Case Study

Generation and composition of municipal solid waste: case study, extension 7, Palapye, Botswana

Moatlhodi Wise Letshwenyo[1,2] · **Dirang Kgetseyamore**[1,2]

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Abstract
The rapid population growth and industrialisation has contributed to the production of large quantities of solid wastes that should be managed properly. This study was conducted to investigate the generation and composition of solid wastes at different income levels during weekdays and weekends in a particular zone in Palapye municipality (Extension 7), Botswana. The study was conducted through sampling of wastes at source and analysis at the laboratory. In increasing order, the generation rates were 0.17 ± 0.11, 0.17 ± 0.0, 0.10 ± 0.02 and 0.08 ± 0.01 kg/capita/day in high, middle, lodge (commercial) and low income household during weekdays respectively. The corresponding generation rates during weekends were 0.38 ± 0.23, 0.34 ± 0.0, 0.22 ± 0.0 and 0.27 ± 0.21 kg/capita/day, respectively. Food wastes represented the highest composition and in decreasing order was 48.4 ± 24.6, 68.1, 59.4 ± 2.47, and 51.8 ± 5.1% respectively, during weekdays. The corresponding composition during weekends was 73.8 ± 25.7, 86.4, 62.6 ± 39.8 and 49.8%, respectively. The densities of the wastes were 383.5 ± 213, 493.8 ± 454, 580.9 ± 436, and 431 ± 188 kg/m^3 respectively, from high, middle, low- income households and commercial entity during weekdays. The corresponding densities during weekends were 568 ± 105, 270 ± 0.0, 352.8 ± 149 and 833 ± 0.0 kg/m^3 respectively. Indiscriminate wastes disposal were observed at the dumping site which was not controlled and therefore posing as a health hazard to both human beings, animals and the environment in general. To conclude, large quantities of wastes are generated by high income-households and more is produced during weekends with food wastes representing the highest composition. The information from the study can inform the policy makers and public health specialists to plan engineered waste management system for the town.

Keywords Generation rates · High income · Middle income · Low income · Solid wastes

1 Introduction

Rapid population increase and urbanisation has resulted in high generation and significant change in the composition of wastes [17]. Reliable data on the solid wastes generation and their composition are crucial for the decisions that have to be enforced for the proper solid waste management systems [17].Information on the amount of waste produced and the composition of waste is needed for the basic planning, operation and informed decisions on the management systems of solid wastes [1]. If not properly managed, the wastes have long term environmental degradation for both human beings and the environment [6]. Guermoud et al. [6] conducted a study and reported the average composition of municipal solid waste as 64.6, 15.9, 10.5, 2.8, 1.9, 2.3, and 2% organic matter, paper-cardboard, plastic, glass, textile, and diverse wastes respectively. Different solid wastes generation rates have been reported, for instance, in 2003, average generation rate in Malaysia was 0.5–0.8 kg/capita/day [13] with a reported forecasted

✉ Moatlhodi Wise Letshwenyo, letshwenyom@biust.ac.bw; Dirang Kgetseyamore, dirang.kgetseyamore@studentmail.biust.ac.bw
| [1]Faculty of Engineering and Technology, Botswana International University of Science and Technology, Private Bag 16, Palapye, Botswana. [2]Department of Civil and Environmental Engineering, Botswana International University of Science and Technology, Private Bag 16, Palapye, Botswana.

increase by 2020. Solid waste generation rate has been conducted in different cities and for instance, rates between 0.22 and 0.66 kg/capita/day have been reported in India [12].

In some areas, solid wastes are collected and then disposed of in areas that are not engineered sanitary landfills but just dumping sites [10], leaving the wastes uncovered due to lack of equipment and engineering aspect of a landfill. Yukalang et al. [21] conducted a research on obstacles to successful municipal solid waste management in a rapidly urbanising area in Thailand. Indiscriminate waste dumping was observed along roadways, and even at landfills where the wastes were left open without any covers. Lack of equipment such as weigh bridges at landfills has been reported as one of the factors that contribute to unavailability of data such as generation rate in some countries (Gidarakos et al. 2006).

Few studies have been conducted on the generation rates and composition of wastes at different income levels for differing households. For instance, Gomez et al. [7] conducted a study on solid waste generation in three categories of income levels in Mexico and observed an increase in waste generation as income level increased. It has been reported by Gupta et al. [9] that factors that influence quantity and composition of wastes include average income level, sources of wastes, population, social behaviour, climate, industrial production and market for waste materials. Such factors must be considered during these studies. Similarly, Gallardo et al. [5] conducted a study on the analysis of waste selective collection at drop-off systems and observed varying compositions of the wastes during different study periods and zones of the area.

The purpose of this study was to determine the generation rates and composition of solid wastes from households of different income levels during weekdays and weekends at extension 7, Palapye in Botswana. A similar study was previously conducted in the same town at a different location (Extension 4) and different distributions or proportions of households of income status [3]. The findings of the study can be used by policy makers and public health experts in the area for planning an engineered solid waste management system which includes disposal option. Currently there is no engineered solid waste management system in the area and this poses as a health hazard to human health and the environment at large.

The paper is organised in such a way that the Materials and methods section describes the materials that were used and how they were prepared. The experimental methods that were used are explained and also how the analysis of the results was conducted. The next section presents the results and discussions of the study and their significance, and compares them to previous studies and the key features are explained. The results are presented in tables and figures and the data is in tables and figures is referred to. The overall knowledge contribution of the paper has been spelled under the section. The last section concludes the study and it is the last section and it is a take home of the study. Under the section, the most important results and their consequences are drawn together.

2 Materials and methods

2.1 Study area

This research was conducted at extension 7 suburb in Palapye, a town in Botswana situated about halfway between Francistown and Gaborone. The population of Palapye was 36,211 during 2011 population census and its geographic location is at latitude – 22˚33′00″ and longitude 27˚08′00″ at elevation 919 m and average annual daily temperature for the area is 29.25˚C ± 3.7˚C and average annual night temperature is 12.58˚C ± 4.5˚C. The wind blows from Easterly to Westerly direction at 6 km/hour.

2.2 Sampling

Households were first categorised into high, middle and low income status (Table 1) as per Miezah et al. [14]. This was also the same protocol adopted by Dikole and Letshwenyo, [3] at a different location (Extension 4) in the same town. There were 10 houses sampled from each level of

Table 1 Protocol for classifying households according to income level [14]

Low income	Middle income	High income
Mostly tenants	Both tenants and owners	Occupants own house
Low population density	Middle population density	High population density
Unreliable electricity	Unreliable electricity sometimes	Reliable electricity
Poor community layout	Normal community layout	Good community layout
Poor water supply	Unreliable water supply	Potable water supply
Poor security	Moderate security	High level security
Poor road and drainage systems	Average road and drainage systems	Good road and drainage systems

income household. Storage containers were provided for each house sampled. Waste bags were collected on a weekly basis on Fridays for wastes generated during weekdays and Mondays for wastes generated during weekends. After collection, the wastes were prepared at the university laboratory for physical analysis that included composition and generation rates. The wastes were separated into different categories such as plastics, glass, food, paper and cardboard, textile, yard waste, and tin. Each category was then compacted and placed into a calibrated 5 L bucket of known mass to measure volume and then placed onto an electronic scale to measure the mass of the wastes.

The per capita waste generation of each household was calculated as follows:

$$\frac{\text{Mass of wastes generated (kg)}}{\text{Number of peopl e} \times \text{number of days}} \quad (1)$$

The density of the sample was determined as per the following equation:

$$\frac{\text{Mass of the sample (kg)}}{\text{Volume occupied by sample } \left(\text{m}^3\right)} \quad (2)$$

The percent composition of the waste fraction was determined as per the equation below:

$$\text{waste composition (\%)} = \frac{\text{Mass of wastefraction (kg)}}{\text{Total mass of the waste (kg)}} \times 100\% \quad (3)$$

3 Results and discussion

3.1 Generation rate

Figure 1 shows the average generation rates of solid wastes from each household and commercial place during weekdays and weekends. In increasing order, the generation rates were 0.17 ± 0.11, 0.17 ± 0.0, 0.10 ± 0.02 and 0.08 ± 0.01 kg/capita/day for high, middle, lodge (commercial) and low income households during weekdays respectively. The corresponding generation rates during weekends were 0.38 ± 0.23, 0.34 ± 0.0, 0.22 ± 0.0 and 0.27 ± 0.21 kg/capita/day respectively. The results indicate an increase in generation rates during weekends with high, middle, low income and lodge increasing by 124, 100, 120 and 238% respectively. All the increases were over 100% indicating that more wastes are generated during weekends. The results also reveal a significant difference between weekdays and weekends generation rates ($P = 0.002$). This might be because people spend most of their times at work during weekdays and during weekends that is when people do shopping, and some

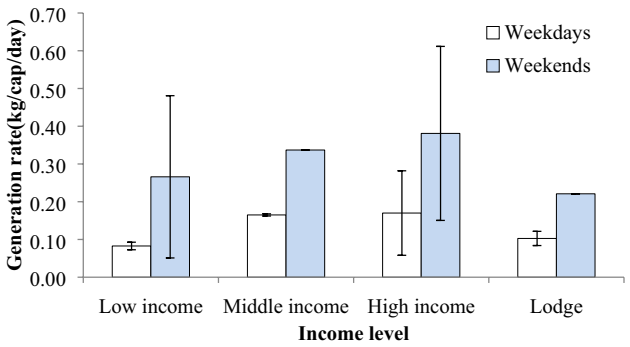

Fig. 1 Solid waste generation rates for different households during different times of the week

visit their families. The other reason could be due to social activities conducted during weekends such as partying, funeral services, and weddings and other social gatherings. A similar study conducted in a different location [3] observed generation rates of 0.104 ± 0.03, 0.09 ± 0.07 and 0.114 ± 0.0 kg/capita/day respectively for high, middle and low income households during weekdays. The generation rates were in contrast to the findings of this study and this might have been due to differing economic status and social interests. The corresponding weekend generation rates observed by the same authors were 0.364 ± 0.143, 0.177 ± 0.03 and 0.038 ± 0.0 kg/capita/day. Though the generation rates between the two locations in the same town differed, it was true that more wastes are generated during weekends.

The other observation was that, high and middle-income households generated large quantities of wastes followed by lodge and low-income households during weekdays. However, it was observed that during weekends, high-income households still generated a large quantity of wastes followed by middle income, low income and commercial place being the last. This can be attributed to purchase power as residents of high income households have enough money to spend than middle and low income groups. As for the lodges, people go there just to spend the night and do less shopping as they are catered for, especially food in the lodge. Usually people use lodges for spending the night during conferences, workshops, meetings or just as a stopover, hence less wastes generated. The findings for the lodge compare to the finding by Diaz-farina et al. [2] who observed generation rates of 0.28 kg/bed within a hotel accommodation in Tenerife, Spain. Gu et al. [8] have reported the largest quantity of wastes during weekends with 0.2912 kg/cap/day and 0.2936 kg/cap/day generated respectively, on Saturdays and Sundays, and the results are similar to the findings of this study. This was attributed to people going for shopping during weekends. The same was observed

by Owamah et al. [15] who reported that more wastes are generated during weekends than weekdays, which was the same as the findings of this study. The generation rate in this study is lower than 0.61 kg/capita/day reported for Mostaganem city in Algeria by Guermoud et al. [6] which was 1.60 times higher than the generation rate for high income households during weekend for this study. Since this study was conducted in a particular area in a town, not a city, this might be the reason for the difference. People in a city will have high income to spend and consume more hence large quantities of wastes generated.

The results are comparable to the average generation rate of 0.259 kg/capita/day for 12 rural communities in Iran reported by Taghipour et al. [18]. However, the generation rate for each of the 12 areas studied ranged from 0.248 to 0.750 ± 0.18 kg/capita/day suggesting that other factors such as season of the year, and geographic location could have influenced generation rates in the study areas. The findings are also comparable to that reported by Miezah et al. [14] of 0.2 to 0.8 kg/person/day in Ghana. The same study conducted by Miezah et al. [14] observed that high income households generated large quantity of wastes followed by middle-income and lastly by low income group. A study conducted by Jadoon and Adila [11] observed that for all income levels, the generation of solid wastes was high for wastes collected on Mondays, which was the wastes generated during weekends as a result of social activities taking place during weekends. It can be concluded that sampling an area in a town to determine the generation of wastes can give reliable results which can be used in the planning for waste management. Moreover, studying the generation of different income levels as well as differentiating wastes generated during weekdays and weekends can help in planning for waste storage, transportation, on-site handling and disposal of these wastes.

3.2 Solid waste composition

Knowing the composition of the wastes generated is a significant factor that can help in coming up with the best methods of recycling, reuse, processing, storage, transportation and final disposal options [18]. The average composition by mass of wastes from low-income households during weekdays and weekend are shown in Fig. 2. In a descending order, the average composition was food (48.4 ± 24.6), tin (29.9 ± 7.8), glass (20.1 ± 6.9), yard (19.0 ± 0), paper-cardboard (17.7 ± 23.8), plastic (11.4 ± 14.5) and textile wastes (0.0) % during weekdays. The corresponding average composition during weekends was 73.8 ± 25.7, 17.2 ± 0, 0, 0, 9.4 ± 0, 10.7 ± 10.0 and 0% respectively. These results show an increase by 52% for food wastes, 42.5% decrease for tin, 100% decrease for glass and yard wastes, 17.5% decrease of paper-cardboard, and 100% increase for plastic and non for textile wastes.

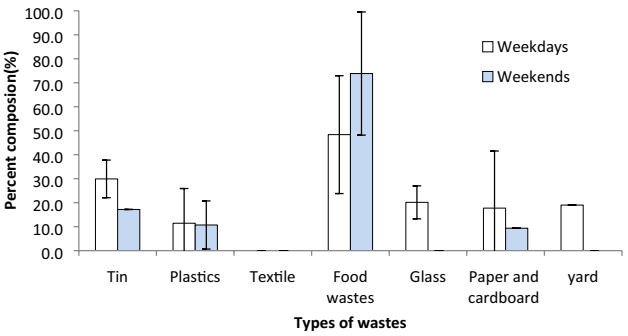

Fig. 2 Composition of solid wastes from low-income households generated during the different times of the week

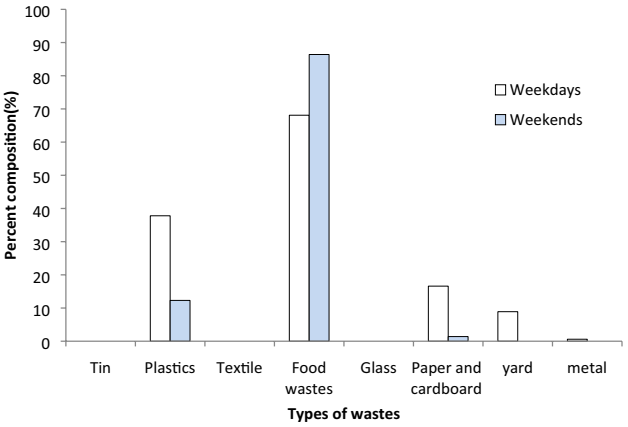

Fig. 3 Composition of solid wastes from middle-income households at different times of the week

The average composition of wastes from middle-income households was 68.1, 37.8, 16.6, 8.9, 0.60, 0, 0 and 0% respectively during weekdays, for food, plastics, paper-cardboard, yard, metals, glass, textile and tin Fig. 3. The corresponding compositions during weekends were 86.4, 12.3, 1.4, 0, 0, 0, 0 and 0% respectively. The compositions were either increasing or decreasing. Observed increase was 26.9% for food wastes, but all the other showed decreases in composition by 67.5, 91.6, 100, 100 and 0% for plastics, paper/cardboard, yard wastes, metals and the rest respectively.

Solid wastes composition from high-income households were decreasing from 59.4 ± 2.47, 32.2 ± 26.81, 11.6 ± 1.15, 9.6 ± 4.29, 2.3 ± 0.44 and 0.5 ± 0% for food, glass, paper/cardboard, plastics, tin and textile wastes, respectively during weekdays (Fig. 4). The corresponding composition during weekends was 62.6 ± 39.8, 25.3 ± 0, 10.6 ± 1.5, 7.3 ± 0.5, 7.0 ± 2.7 and 0.0%, respectively. Increases by 5.4 and 204% were observed in the case of

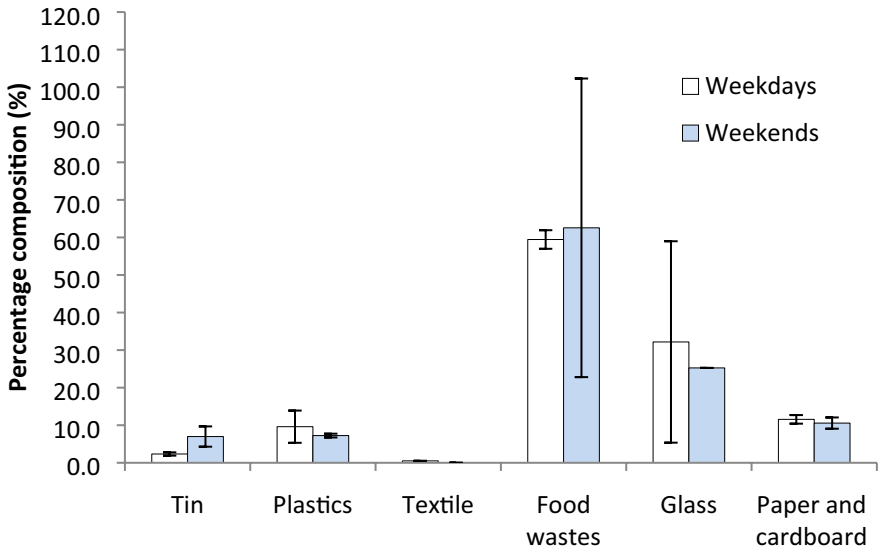

Fig. 4 Solid wastes composition from high-income households generated during the different times of the week

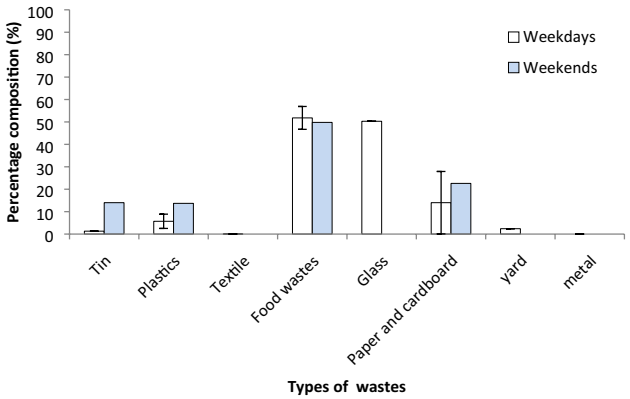

Fig. 5 Composition of wastes from lodge generated during weekdays and weekends

food and tin wastes, respectively. The observed decreases were 21.4, 8.6, 24 and 100% in the case of glass, paper/cardboard, plastic and textile wastes, respectively.

The average composition of the wastes generated from commercial entity (lodge) during weekdays was 51.8 ± 5.1, 50.3 ± 0.0, 14 ± 13.9, 5.7 ± 3.2, 2.4 ± 0, 1.3 ± 0, and 0.03 ± 0 and 0 ± 0%, respectively for food, glass, paper/cardboard, plastics, yard, tin, textile and metals. The corresponding average composition of wastes generated during weekends were 49.8, 0.0, 22.6, 13.7, 0.0, 14.0, 0.0, 0.0 and 0%. The results indicate that food wastes are generated in large quantity even during weekends followed by paper and plastic wastes. These results suggest that food is cooked in large quantities resulting in wastage (Fig. 5).

The results have revealed that for all the categories of income levels studied during weekdays and weekends, there is a similar pattern of food wastes being generated in large quantity than other wastes. It is surprising to observe that even in low income households, large quantities of food are still thrown away as wastes. A study conducted by Edjabou et al. [4] reported a large percentage of food wastes in Danish households and explained that easy accessibility to shops determines the amount of food that households purchase. Those leaving far from shopping areas will buy large quantities than those leaving near shopping areas. This might be the same reason for high food wastage in this study as the nearest shopping mall was almost 5 km away, hence the need to drive there. A similar study conducted by Gidarakos et al. (2006) in Greece reported food waste composition of 39.15%, followed by paper and plastic wastes at 19.94 and 16.85% respectively. Similarly, Palanivel and Sulaiman, [17] observed similar results where it was reported that food wastes during winter and summer represented the highest composition of organic wastes in a study conducted in Muscat, Sultanate of Oman. This was comparable to this study, except that glass and tin wastes were also found to occupy higher percentages. Papers and plastics are normally used for packaging, hence the observed high percentages.

The high percentages of wastes such as recyclables including paper, plastics, glasses and tins suggest that reuse and recycling is poorly practiced in the area. A similar study conducted in Malaysia observed that food, paper and plastic wastes occupy 80% of the wastes which is almost similar to the observation in this study where the three categories occupy over 80% of the total wastes. Except for the commercial entity, large amounts of wastes were generated during weekends than during weekdays for all the three different households. The findings are similar to a study conducted by Dikole and Letshwenyo [3] in

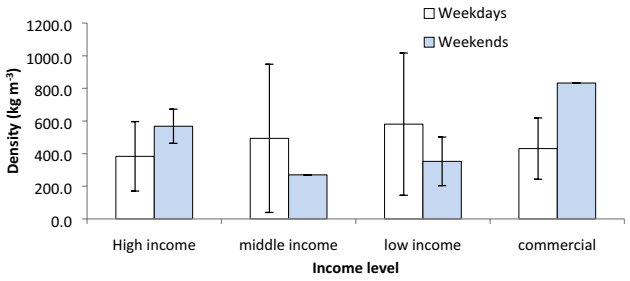

Fig. 6 Densities of the waste samples during weekdays and weekends

the same town but at different area where it was observed that recycling was rarely practised.

3.2.1 Solid wastes density

The densities of the wastes differed during weekdays and weekends for the households (Fig. 6). For high-income households, the density increased by 48.1% during the weekends, but as for middle income, the density decreased by 45.3% during weekends. The same was observed for low income households with the density decreasing by 39.3% during the weekends. However, there was an increase of 93.3% during weekends observed under commercial place. The density of the wastes is important for determining the sizes of storage facilities, the type of collection vehicle and the design of the disposal facility. High density observed for commercial area might have been due to the presence of glass, tin and yard wastes which were in significant quantity. This could be true for high income households which had significant percentages of tin and glass.

4 Solid waste management in the studied town

Currently, there is no engineered solid waste management system in place in the studied area. The Council or municipality is responsible for public health issues which includes the management of solid waste from the generation point up to the disposal of the wastes. Households in the area are responsible for the provision of storage facilities. Wastes are placed in one container which can be metal containers or polythene bags. It was evident during the study period that there is no public awareness in waste reduction, re-use, recycle and recovery which can be determined from the composition of the wastes generated [15]. Similarly, it has also been reported by Gallardo et al. [5] that the first of waste hierarchy focuses on prevention, which is followed by re-use, recycling, recovery and final waste disposal. It has been reported that in developing countries separation of solid wastes at households is seldom practised [16] similar to the findings of this study. Placing wastes in the same storage container makes it difficult for recycling since food wastes have high moisture content and this makes it difficult to retrieve wastes such as paper or cardboards.

It was found that there were a few Council vehicles for collection and transportation of wastes and these were unreliable, which lead to households engaging private trucks for waste collection and disposal to a dumping site at a monthly fee. Such private vehicles also collect wastes from commercial and industrial areas.

At the dumping site, the wastes are dumped indiscriminately, though there is a small area where the wastes are covered using soil cover (Fig. 7). Another observation was that the movement of vehicles bringing the wastes to the dumping site is not properly controlled. Though there is security provided, sometimes there is no security personnel or Council staff to direct the vehicles to unloading sites. No data is available from the authorities concerning waste management system which is crucial for any future planning.

The dumping site is an environmental hazard to the people leaving near the area. There is always fly nuisance during summer which might transmit diseases to the people. It was also observed that some people were scavenging at the dumping site, hence exposed to environmental hazards. The same was observed by Yoada et al. [20] who reported that wastes dumped indiscriminately can serve as breeding grounds for rodents and flies, hence increasing the spread of different diseases. Uncontrolled burning of wastes such as plastic and papers at the dumping site will increase the risks of air pollution by toxic gases and these have high carbon foot

Fig. 7 Indiscriminate dumping of wastes at the dumping site, the waste is not covered or compacted

print which will degrade the ozone layer, thus contributing to climate change. Some plastic wastes are blown by wind to the nearby households and roads making the environment not attractive which is not appealing to tourism, environment and is health risk to the animals and human health. Presence of plastic bags at the dumping site is a further proof that recycling or reuse is hardly practised by the local community. It has been reported that continuous indiscriminate disposal of solid waste is linked to poverty, poor governance, urbanisation, population growth, poor standard of living and low level of environmental awareness [9].

5 Conclusion

This study investigated the generation and composition of municipal solid wastes in low, middle, high income households and a commercial lodge during weekdays and weekends. It was observed that high income households generate large quantity of wastes which might be attributed to high income level. It was also found that large quantities of wastes are generated during weekends which might be due to social activities and shopping during weekends. Food wastes comprised of the large portion of the wastes which can result in high moisture content and discourage recycling since the wastes are stored in the same containers. In general, comparing composition, generation rates of wastes at different income levels can give results that can be used for solid waste management purposes since the results do not differ much from what has been observed elsewhere. The results from this study will form the basis of initial planning for an engineered solid waste management system for the town. The study did not involve the whole village, but only part of the village. In addition, the study was conducted during one season of the year, winter. It is recommended that in future the study should cover the whole village since there is no engineered solid waste management in the area. In addition, the season of the year has impact on solid waste generation, and future studies should aim at comparing waste generation during different seasons of the year. Public education is needed to sensitize the community about waste recycling and reuse at source of generation which will save the management costs and also generate income for the people. The organic fraction of the wastes was dominant and can therefore future studies can be conducted on the possibility of use as feedstock for the production of compost and biogas.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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