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QUANTIFICATION ASSESSMENT OF MUNICIPAL SOLID WASTE AS AN EVALUATION APROPOS OF SUSTAINABLE WASTE MANAGEMENT IN KUCHING

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Abstract: The quantification and characterisation of municipal solid waste are indispensables for waste management forethought. This study quantified the municipal solid wastes from three principal council areas in Kuching, the capital city of Sarawak, Malaysia which are the Kuching South City Council, Kuching North City Hall and Padawan Municipal Council to evaluate and analyse the contemporary waste trend and differentiate between the waste streams. The municipal solid waste samples are amassed directly from the source location and categorised according to the socio-economic level of the sampling location sites. This study discovered that there is no significant difference in the waste composition trend generated by the residents in different residential areas. The composition of the solid wastes was found to vary in different socio-economic categories. Organic waste is found to be the highest waste component in all socio-economic groups. The top three municipal waste compositions from the residential areas are organic wastes (61.58% *w/w*), plastics (12.06% *w/w*) and nappies/sanitary napkins (11.67% *w/w*), which ranged from 44.57% to 72.08%. This study provides a recent waste trend database with a detailed analysis of the differences between the waste streams for sustainable waste management in Kuching.

Keywords: Kuching, municipal solid waste, waste characterisation, waste management, quantification assessment.

Introduction

According to the World Bank Group (Kaza *et al.,* 2018), the rate of global waste generation is approximately 0.74 kg of waste per capita per day. An uptrend in waste generation was reported, with the global municipal solid waste production at 1.3 billion tonnes in the year 2012 increasing to 2.01 billion tonnes in the year 2016. It is expected to reach 2.59 billion tonnes in 2030. In Malaysia, the waste generated per capita per day is higher than the global municipal solid waste generation rate, which is 1.21 kg of waste per capita per day for the year 2016. With the recent rapid development of Kuching, the capital city of Sarawak, Malaysia, the rate of population has increased rapidly, thus more solid waste is generated, which will threaten the sustainable development of the city. A report by Tang (2020) revealed that 690,000 kg of municipal solid waste was generated in the city every day.

Failure to dispose waste properly and sustainably would significantly increase social and environmental problems. Social and environmental problems due to solid waste mismanagement are a worldwide challenge. For instance, open dumping and open burning of solid waste significantly increase the risk to people's health and the environment (Ferronato & Torretta, 2019). Open burning of hazardous waste may result in the emission of dioxins, furans and particulate matter (World Health Organisation, 2018). Taha *et al.* (2011) highlighted that the operation of a non-engineered landfill will contaminate underground water sources due to the leachate generated from solid waste.

The current common universal practice of treating and disposing solid waste is recycling, composting, anaerobic digestion, incineration, landfilling, open dumping and dumping in waterways. The disposal method mostly depends on the country's income level. In low-income countries, more than 90% of the solid waste is not treated and disposed through open dumping, compared with high-income countries, in which most of the solid wastes were disposed at landfills, incinerated and collected for recycling (Kaza *et al.,* 2018). It was also found that 242 million tonnes of plastic waste were generated and 1.6 billion tonnes of carbon dioxide-equivalent greenhouse gases were emitted from solid waste management systems in 2016 (Kaza *et al.,* 2018). The absence of proper solid waste management will lead to water and air pollution.

In order to increase awareness and prevent further damage to the environment, especially in low-income and developing countries, the zero-waste concept was introduced in 2002 by the Zero Waste International Alliance. Zero waste is defined as the conservation of all resources through responsible production, consumption, reuse and recovery of all products, packaging and materials without burning them and without discharges to land, water or air that threaten the environment or human health (Zero Waste International Alliance, 2018). Over the last two decades, the zero-waste hierarchy has shifted from a widely recognised 3R (Reduce, Reuse, Recycle) concept to a 7R concept, which has 4 additional elements, namely "Rethink", "Recovery", "Residuals Management" and "Regulations". The concept prioritises the conservation of natural resources to achieve the Sustainable Development Goals.

In 2016, the Solid Waste Management and Public Cleansing Corporation (2017) reported that Malaysia's recycling rate was 21% *w/w,* which is much lower than Singapore, which has a recycling rate of 59% *w/w*. To achieve sustainable development, Peninsular Malaysia implemented force recycling in 2015. Compared with Peninsular Malaysia, the recycling rate in Sarawak is even lower (National Solid Waste Management Department, 2013). Besides, there has been no municipal solid waste composition study at the local authority level (Tang, 2020). Recent and reliable data from solid waste (SW) characterisation study is required for the implementation of sustainable and zero-waste management in Sarawak. Facts on the composition of disposed wastes are crucial for the planning and decision-making of a sustainable waste management system. Efficient methods are needed to assess the effects of legislative, logistic and technical measures on the waste streams. Routine determination of waste composition and trends is essential to assess the effect of such measures (Brunner *et al.,* 2004). This study will evaluate and analyse the current waste trend and compare the differences between the selected waste streams, which prioritise recovery, recyclable opportunities and suggest new strategies for waste management forethought.

Solid Waste Composition

To achieve sustainable solid waste management in recycling and prevent waste to the energy system, waste characterisation is the first step that needs to be performed. Solid waste composition varies according to countries and it depends on government policy and socioeconomic activity of a country. Table 1 shows the global waste composition of different regions. The waste composition varies according to the country's development status. The organic waste composition is decreased in more developed countries, such as the United States of America and European countries. Developed countries generate less food waste, but more paper waste in terms of solid waste composition as shown in Table 1.

Table 1: Waste composition in different regions (Kaza *et al.,* 2018)

Region	Waste Composition (% *w/w*)							
	Organic Food	Glass	Metal	Paper	Plastic	Rubber	Wood	Others
East Asia	53	2.6	3	15	12	<1	2	12
South Asia	57	4	3	10	8	2	1	15
Europe and Central Asia	36	8	3	18.6	11.5	<1	1.6	21
Latin America and the Caribbean	52	4	3	13	12	<1	<1	15
Middle East and North Africa	58	3	3	13	12	2	1	8
North American	28	4.5	9.3	28	12	9	5.6	3.6

The National Solid Waste Management Department of Malaysia under the Ministry of Housing and Local Government has disclosed the solid waste composition, characteristics and existing practice of solid waste recycling in the country from September 2011 to September 2012 (National Solid Waste Management Department, 2013). Few research studies on waste composition have been carried out in Malaysia as shown in Table 2. Similar to the data on global waste composition, organic waste makes up most of the waste composition in all the studies.

Current Practices of Solid Waste Management

The Solid Waste and Public Cleansing Management Act 2007 (Act 672) has been enforced and implemented in Malaysia since September 2011. The act clearly defines solid waste as any scrap material or other unwanted surplus substance or rejected product arising from the application of any process and any substance required to be disposed of as being broken, worn out, contaminated or otherwise spoiled. In a solid waste management system, waste is typically divided into four main groups:

Table 2: Waste composition in Malaysia

Location	Waste Percentages (% *w/w*)							
	Organic Waste	Paper	Plastic	Metal	Glass	Textiles	Hazardous Waste	Others
Taman University, Johor*	64.5	9	14.5	1	2.5	0.5	-	8
Kampung Kuala Pansun, Selangor**	48.4	14.5	21.6	5.6	2.7	2.1	0.9	4
Malaysia***	56	13	19	3	2	4	-	3
Malaysia (survey)****	51.7	8.5	13.2	2.7	3.3	3.1	1.3	16.2

*(Kadir & Sani, 2016)
**(Mohamad Sabri, 2015)
***(Agamuthu, 2009, as cited in Agamuthu & Fauziah, 2010)
****(National Solid Waste Management Department, 2013)

(1) Municipal waste which includes household waste, commercial waste and demolition waste, (2) hazardous waste which includes industrial waste, (3) biomedical waste which includes clinical waste and (4) particular hazardous waste, which includes radioactive waste, explosive waste and electronic waste (e-waste).

In the solid waste management hierarchy, the disposal of waste is always the last option. In developed countries such as Germany, a landfill ban is implemented for untreated municipal solid waste from June 1, 2005. Instead of sending solid wastes to landfills, they are reused, recycled or incinerated to generate energy. In 2015, 14% of the raw materials used by German industries are recovered from waste (Nelles *et al.,* 2016).

According to the World Bank Group (Kaza *et al.,* 2018), an average of 40% of solid waste is disposed of in landfills. In Kuching, approximately 80 per cent of solid waste is disposed of in landfills, which is twice the amount of global landfill waste. Another portion of municipal solid waste is disposed through open dumping or open burning and part of it is extracted for recycling. The results of the findings indicated that the recycling activity in the city is not fully optimised.

Social-economic Parameter

Generally, waste composition varies according to socioeconomic grouping, as well as commercial and industrial activities (Kaza *et al.,* 2018). The same trend was observed in Kuala Lumpur, the capital of Malaysia, as shown in Figure 1 (Kathirvale *et al.,* 2004). Similar to the global solid waste composition trend, the organic waste composition increases when the income level decreases.

Commercial Solid Waste

According to a report by the National Solid Waste Management Department (2013), the average commercial waste composition is different from the household solid waste and it contains more recyclable items. The waste composition is summarised in Figure 2.

The commercial solid waste composition is dependent on business activities. For instance, the market area is expected to generate more organic waste, whereas logistic companies usually generate more paper and plastic wastes.

Towards a Sustainable Solid Waste Management Plan

Although a number of waste composition studies have been carried out in Malaysia, most of the studies were carried out through surveys, which

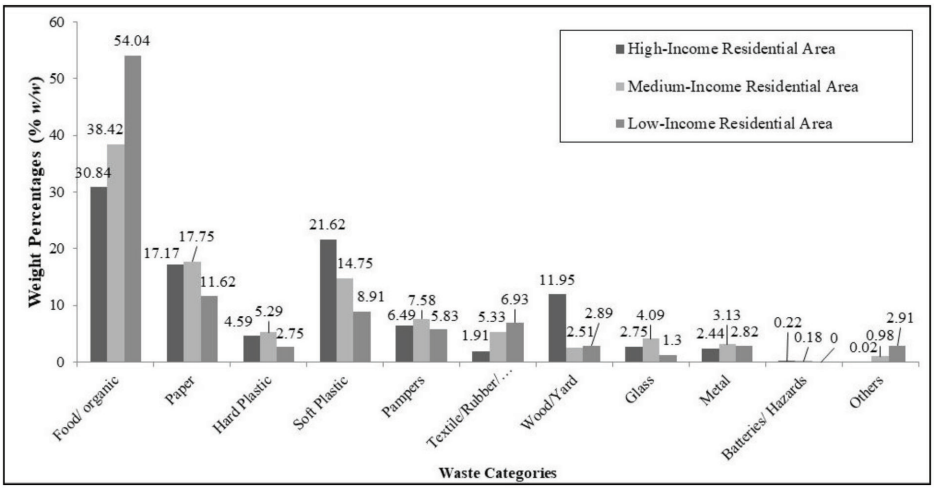

Figure l: Waste composition in Kuala Lumpur (Kathirvale *et al.,* 2004)

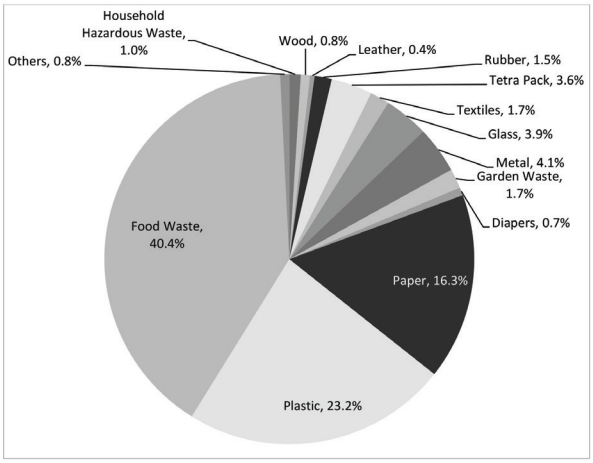

Figure 2: Commercial waste composition (National Solid Waste Management Department, 2013)

may not represent real conditions. Furthermore, there has been no recent waste composition study at the local authority level in Kuching. In line with the recent global digitalisation trend, at the local scene, the Sarawak Multimedia Authority and Sarawak Digital Economy Corporation are spearheading the digital economy initiatives which were put in full force in 2018 through the Sarawak Digital Economy Strategy 2018-2022. As businesses conducted through digital platforms gain popularity, the lifestyle of residents in Kuching has changed drastically. Thus, this study observed the changes in the solid waste composition trend. With the latest characterisation and quantification of municipal solid waste, a more effective solid waste management plan can be developed to achieve sustainable development in the city.

Materials and Methods

Study Area

This study focused on three principal council areas of Kuching, the capital city of Sarawak, which are the Kuching South City Council, Kuching North City Hall and Padawan Municipal Council, with a population of 711,500 in 2020, according to the Department of Statistics Malaysia. The solid wastes were collected by Trienekens Sarawak twice a week and transferred to a landfill at the Kuching Integrated Waste Management Park. A total of 19 sampling points involving different socioeconomic levels and commercial groups in Kuching were selected for this study. The details on the selected sampling locations are shown in Table 3 and Figure 3. Table 3 summarises the collection areas with the description of the sampling locations. Figure 3 illustrates the locality of the sampling locations on a map. The category of the area is presumed according to the value and type of the houses and the nature of the activities in the area. The income levels of the households are categorised based on the types of houses and the market value of the properties.

Table 3: Details of the sampling locations

Sampling Numbers	Category
1.	Low-income residential area
2.	Medium-income residential area
3.	High-income residential area
4.	Condominium
5.	Low-cost apartment and flat
6.	Dayak village
7.	Malay village
8.	Chinese commercial area
9.	Malay commercial area
10.	Shopping mall
11.	Malay market

12.	Chinese market
13.	Government office
14.	Petrol station
15.	Public hospital
16.	Private hospital
17.	School
18.	Private university
19.	Hotel

Equipment and Materials for Waste Sorting

The solid waste samples were collected from the predefined areas (Table 3) in a 1,000 L communal bin. If the sample collected was more than 136 kg, it was mixed homogenously and reduced by using a shovel. A calibrated platform scale with a capacity of 150 kg was used to weigh the solid waste samples. The sorted items are placed into a plastic bag for weighing purposes. Vinyl gloves, safety shoes, dust masks and safety glasses were used as personal protective equipment throughout the whole sorting process.

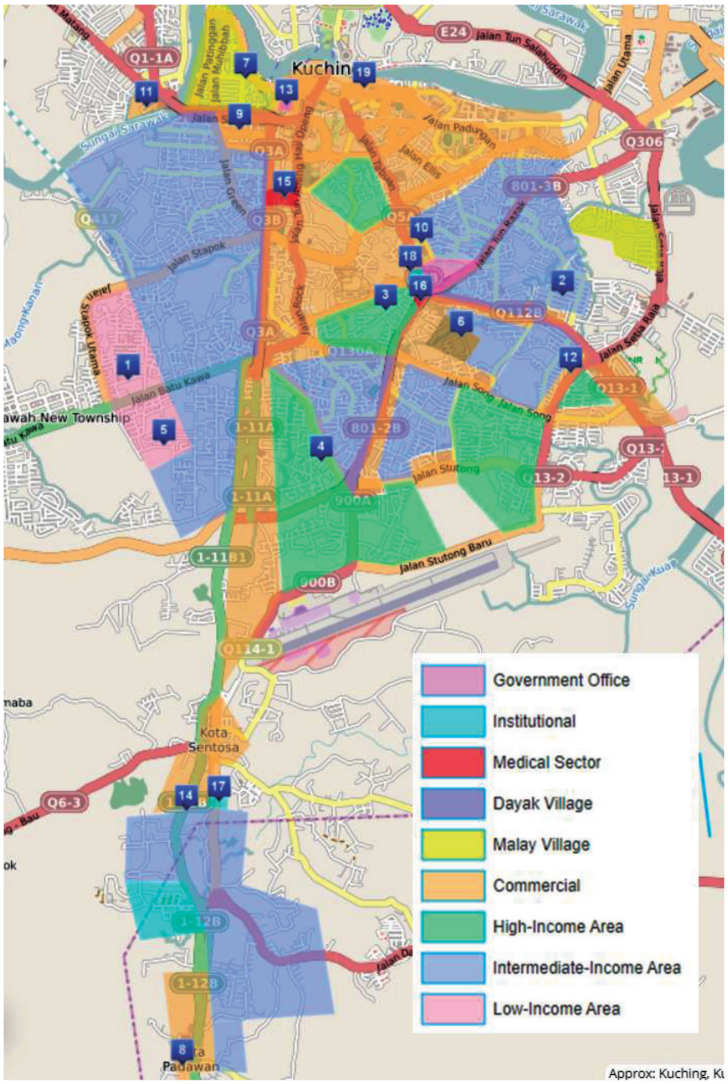

Figure 3: Locality of the sampling locations according to the sampling numbers

Methodology

The sampling for this study was conducted on site, instead of from the collection truck as the solid waste generated from different groups is mixed in the collection truck. Furthermore, the solid waste sampled from the truck could not represent the pre-selected group accurately. About 0.5 m^3 of solid waste was sampled from the 1,000 L communal bin at each selected area. It is assumed that the sample in the communal bin represents the solid waste generated by the residents in the selected area, with similar daily lifestyles and activities. The samples were collected and stored in the 1,000 L communal bin and transferred to the Kuching Integrated Waste Management Park for the sorting process. The samples were weighed using a platform scale (Ishida, MTX-150) with a capacity of 150 kg. The samples were manually sorted into plastic bags according to the pre-selected categories. The sorted samples in plastic bags were weighed and the weight of the plastic bags was deducted before they were recorded in a sampling sheet. The sampling process was repeated a minimum of four times for the same location. The same method was used for all the predefined areas.

Category of Solid Waste

The solid wastes were sorted out manually according to the 11 categories: (1) Organic waste and biodegradables such as food and fruits waste, garden waste and wood, (2) paper waste which is further sorted to cardboards, newspapers, office papers, magazines and mixed paper, (3) tetra packs, (4) glass, (5) plastics which are further sorted to polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC) and other plastics, (6) metal, (7) construction waste, (8) hazardous waste and e-waste, (9) nappies and sanitary napkins, (10) leather, textile, rubber and (11) materials that do not fit in any of the above categories. The weight of the wastes from each category was recorded in the datasheet.

Results and Discussion

Residential Area

The solid waste samples from the residential areas were collected from different socioeconomic levels, such as from landed properties to the multi-storey properties, according to the details of the sampling locations as listed in Table 3. Seven groups of the residential areas of samplings (Route 1 to Route 7) were carried out. Figure 4 shows the overall municipal waste composition of the selected residential areas in Kuching. Organic waste makes up most of the composition (61.58% *w/w*), followed by plastics (12.06% *w/w*). The number of nappies

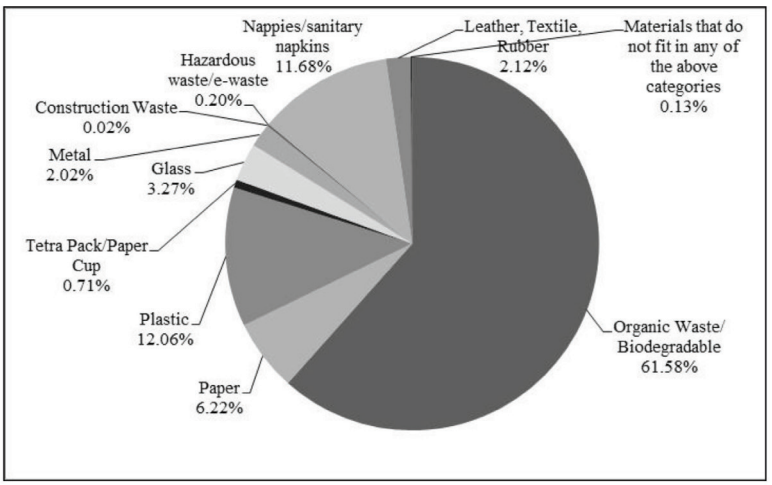

Figure 4: Overall waste composition of municipal solid waste from the residential areas in Kuching

and sanitary napkins is 11.67% *w/w* which is similar to the report by the National Solid Waste Management Department (2013).

Socioeconomic Parameter

The categories of residents are based on the types and market value of the houses and the majority ethnic group in the selected areas. For instance, the area where the majority of the houses are single-storey terrace houses area will be presumed to be a low-income residential area, the area with double-storey terrace houses will be presumed as a medium-income residential area and the area with semi-detached houses will be presumed as a high-income residential area. The study found that the majority of residents at the sampling Routes 6 and 7 are Dayaks and Malays, respectively. For multi-storey properties, this study assumed that most of the residents who lived at low-cost apartments and flats (Route 5) are from the low-income group, whereas those who lived in condominiums (Route 4) are provided with more facilities such as a swimming pool, gated security system and are from the high-income group.

This study discovered that there was no significant difference in the sequence of waste categories for all residential areas (Figure 5 and Appendix I). The main component in the residential municipal solid wastes is organic waste, which is more than 50% *w/w* for all the residential areas. Although most studies showed that organic waste composition was higher in lower-income areas, it did not apply to this study. This might be due to the enforcement of the recovery movement control order (RMCO) and conditional movement control order (CMCO) in the sampling areas during the sampling period as a consequence of the prolonged COVID-19 pandemic. During the RMCO and the CMCO, the movements of the residents were restricted and people were encouraged to stay home. Under the new norm due to the pandemic, the lifestyle has changed. Residents who were restricted from going to work and were working from home most likely had their meals at home.

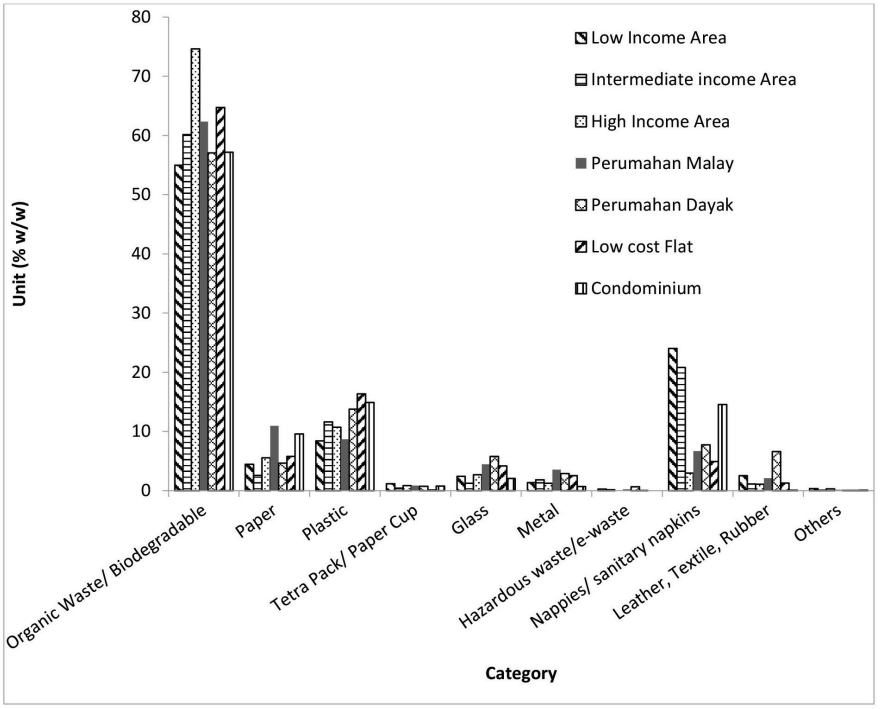

Figure 5: Solid waste composition at residential areas according to socioeconomic level

Hard polypropylene which is commonly used to pack food is found in higher compositions in high-income areas. The hard polypropylene composition at the high-income residential and condominium were found to be 1.5% *w/w* and 2.44% *w/w*, respectively. This can be explained as food delivery services were gaining traction and were in high demand during the RMCO and the CMCO periods, especially for residents in the high-income category. At the same time, this will increase the composition of organic waste among the solid wastes generated.

Plastic waste is the second highest waste component found in the municipal solid waste samples in low-cost flat, condominium, Dayak village and high-income residential areas, which are 16.36% *w/w*, 14.92% *w/w*, 13.76% *w/w* and 10.7% *w/w*, respectively. Although the plastic compositions from these areas are higher than 10% *w/w*, most of the plastics were found to be soft plastic bags (LDPE/PP) and food packaging which are low in recycling value (Brouwer *et al.,* 2020) and not commonly recycled in Malaysia (Alyssa & Wong, 2019). Soft plastic bags are widely used as packaging and disposable storage bags. They are seldom taken by recyclers and commonly reused as trash bags or throw away as waste. For the wastes collected from the low-income residential and medium-income residential areas, the second-highest waste composition was nappies and sanitary napkins which were recorded to be 24.03% *w/w* and 20.83% *w/w*, respectively. These results are in line with the Sarawak population data for 2020 where 6.65% of the residents in Sarawak are below 4 years old, 48.1% of the residents are female (Department of Statistics Malaysia, 2021). A different finding was discovered in the Malay village area, where the second-highest component is paper (10.97% *w/w*).

Overall, less than 15% *w/w* of the common recycling items, such as cardboards, newspapers, office papers, HDPE and PET, glass and metal were discovered in all the residential areas, except the Malay village (19.81% *w/w*) and the low-cost apartment and flat areas (15.83% *w/w*) as displayed in Figure 6. The low percentage of recycled items in the majority of the areas reveals the acceptable level of awareness in reusing and recycling among Kuching residents. No hazardous waste was found in samples collected from the high-income area and condominium, compared with the other residential area, which had waste in said category ranging from 0.03% *w/w* to 0.68% *w/w*. The awareness of hazardous waste handling in the high-income residential area is higher compared with the low-income residential area.

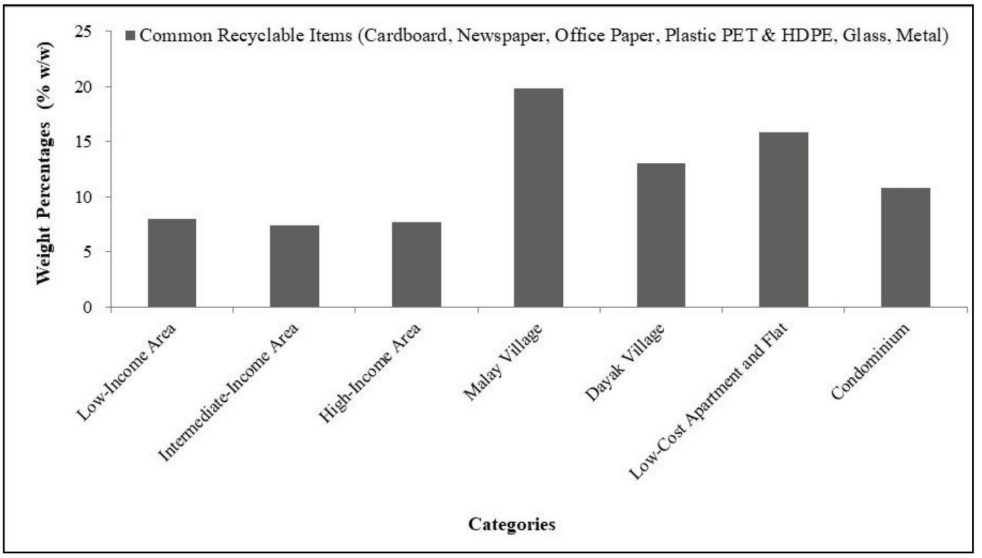

Figure 6: Common recycling items at the different residential areas

Commercial Area - Commercial Entities

Solid waste samples were collected from commercial entities, including traditional shophouses, shopping complexes and government offices. The composition of solid wastes in the commercial areas is very much dependent on the nature of the business in the areas (Figure 7 and Appendix II). This study found that organic waste is the highest waste component in all commercial areas, with values ranged from 44.57% *w/w* to 72.08% *w/w*. At all commercial entities, the most common type of business is food-related such as food courts, restaurants and fast-food outlets. Therefore, organic waste is always the highest waste component in the food-related business commercial areas.

In the Chinese commercial area, the second-highest waste component is paper, which is 26.82% *w/w*. The main type of paper found is cardboards which is commonly used as packaging when goods are purchased in bulk. The composition of cardboards is higher compared with other commercial areas. This finding is in agreement with the interviews conducted with a few shop owners in the commercial areas regarding their recycling activities. The cardboards were separated at the source for reuse and recycling by the shops that are consistently generating a huge number of cardboards. The cardboards are disposed as solid waste when their condition is dirty and not suitable for reuse or recycling. At the shopping mall, although the composition of paper is 17.92% *w/w*, the main type of paper is mixed paper which is hard to recycle. This finding validated that paper recycling, especially cardboards is practised at department stores at shopping malls and hotels as seen during the sample collection. The results are also in line with the findings by the National Solid Waste Management Department (2013), in which 86.2% of the supermarkets practises recycling whereas only 40.6% of retail stores do so.

At the Malay commercial area and government offices, the second-highest component of waste is plastic waste, at 15.29% *w/w* and 19.23% *w/w*, respectively. The main

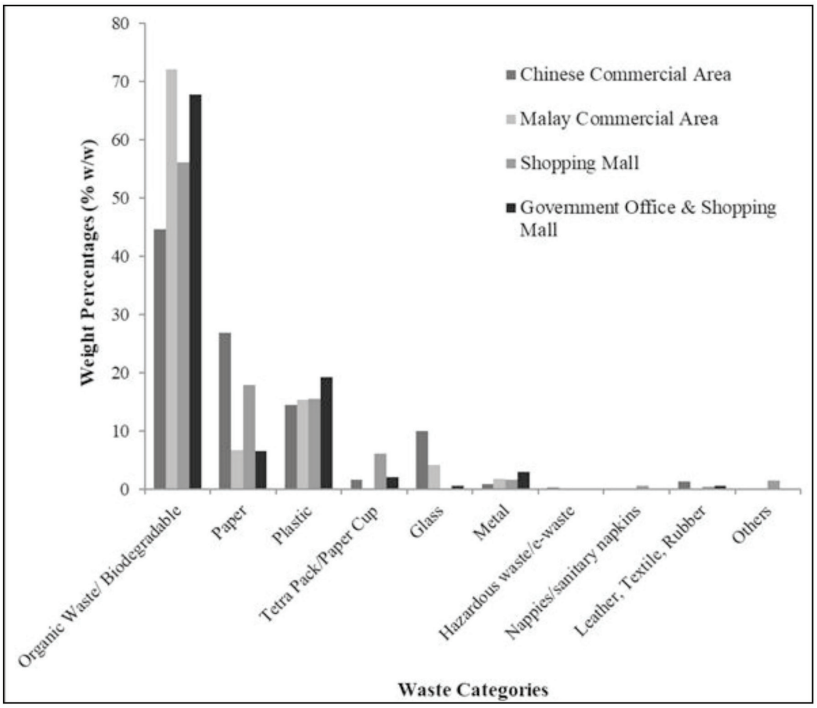

Figure 7: Waste composition at the commercial area – commercial entities

type of plastic waste extracted is soft plastic bags, PET and PP, which are commonly used as food packaging. Nowadays, plastic cups and plastic cutleries are used in many food courts for the convenience of food providers. It is also observed that tetra packs found in the commercial areas is higher compared with the residential areas. Although tetra packs and paper cups are mainly made from paper, it is not collected by recyclers as it requires higher technology and costs to separate the aluminium and plastic layer from the paper (Zawadiak *et al.,* 2017).

The glass compositions in both Chinese and Malay commercial areas were found to be relatively high at 9.92% *w/w* and 4.15% *w/w*, respectively. Nowadays, although the overall recycling rate has increased, glass recycling, however, has decreased as many recycling companies realise that very little income can be gained through recycling glass.

Commercial Area – Market

The selected wet markets for the waste sampling in this study are the Malay (Route 11) and the Chinese markets (Route 12). Both markets are similar in business activities but located in an area frequented by different ethnic groups. The organic waste composition of the samples from the Malay market (84.08% *w/w*) and the Chinese market (83.57% *w/w*) is in great proportion (Figure 8 and Appendix III), which is in line with the nature of the business in the areas. Although the waste generators are from different ethnic groups, both areas have a very similar waste composition. The second and third highest compositions from both markets are plastic and paper wastes, which were all generated from the packaging of fresh produce, meat, seafood and other consumption-oriented perishable goods. The National Solid Waste Management Department (2013) revealed that approximately 74.6% of the wet market exercises recycling as a sustainable practice. As reported by Ramdzan *et al.* (2018), various methods have been conducted for organic waste composting, which are mostly organised by city councils in Malaysia. For instance, a mechanical method was utilised by Syarikat Alam Flora Sdn. Bhd. in Putrajaya and Bio-Regen method is used in Bayan Baru, Pulau Pinang. On the flip side, this study reveals the inadequacy of organic waste management for wastes generated by the wet markets.

Commercial Area – Hotel

The hotel in Kuching served as one of the quarantine accommodation locations during the RMCO period. As a consequence, a huge quantity of food packaging waste was encountered during the sample sorting and analysis for Route 19 (Figure 9 and Appendix IV), which made up the majority part of the 2.13% *w/w* hard PP found in the waste samples. The quantitative assessment from the sample evaluation indicated that recycling activity is practised at the hotel. The compositions of plastic and paper were only 10.92% *w/w* and 7.4% *w/w*, respectively, which were mainly consisted of soft plastics and mixed papers which have low recycling value. Recycled items, such as cardboards and office papers, made up an extremely small percentage of the solid wastes. This result confirms that capturing recyclables is supported by waste owners in the hotel industry, which is in accordance with the green hotel concept. The green hotel concept has received great attention recently in the tourism and hospitality industry. The world's leading hotel group has begun to address the Sustainable Development Goals (SDGs) in their sustainable business strategies. One of the fundamental practices in achieving the SDGs is by adopting recycling into their business ecosystem (Jones & Comfort, 2019).

Commercial Area – Petrol Station

Figure 10 illustrates the waste composition from Route 14. The amount of waste generated at the petrol station is very low and the waste was mainly generated by the employees. This study showed that recycling activity was unlikely as 10.74% *w/w* of office paper waste and 5.25% *w/w* of recyclable plastic waste (mainly the PET

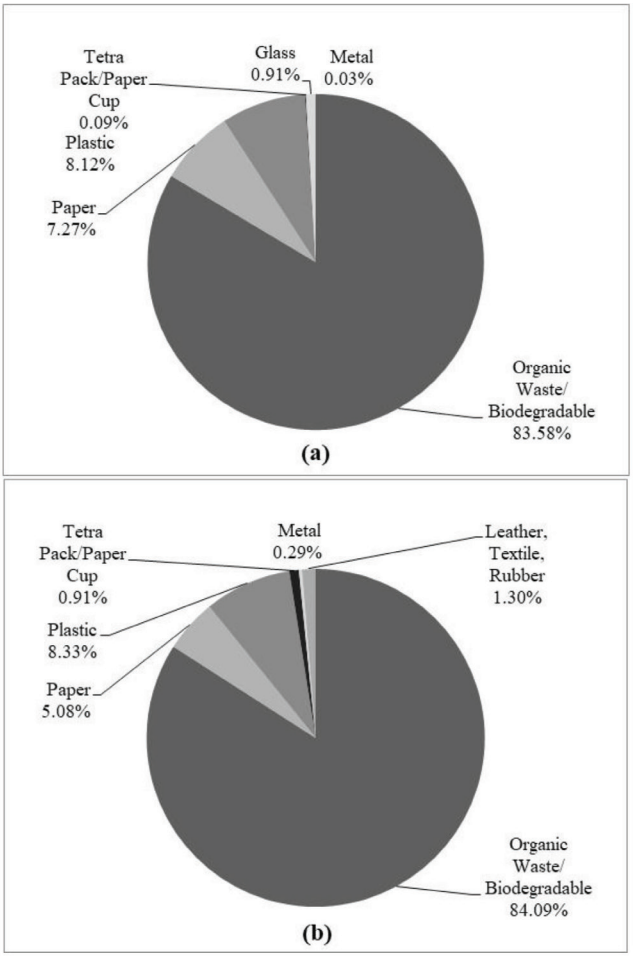

Figure 8: Waste composition at (a) Chinese and (b) Malay markets

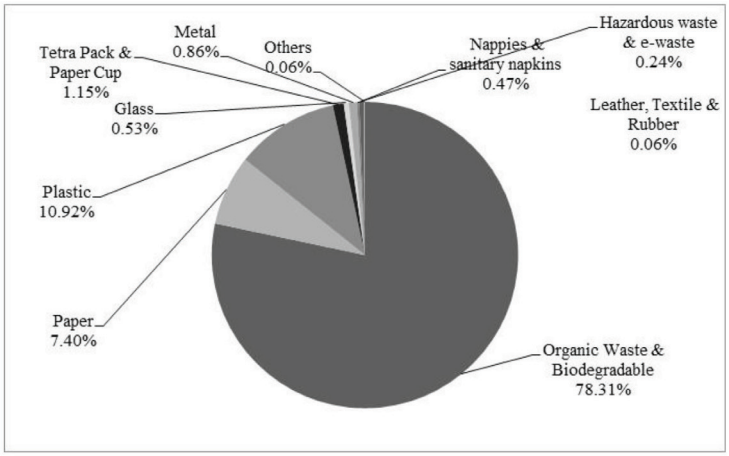

Figure 9: Waste composition at hotel

and the HDPE) were recovered from the waste samples (Figure 10 and Appendix V). Taking into account the absence of reused and recycling strategies at the petrol station and considering the number of recyclable items generated, it is recommended that waste bins to segregate used paper be placed at the petrol station to encourage a commitment towards sustainable practices.

Institutional Area - Medical Service Sector

The institutional area is defined as facilities and services for public needs. These include government and private sectors such as hospitals, clinics, schools and universities. The waste compositions of both public (Route 15) and private hospitals (Route 16) are significantly different compared with other aforementioned categories. The organic composition in the public hospital waste samples is 59.08% *w/w* while only 26.86% *w/w* of organic waste is identified in the private hospital waste samples (Figure 11 and Appendix VI). The food packaging (PP/PET composition) waste at the government hospital is also at a substantial amount compared with the private hospital. It might be due to the availability of a food court and canteen services to the public and patients in the public hospital while the private hospital only provides food services to their patients. The mixed paper percentage is discovered to be at high (≈18% *w/w*) at both places. This may be due to the frequent usage of disposable tissue papers at both the hospitals for hygiene purposes. The hazardous waste found at the private hospital is 28.59% *w/w*. The clinical waste was stored in a yellow plastic bag and separated from the general waste during sampling. Clarification was sought with the person in charge at the private hospital. Subject to type and amount of medical waste generated, usually the hospitals have quite a few alternatives in terms of disposal. Prior to the transportation of the medical waste from a medical waste generator, on-site and off-site alternatives are usually available, where some of the waste must be properly treated on site to reduce and eliminate the infectious potential of said waste before it is transported off to the disposal location (Taslimi *et al.,* 2020).

Institutional Area - Education Sector

Similar to the residential and commercial areas, organic waste was the highest waste component found in the academic institution area, which is 42.34% *w/w* at the school (Route 17) and 52.71% *w/w* at the private university (Route 18) as shown in Figure 12 (Appendix VII). The

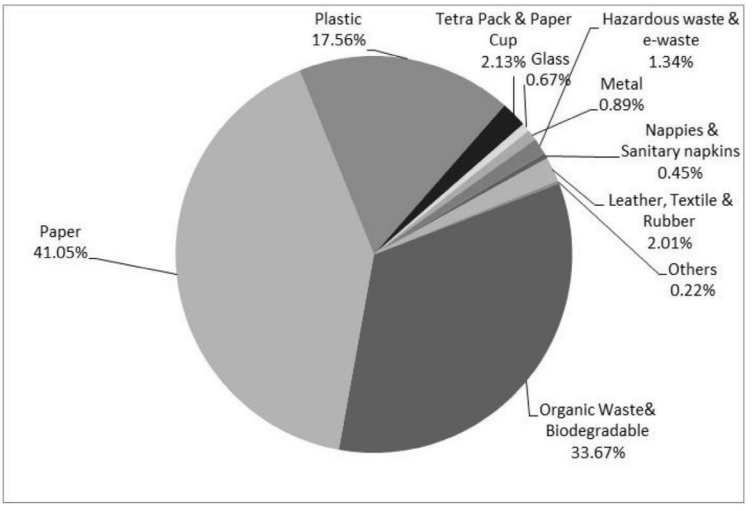

Figure 10: Waste composition at the petrol station

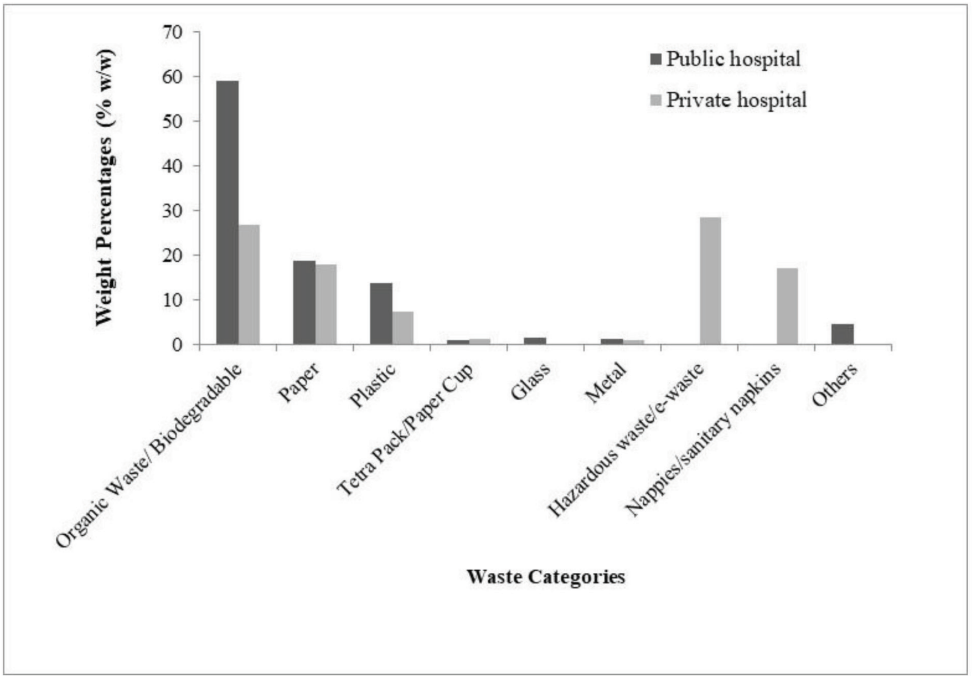

Figure 11: Waste composition at the institutional area - medical service sector

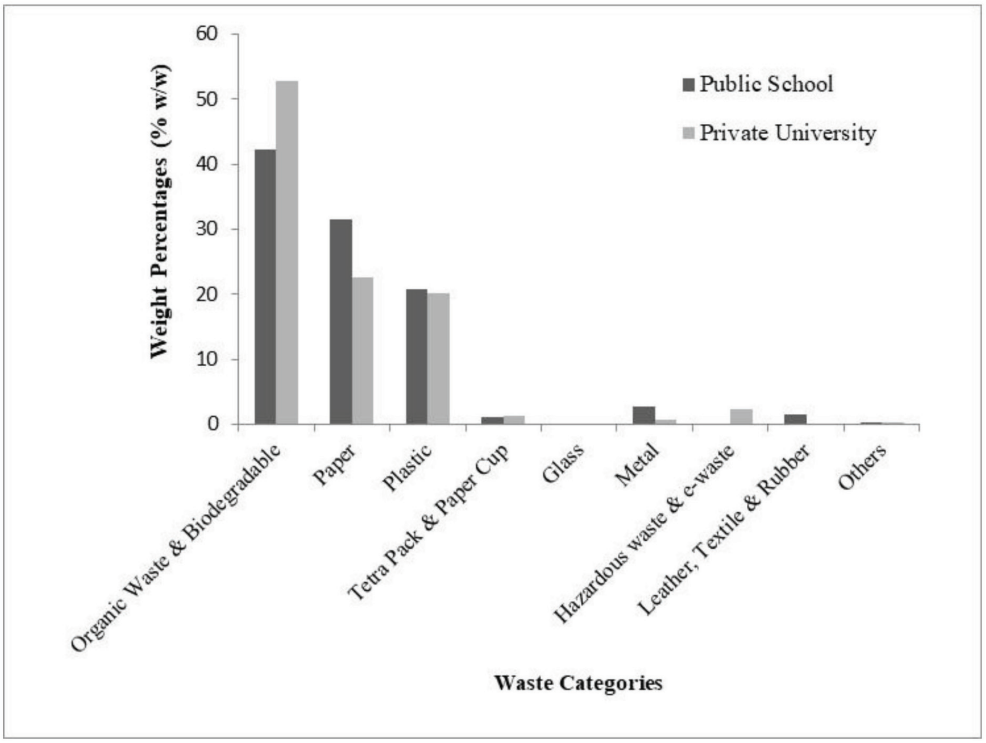

Figure 12: Waste composition at the institutional area - the education sector

second and third highest waste components for both areas are plastic and paper wastes. However, it is observed that the paper recycling practice might not be in place at the school as the office paper percentage was recorded to be 10.94% *w/w*. The phenomenon is dissimilar to the waste samples collected from the private university. Although a high waste percentage of paper is also found at Route 16, the recovered papers are mainly mixed papers that are hard to recycle. The plastic percentage for both routes is found to be above 20% *w/w*, which consists mainly of soft plastics, which is scarcely sourced by most recyclers in the country.

Conclusion

The waste composition of municipal solid waste is important for the future waste management system. The waste compositions in this study show that organic waste is the main waste generated by the residents of Kuching. Waste composting should be encouraged to reduce the organic waste generated. Besides, legislative measures can be adopted, as currently in Malaysia, there is no legislation yet to tackle the food waste problem. In February 2016, France introduced a new law that banned supermarkets from destroying unsold food products. The same movement was seen in China when the food waste law was officially approved by the Standing Committee of the National People's Congress (NPC) in April 2021. Both countries found a substantial reduction in food waste following the implementation of the new law. Recycling awareness is improving as low percentages of recycling items were at most of the locations. However, plastic waste remains a great threat to the environment. The nationwide "No Plastic Bags on Saturdays" was launched 10 years ago. However, this study reveals the need to boost the reduction of plastic waste as soft plastics found in the waste compositions in this study remain high. This study also showed that the majority of the people still lacked awareness in reducing plastic waste, especially single-use plastic bags. Thus, future waste management forethought should prioritise the waste management of organic waste and soft plastics. The aim of waste management should focus on maximising the practical benefits of extracting from products and generating the minimum amount of waste. The consummate waste management alternative is preventing waste generation at the outset.

Recycling activities are mostly practised by commercial waste generators, which generated a large number of recycled items, but not by small enterprises. This is most likely due to the fact that the profit gained from the recycling activities was not significant if only a small number of recyclables is available. Hence, it is recommended that the authorities encourage recycling practices in both residential and commercial areas. Waste composting should be encouraged in market areas to reduce the generation of organic waste.

A high percentage of recycling items are found in institutional wastes, especially from the education sector. This may signal the fact that students might be still lack reuse and recycling awareness. Thus, reuse and recycling awareness campaigns and activities in schools and universities should be prioritised for environmental sustainability. In conclusion, effective waste sorting is undeniably necessary through the manual segregation at the waste generator location, followed by a pre-sorting process in materials recovery facilities.

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Appendix

Appendix I: Weight percentages (% *w/w*) of solid waste in the different residential areas according to their social-economic level

Category	Low-income Area	Intermediate-income Area	High-income Area	Malay Village	Dayak Village	Low-cost Apartment and Flat	Condominium
1. Organic waste/biodegradable	54.98%	60.14%	74.62%	62.33%	57.05%	64.73%	57.18%
2. Paper	4.44%	2.59%	5.54%	10.97%	4.66%	5.77%	9.60%
(a) Cardboard	2.58%	0.41%	2.31%	0.58%	0.90%	0.82%	2.61%
(b) Newspaper	0.19%	0.18%	0.00%	0.14%	1.81%	0.16%	0.30%
(c) Office paper	0.02%	0.06%	0.04%	8.53%	0.00%	0.16%	2.99%
(d) Mixed paper	1.64%	1.94%	3.20%	1.73%	1.96%	4.62%	3.70%
3. Plastic	8.41%	11.63%	10.70%	8.67%	13.76%	16.36%	14.92%
(a) PET	0.75%	1.38%	1.23%	1.07%	1.20%	6.23%	1.05%
(b) HDPE	0.65%	2.32%	0.19%	1.48%	0.41%	1.70%	1.08%
(c) LDPE/soft plastic (PP/others)	5.56%	6.64%	7.20%	4.47%	10.83%	7.15%	8.81%
(d) PP (hard)	0.97%	0.62%	1.50%	0.77%	0.49%	0.88%	2.44%
(e) PS	0.48%	0.68%	0.46%	0.33%	0.38%	0.26%	0.71%
(f) PVC	0.00%	0.00%	0.08%	0.00%	0.45%	0.13%	0.82%
(g) Other plastic	0.00%	0.00%	0.04%	0.55%	0.00%	0.00%	0.00%
4. Tetra pack/paper cup	1.16%	0.44%	0.85%	0.85%	0.75%	0.13%	0.78%
5. Glass	2.42%	1.23%	2.70%	4.47%	5.79%	4.20%	2.09%
6. Metal	1.35%	1.82%	1.23%	3.54%	2.90%	2.56%	0.71%
7. Construction waste	0.12%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
8. Hazardous waste/e-waste	0.29%	0.15%	0.00%	0.22%	0.68%	0.03%	0.00%
9. Nappies/sanitary napkins	24.03%	20.83%	2.96%	6.67%	7.75%	4.92%	14.57%
10. Leather, textile, rubber	2.56%	1.12%	1.08%	2.11%	6.62%	1.28%	0.07%
11. Materials that do not fit in any of the above categories	0.24%	0.06%	0.31%	0.16%	0.04%	0.03%	0.07%

Appendix II: Composition of solid waste in different commercial entities

Type of Waste	Percentage (% *w/w*)			
Category	**Chinese Commercial Area**	**Malay Commercial Area**	**Shopping Mall**	**Government Office and Shopping Mall**
1. Organic waste/biodegradable	44.57%	72.08%	56.10%	67.76%
2. Paper	26.82%	6.72%	17.92%	6.51%
(a) Cardboard	15.36%	1.69%	0.73%	0.60%
(b) Newspaper	6.13%	0.61%	0.00%	0.00%
(c) Office paper	0.20%	2.70%	0.00%	0.45%
(d) Mixed paper	5.14%	1.72%	17.19%	5.46%
3. Plastic	14.46%	15.29%	15.58%	19.23%
(a) PET	1.50%	0.84%	3.32%	4.97%
(b) HDPE	0.40%	0.00%	0.94%	0.79%
(c) LDPE/soft plastic (PP/ others)	10.57%	13.71%	8.47%	6.16%
(d) PP (hard)	1.05%	0.47%	2.03%	5.96%
(e) PS	0.40%	0.27%	0.57%	1.14%
(f) PVC	0.55%	0.00%	0.26%	0.20%
(g) other plastic	0.00%	0.00%	0.00%	0.00%
4. Tetra pack/paper cup	1.60%	0.00%	6.08%	2.14%
5. Glass	9.92%	4.15%	0.21%	0.65%
6. Metal	0.94%	1.76%	1.66%	2.93%
7. Construction waste	0.00%	0.00%	0.00%	0.00%
8. Hazardous waste/e-waste	0.30%	0.00%	0.00%	0.20%
9. Nappies/sanitary napkins	0.00%	0.00%	0.52%	0.00%
10. Leather, textile, rubber	1.40%	0.00%	0.47%	0.60%
11. Materials that do not fit in any of the above categories	0.00%	0.00%	1.45%	0.00%

Appendix III: Composition of solid waste in the market area

Type of Waste	Percentage (% *w/w*)	
Category	**Malay Market**	**Chinese Market**
1. Organic waste/biodegradable	84.08%	83.57%
2. Paper	5.08%	7.27%
(a) Cardboard	0.98%	5.90%
(b) Newspaper	1.24%	0.73%
(c) Office paper	0.03%	0.30%
(d) Mixed paper	2.83%	0.33%
3. Plastic	8.33%	8.12%
(a) PET	0.36%	0.15%
(b) HDPE	0.00%	0.00%
(c) LDPE/soft plastic (PP/others)	6.22%	7.61%
(d) PP (hard)	1.63%	0.30%
(e) PS	0.10%	0.06%
(f) PVC	0.00%	0.00%
(g) Other plastic	0.03%	0.00%
4. Tetra pack/paper cup	0.91%	0.09%
5. Glass	0.00%	0.91%
6. Metal	0.29%	0.03%
7. Construction waste	0.00%	0.00%
8. Hazardous waste/e-waste	0.00%	0.00%
9. Nappies/sanitary napkins	0.00%	0.00%
10. Leather, textile, rubber	1.30%	0.00%
11. Materials that do not fit in any of the above categories	0.00%	0.00%

Appendix IV: Composition of solid waste in hotel

Type of Waste	Percentage (% *w/w*)
Category	**Hotel**
1. Organic waste/biodegradable	78.31%
2. Paper	7.40%
(a) Cardboard	0.18%
(b) Newspaper	0.27%
(c) Office paper	0.00%
(d) Mixed paper	6.95%
3. Plastic	10.92%
(a) PET	1.04%
(b) HDPE	0.15%
(c) LDPE/soft plastic (PP/others)	6.63%
(d) PP (hard)	2.13%
(e) PS	0.74%
(f) PVC	0.24%
(g) Other plastic	0.00%
4. Tetra pack/paper cup	1.15%
5. Glass	0.53%
6. Metal	0.86%
7. Construction waste	0.00%
8. Hazardous waste/e-waste	0.24%
9. Nappies/sanitary napkins	0.47%
10. Leather, textile, rubber	0.06%
11. Materials that do not fit in any of the above categories	0.06%

Appendix V: Composition in weight percentages (% *w/w*) of solid waste at the petrol station

Category	Petrol Station
1. Organic waste/biodegradable	33.67%
2. Paper	41.05%
(a) Cardboard	5.48%
(b) Newspaper	0.22%
(c) Office paper	10.74%
(d) Mixed paper	24.61%
3. Plastic	17.56%
(a) PET	3.80%
(b) HDPE	1.45%
(c) LDPE/soft plastic (PP/others)	10.18%
(d) PP (hard)	1.45%
(e) PS	0.56%
(f) PVC	0.11%
(g) Other plastic	0.00%
4. Tetra pack/paper cup	2.13%
5. Glass	0.67%
6. Metal	0.89%
7. Construction waste	0.00%
8. Hazardous waste/e-waste	1.34%
9. Nappies/sanitary napkins	0.45%
10. Leather, textile, rubber	2.01%
11. Materials that do not fit in any of the above categories	0.22%

Appendix VI: Composition of solid waste in the private and public hospital

Type of Waste	Percentage (% *w/w*)	
Category	**Public Hospital**	**Private Hospital**
1. Organic waste/biodegradable	59.08%	26.86%
2. Paper	18.75%	17.84%
(a) Cardboard	2.14%	0.00%
(b) Newspaper	0.00%	0.00%
(c) Office paper	0.00%	0.38%
(d) Mixed paper	16.61%	17.46%
3. Plastic	13.73%	7.51%
(a) PET	3.69%	0.70%
(b) HDPE	0.16%	0.11%
(c) LDPE/soft plastic (PP/others)	5.45%	5.78%
(d) PP (hard)	3.37%	0.65%
(e) PS	0.91%	0.27%
(f) PVC	0.16%	0.00%
(g) Other plastic	0.00%	0.00%
4. Tetra pack/paper cup	1.01%	1.14%
5. Glass	1.60%	0.00%
6. Metal	1.28%	0.97%
7. Construction waste	0.00%	0.00%
8. Hazardous waste/e-waste	0.00%	28.59%
9. Nappies/sanitary napkins	0.00%	17.08%
10. Leather, textile, rubber	0.00%	0.00%
11. Materials that do not fit in any of the above categories	4.54%	0.00%

Appendix VII: Composition of solid waste in the government school and private university

Type of Waste	Percentage (% *w/w*)	
Category	**Public School**	**Private University**
1. Organic waste/biodegradable	42.34%	52.71%
2. Paper	31.46%	22.65%
(a) Cardboard	1.53%	1.00%
(b) Newspaper	0.00%	0.33%
(c) Office paper	10.94%	0.00%
(d) Mixed paper	18.98%	21.32%
3. Plastic	20.68%	20.23%
(a) PET	0.71%	2.75%
(b) HDPE	0.71%	0.08%
(c) LDPE/soft plastic (PP/others)	11.65%	13.74%
(d) PP (hard)	4.32%	2.58%
(e) PS	3.28%	0.92%
(f) PVC	0.00%	0.17%
(g) Other plastic	0.00%	0.00%
4. Tetra pack/paper cup	1.15%	1.25%
5. Glass	0.00%	0.00%
6. Metal	2.68%	0.67%
7. Construction waste	0.00%	0.00%
8. Hazardous waste/e-waste	0.00%	2.33%
9. Nappies/sanitary napkins	0.00%	0.00%
10. Leather, textile, rubber	1.53%	0.00%
11. Materials that do not fit in any of the above categories	0.16%	0.17%