords

Characterization • Energy potential • Quantification • Municipal solid waste

Introduction

Population increase, rapid urbanization, booming economy, and the rise in the standard of living in developing countries have greatly accelerated the rate, amount and quality of the municipal solid waste generation. Solid waste is inextricably linked to urbanization and economic development, a mammoth amount of waste being generated from various sources across the globe and estimated to reach 4.3 billion urban residents generating about 1.42 kg/capita/day of municipal solid waste by the year 2025. The quantity and the composition of the municipal solid waste are critical for the determination of the appropriate handling and management of the wastes [1]. Such information is essential and useful to put up the solid waste to energy conversion facility within the municipality. But, urban waste mostly ends up at dumping locations within or outside the city in developing countries. As a consequence, the Solid Waste Management System (SWMS) needs to be updated to suit the waste quality, quantity and composition. Conventional solid waste management focuses largely on waste collection and disposal (landfills). Only limited attempts are made to adopt integrated waste management practices that involve waste reduction at the source, resource recovery and recycling [2]. As a result, many cities in developing countries are facing environmental and health risks while losing economic opportunities in terms of the resource value of the waste. Municipal solid wastes, collected from cities, have recently thought as one of the important renewable energy resources. Recovering energy by means of a number of energy generation processes such as combustion, pyrolysis and gasification from municipal solid waste is feasible[3].This method will reduce the quantity of incoming solid waste to dumping site and also open opportunities for new technologies in treating MSW. The first step to understand the feasibility of centralized composting and energy conversion (gasification and incineration plan) is to obtain the basic data regarding to quantity and quality of generated MSW [4]. The study aims to determine the waste compositions and characteristics at Metu town as a measure towards effective waste management.

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Materials and Methods

Study area

This study was conducted at Metu town, south-western Ethiopia. Metu town is located 590 kms south west of Addis Ababa [5]. The town is located at latitude and longitude of 8°18′N 35°35′E and an altitude of 1605 meters. The town is divided in to 3 sub-cities (kebeles). According to data obtained from housing development section and municipality of the town, there were about 10,235 households, 1,557 commercial establishments and 32 institutions.

Household sampling technique and sample size

Metu town administration has three kebeles and 11,824 housing units. All kebeles were selected for this study [6]. The required sample size was calculated using sampling ratio of 0.013 (13 housing units per 1,000 housing units) at a standard error of 5% indicated in Nordtest method. Sample size was proportionally allocated for the three selected study kebeles. For this study, waste sample was collected from 137 households, 32 commercials and 17 institutions [7]. Individual housing units that participated in the study were drawn by systematic random sampling method. Sample of the generated solid waste data was collected from all sampling areas once a day at a fixed time for seven consecutive days in two seasons namely: dry (January), and rainy (July) seasons.

Data collection procedure

Direct sampling, sorting, weighting and quartering of wastes from the study households, commercials and institutions were conducted for one week in two seasons, but one day before the actual sample collection period solid waste in the sample housing units were collected and discarded assuming that it was composite of waste stored for more than one day [8]. For each study units waste collection bags were given labelled with its house code to store their generated solid waste on it, adult person from each study unit was asked to participate in the study then he/she asked to answer the questions of study questionnaire/checklist and give him/her the structures regarding the storage and handling of their solid waste samples and they were strictly advised to put all their generated solid waste in distributed bag every day during the study period. Sample collectors were properly trained on sample collection, sorting [9], weighting and registration and after a week sample collectors brought the samples to the strategically selected working site.

The sorting site was prepared and arranged to make all sorting and analysis activities easily achieved. Plastic sheet was used to cover ground of sorting site, digital scale was used to weighing solid waste samples, specific plastic container was used to measure solid waste volume, plastic bins were used to sort waste categories [10]. Well trained Health extension workers were responsible of sorting site management and supervision, data registration, and safety measurement implementation, twelve trained technical workers participated in solid waste analysis and manual segregation activities.

The solid waste samples which were collected in first day were excluded to ensure that the analyzed samples were not affected by accumulation of solid waste from the prior days before starting of the study [11], solid waste samples of a week (seven consecutive days) were analyzed and segregated into its main components. The total solid waste samples which were arrived to sorting site and analyzed were 357 samples.

Solid waste samples of each households [12], commercials and institutions were analyzed, every sample weighed (in kg) by digital scale its maximum capacity is 50 kg and the weight of solid waste registered using reference data sheet, then all collected samples were subjected to volume measurement and registered, the solid waste volume and corresponding weight were registered in reference data sheet to calculate solid waste density. After volume measurement solid waste was subjected to manual segregation into main components such as biodegradable, plastic, paper, metals, textile, leather and rubber, sanitary products, hazardous waste, wood scraps, complex products, glass, inert, fines and miscellaneous. Every solid waste category was weighed and registered using reference data sheet [13]. Homogenized samples with appropriate sampling, handling and transportation mechanism were taken to laboratory for proximate analysis and calorific value determination.

All samples analysis procedure and activities were implemented according to standards data sheets which are recommended by used to register information regarding solid waste weight, volume and components. Registered data were subjected to Microsoft Excel to calculate the average of solid waste generation rates, average of solid waste densities [14], and percentages of the main solid waste components.

Generation rate and physical composition (weight and volume)

Physical composition measurements were performed at the strategically selected working site. Sub-product classifications were based on the technical standard and it was modified with additional categories. Sample weight was measured by weight balance.

The physical composition (%) of each of waste components was calculated by the formula

Percentage composition of waste fraction:

Percentage of waste composition=weight of separate waste/Total of mixed waste sampled ×100

The per capita waste generation was also determined as per the mixed or the total waste collected in a day and also the separated fractions using these formulas:

Domestic waste generation rate=Weight of MSW/no. of persons in HHS8 total days

Waste generation rate=Wt of MSW/Total no. of employees × no. of days

Quartering method

Quartering was evaluated for precision and efficiency in the analysis of municipal solid waste. These were divided into four sections after cutting large pieces and mixing, and two diagonal sections are again mixed [15]. We repeat the procedures several times until solid waste weight is 100 kg to 200 kg.

Laboratory analysis

Proximate analysis: The proximate analysis, gives percent of moisture content, ash content, volatile matter and fixed carbon, were determined by putting the samples to different range of temperature (100°C to 950°C). The laboratory methods to measuring the proximate analysis of samples in this study were conducted according to ASTM standards described [16].

Moisture content (ASTM D 3173): The sample will be dried in an oven at 105°C for one hour to a constant weight. The percent MC was calculated as a percentage loss in weight before and after drying for each solid waste component.

Ash contents (ASTM D 3174): The ash content was determined by drying the samples and burning at 750°C for 1 hour in a furnace.

Volatile matter (ASTM D 3175): The dried sample will be heated at 950°C for seven minute in muffle furnace. After combustion, the samples were weighed to determine the ash dry weight, with volatile solids being the difference between the dried solids and the ash

Fixed carbon: The carbon content in the ash sample was determined by removing the mass of volatile from the original mass of the sample using the following equation: $FC = 100 - (\%MC + \%AC + \%VS)$

Where: FC is fixed carbon, MC is moisture content, AC is Ash content, VS is Volatile matter

Calorific value determination: The calorific value, expressed as kcal/kg or KJ/Kg, was determined using Bomb calorimeter (ASTM D 5865-85) in which the heat generated at a constant temperature of 25°C from the combustion of a dry sample is measured.

Results and Discussion

Generation rate and waste composition studies

The generation rate and composition of municipal solid waste varied considerably according to life style, commercial activities, population behavior and consumption patterns and economic growth rates that depend on season [17]. In the current study, generation rate and waste composition seasonal variations were statistically significant ($p \le 0.05$) (Table 1). The total municipal solid waste generated by Metu town was estimated to be 35,649 kg/day, among it more than 80% were from households, 16% from commercials or market area and less than 1% from institutions [18]. This findings was similar with several studies reported that the municipal solid waste that are generated from the developing countries are mainly from households (55% to 80%), followed by market or commercial areas (10% to 30%).

The average daily household generation rate of Metu town was 0.378 ± 0.05 kg/capita/day, this is in agree with the literature cited by Assefa and kifle [5,19], however it is contradicted with the average of solid waste per capita generation rate in Jimma town (0.56 kg/cap/day). The variation in results may be attributed to change in socio-economic, lifestyle of the people, urbanization and population growth, physical conditions and time difference. Similarly, the waste generation rate was also conducted for commercials and institutions which indicated that 0.024 ± 0.01 kg/floor area/day and 0.137 ± 0.05 kg/employee/day respectively.

The composition of waste is an essential consideration as its quantity in effective planning development of waste management systems. Biodegradable waste that include cooked or uncooked food items; food leftovers; coffee grinds; fruit and vegetables; meat and fish; pet foods; flowers; fruit and vegetable garden waste; grass cuttings; hedge trimmings; leaves; pruning; tree branches; weeds originating from domestic kitchen or commercial canteen, domestic garden or municipal park, garden, institutions comprise the largest component of Metu town municipal solid waste management stream which accounts 50.5%. Similar findings are also highlighted in several studies in the literature, showing that waste generated in Ethiopian cities as well in other developing countries contains a large percentage of biodegradable materials [20].

The products that comprise paper and paperboard wastes are newspapers, magazines, office papers, tissue paper, cigarette packages and towels, paper plates and cups, corrugated boxes, milk cartons which comprise 12.66% by weight. The high biodegradables (organics and papers) recorded in this study, 63.04%, could serve as a guide for bioconversion programmes such as biofuel production and composting. A careful segregation of this fraction can serve as raw material base for value addition of waste and a safe haven for disposal of this problematic waste [21]. Plastic products comprise 10.17% of the total municipal solid waste in Metu town this could be because of the increasing use of plastic products in packaging. Plastics are also being used as stretched HDPEs in sachet water packaging, PET bottles for bottling drinks and water, LDPEs and PS as bags.

Metals comprising 1.53% of the total municipal solid waste consists mainly of aluminum (foil), ferrous metals (iron and steel found in appliances, furniture, and corroded metal scrap, containers and packaging materials). Glass products comprise 1.15% of the total municipal solid waste and occurred primarily in the form of containers as soft drink bottles [22], bottles and jars of food, and other consumer products. Textile (occurred in discarded clothing, footwear) and rubber and leather products (occurred in bicycle tires, Leather (clothing and shoes) were found in Metu municipal solid waste stream in small amount (1.07% and 1.46% respectively). Some hazardous materials (insignificant amount) were also recognized in municipal solid waste stream of Metu town such as paint strippers, batteries and paint residues. The recyclables including plastics, textiles, metals, glass, rubber and leather on the other hand formed about 22% of the waste stream which is high enough for utilization in any recycling activity (Table 2).

Waste density and volume

The most important aspect of municipal solid waste management is the quantity of waste to be managed. This determines the size and number of functional units and equipments required for managing the waste [23]. The quantities are measured in terms of weight and volume. In this study, solid waste quantities were estimated on the basis of waste generation using the most commonly used weight volume analysis method. The density of the sampled waste in the study area was 151.55 kg/m^3. This is in agreement with values documented by Peavy, et al. which shows that none-compacted MSW densities range from 100 to 280kg/m^3 [24]. The significance of density in MSW is that it enables to decide for storage, collection, transportation of waste, and in designing of sanitary and bioreactor landfills and the managers to plan and identify the capacity of waste haulage vehicles to be used (Table 3).

Table 1. Generation of municipal solid waste from different Sector of Metu town, South-west Ethiopia.

Sector	Waste generated (kg)		
	Dry season	Wet season	Average
Total Municipal solid waste generated/day	31,492.19	39,806.19	35,649.19
Residential waste generation/day	26,437.02	33,072.40	29,754.71
Generation rate (kg/person/day)	0.345	0.412	0.378
Waste generated by commercial area/day	4,987.57	6,568.32	5,777.95
Generation rate (kg/floor area/day)	0.02	0.028	0.024
Waste generated by Institutions/day	67.6	165.47	116.54
Generation rate (kg/employee/day)	0.103	0.171	0.137

Table 2. Types of waste generated and composition of sampled municipal solid waste from Metu town, South-west Ethiopia.

		Seasonal waste generated (kg)			
S.No	Waste components	Dry	Wet	Mean ± SD	Weight (%)
1	Biodegradable/Organic waste	12,044.75	17,935.56	14,990.15 ± 4,165.43	50.38
3	Paper and Cardboard waste	3,565.88	3,970.97	3,768.43 ± 286.44	12.66
4	Plastics waste	2,773.46	3,276.05	3,024.76 ± 355.38	10.17

5	Glass waste	528.28	165.46	346.87 ± 256.55	1.17
6	Metals waste	449.04	463.28	456.16 ± 10.07	1.53
7	Textiles waste	1,452.77	661.83	1,057.3 ± 559.28	3.55
8	Sanitary products waste	396.21	430.19	413.2 ± 24.03	1.39
9	Bones waste	713.18	297.82	505.5 ± 293.7	1.7
10	Wood scraps waste	792.42	989.43	890.93 ± 139.31	2.99
11	Leather and Rubber waste	554.69	238.26	396.48 ± 223.75	1.33
12	Hazardous waste	184.9	46.33	115.61 ± 98	0.39
13	Complex products	528.28	330.91	429.6 ± 139.6	1.44
14	Inert	818.83	1,025.83	922.3 ± 146.4	3.1
15	Fines	184.9	1,373.29	779.1 ± 840.3	2.62
16	Miscellaneous	1,426.35	1,892.83	1,659.6 ± 329.9	5.58
	Total	26,413.93	33,098.05	29,755.99 ± 4726.4	100

Table 3. Average density of municipal solid waste components in Metu town, South-west Ethiopia.

Components	Weight (kg)	Volume (m^3)	Density (kg/m^3)
Biodegradable/Organic waste	14,990.15	58.64	255.63
Paper and Cardboard waste	3,768.43	16.42	229.5
Plastics waste	3,024.76	46.61	64.9
Glass waste	346.87	1.8	192.7
Metals waste	456.16	0.89	512.54
Textiles waste	1,057.30	7.45	141.92
Sanitary products waste	413.2	7.18	57.55
Bones waste	505.5	4.68	108.01
Wood scraps waste	890.93	8.62	103.36
Leather and Rubber waste	396.48	7.87	50.38
Hazardous waste	115.61	3.13	36.94
Complex products waste	429.6	5.19	82.77
Inert products	922.33	6.78	136.04
Fines products	779.1	6.67	116.81
Miscellaneous	1,659.59	14.41	115.17
Total	29,755.99	196.34	151.55

Chemical waste composition analysis

The awareness of chemical characteristics of waste helps in deciding and setting up a good waste processing and disposal facility in the city and in determination of efficiency of a waste treatment process. Proximate analysis involves determination of moisture content, volatile matter, ash content and fixed carbon of sample [25]. The analysis was performed according to ASTM method. The average value of moisture content was found to be 39.6%. High moisture content of solid waste has negative and undesirable effect on applicability of the waste for energy recovery as it adds weight to the fuel without adding to the heating value. Result from moisture content analysis directly affected by the quantity of organic waste in waste stream.

As observed, the moisture content of the municipal solid waste in Metu town varied significantly, depending on the type of material. As expected [26], biodegradable waste had the highest moisture contents (67.92%), due to their stronger water sorption ability. Other materials such as plastic waste and paper waste had contained small amounts of moisture (less than 4%), due to their hydrophobic properties. Those solid waste products which had small moisture content had higher volatile matter higher than 86%, which indicates that most of the municipal solid waste will be converted into gas or liquid products during a thermal process (Table 4).

Energy recovery potentials

Calorific value is the amount of heat generated from combustion of a unit weight of a substance [27], expressed as kcal/kg (KJ/Kg). The calorific value is determined experimentally using Bomb calorimeter in which the heat generated at a constant temperature of 25˚C from the combustion of a dry sample is measured. Since the test temperature is below the boiling point of water, the combustion water remains in the liquid state. However, during combustion the temperature of the combustion gases remains above 100˚C so that the water resulting from combustion is in the vapor state shows typical values of the residue [28]. The experimental result indicated that the energy content of the Metu town municipal solid waste were 3,290.04 kcal/kg for organic waste, 3,305.32 for paper and cardboard waste, 1,349.40 kcal/kg for bone waste and 3,819.33 kcal/kg for wood scrap waste (Table 5). The moisture contents of mixed solid waste in Metu town was found in a desirable range of important waste parameters (moisture content<45) for technical viability of energy recovery [29], the calorific value of collected solid waste indicates that it can be incinerated without providing additional fuel and revealed the suitability of Metu town combustible municipal solid waste as energy recovery option (Table 5). The results indicated that such refuse is amenable to several disposal options with less adverse impact on the environment [30]. It is well-known that MSW can be used to generate electricity and biogas, which has positive environmental implications that is reduction of greenhouse gas emissions from sanitary landfills and the replacement of highly polluting energy sources (oil, coal and natural gas).

Table 4. Average proximate analysis results of Municipal solid waste in Metu town, South-west Ethiopia.

Waste components	Moisture Content (%)	Volatile matter (%)	Fixed Carbon (%)	Ash Contents (%)
Biodegradable or Organic waste	67.82	22.46	4.87	4.85
Paper and Cardboard waste	3.81	86.11	5.27	4.81
Plastics waste	2.79	91.41	3.79	2.01
Textiles waste	11.32	66.79	14.88	7.01
Sanitary products waste	57.68	31.21	6.14	4.97
Wood scrap waste	21.64	65.48	1.14	11.74
Bone waste	3.48	67.81	6.43	22.28
Rubber and Leather waste	15.38	50.37	14.64	19.61

Table 5. Energy contents (Heat value) of selected MSW components.

Waste components	Seasonal Calorific Value (kcal/kg)		
	Dry	Wet	Average
Biodegradable or Organic waste	3,375.26	3,204.81	3,290.04
Paper and cardboard waste	3,362.54	3,248.10	3,305.32
Wood scrap waste	4,289.33	3,349.33	3,819.33
Bones	1,639.20	1,059.60	1,349.40

Conclusion

Physical characterization showed that a high organic content with combustible matter consisting of organic, paper, plastic, wood scrap, and textile waste comprised 79.95% of the total waste of Metu town municipal solid waste, suggesting that both decomposable and combustible matter is high. Estimates of the energy content of Metu town municipal solid waste were made based on Experimental heating led to an estimation of 3,290.04 kcal/kg for organic waste, 3,305.32 kcal/kg for paper and cardboard waste and 3,819.33 kcal/kg for wood scrap waste. Generally the heating value of the town municipal solid waste make it attractive feeds for clean energy production instead of fossil-based solid fuels and can be alternative to the conventional fuels partially due to their high calorific value. Therefore, the high organic content of municipal solid waste in Metu town provides a window of opportunity for municipal solid waste recycling through composting and/or biogas production through anaerobic digestion.

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