DEVELOPMENT OF AN IMPROVED PROTOCOL FOR HETEROGENEOUS WASTE CHARACTERISATION

SIVAPALAN KATHIRAVALE

FACULTY OF SCIENCE
UNIVERSITY OF MALAYA
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SIVAPALAN KATHIRAVALE

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This work is dedicated to my loving parents Kathiravale Saravanamuthu and Sarasvathi Sinnappoo who spent their life ensuring the best for their children while encouraging us to reach for the stars. Your drive and perseverance will always be a guiding light in my life.

To my lovely wife, Kanageswari Kanagaretnam, thank you for accepting me into my life. Your patience and encouragement has brought me to the closure of a major chapter in my life spanning over the years. The life that we have shared has been and will always be the treasure of my life while realizing that believe in the almighty Lord Shiva. The bundle of joy that you gave me in our daughter, Akshera Shree, is beyond words. Seeing her growing up gave me new vigor in completing this work.

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DEVELOPMENT OF AN IMPROVED PROTOCOL FOR HETEROGENEOUS WASTE CHARACTERISATION

ABSTRACT

Waste Management in Malaysia over the last 15 to 20 years has been on the brink of change. Currently, waste management method is still very dependent on landfilling but there have been technologies introduced like incinerators and Material Recovery Facilities. Almost all of these facilities have either been closed or operating at far below the designed parameters due to the in-ability of the treatment process to handle the complexity of the waste being delivered for treatment. Investigations lead to the fact that the waste characteristics did not reflect the actual condition of the waste. The problem with waste management in Malaysia is the fact that no source separation is in practice. This is compounded with the fact that Malaysia is a multi-cultured society and a heaven for food. These facts only add to the variety of waste that is generated, making it impossible to predict the kind and quantity of waste that is generated. Addressing these problems, waste characteristics from 2000 to 2014 was used in this study as a basis towards inferring relationships between these data. The objective was to identify which were the best protocol for characterization of waste, taking into account the various methods that were available while looking at some critical parameters in the characteristics; i.e. moisture content and the calorific value of the waste. Methods on how to sample the waste and what was the best approach to sample a 5 ton truck load of waste, to give the most accurate but yet not costly and time consuming were studied. Another analysis which contributed strongly was the number of components into which the wastes are sorted into. In the year 2000 the number of components that the waste was sorted into was less than 15 components but by 2012 the number of components had increased to about 25 components, thus the re-distribution of the weight percentage of the waste component. Next, was to look into the method by which moisture content was recorded and analysed during a sampling process. There was a big variance between the amounts of moisture reported versus the actual amount of water observed in the waste samples. Finally, the analysis of calorific value requires very tedious analysis which was time consuming and expensive. This study used equations to predict the calorific value of the waste. The results showed that the Cone and Quarter method was sufficiently representative of the truck load of the waste while being able to have the necessary accuracy to portray the waste characteristics while being affordable and timely. The study proved that waste must be sorted into as many components as possible to understand the waste better. As for the moisture content analysis, the study proved that there was a need to address the leachate and the moisture content during the sampling phase which could contribute up to 20% more moisture in the sample. A predictive method using equations that was formed based on local waste characteristics such as the physical composition of the waste, the proximate content and the ultimate content of the waste was used in this study. These equations were then tested with available equations to predict the calorific value of the waste. This study was able to prove that the physical parameters equation gives the best prediction. Based on the above findings, the study was able to show an improved protocol that could be adopted for the batter understanding and solving the waste generated in Malaysia.

Keywords: solid waste, waste characterization, characterization protocol, moisture content, calorific value

PEMBANGUNAN SERTA PENAMBAHBAIKAN PROTOKOL UNTUK KARAKTERISASI SISA PEPEJAL HETEROGENEOUS

ABSTRAK

Pengurusan sisa di Malaysia dalam tempoh 15 hingga 20 tahun yang lalu telah berada di ambang perubahan. Kaedah pengurusan sisa masih sangat bergantung kepada keadah penimbusan terbuka tetapi terdapat beberapa insinerator mini dan Material Recovery Facility (MRF) yang telah diimplementasi. Malangnya, hampir semua kemudahan ini sama ada telah ditutup atau beroperasi jauh di bawah keupayaan kerana proses rawatan tidak dapat menangani kerumitan sisa yang dihantar untuk rawatan. Masalahnya pencirian sisa pepejal yang sedia ada tidak mengambarkan keadaan sebenar sisa tersebut. Di Malaysia, kerajaan telah menggalakkan pemisahan pada sumber, namun demikian sisa pepejal perbandaran masih dibuang tanpa sebarang pengasingan di punca. Ini diburukkan lagi dengan hakikat bahawa Malaysia adalah sebuah masyarakat berbilang kebudayaan dan juga syurga untuk makanan. Fakta-fakta ini hanya menambah kepada kepelbagaian sisa yang dihasilkan. Untuk menangani masalah-masalah ini, kajian ini melihat ciri-ciri sisa yang telah di diterbitkan dari tahun 2000-2014. Objektifnya adalah untuk mengenal pasti protokol yang terbaik bagi pencirian sisa pepejal. Objektif kajian ini adalah untuk mengambil kira pelbagai kaedah yang sedia ada untuk mengnalisa sisa serta melihat beberapa parameter kritikal ke arah rawatan iaitu kandungan lembapan dan nilai kalori sisa. Keadah untuk mengambil sampel serta bagaimana untuk mengambil sample untuk mengambarkan sisa dalam sebuah lori 5 ton dengan menbilkira kos dan masa yang di perlukan untuk menjalankan kajian ini di analisa dalam kajian ini. Antara factor yang menyumbang kepada ini adalah bilangan komponen dalam sisa pepejal, di mana pada tahun 2000, bilangan komponen adalah kurang daripada 15 komponen tetapi dalam tahun 2012 bilangan komponen telah meningkat kepada 25 komponen yang boleh menjadi sebab untuk perbezaan yang di

nyatakan. Keadah untuk menentukan kandungan kelembapan sisa semasa memjalankan kerja pensampelan perlu adalah penting. Dari pemerhatian, jumlah kelembapan yang di laprkan adalah sangat kurang berbanding dengan kelembapan yang di perhatikan pada sisa. Keadah menentukan nilai kalori pada sisa pada masa kini adalah sangat remeh serta memerlukan kos yang tinggi dan masa yang panjang. Keadah menentukan nilai kalori dengan mengunakkan persamaan telah di kaji. Keputusan menunjukan yang kaedah persampelan 'Cone and Quarter' dapat mengurangkan saiz sampel dan aktiviti pencirian adalah lebih terperinci, dan lebih komponen telah dicapai manakala ketepatan dalam proses menyusun juga pesat meningkat tetapi adakah saiz sampel mencukupi? Bagi analisis kandungan kelembapan, kajian membuktikan bahawa terdapat keperluan untuk menangani kandungan lembapan semasa fasa pensampelan yang boleh mengenalpasti kelembapan kira-kira 20% lebih dalam sampel yang tidak diambil kira sebelum ini. Bagi nilai kalori sampel, analisis adalah satu proses yang rumit dan panjang dan sering keputusan tidak boleh diulangi kerana saiz sampel yang terhad untuk dianalisis menggunakan kalorimeter bom. Beberapa persamaan telah di gunakan untuk menentukan nulai kalori sisa yang di analysa. Dengan mengunakan persamaan yang di bangunkan di Malaysia bersama dengan persamaan yang sedia ada, kaedah ramalan telah dicuba dan kajian ini dapat menunjukkan bahawa parameter persamaan fizikal memberikan ramalan yang terbaik. Akhir sekali, kajian ini dapat menangani beberapa protokol yang boleh diguna pakai untuk memahami ciri sisa di Malaysia

Kata Kunci: sisa pepejal, pencirian sisa, kaedah pencirian sisa, kandungan kelembapan sisa, kandungan nilai kalori

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LIST OF SYMBOLS AND ABBREVIATIONS

ANM	:	Agensi Nuklear Malaysia
CV	:	Calorific Value
LA	:	Local Authority
MS	:	Malaysian Standard
MSW	:	Municipal Solid Waste
RDF	:	Refuse Derived Fuel
RM	:	Ringgit Malaysia

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CHAPTER 1: INTRODUCTION

1.1 Background

Waste, regardless of its kind (either in solid or liquid form) was produced since the dawn of human existence and it is not excessive to say, waste was the first thing generated before people are able to contribute to the betterment of lives. Indifferent of the various definitions, the problems regarding the disposal and management of waste have then never been out of the issues of open discussion. This controversial subject has become more severe when the growth of waste has reach to its critical condition due to the increasing demands on the consumption of natural resources and raw material in the creation of products to enrich people's lives (Al-Khatib et al., 2010; Batool et al., 2008). Hence, the current and future generations must ensure that all resources shall be preserved, fully utilized and well managed.

Generation rates of Municipal Solid Waste vary according to the economic and social standing of a country. This in return will also affect the management style of the MSW generated. Generally, the higher income countries generate more waste, recycle more and have the money to employ new technology to treat their waste. As for the lower income countries, the waste generated is more organic in nature, which calls for lesser recycling, whereas disposal is by open dumping (Batool et al., 2008). The effects of this naturally would mean that in the lower income countries pollution to the water and air is huge as compare to the more developed countries. However, on the other hand, does waste alone generate harmful gasses that pollute the world or does manufacturing, transportation and power production, which is rampant in the more industrialized countries contributing more towards pollution? This subject is argumentative and could be discussed at length. However, the environment cannot wait for its population to debate on the above matter. Action needs to be taken in a world where economic power determines the treatment method. Hence, the idea of recovering all 'wealth' in the waste is essential to ensure that even the poorest countries could benefit from all waste management technologies. For this to work, recycling, reuse and recovery of energy is essential in an integrated approach towards waste management landfill (Bernache, 2003; Dennison et al., 1996; Sujauddin et al., 2008; UNEP, 2017).

Over the years, Malaysia has taken many steps to introduce new technology to tackle the MSW problem. The establishment of a new regulation dedicated to governing over the waste industry shows that the government is serious in implementing waste management solutions. The way forward for the waste industry has been pointed in the direction of Holistic Waste Management where all different types of waste generated are to be governed under the National Solid Waste Department while moving from a public funded industry to a more private investment-based business and product driven market. This is in line with international movements where the concept of Circular Economy is currently being implemented and the call to recover the resources in the waste stream is essential for sustainable development (Salleh & Kathiravale, 2000; Yunus et al., 2000).

1.2 Problem Statement

Unfortunately, comprehensive data on the characteristics of municipal solid waste (MSW) generated in Malaysia is not available. There has been a lot of work done and data published by the local research community but the method by which the data were obtained is unknown and furthermore the data are outdated. MSW characteristics are dependent on the components that make up the waste. In most developed countries the waste is segregated, whereas in Malaysia, the MSW is discarded indiscriminately (Aziz, 1996).

Hence the scenario at hand was how to establish the characteristics of 30,000 tons of heterogeneous waste generated daily which is made up of at least 30 to 50 different components. Current methodologies, which are referred to by most around the world, require only 200 kg samples for the establishment of the components. After this, only a 2 kg sample was required to be sent to the laboratory to be analysed. Of course, the sample size was more than enough for the analytical instruments that are currently being used to establish the proximate, ultimate, calorific value and the elemental analysis of the MSW. Most of the analytical instruments require less than 1 g of sample for analysis (Dahlén & Lagerkvist, 2008; Liikanen et al., 2016; Saidan et al., 2017). The question again, was how to get a representative 1 g sample from the heterogeneous waste generated daily?

At the same time, with the change in management method from dumping to processing, the requirement to monitor the characteristics of the waste has increased. The concept of converting MSW to Refuse Derived Fuel (RDF) had changed the needs in the waste industry where monitoring the waste that was being processed was essential in ensuring the product. The analysis equipment has to be robust and able to analyse on-line. Hence the analytical industry will have to change from a limited small sample to a large-scale sample and be able to give on-line results.

Malaysia is still in the process of adopting to the best practice for the management of MSW that is being generated. Previously, the management method depended solely on open dumps. Data dated as far back as 2000 indicate that there were nearly 200 landfills of which more than 90% were open dumps. Another alarming indication was that most of these dump sites had a life span of less than 2 years (Hassan et al., 1998; Rozainee et al., 1999). Sixteen years has passed and many of them are still in operation causing various kind of environmental damage such as fresh water pollution and air pollution.

A National Solid Waste Strategic Plan was developed in 2003 that embraced all aspect of waste hierarchy as stipulated in the Integrated Waste Management System. The plan advocates the concept of Best Available Technology Not Entailing Excessive Cost or Best Available Technology Suiting Socio Economic Standing that will give good promise, thus certainly conforms to Malaysian needs in MSW management. In the above pursuit, many new projects had been mooted and implemented with their effect on the waste management problem still being evaluated. Listed below are a few notable projects that have been or are being implemented:

- Incineration with a name of Thermal Oxidation Plant underwent research and development on a pilot plant had successfully lead to the award and construction of a commercial plant built on the island of Labuan in 2000
- Sanitary landfill – development and upgrading to Level 3 & 4 – example of 3 projects that have been implemented
    - 2001 – Pulau Burong, Penang
    - 2003 – Selong, Johor
    - 2005 – Bukit Tagar, Selangor
- Refuse Derived Fuel underwent research and development in a pilot plant that lead to a commercial plant built to treat waste in the area of Kajang, Selangor. The plant was ready in 2006 but due to some management and financial issues the plant was closed in 2014 and sold for scrap in 2016.
- 4 Mini Incinerators at Pulau Langkawi, Pulau Pangkor, Pulau Tioman and Cameron Highlands which were commissioned in 2015 and 2016 but had failed to operate on a continued basis and were re-tendered for rectifications and upgrading in 2017 to new operations teams.
- A national waste characterization study carried out in 2012 and 2013 to establish the waste characteristic of MSW by each state and by the various waste generators.

Sadly, almost all the above projects have met with abrupt ends or even if still in operation, these facilities are operating a far below their desired output. One of the main reasons for this is the variability of the MSW being sent and the lack of understanding on the characteristics of the waste either its physical or chemical composition. This boils down to the basic, which says when you don't understand the problem, it is impossible to solve it. The next sub section gives a short description of some of the technologies that have been implemented during the period of this study on which the candidate was actively involved in the implementation and the reasons for the non-performance.

1.2.1 Thermal Oxidation Plant in Labuan (Mini Incinerator)

Labuan is a tourist island in Malaysia and along with the other islands in Malaysia was facing an acute problem with the disposal of the waste generated on the island. On an island, to find landfill space was almost impossible and if there were any, it would have filled up very fast. Hence, a solution was sought trough the incineration option. This option would reduce the MSW not only by volume but also by weight. This brought about the need to design and build an incinerator; and the option was identified for the Labuan Island.

Heeding this call, a local company Chain Cycle Sdn Bhd got into a venture to import the incineration technology from United States of America. The initial research was carried out with the collaboration of Malaysian Nuclear Agency (ANM) and a government Industrial Grant Scheme amounting to RM5 million funded the pilot plant. It is important to note at this point that the design of the pilot plant was from USA. As such, all testing results were given back to the parent company in USA to do the design of any commercial plant to be carried out later. The pilot plant located at ANM Complex, Bangi, carried out the testing from 1998 to 2000 (Rozainee et al., 1999; Salleh & Kathiravale, 2000). Tests were carried out with from waste material from office, some market waste and industrial wastes. Figure 1.1 shows the typical Thermal Oxidation Plant.

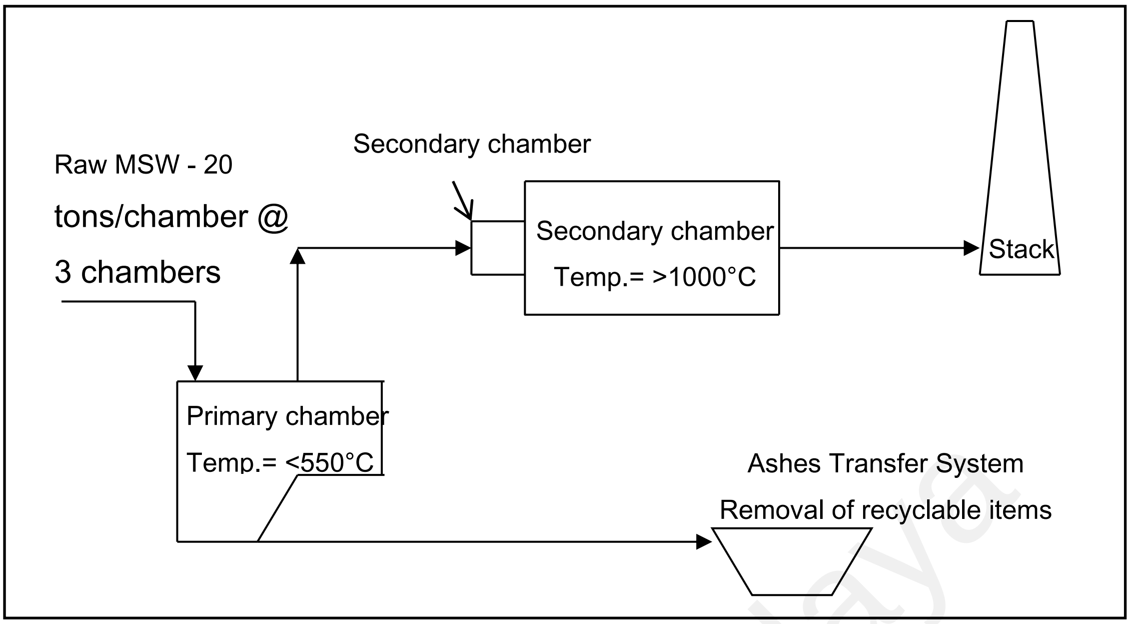

Figure 1.1: Layout of the Thermal Oxidation Plant, Labuan

The success of the pilot plant led to the award of a commercial plant to be built in Labuan. The contract awarded by the Government of Malaysia was a build and transfer contract. The conditions were that the plant should have a capacity of 40 tons/day. Together with this the company gave an assurance that the operation cost would be USD 15/ton MSW and that the plant would not require any emissions gas treatment equipment yet meeting local Department of Environment air regulations (Yunus et al., 2000).

In 2002 the plant was ready and in 2003 and 2004, ANM followed the commissioning and auditing of this plant. However, the plant failed to meet the requirements of the government contract and also the companies' assurances. Upon commissioning, the plant could only burn 40 tons of waste in 50 to 55 hours. The cost of such a cycle was at RM 70/ton MSW. Apart from that the stack gasses were being emitted at 1000°C, which caused environmental damage when cooling down in the open atmosphere.

Currently, the plant has been shut down and decommissioned while the government is waiting for an integrated solution to the MSW problem in Labuan. Apart from that, there are a few reasons and lessons that surfaced from this project and among them are:-

- The main reason for the failure to burn the waste was that the moisture content of the waste recorded was higher than that recorded in the initial waste characterization done. Malaysian MSW contains 60% inherent moisture and 10% free water in terms of Leachate; and to dump this waste directly into an incinerator was wrong. At the same time the variation in the moisture content also lead to the variation in the calorific value of the MSW. As such, during any sampling process among the very necessary parameters to be monitored are the physical composition, the moisture content and the calorific value.

- Labuan has a high content of inters, (glass & tins) which only absorb heat during combustion without contributing to the combustion process. This too absorbed high amounts of fuel.
- An essential part of the process was for the waste to be treated without any pre-processing. This would translate into allowing the leachate to be dumped directly into the incinerator. Little attention was paid to the waste characterization process where only 10 samples were used to design the plant. Further investigation found that the design of the plant was based on the average values from the waste characterization program whereas it should have taken into consideration the minimum and the maximum values of the waste composition and the moisture content of the waste and the plant should have been able to perform based on these maximum and minimum range of characteristics. The above wrong considerations were the main attributes for the failure as the design did not accommodate for the full range of the waste characteristics.

1.2.2 Refuse Derived Fuel (RDF) Plant, Kajang

Recycle Energy Sdn. Bhd, a company responsible for developing this technology in Malaysia, started introducing the RDF idea way back in 1993, after procuring the know-how from Bangalore Blended Fuel Ltd., India. The company pursued this option in belief that the Government of Malaysia or Private Waste Concessionaires appointed by the Government in MSW management to take up this non-expensive RDF technology. However, the reception to this technology was rather negative, for myriads of reasons.

However, in 2002 a pilot plant, having a capacity of 15 t/d, was set up in Kajang, Selangor. It was financed wholly by Recycle Energy Sdn. Bhd with research collaboration done with Malaysian Nuclear Agency and University Putra Malaysia. After 3 years of research work and fine tuning the operations of the plant, a commercial scale plant was awarded to the company to cater for the area of Kajang, Selangor, Malaysia which at that point of time was generating 700 tons of waste a day. This commercial plant was privately funded and estimated to cost RM 40 million. This would mean that the capital investment would be at RM 38,000/ton as compared to incineration, which was estimated at RM 330,000/ton and by sanitary land filling at a cost of RM 30,000 /ton. Apart from that; the company gave a guarantee that the operation cost of the plant would be at par with the existing land filling operating cost of RM 8/ton. This was an attractive commercial offer to the government and the commercial plant started operations in 2006. This commercial plant was designed to have a capacity to handle 240 tons/line with 4 lines in operation daily (Hassan et al., 1998; Salleh & Kathiravale, 2000).

Among issues faced during the commissioning zeroed to the unexpected amount of organic waste that choked major critical equipment, such as trammel, dryers, shredders, etc. The plant operators reported that the organic waste content to be in the range of 75% which deviates by almost 10 –15% from the pilot plant waste study, conducted by

ANM and University Putra Malaysia. In summary, the difficulties and successes that were faced in the plant commissioning is focused to the nature of waste characteristics, which is very heterogeneous and could not be reflected even during pilot plant studies. Hence, the results indicate that: -

- The sorting process is in place with minor adjustments
- The need to address the high organic content in the MSW
- The need to have a good and wholesome approach to the waste characterization issue

Lessons learned from the implementation of the above projects are such as the need to add local R&D and technical know-how to improve the workability of the projects with a good understanding of the waste characteristics. However, the research capability and the experience in Malaysia were still at an infant stage and the need to depend on foreign know-how and experience was essential. At the same time a good knowledge of the kind of MSW that is being generated in Malaysia is essential in making the appropriate waste management decision. Nevertheless, waste characteristics data used to design and evaluate these projects were by far inferior and needs to be enhanced with a good understanding of how and what is generated, and this will give a good picture of what is to be managed. In most cases or projects, a very limited number of samples are taken for physical and chemical analysis, with no consistency in the sampling method. As such the results stand alone and cannot be used to be compared with previous results; if there is one in the first case. Hence, setting the sampling method and frequency, followed by the physical and chemical analysis and finally the reporting procedure plays a big part in ensuring the right type of treatment is administered to obtain the desired results in Municipal Solid Waste Management.

1.3 Research Boundaries

The study was to establishment an improved protocol or approach for MSW characteristics in Malaysia. MSW has often been classified as wastes generated from urban and sub urban areas which cover all types of residential, commercial, Institutional and even light industrial activities within a stipulated municipality. The study addressed the MSW generated in the residential areas, however due to the current practice of collection routes covering all other sources of waste generators, a careful selection was done to ensure that the residential portion makes up at least 60% of the truck load of waste that was sampled and analysed. Notwithstanding that, the study highlighted the characteristics of several sources of MSW as explained above with some description on the sources given below: -

- the three types of residential of Low, Medium and High income – identified by the types of houses in each area where low is for squatter, village, single story and low cost flats; medium is classified by the 2 story interlink houses, apartments and condos; and the semi D and bungalows are classified as high income residential areas.
- Institutional – covered all academic premises, medical and governmental premises
- Commercial – any premise which had commercial activity
- Industrial – light industrial lots and shop houses with some industrial activities.

MSW goes from generation in the premise (As Generated) to curb side collection (As Discarded) to final disposal (As Disposed) at a treatment centre or landfill. This study was aimed to highlight the characteristics right from generation to disposal but the research boundary was more on the As Disposed; as most data generated in the past highlighted the waste characteristics on an As Disposed basis to be compared and analysed.

Another research boundary was to be based on the geographical location of the waste. Highlighting the overall characteristics of MSW in Malaysia was difficult as historical data was hard to get while new analytical data needed high cost and long durations to be obtained. Hence, the study highlighted the MSW generated in all the various states in Malaysia, but the focus of the analysis was on a few areas, namely Kuala Lumpur, Penang and Labuan which has substantial amount of historical data for comparison. The final boundary for the study was the time frame of the data used for the study. This study analysed data sets form projects occurring from the year 2000 to 2014.

1.4 Research Aim and Objectives

In order to carry out proper waste management, one must first know what is to be managed. Hence, to manage the waste, a good understanding of the waste characteristics was necessary which includes the composition, physical, chemical and biodegradability of the waste was essential if the proper treatment was to be met out. In Malaysia, the standard protocol for the characterization of municipal solid waste was approved in July 2012. This study adopted the recently developed protocols and compared it to the standards used previously while introducing improvements that would make waste management decisions more meaningful, accurate and cost effective. The objectives of the study were:

1. To review and determine methods on how best to analyse waste generated and the components that make up the waste;
2. To review and improve the moisture content analysis in the waste and its components while taking into account precautions during sampling;
3. To determine the calorific value of the waste using established equations;
4. To establish an improved protocol for the sampling, analysis and reporting of Municipal Solid Waste (MSW) especially for Malaysia.

1.5 Scope of this Research

1. Establishment of Sampling Plan
    a. Establishment of area of study - to consider the various issues governing the selection of the study area
    b. Establishment of number of samples – based on the area of study, to establish the number of samples that would be representative based on statistics
    c. Identification of the samples to be picked up within the study area; by distributing the pre-determined number of samples to represent the socioeconomic status of the area of study
    d. Identification of the duration and specific time frame to take the samples

2. Sampling of the waste material
    a. Due to heterogeneous composition, to conduct various sorting procedures at laboratory and in field to establish the most appropriate with cost and time considerations together with obtaining representative samples for analysis.
    b. To look into the safety and health measures while carrying out the above activities

3. Analysis of samples
    a. To carry out analysis of the samples for physical and chemical based on current established methods
    b. To create reporting basis for these data that would be common based on the sampling and analysis procedures. This would allow for these data to be used in the future to apply the appropriate treatment technology.
    c. Based on the finding above to recommend sets of protocol that could be used

4. Comparison of mathematical models to predict the waste characteristics

   Based on the data established above, analysis will be done to predict the calorific value based on chemical properties, physical properties and the components that make up the waste

1.6 Research Output

This research would develop an improved protocol for the characterization of municipal waste could be used for all types of waste generated in Malaysia or even for the region. The proposed protocol will have among other outputs such as: -

- Best methods to sample and analyse the waste to give accurate picture on the characteristics which can be used to design the waste management facilities
- Ensure all moisture in the waste is accounted for by introducing new steps to account for the moisture during sampling and transportation of the waste material for site to laboratory
- Method of analysis for multi component waste
- Physical and chemical analysis on component and mix basis
- Reduce cost and time for getting the calorific value of the waste by employing equations to predict the calorific value.
- Health and safety measures during sampling and analysis

It is well understood that information on waste characteristics are scarce, not available or not understood. At a time where the shift in energy production has changed from full concentration on fossil fuel to alternative energy including nuclear power, waste as a resource, which entails for all processes, needs to be addressed. These protocols will ensure that waste characteristics are understood and can be used to address issues related to the treatment technologies that would be needed, which are related to the basic knowledge of waste characteristics. This improved protocol will be forwarded to the National Standards Committee for adaptation.

1.7 Benefits of this Research

From this study, several benefits could be established for the private sector who are now embarking on privatizing the waste management industry in Malaysia, the Government of Malaysian and the general public, and they are:

- The development of an improved protocol to characterize waste will ensure that these data will be accurate for designing and running new waste management facilities and lead to better management of the waste
- The usage of mathematical models will reduce cost and time in establishing the characteristics
- Good and accurate databases on waste characteristics will allow the Government to know the current situation of the waste and allow for the prediction of the future situation for waste management in the country.

This study was meant to cater for the potential growth in the volume of waste material in correspondence to the growth of the population. At the same time, as cost become higher, the need for more simplified methods while addressing accuracy and timing is essential in analysing the waste. The study could be forwarded to the Malaysian Standards Committee on Solid Waste for it to adopt the findings.

1.8 Limitation of the Study

The limitations of this study are as follows: -

1. Commitment from the project owner or the industry

   The unwillingness and the lack of understanding with the main objective of keeping cost low, often puts MSW characterization work at the last item on the need to do list in any project or planning for waste management facility. There is no real commitment to understand the waste being generated over the period of design and commissioning of a facility which can take up to 2 years. Most often a waste characterization studies would be done at the beginning to fulfil the EIA requirements which is done as early as 18 to 24 months before the project goes to commissioning and most certainly the characteristics would have changed by this time.

2. Confidentiality

More often, the data would not be shared or the methods by which the samples are taken would not be fully disclosed to protect the investment in the project. This leads to some data although published but would not be able to be used for comparison.

3. Cost Factor

This is the most important factor to affect this study. Moreover, waste project is very hard to come-by and mostly at the beginning stages with limited funds thus limiting the data mining process. Very often waste characteristics fluctuation is seen as not an important fixture and can be handled by the facility once it is up and running.

4. Time factor

Waste management planning is done on very long-term basis and to the tune of 5 to 10 years once by the government. In that time very few project or facilities are built, and these too take between 2 to 3 years to be designed. Thus, getting the necessary data for the study, with this kind of timing factor was difficult.

5. Manpower Factor

Waste characterization sampling needs a lot of manpower to get the samples and the sorting of these samples into the various components. With the fact of cost limitations, only very lowly educated and even scavengers were used to do the sampling and sorting process which could lead to lack of understanding on the components to be sorted.

6. Volume of waste to be sorted

Waste is a perishable item, and needs to be sorted into its components immediately, which can be done in small volumes but when a whole truck load is taken into consideration, this is impossible what more if this exercise is to be repeated to ensure repeatability of the results obtained for scientific purpose.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter gives a picture of what is waste while zooming into municipal solid waste. The focus was on the different sources and types of MSW generated in the premise, disposed out of a premise for the process of collection and finally disposal to a facility or at a landfill. There is a small portion of about 15% which is being recycled. The aim of the literature study would be to determine which method was the waste being characterized and reported. The need to understand the physical composition of the waste, followed by the physical characteristics and finally the chemical and heavy metal content of the waste stream. These are the minimum parameters that would influence the decision making in a waste management plan or a facility design. The need to understand the parameters that greatly fluctuate due to varying seasons, culture, geographical nature, income status and many more needs to be understood and captured for a good and guided decision making process.

2.2 Definition of Municipal Solid Waste in Malaysia

The Solid Waste and Public Cleansing Management, Act 2007 Part I: Preliminary - Interpretation defines solid waste and controlled solid waste as;

a) any scrap material or other unwanted surplus substance or rejected products arising from the application of any process;
b) any substance required to be disposed of as being broken, worn out, contaminated or otherwise spoiled; or
c) any other material that according to this Act or any other written law is required by the authority to be disposed of, but does not include scheduled wastes as prescribed under the Environmental Quality Act 1974, sewage as defined in the

Water Services Industry Act 2006 or radioactive waste as defined in the Atomic Energy Licensing Act 1984.

"Controlled solid waste" means any solid waste falling within any of the following categories:

- Commercial solid waste
- Construction solid waste
- Household solid waste
- Industrial solid waste
- Institutional solid waste
- Imported solid waste
- Public solid waste
- Solid waste which may be prescribed from time to time

As Generated Waste

As Generated Waste are solid waste produced from its source. It is also the summation of waste retained by the generator for other purposes and waste discarded for collection. Generation refers to the weight of materials and products as they enter the waste management system from residential sources but before recovery or combustion. Pre-consumer (industrial) scrap is not included in the generation estimates. Source reduction activities (e.g., backyard composting of yard trimmings) take place ahead of generation.

As Discarded

As Discarded waste are solid waste placed at the collection point (e.g. Kerbside, Roll-off Roll-on (RoRo) Bins) and to be collected by licensed waste collector/contractor.

As Disposed Waste

As Disposed waste are solid waste taken from the collection points and delivered to solid waste management facilities (e.g. Sanitary Landfill).

Figure 2.1 below gives a schematic description of the various generation points and the points at which the sampling can be carried out.

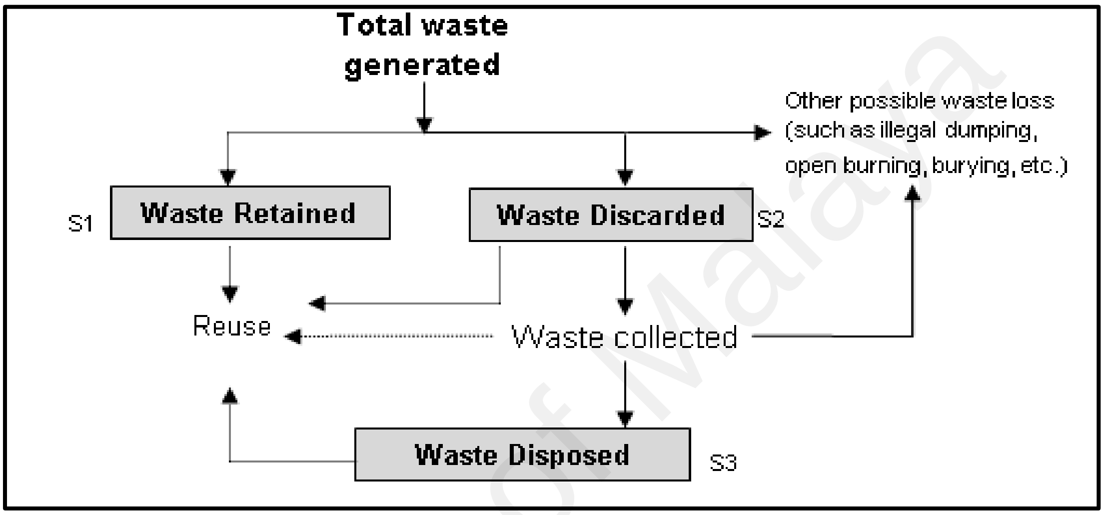

Figure 2.1: Flow Chart of Waste from House to Final Disposal

2.2.1 Scope and Value Chain of the Waste Sector

In addressing the scope and value chain of the waste sector, Table 2.1 summarized the description of the various activities in the sector while highlighting the targeted responses that would require, ensuring sustainability of resources in the waste industry.

The waste management sector is very attractive because of the abundance in opportunities that needs improvements and these improvements can be made rather easily. However, the probability of success is rated lower due to the numerous challenges faced by the solid waste sector with the general cultural habits and behaviours of the current population that are the most difficult to change.

Table 2.1: Scope and value chain of the waste sector (Adapted from: MIGHT (2014)

	Scope	Value Chain	Target
Waste Prevention	**Waste Reduction**	**Waste Generation** • Awareness and behavioural change – software approach • Management systems– software & Hardware approach • Technological changes – hardware approach • Water Footprint / LCA / MFA	• Decreased demand for raw materials. • Decreased demand for energy • Decreased demand for water
	Waste Reuse	**Waste Storage** • Storage efficiency • Efficient segregation for a potential resource (will facilitate in choosing the right treatment methods for different types of waste) at source • Improve collection efficiency	• To maintain quality of waste • To add value to waste • To adhere to standards and regulations
Waste Diversion	**Waste Recycling**	**Waste Haulage/ Collection/ Transportation** • Appropriate design of vehicle and its end-of-life • Appropriate route of collection for effective collection and transportation • Transfer and transport facilities (e.g. Transfer stations) **Waste Transformation** • Recovery and reuse of recyclable materials – process waste to recover commercially valuable materials or products • Decomposing of organic matter via: - Composting - Anaerobic digestion • (Organic products can be used as mulch, compost, landscaping waste gas captures can be used for generating electricity and heat)	• To reduce GHG emission • To reduce maintenance cost (increase ROI) • To adhere to OSH requirements • To adhere to standards and regulations
	Waste Treatment	**Waste Transformation** • RDF • EfW/ WtE • Thermal treatment • Pyrolysis • Gasification • Refined waste into other chemical products (chemical refinery) • Refined solid residue into product such as activated carbon	• Reduce waste sent to landfill • As alternative energy sources
Waste Disposal	**Waste Disposal**	**Waste Disposal** • Landfill with energy recovery • Landfill without energy recovery	• Safe post closure – ex landfill can be used after closure • As alternative energy sources • Reduction of GHG • Reduction of leachate pollution

2.3 Global, Regional and Local Trends on MSW

According to the report by UNEP in the Global Waste Management Outlook 2015, Global generation of Municipal Solid Waste is now about 1.2 Billion tonnes/yr of which more than 70% ends up in landfills and open dumps. It is estimated that emissions for landfills and open dumps contribute about 30 to 35 million tons of Methane annually to the world's total Methane emissions of about 550 million tonnes/yr.

Based on various reports, the waste sector is facing four categories of challenges which includes;

i. increasing growth in the quantity and complexity of waste streams associated with rising incomes and economic growth;
ii. increasing risk of damage to human health and ecosystems;
iii. the economic unattractiveness of the waste 3Rs; and finally,
iv. the sector's contribution to climate change

In Malaysia, specific data on the amount of methane generated and captured is not available. However, the amounts should be very high as the current management practice is to dump raw MSW into open dumps and non-sanitary landfills. Latest statistics from the Department of National Solid Waste Management; as of 2014 indicate that Malaysia has about 296 disposal sites of which 165 are still in operation. The other 131 sites are closed. Off the 165 operating sites, only 8 are of sanitary status. In other words, off the 33,000 tons of MSW generated/day only 22% ends up in secure landfills (JPSPN, 2013). Municipal solid waste management has become the most challenging problems and presents a serious challenge to authorities due to its generation in large quantities. As shown in Figures 2.2 and 2.3 (UNEP, 2015, 2017) generation of MSW has increased regardless of countries status.

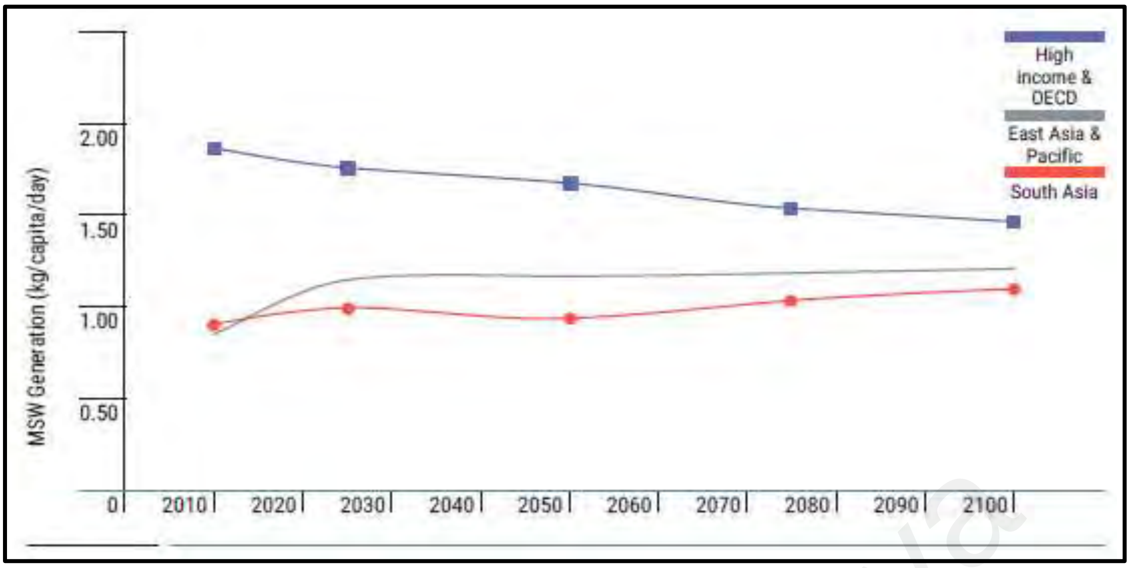

Figure 2.2: Generation Rate Trends of Municipal Solid Waste Based on Country Income (Adapted from: UNEP (2015)

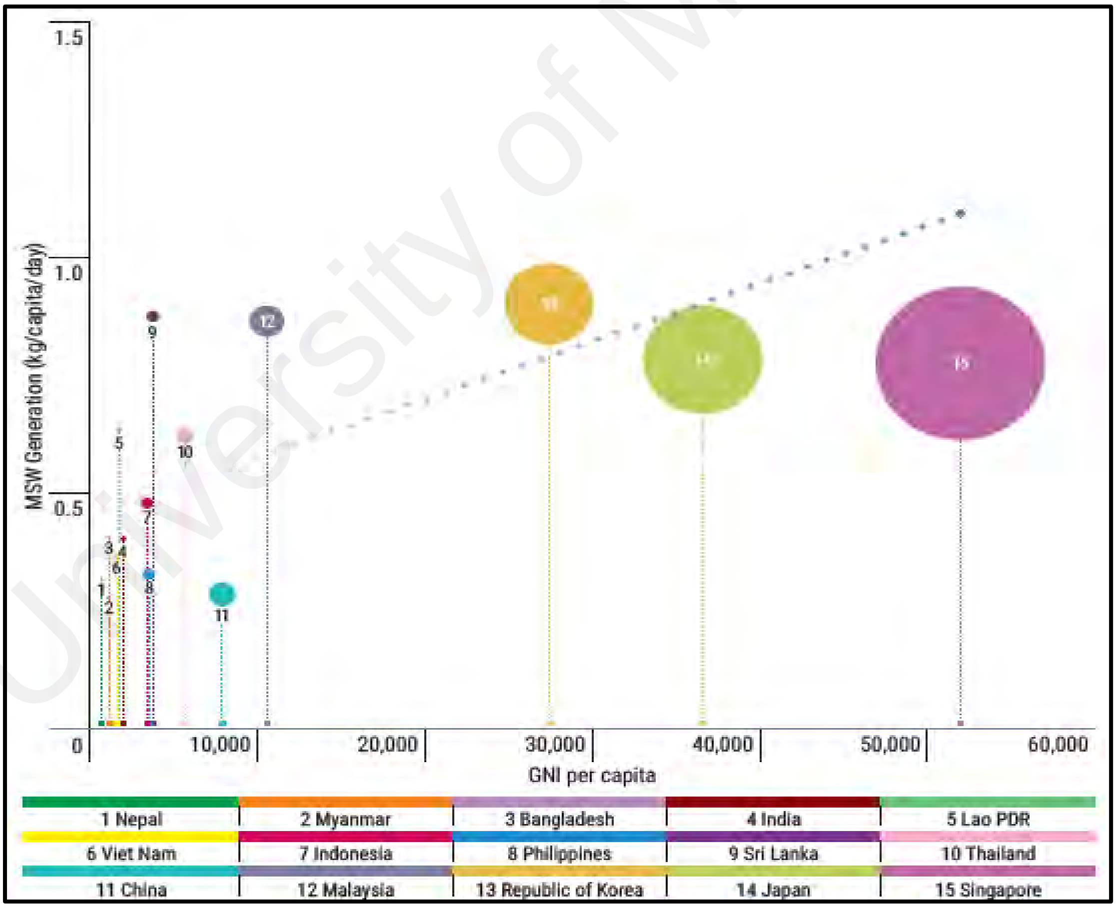

Figure 2.3: MSW Generation related to GNI per Capita in Selected Asian Countries (Adapted from: UNEP (2017)

Table 2.2: Waste collection typologies by GDP per capita (Bandara et al., 2007; Beigl et al., 2008; Götze et al., 2016; UNEP, 2015)

Particulars	Low-income countries	Middle-income countries	High-income countries
GDP in RM/capita/year	< 5,000	5,000 – 15,000	5,000 – 15,000
Average consumption of paper and cardboard by kg/capita/year	20	20 – 70	130 – 300
Municipal waste (kg/capita/year)	150 – 250	250 – 550	750
Formal collection rate of municipal waste	< 70%	70% – 95%	> 95%
Statutory waste management framework	No or weak national environmental strategy, little application of the statutory framework, absence of statistics	National environmental strategy, Ministry of the Environment, statutory framework but insufficient application, little statistics	National environmental strategy, Ministry of the Environment, statutory framework set up and applied, statistics
Informal collection	Highly developed, substantial volume capture, tendency to organise in cooperatives or associations	Developed and in process of institutionalisation	Quasi non-existent
Municipal waste composition (% weight basis)			
Organic/fermentable	50 – 80	20 – 65	20 – 40
Paper and cardboard	4 – 15	15 – 40	15 – 50
Plastics	5 – 12	7 – 15	10 – 15
Metals	1 – 5	1 – 5	5 – 8
Glass	1 – 5	1 – 5	5 – 8
Moisture content	50% – 80%	40% – 60%	20% – 30%
Calorific value (in kcal/kg dry basis)	800 – 1,100	1,100 – 1,300	1,500 – 2,700
Waste treatment Uncontrolled landfills	> 50% Informal recycling 15%	Landfill sites > 90%, start of selective collection, organised recycling 5%, coexistent informal recycling	Selective collection, incineration, recycling > 20%
Informal recycling	Highly developed, substantial volume capture, tendency towards cooperative or associations	Developed and in process of institutionalisation	Quasi non-existent

In the local context, Malaysia is one of the most developed countries in South-East Asia with the population of 32 million inhabitants in 2018 faces escalating municipal solid waste management including the disposal. In Peninsular Malaysia, the total quantity of MSW generated has increased from 19,100 tons per day in 2005 to 23,000 tons per day in 2010 or an average of 1.17 kilogram per capita per day, a growth parallel with the urban areas in many other Asian countries. This figure has escalated to 27,802 tons/day in Peninsular Malaysia, as reported in a Survey on Solid Waste Composition, Characteristic and Existing Practice for Solid Waste Recycling in Malaysia in 2012 (JPSPN, 2013).

The world market for municipal waste, from collection to recycling, is worth in OECD countries, the cost of municipal waste management is about RM 120 billion/year, and while for industrial waste is RM 150 billion/year. Developing countries illustrate 20-50% of recurring budget of municipalities spent on solid waste management although only 50% of urban population is covered. In low-income countries collection alone drains 80-90% of total waste management budget estimated RM 410 billion a year. This estimate can only be indicative since assessing the exact market size is difficult given the lack of reliable data, particularly in developing countries, and existing data being limited to the “formal” component of the waste-management sector (Götze et al., 2016; Gu et al., 2017; UNEP, 2017).

In order to consider best practices in addressing environmental related issues in solid waste management, it is very important to look into the overall contribution of waste and to compare with different countries as shown in Table 2.2. Zooming in on the waste characteristics, it is evident that there is a drastic change from the low income to the high-income countries and this also changes the management method. This goes to show that a good understanding of the physical components and the chemical composition of the MSW is essential in ensuring proper waste management solution.

2.4 Malaysian MSW Generation Rates

MSW consists of everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint and batteries. It does not include medical, commercial and industrial hazardous or radioactive wastes, which must be treated separately. Population and development have brought upon mankind the problem of ensuring the safe disposal of the Municipal Solid Waste to ensure the longevity of their environment. Over the past decade, Malaysia has enjoyed tremendous growth in its economy. This has brought about a population growth into the capital city, along with a great influx of foreign work force too. The side effect of this can be reflected in Table 2.3, which indicates the amount of waste that was generated in Kuala Lumpur from 1970 to 2005 (Salim, 1993; Salleh & Kathiravale, 2000).

Table 2.3: Municipal solid waste generated in Kuala Lumpur (Adapted from: Aziz (1996)

Year	MSW Generated (tones/day)
1970	98.8
1980	310.5
1990	586.8
1998	2257
2000	3070
2005	3478

Based on the above, there have been scarce data on the MSW generated or dumped by Kuala Lumpur. On a different note, a survey carried out by a firm for the city council back in 1993, shows the generation of MSW in a few areas in Kuala Lumpur to be as described in Table 2.4 (Aziz, 1996).

Table 2.4: Waste generated by various sectors in selected districts in Kuala Lumpur (Adapted from: Aziz (1996)

District	Residential	Industry	Commercial	Office	Market	Hospital	Wood Waste			Others	Total
							Road	Park	Fallen Tree		
Kepong	103.2	83.7	13.6	3.1	25.7	0.7	26.5	0.0	14.3	131.3	402.1
Setapak	111.3	6.9	39.8	7.1	4.8	5.1	14.0	2.6	6.3	9.0	206.9
City Center	182.8	68.0	157.1	41.5	24.1	8.3	40.6	13.3	16.7	132.2	654.5
Damansara	95.7	12.7	17.5	6.4	0.4	2.8	8.7	0.2	8.6	42.7	195.7
Cheras	69.8	34.2	24.5	6.1	6.9	0.6	23.1	4.7	8.4	34.2	212.5
Old Klang Road	67.8	29.1	15.2	3.9	4.8	0.0	29.0	1.5	16.5	23.9	191.8
Outskirts	16.4	18.8	6.3	0.9	1.1	0.0	2.0	1.4	0.7	12.9	60.5
Total	647.1	253.4	244.1	68.9	67.8	17.5	143.9	23.7	71.5	386.2	1924.0
Percentage	**33.6**	**13.2**	**12.7**	**3.6**	**3.5**	**0.9**	**7.5**	**1.2**	**3.7**	**20.1**	**100.0**

From the table it is obvious that the housing areas generated the most amount of waste. An analysis of Table 2.4 will also show a big amount of waste coming from sources classified as others. These could be from construction sites, which do clearing of building rubble.

Although the volume is small but building rubble is very heavy material and this could account for a lot by weight. There is also waste that come from the cleaning of the rivers and road sweepings which is carried out by the city council workers daily which contribute to the amount under the others category in Table 2.4. There is also waste from hospitals and industries in the table. These are waste that is categorized as not scheduled or normal waste, which is generated within their premises. It is not to be mistaken with the hazardous waste that is generated by the industries and also the biologically hazardous waste, which is generated by the hospitals and private clinics within Kuala Lumpur.

More recently, the National Solid Waste Management Department conducted a survey to establish the quantity of MSW that is going to be generated in Malaysia for planning purpose. The survey established that the quantity of waste generated by households in Malaysia would hit 27,000 Mt/d in 2015 and would reach 36,000 Mt/d in 2020 as shown in Figure 2.4 below.

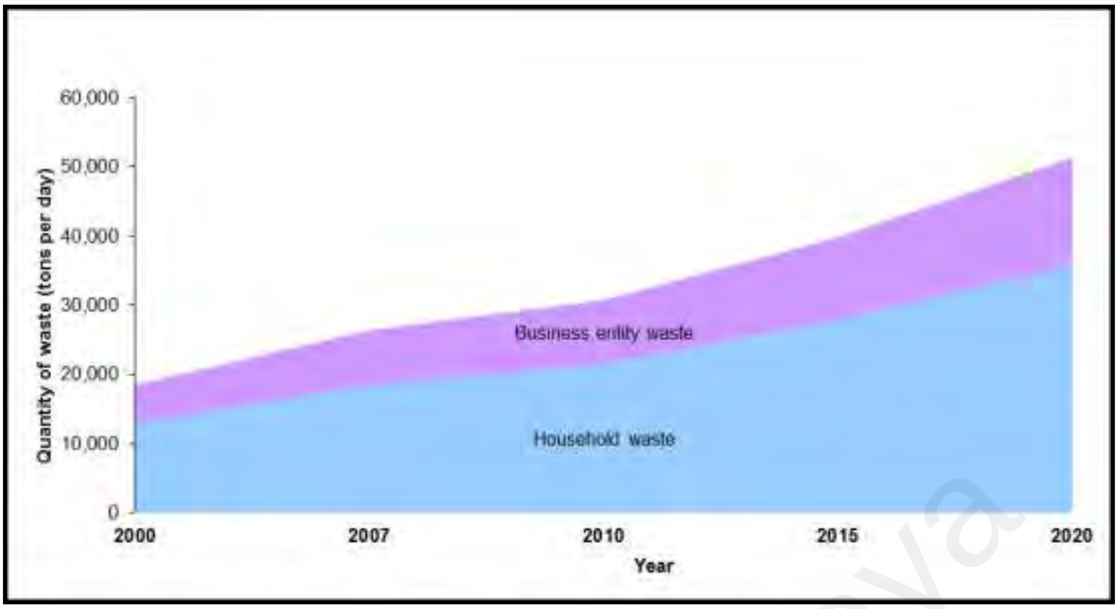

Figure 2.4: Household and Business Solid Waste Projection for Malaysia (2007- 2020) (Adapted from: JPSPN (2013)

The same study, which was considered as the most recent and updated comprehensive data for each state in Malaysia and the corresponding population growth to show the amount of MSW that, will be generated from 2000 to 2020 in Table 2.5 (JPSPN, 2013). The study assumes a linear rate of generation and also a linear population growth without taking into account reduction in consumption and recycling which can have a great effect on the amount of MSW generated and disposed.

On the other hand, waste generation rates can also be describes as a function of per capita basis. Very often MSW generation rates are given as an absolute figure in terms of Mt/day or kg/capita/day. Before this the data on MSW was presented as Mt/day basis.

An old indicative survey done in the 1980's of Petaling Jaya, shows some comparative data which for Malaysia could be one of the very few such data available in the public domain (Aziz, 1996; Kaur & Singh, 1995). The results indicated that the average generation rate of the various sources and this is pictured in Table 2.6.

Table 2.5: Waste generation estimation by population for districts in Malaysia (2000 to 2020) (Adapted from: JPSPN (2013)

LAs	Population within District 2000	Study estimation			Population within District 2004	Study estimation	Projected Population within District on 2007	Study estimation		
		Total Quantity of waste (tpd) 2000	Quantity of household waste (tpd) 2000	Quantity of commercial & institutions waste (tpd) 2000		Total Quantity of waste (tpd) 2004*		Total Quantity of waste (tpd) 2007	Quantity of household waste (tpd) 2007	Quantity of commercial & institutions waste (tpd) 2007
Johor	2,584,997	2,154	1,508	646	2,853,353	2,636	3,072,749	3,071	2,149	921
Kedah	1,571,077	1,309	916	393	1,734,175	1,602	1,867,517	1,866	1,306	560
Kelantan	1,287,367	1,073	751	322	1,421,012	1,313	1,530,275	1,529	1,070	459
Melaka	605,239	504	353	151	668,071	617	719,439	719	503	216
N. Sembilan	829,774	691	484	207	915,915	846	986,341	986	690	296
Pahang	1,229,104	1,024	717	307	1,356,701	1,253	1,461,018	1,460	1,022	438
Perak	1,973,368	1,644	1,151	493	2,178,229	2,012	2,345,714	2,344	1,641	703
Perlis	198,288	165	116	50	218,873	202	235,702	236	165	71
Pulau Pinang	1,231,209	1,026	718	308	1,359,024	1,256	1,463,521	1,462	1,024	439
Selangor	3,952,817	3,293	2,305	988	4,363,170	4,031	4,698,657	4,695	3,287	1,409
Terengganu	880,234	733	513	220	971,614	898	1,046,322	1,046	732	314
WP Kuala Lumpur	1,305,792	1,088	762	326	1,441,350	1,332	1,552,176	1,551	1,086	465
WP Labuan	70,871	59	41	18	78,228	72	84,243	84	59	25
Putrajaya							51,481	51	36	15
Sarawak	2,009,893	1,674	1,172	502	2,218,546	2,050	2,389,131	2,387	1,671	716
Sabah	2,468,246	2,056	1,439	617	2,724,482	2,517	2,933,969	2,932	2,052	880
TOTAL	22,198,276	18,494	12,946	5,548	24,502,743	22,638	26,438,255	26,419	18,494	7,926

Notes:Base year population used : based on 2000 Census by Dept of Statistics. Projection is based on estimation as follows:- (1) Growth Rate for Household Waste Generation = 2%^ (2) Growth Rate for commercial & Institutions Waste Generation = 4%^ (3) Percapita household waste generation rate = 0.628^ (4) Percapita commercial waste generation rate = 0.269^ (5) Assuming % of Household waste from total waste = 70%^^ (6) Assuming % of commercial waste from total waste = 30%^^ (7) An additional 10% is added to the commercial estimates ^ Adopted from page 2-14 from The Study on National Waste Minimisation in Malaysia - supporting report 1 - additional information

LAs	Projected Population within District on 2010	Total Quantity of waste (tpd) 2010	Quantity of household waste (tpd) 2010	Quantity of commercial & institutions waste (tpd) 2010	Projected Population within District on 2015	Total Quantity of waste (tpd) 2015	Quantity of household waste (tpd) 2015	Quantity of commercial & institutions waste (tpd) 2015	Projected Population within District on 2020	Total Quantity of waste (tpd) 2020	Quantity of household waste (tpd) 2020	Quantity of commercial & institutions waste (tpd) 2020
Johor	3,309,015	3,579	2,505	1,074	3,743,846	4,629	3,240	1,389	4,235,819	5,999	4,200	1,800
Kedah	2,011,111	2,175	1,523	653	2,275,388	2,813	1,969	844	2,574,393	3,646	2,552	1,094
Kelantan	1,647,939	1,782	1,248	535	1,864,491	2,305	1,614	692	2,109,501	2,988	2,091	896
Melaka	774,757	838	587	251	876,567	1,084	759	325	991,755	1,405	983	421
N. Sembilan	1,062,181	1,149	804	345	1,201,760	1,486	1,040	446	1,359,681	1,926	1,348	578
Pahang	1,573,357	1,702	1,191	511	1,780,109	2,201	1,541	660	2,014,030	2,853	1,997	856
Perak	2,526,078	2,732	1,913	820	2,858,025	3,534	2,473	1,060	3,233,593	4,580	3,206	1,374
Perlis	253,825	275	192	82	287,180	355	249	107	324,918	460	322	138
Pulau Pinang	1,576,052	1,705	1,193	511	1,783,158	2,205	1,543	661	2,017,479	2,857	2,000	857
Selangor	5,059,940	5,473	3,831	1,642	5,724,858	7,078	4,955	2,123	6,477,151	9,174	6,422	2,752
Terengganu	1,126,774	1,219	853	366	1,274,841	1,576	1,103	473	1,442,366	2,043	1,430	613
WP Kuala Lumpur	1,671,524	1,808	1,266	542	1,891,176	2,338	1,637	701	2,139,692	3,030	2,121	909
WP Labuan	90,721	98	69	29	102,642	127	89	38	116,130	164	115	49
Putrajaya	54,087	59	41	18	61,194	76	53	23	69,236	98	69	29
Sarawak	2,572,833	2,783	1,948	835	2,910,924	3,599	2,519	1,080	3,293,444	4,665	3,265	1,399
Sabah	3,159,564	3,418	2,392	1,025	3,574,756	4,420	3,094	1,326	4,044,508	5,525	3,867	1,657
TOTAL	28,469,757	30,794	21,556	9,238	32,210,917	39,824	27,877	11,947	36,443,696	51,413	35,989	15,424

Table 2.6: Waste generation rate in Petaling Jaya, Malaysia (Adapted from: Aziz (1996) & Kaur & Singh (1995)

Source	Average
Residential low income	0.46 kg/capita/day
Residential medium income	0.37 kg/capita/day
Residential high income	0.60 kg/capita/day
Squatters	0.61 kg/capita/day
Shops	2.25 kg/shop/day
Shopping complexes	0.004 kg/sq. ft/day
Hotels	0.9 kg/room/day
Office complexes	0.022 kg/sq. ft/day
Institutional	70 kg/ha/day
Industrial	440 kg/ha/day
Wet markets	3.92 kg/stall/day
Night markets	1.30 kg/stall/day
Hawker stalls	2.00 kg/stall/day

Unfortunately, there is no indication on what is the population at the time of study, but could be estimated from historical data, how much of this waste actually reaches the landfill, and at what rate is the generation rate going to change either positively or the other way and also the publisher has itself indicated that the values are only an average and may change with time and place. The positive indication is that the dwellers in Petaling Jaya is almost the same as Kuala Lumpur in terms of culture and lifestyle, and as such the data in the table could be used as an indication on the amount that is generated by the population in Kuala Lumpur.

Moving forward in time, the recent National Waste Characterization Survey has also provided with the national generation rates with the corresponding MSW generation rate for 2012 as shown in Table 2.7. There are some variations between the total waste generated in table 2.6 and 2.7, but this could be due to the different sources of base data used in achieving the results.

Table 2.7: Average Household Waste Generation Rate in 2012 for Malaysia (Adapted from: JPSPN (2013)

Housing Type	Urban			Rural			Overall		
	Population	Per Capita (kg/capita/day)	Total (MT/day)	Population	Per Capita (kg/capita/day)	Total (MT/day)	Population	Per Capita (kg/capita/day)	Total (MT/day)
Low cost Landed	2,675,954	0.74	1,988	2,019,579	0.69	1,397	4,695,533	0.72	3,384
Low cost High-rise	3,778,052	0.63	2,394	830,781	0.71	586	4,608,833	0.65	2,981
Medium cost Landed	8,167,292	0.89	7,245	3,377,231	0.67	2,276	11,544,523	0.82	9,521
High-Medium cost High-rise	2,366,232	0.89	2,095	-		-	2,366,232	0.89	2,095
High cost Landed	3,137,440	0.73	2,303	1,981,574	0.68	1,343	5,119,014	0.71	3,646
Total	20,124,970	0.80	16,025	8,209,165	0.68	5,601	28,334,135	0.76	21,627

Note: the population of each housing type by urban and rural was estimated based on the ratio in Property Stock Report 2010 and Census 2010

Now that a good picture of the amount of waste that is generated has been established along with the per capita generation rates, it can be concluded that the data available is recent and accurate enough. As such this study did not deep dive into the establishment of the overall generation rates of the waste.

2.5 Waste Characterization

Moving forward, understanding the kind of MSW that is generated would be essential in tackling the management problem and to understand the waste that is generated and disposed, there is a need to understand the value chain which was described in Table 2.1. Apart from knowing the value chain, understanding the process involved in establishing the characteristics of any MSW stream is necessary and that is:

1. Establishing a sampling plan and choosing the number, type and location of the samples.
2. Establishing by which method the samples will be obtained and what will be the final quantity that is needed for the sorting procedure into the various components
3. Establishing the composition of the waste by sorting and reporting this composition.
4. Establishing the characteristics of the MSW based on physical and chemical analysis and reporting these results.

These are the common steps taken in sampling and reporting of MSW characteristics. However, there are many approaches in carrying out each step and the aim of the following sections will be to look into these approaches in a practical and cost-effective manner in order to provide with the most accurate account of the MSW characteristics.

An important note to understand was that MSW generally is a combination of many types of unwanted material, discarded indiscriminately, with the possibility to react with one another in a very large quantity. The human factor, season, society influence, and many more factors do influence the characteristic of the MSW. Having all the variability, the attempt now was to establish a reliable and as accurate account of this waste stream, knowing fully that a full sampling is impossible due to the huge volume. As such, the task is to find the most appropriate amount of sample and sample size that would be considered representative and form that to carry out further analysis to determine the composition and characteristics of the waste.

2.6 Waste Sampling Plan

The focus of this study was to establish an improved protocol for sampling of waste and as such it would good that the study established the current data available and how much of it can be used as an indicative figure of a benchmark towards future studies. As mentioned, this study used waste characteristic from the years of 2000 to 2014. Although, it can be said that many studies were carried out either for academic purpose or for project purpose and even for planning purpose, most of these works end up in some private collection and it is very difficult to get the data for comparison purpose. However, there is one study that was carried out by the National Solid Waste Department and it is considered as the most comprehensive database in the public domain to date.

The candidate was one of the key personal in establishing the sampling methodology for this study which was based on the Malaysian Standard document MS 2505: 2012 - Guidelines for sampling of household solid waste - Composition and Characterization Analysis (Malaysia, 2012). Based on the existing Malaysian Standard, it can be deduced that the method in which the establishment of samples for the National Survey would have been well selected taking into consideration the seasonal, behavioural and geographical variance that will influence the composition of the waste. As such, this study accepted and adopted the Malaysian Standard as the most suitable document for sampling of heterogeneous waste and was used to describe the results of the composition and characterization of waste in Malaysia.

2.7 Waste Sorting Method

After establishing the sampling plan in which the time, number, location and duration of the sampling has been determined, the next was to obtain the sample from the garbage truck. As established in the last section, the study adopted the Malaysian Standard as its main referral document in which the document was very explicit in establishing the number of samples. However, when the method by which the samples are to be taken, the Standard gives a choice between the 'Truck Load' method and the 'Cone and Quarter' method without identifying any particular choice. In searching literature, it can be found that sampling of the MSW can basically be carried out by these four different procedures as listed below: -

1. 'Truck Load Method', where the whole contents of an identified truckload were sorted to account for the composition of the waste.
2. 'Cone and Quartering Method', where the contents of an identified truckload are unloaded on to a clean area and quartered until a manageable amount of waste is achieved (about 200 kg) before sorting.
3. 'Spot Sampling Method', where an amount of waste (about 30–50 kg) is taken from a few truck (about 8-10 trucks) to form a sample size of about 200 kg which is then sorted.

4. ‘Laboratory Sampling Method’, where the contents of a truck are unloaded, quartered and reduced until a 20 kg sample is achieved, which is parcelled for laboratory sorting.

There has been no indication on which the most superior method is however taking into consideration the time factor taken for sorting the sample and the manpower needed to carry out such a sampling activity and the related cost factor, there is a need to determine the most accurate method. Most of literature only speaks about keeping the area of sampling and sorting pre-cleaned and dried before each sampling and sorting activity. Other descriptions are often limited to samples being weighed as soon as they were taken from the source. Once the sampling and sorting activity was done, all the sampled material was weighed and accounted (Abu Qdais et al., 1997; Alhumoud et al., 2007; Boer et al., 2010; Bolaane & Ali, 2004; Edjabou et al., 2015; Miezah et al., 2015). Hence, establishing a sampling method will be one of the points that this study will look at answering.

There are many methods for the establishment of waste components and analysis in the world. Table 2.8 gives an overview of some of the methods available around the world looking at the method; the institution from which it has come from; base of the sampling size, the sampling method and even the sorting procedure. The list on Table 2.8, was used as a guide to the various kind of stratification methods, the sub sampling method and the sorting process.

As for Malaysia, historically there has been no standard test method for sampling and analysis of MSW. Until the year 2012, most of the sampling and analysis was done in accordance with American Standards. This standard describes the procedures for measuring the composition of unprocessed municipal solid waste by employing manual sorting.

Table 2.8: Methods for solid waste component sampling and analysis (Abu Qdais et al., 1997; Alhumoud et al., 2007; Boer et al., 2010; Bolaane & Ali, 2004; Buenrostro et al., 2001; Dahlén & Lagerkvist, 2008; Den et al., 2012; Edjabou et al., 2015; Miezah et al., 2015; Ojeda-Benitez et al., 2003; Qu et al., 2009; Riber et al., 2009; USEPA, 2002)

Institution	Method	Base of size of sample	Stratification – for sample location	Sub Sampling method	Sorting procedure	Components to be sorted into
American Society for Testing and Materials	Standard test method for determination of the composition of unprocessed municipal solid waste (ASTM D5231-92)	Mass	Selection of vehicles arriving to a specific waste treatment site	Coning and quartering of waste from cross section of discharge load	Manual	13
Department of Environment and Mechanical Engineering, The Open University, Milton Keynes, United Kingdom	Assessing the composition of municipal solid waste. Method developed from the Environment Agency of England and Wales	Number of Households	Community type, collection variables	NA	Manual	38
California Integrated Waste Management Board	Uniform waste disposal characterisation method	Mass	Geographic, climatic, demographic, economic, single/multi family, self- haul	Single Family – from a 16 cell grid over a discharge load Multi Family – Cross section of dumpster	Manual	9
The Netherlands National Institute of Public Health and Environmental Protection	Physical investigation of the composition of household waste in the Netherlands	Number of Households	11 socio economic categories, collection variables	Combined manual with conveyor belt, drum sieve, magnets, vibrator and cyclone		14
European Commission, 5th Framework Program, Vienna, Austria	SWA-tool, Methodology for analysis of solid waste	Volume of waste bins	Residential, structure, collection variables and others	NA	Combine manual and screening	12
Lulea University of Technology, Sweden	Household waste generation rate and composition	Number of Households	Socio economic, Single/multi family	NA	Manual	
Lulea University of Technology, Sweden	Household waste composition studies; Methods and Trends	Number of Households	Geographic, demographic, single/multi family, self-haul, collection variables	NA	Manual	19
Institute of Environmental Engineering, Lausanne, Switzerland	A goal-oriented characterisation of urban waste	Mass	Socio economic and others	NA	Manual	47
South African institution of Civil Engineering	Appropriate approach in measuring waste generation, composition and density in developing areas	Number of households	Socio economic	NA	Manual	8

Table 2.8, continued.

Institution	Method	Base of size of sample	Stratification – for sample location	Sub Sampling method	Sorting procedure	Components to be sorted into
Nordtest, Finland	Solid Waste, Municipal; sampling and characterisation	Number of households	NA	Coning and quartering	Combine manual and screening	11
Dalarna University College, Sweden	Waste Component analysis as a planning tool	Percentage of Population	single / multi family, collection variables	From a 20 cell grid over a discharged, flattened load	Manual	10
University of Central Florida, USA	Methodology for conducting composition study for discarded solid waste	Mass	Selection of vehicles arriving to a specific waste treatment site	Coning and quartering of waste from cross section of discharge load	Manual	13
Environmental Engineers' Handbook, USA	Solid Waste characterisation method	Mass	Selection of vehicles arriving to a specific waste treatment site	Discussed several sub sampling procedures	Manual	2
NSR research, Sweden	NSR Solid Waste Characterisation Method	Mass	single / multi family, community	Modified coning and quartering	Manual	20
The Swedish Association for Waste Management	Municipal solid waste composition analysis manual	Mass	single / multi family, collection variables	Cross section of elongated, flat pie	Manual	9
Swiss Agency for the Environment, forests and Landscape	A survey of the composition of household waste	Mass	Community type, socio economic, collection billing system and geographic		Manual	17
International Energy Agency (IEA)	Work on Harmonising sampling and analytical protocols related to municipal solid waste conversion to energy	Mass	Collection variables	Discussed some sub sampling procedures	Manual	9
MODECOM™, France	A method for characterisation of domestic waste	NA	NA	NA	NA	NA
US EPA	Characterisation of Municipal Solid Waste in USA	NA	NA	NA	NA	NA
Bovay Northwest Inc, USA	Cost effective solid waste characterisation methodology	NA	NA	NA	NA	NA

2.8 Waste Composition in Malaysia

Moving from the sampling plan and method, this section zooms into the results of the sampling process which is the composition of the MSW and followed by the physical and chemical characteristics of the waste. MSW is generated by many sources in Malaysia namely, by households, industries, institutions and commercial premises. This section will look at the literature of data available to show the composition of the MSW by these sources.

2.8.1 Household Waste Composition -National Waste Characterization Report

This section presented the findings of the Household waste for Malaysia, Urban and Rural, and for some zones, namely Northern, Southern, East Coast, Klang Valley, Sarawak and Sabah. The National Survey has also presented the results from the As Generated, As Discarded and As Disposed waste.

From the comprehensive sampling plan done and the results for waste composition data from sampling at the 18 Local Authorities (LAs) and number of households were used to develop the waste composition for the waste in Malaysia. The waste composition study data collection was by housing types, namely Low, Medium and High in each of the 18 LAs over a week cycle. The results for the samples taken in a week were averaged to obtain the waste composition result of each housing type of a LA. Figure 2.5 (JPSPN, 2013) presents the overall average waste composition of the waste generated in Malaysian by households.

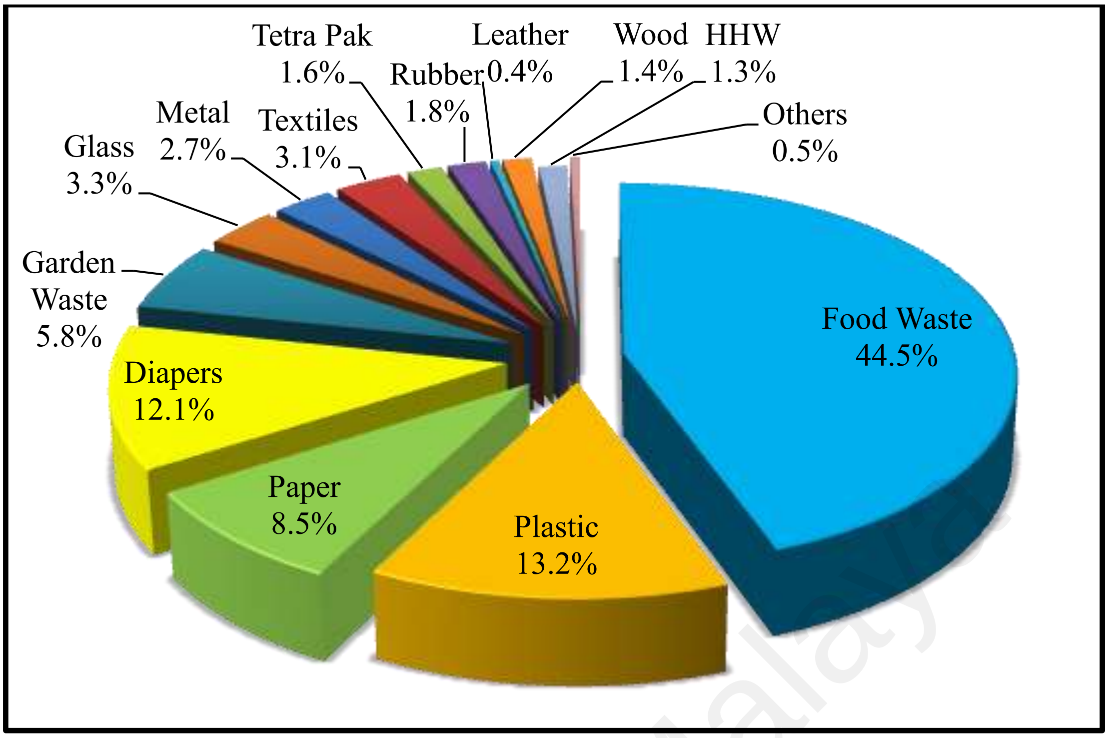

Figure 2.5: Malaysian Household Waste Composition (As Generated). Note: HHW – Household Hazardous waste; Wood – Wood + Peel / Husk (Adapted from: JPSPN (2013)

Table 2.9 (JPSPN, 2013) on the other hand, presents the breakdown of the waste components from all the "As Generated waste", all the "As Discarded" in the households and all the "As Disposed" at the Landfill in the country. In this case the study assumed that the composition study conducted on the incoming waste at the landfill sites was primarily from the households.

The biggest component in the national waste composition was food waste constituting about 44.5 per cent followed by plastics and paper were 13.2 per cent and 8.5 per cent respectively. The biggest deviation in the waste composition is the quantity of the waste component "Diapers" found in the waste. An alarming 12.1 per cent of the waste contained disposable diapers and disposable feminine sanitary products.

Table 2.9: Waste Components Generated, Discarded and Disposed from Malaysian Households (Adapted from: JPSPN (2013)

	Waste Components	As Generated MT/day	As Discarded MT/day	As Disposed MT/day
Organics	Food Waste	9,685	8,563	8,492
	Garden Waste	1,252	1,240	1,445
	Wood	88	88	92
	Peel/Husk	206	217	248
Paper	Mixed Paper	310	286	273
	Newsprint/Old Newspaper	677	475	360
	Cardboard	841	697	567
Plastics	Polyethylene Terephthalate (PET)	538	463	374
	High-Density Polyethylene (HDPE)	774	610	604
	Polyvinyl Chloride (PVC)	107	92	90
	Low-Density Polyethylene (LDPE)	832	782	717
	Polypropylene (PP)	290	263	188
	Polystyrene (PS)	293	293	299
	Other Plastics	16	16	33
Glass	Glass Bottle	707	528	521
	Sheet Glass	12	30	59
Metals	Ferrous Metal	383	336	211
	Aluminium	197	160	85
	Other Non-Ferrous Metals	15	15	16
Household Hazardous Waste	Batteries	23	22	22
	Fluorescent Tube	56	48	48
	E-Waste	30	52	52
	Aerosol Cans	155	140	140
	Paint Container	20	20	20
Others	Tetra Pak	343	308	282
	Diapers	2,625	2,625	2,625
	Rubber	309	309	399
	Textiles	661	660	660
	Leather	84	85	99
	Porcelain / Ceramic/Stones	93	95	289
	Other Minor components	5	8	48
	Total	**21,627**	**19,526**	**19,358**

Although the initial presentation of the results is in percentages as in Figure 2.4, but the subsequent results in the report were converted into net weight in Kg and tonnes to show the difference in the reduction of the weight as the MSW goes from curbside to the disposal grounds in the landfill. As an example, the amount of Food waste generated in Malaysia from the households on a daily basis was about 9,685 MT. This quantity reduces to 8,563 MT and 8,492 MT as the waste moves from the point of generation to point of disposal at the landfills. This reduction in the food waste is reported to be attributed to the rapid degradation of the waste over time and the release of the inherent moisture content as leachate.

The report goes on to show some information on newspaper where using the information on the total number of newspaper printed in 2010 provided by the Audit Bureau of Circulations, Malaysia and the actual weight of the newspaper, it was determined that the total weight of all newspapers produced was approximately 1,100 MT per day. Assuming about 10% of this gets used for other purposes the average amount of newspaper waste generated daily is 990 MT.

Table 2.10 gives a variation on the reported basis where the average quantity of household waste generated by each person in a day is presented on the housing types. The amount of food waste, garden waste, newspaper, HDPE and diapers generated is found to be increasing as the type of housing moves from low cost to high cost housing.

Table 2.12 (JPSPN, 2013) on the other hand is the average quantity of Malaysian waste components for waste generated in the urban and rural households. The amount of waste generated daily by a person in the urban area is approximately 0.8 kg. as compared to the rural area where it was found to be only 0.68 kgs. and noticeably diapers generated by one person was highest in the Klang Valley followed by Southern Zone. Again, the report has chosen to present the figures as an absolute number rather than presenting the results as a percentage figure. Finally, Table 2.12 presents the average quantity of household waste generated by each person in a day for 6 zones. The major difference between the 2 groups of Rural and Urban is the increase in Food waste showing with the increase in urbanization, households waste more food.

Table 2.10: Household Waste Composition for Low, Middle and High cost houses in grams/capita/day (As Generated) (Adapted from: JPSPN (2013)

Waste Components		Low cost	Medium cost	High cost
Organics	Food Waste	299.21	337.95	358.79
	Garden Waste	30.68	47.50	55.34
	Wood	3.52	3.39	1.98
	Peel /Husk	8.22	5.91	5.94
Paper	Mixed Paper	10.83	9.44	13.63
	Newsprint/Old Newspaper	23.51	33.49	39.95
	Cardboard	23.88	31.02	34.67
Plastics	Polyethylene Terephthalate (PET)	14.77	20.03	13.48
	High-Density Polyethylene (HDPE)	20.86	29.73	31.25
	Polyvinyl Chloride (PVC)	2.51	1.82	7.15
	Low-Density Polyethylene (LDPE)	28.44	28.80	27.76
	Polypropylene (PP)	10.07	10.49	7.98
	Polystyrene (PS)	8.34	10.83	12.04
	Other Plastics	0.50	0.77	0.27
Glass	Glass Bottle	22.59	24.91	26.26
	Sheet Glass	0.20	0.33	1.26
Metals	Ferrous Metal	13.55	12.52	13.83
	Aluminium	6.94	5.55	9.72
	Other Non-Ferrous Metals	0.27	0.07	1.56
Household Hazardous Waste	Batteries	0.57	0.50	2.08
	Fluorescent Tube	2.17	1.14	3.49
	E-Waste	1.08	0.71	1.92
	Aerosol Cans	5.59	4.85	6.04
	Paint Container	0.13	1.12	0.71
Others	Tetra Pak	11.21	9.64	14.59
	Diapers	78.94	93.79	106.53
	Rubber	12.08	13.41	14.51
	Textiles	22.78	22.98	21.36
	Leather	3.58	2.13	3.34
	Other Minor components	3.05	2.11	7.83

Table 2.11: Comparison Between Urban and Rural Household Waste (Adapted from: JPSPN (2013)

Waste components		Urban	Rural	Urban	Rural
		MT/day		grams/capita/day	
Organics	Food Waste	7,435.9	2,180.7	369.49	265.64
	Garden Waste	910.0	341.8	45.22	41.64
	Wood	67.3	20.7	3.35	2.52
	Peel/Husk	152.4	53.1	7.57	6.47
Paper	Mixed Paper	213.7	96.4	10.62	11.75
	Newsprint/Old Newspaper	477.7	199.5	23.74	24.30
	Cardboard	603.3	237.7	29.98	28.95
Plastics	Polyethylene Terephthalate (PET)	352.3	187.6	17.50	22.86
	High-Density Polyethylene (HDPE)	541.2	232.5	26.89	28.32
	Polyvinyl Chloride (PVC)	78.9	28.1	3.92	3.42
	Low-Density Polyethylene (LDPE)	575.1	257.1	28.57	31.32
	Polypropylene (PP)	220.1	69.9	10.93	8.51
	Polystyrene (PS)	182.6	110.8	9.07	13.50
	Other Plastics	4.7	12.6	0.23	1.54
Glass	Glass Bottle	516.5	190.4	25.67	23.19
	Sheet Glass	6.3	5.3	0.31	0.65
Metals	Ferrous Metal	262.5	120.5	13.04	14.68
	Aluminium	153.4	43.1	7.62	5.25
	Other Non-Ferrous Metals	6.7	4.5	0.34	0.54
Household Hazardous Waste	Batteries	16.6	6.2	0.83	0.76
	Fluorescent Tube	39.8	16.2	1.98	1.97
	E-Waste	22.5	7.8	1.12	0.95
	Aerosol Cans	118.4	36.6	5.88	4.46
	Paint Container	12.8	6.8	0.64	0.83
Others	Tetra Pak	250.7	91.8	12.46	11.18
	Diapers	1,928.3	697.3	95.82	84.95
	Rubber	288.9	92.2	14.36	11.23
	Textiles	473.2	188.1	23.51	22.91
	Leather	59.7	24.8	2.96	3.02
	Porcelain/Ceramic	60.7	32.3	3.02	3.93
	Minor components	5.1	0.7	0.26	0.09
	Total	16,037.3	5,593.1	796.9	681.33

Table 2.12: Breakdown of Household Waste Components generated by each person for six Regions, in grams/capita/day (Adapted from: JPSPN (2013)

	Waste Components	Northern	Southern	Klang Valley	East Coast	Sarawak	Sabah
Organics	Food Waste	307.51	405.82	416.21	204.27	238.44	225.35
	Garden Waste	40.51	52.06	55.42	29.63	17.57	19.88
	Wood	2.41	2.23	4.71	3.01	5.06	1.52
	Peel/Husk	7.60	6.20	8.01	9.21	6.70	9.10
Paper	Mixed Paper	15.52	13.43	8.69	12.74	10.34	7.53
	Newsprint/Old newspaper	25.41	32.27	41.92	27.02	27.09	22.31
	Cardboard	24.38	30.73	38.03	24.86	31.24	25.01
Plastics	PET	21.29	18.18	19.11	12.70	15.34	19.17
	HDPE	22.38	31.71	33.35	17.32	31.44	28.23
	PVC	4.46	2.07	3.44	3.17	1.47	3.23
	LDPE	27.18	35.85	32.13	24.30	31.82	27.84
	Polypropylene (PP)	9.45	13.79	11.13	7.29	10.87	5.95
	Polystyrene (PS)	12.17	10.02	10.39	10.16	13.26	15.68
	Other Plastics	2.13	0.82	-	-	-	0.48
Glass	Glass Bottle	16.23	27.08	32.64	21.00	31.40	21.97
	Sheet Glass	0.56	0.43	0.29	1.17	0.37	0.16
Metals	Ferrous Metal	14.59	15.44	12.72	13.35	22.21	15.16
	Aluminium	5.18	8.72	7.76	4.68	12.91	6.21
	Other Non-Ferrous Metals	0.41	0.47	0.44	-	0.05	1.14
Household Hazardous Waste	Batteries	0.32	0.39	1.51	0.46	1.46	0.14
	Fluorescent Tube	2.32	2.43	2.48	0.30	1.23	0.42
	E-Waste	0.07	0.54	2.12	1.68	0.32	0.29
	Aerosol Cans	3.12	5.26	7.87	4.59	8.31	3.19
	Paint Container	0.13	1.94	0.54	0.29	-	-
Other Waste Components	Tetra Pak	11.41	12.07	13.52	10.02	10.02	7.94
	Diapers	86.35	113.73	109.93	67.49	57.36	72.59
	Rubber	10.74	10.23	19.73	11.93	13.99	10.61
	Textiles	16.74	16.78	37.01	14.66	26.73	19.15
	Leather	3.91	3.94	2.84	2.04	2.45	0.93
	Porcelain/ Ceramic	2.40	2.31	5.47	1.56	4.79	0.35
	Fine	0.62	-	0.03	0.60	-	-

2.8.2 Household Waste Composition - Other Report

One such published data on the composition of MSW generated from the year 1975 to the year 2000 is shown in Table 2.13 (Aziz, 1996). The data on Table 2.13 indicated that there was a downward trend in the amount of organics in the waste with the others remaining the same from the year 1975 to 1995. There seems to be a drastic change in the composition of the MSW that was generated in Kuala Lumpur from the year 1995 to 2000. It could be linked to the good growth factor of the economy and also to the population boom into the city over the past few years (Aziz, 1996). Although this statement has often been used as the main yard stick towards changes observed in the MSW, unfortunately to date there is no concrete research or data backing this argument.

Table 2.13: Waste composition (%) for Kuala Lumpur (Adapted from: Aziz (1996)

Waste	1975	1980	1990	1995	2000
Organic	63.7	54.4	48.4	45.7	68.4
Paper	7.0	8.0	8.9	9.0	6.4
Plastic	2.5	0.4	3.0	3.9	11.4
Glass	2.5	0.4	3.0	3.9	1.4
Metals	6.4	2.2	4.6	5.1	2.7
Textile	1.3	2.2	-	2.1	1.5
Wood	6.5	1.8	-	-	0.7
Others	0.9	0.3	-	4.3	7.1

Another point of argument is on how the data for the composition was obtained? They are a few methods available to sample and characterize the MSW, and the author did not mention this. The variance could have been caused by the different sampling method. It is also noteworthy that the number of components is very limited to only 8 whereas the National Waste Characterization Survey Report presented in the previous section sorted the MSW into 23 components. Obviously, the more detailed the components, the more accurate the results of the MSW study will reflect, but the workforce and the budget for the sampling that was carried out. It can be said that in the early years of 1980's and 1990's, waste characterization studies were very limited and small in budget thus limiting the sample size and the findings.

Another historical set of data is the data shown on Table 2.13, which is a study carried out in 2001 to establish the preliminary design parameters for a proposed incinerator in Kuala Lumpur. The result shows that there is a drastic drop in the average content of food waste as compared to Table 2.12. However, it is important to note that Table 2.13 gives the data for only 8 components and it can be presumed that all organics has been put into the organic category while in Table 2.12, the organic category has been further segregated into Food, Waste, Yard waste and Other organics which can be summed up to form the same 8 components as in Table 2.13. Again, there is not enough information to do such comparisons.

Table 2.14 (Salleh & Kathiravale, 2000) introduces the physical and chemical properties for Kuala Lumpur MSW. These characteristics are discussed in length in the following sections. Points to ponder from the waste composition data thus presented: -

1. Most of the data focus on the capital city of Kuala Lumpur, whereas the MSW problem is ever-present everywhere. Even the result from the National Waste Characterization Survey is summarized into zones and overall Malaysia. There is a very great need for detailed composition and characterization data to be presented.
2. Time based analysis cannot be carried out due to the variance in the components in which the results has been presented. This is further complicated by the method in which the samples were taken and weather it is taken at source or at the landfill is another question.

Table 2.14: Waste Composition (%) for Kuala Lumpur – 2000 (Adapted from: Salleh & Kathiravale (2000)

Composition (Wet Basis) (wt %)				Proximate Analysis (Wet Basis)				
	Max	Average	Min		Min	Average	Max	Unit
Food/Organic	65.23	40.38	26.05	Moisture	46.46	50.86	54.65	wt %
Mix Paper	23.11	11.91	6.03	Volatile Matter	29.82	34.28	38.80	wt %
News Print	10.24	6.50	3.38	Fix Carbon	1.74	3.46	5.08	wt %
High Grade Paper	4.69	2.23	1.02	Ash	6.93	11.40	15.56	wt %
Corrugated Paper	4.17	1.50	0.12					
Plastic (Rigid)	8.66	3.46	2.08					
Plastic (Film)	17.84	12.76	9.50	**Ultimate Analysis (Dry Basis)**				
Plastic (Foam)	1.73	0.92	0.24		**Min**	**Average**	**Max**	**Unit**
Diapers	5.99	3.70	0.36	Carbon	33.88	41.34	46.48	wt %
Textile	6.38	2.29	0.09	Hydrogen	4.89	6.33	7.50	wt %
Rubber/Leather	2.05	0.63	0.19	Nitrogen	1.49	2.17	2.87	wt %
Wood	2.23	1.45	0.39	Oxygen	16.19	26.98	35.99	wt %
Yard	13.23	5.55	0.11	Ash	14.10	23.19	31.67	wt %
Glass (Clear)	3.07	2.37	0.49					
Glass (Coloured)	4.59	1.54	0.39					
Ferrous	6.27	2.72	0.92		**Min**	**Average**	**Max**	**Unit**
Non-Ferrous	0.37	0.25	0.12	Bulk Density	117.08	238.62	329.17	kg/m3
Aluminium	0.55	0.27	0.07	Lower Calorific Value	1,541.06	2,177.30	2,636.03	kcal/kg
Batteries/Hazards	0.09	0.09	0.08	Total Chlorine (Cl)	2,400.00	8,837.14	27,550.00	ppm
Fine	1.28	0.79	0.30	Cadmium (Cd)	0.01	0.99	3.31	ppm
Other Organic	2.02	1.13	0.24	Mercury (Hg)	0.01	0.27	1.78	ppm
Other In-Organic	8.18	4.71	1.24	Lead (Pb)	3.80	26.76	111.00	ppm
Others	2.27	2.00	1.72	Chromium (Cr)	3.20	14.41	40.10	ppm

3. The source of the waste sampled is very often mentioned as Household, but even in Household there is the high income, the medium income and also the low-income group. Thus, details needed for such data to be available is essential for infer any conclusive management method.

2.8.3 Institutional, Commercial and Industrial Waste Composition

Sections 2.8.1 and 2.8.2 has presented the composition of MSW generated in the household of Malaysia. Unfortunately, MSW is also generated by industrial, institutional and commercial sources. Again, historical data tends to lump all waste characteristics into one table, and it is then labelled as the overall characteristics of the said municipality or city of country.

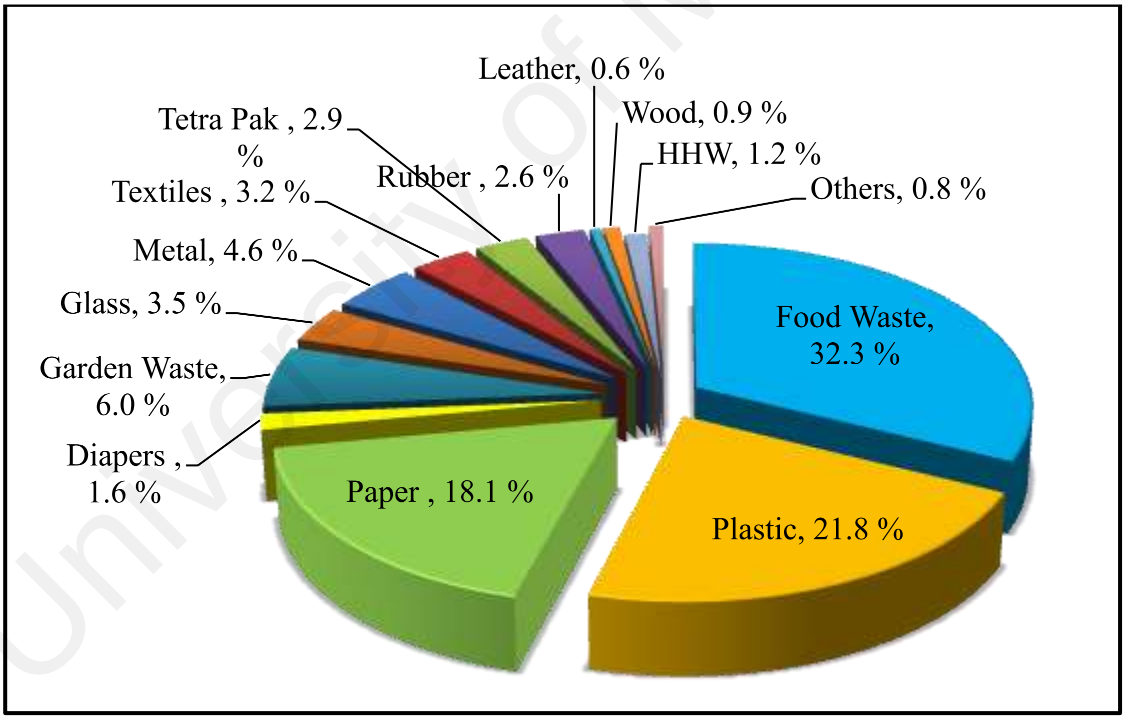

Figure 2.6: Composition of Institutional Waste for Malaysia (Adapted from : JPSPN (2013)

However, when planning and management decisions are to be made these characteristics has to be detailed out, even to the extent of knowing what is the amount of waste generated by each source. Figures 2.6, 2.7 and 2.8 (JPSPN, 2013) gives a good representation of the kind of composition of the MSW generated from Institutional, commercial and Industrial sources.

From Figure 2.6, the Institutional sector comprised of government offices, schools, college, universities, polytechnics, hospitals, clinics, and public transportation facilities. Food Waste was reported to be the highest average with an average of 32 per cent followed by plastics at 22 per cent and paper at 18 per cent. Of course this average food waste percentage is far below the average value produced by the households which was recorded at a value of 44.5% based from Figure 2.5. Nevertheless, it shows that the general population in the institutional sector still produces the same trends of waste but in a smaller proportion the fact that most universities, government officers and hospitals have in house cafeterias which cater for the food needs of its occupations and this would have contributed to the food waste quantities.

The Commercial sector comprises of the following Markets, Supermarkets, Shopping complexes, Hotels, Food courts, Restaurants and Business lots. Figure 2.7 presents the average composition of the waste collected from the various Commercial facilities in Malaysia. Again, the food waste content was the highest component with an average of 40 per cent followed by plastics at 23 per cent and paper at 16 per cent. In this case, most of these commercial areas are well equipped to handle the needs of the population that frequent the places with food courts and restaurants. As such, it is only logical to have almost the same amount of composition with the household waste. However, surprisingly, there is still components like diapers, garden waste and wood material in this source of MSW, indicating that there could be some kind of mixing of sources during the collection truck pathway.

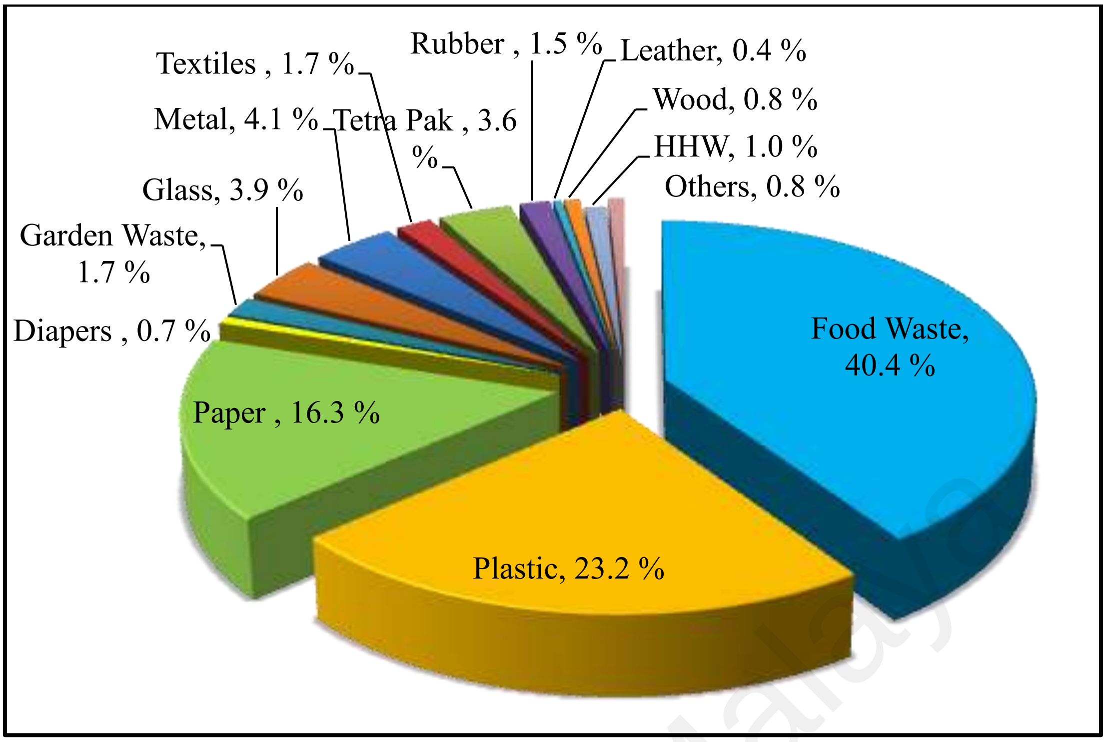

Figure 2.7: Composition of Commercial Sector Waste for Malaysia (Adapted from: JPSPN (2013)

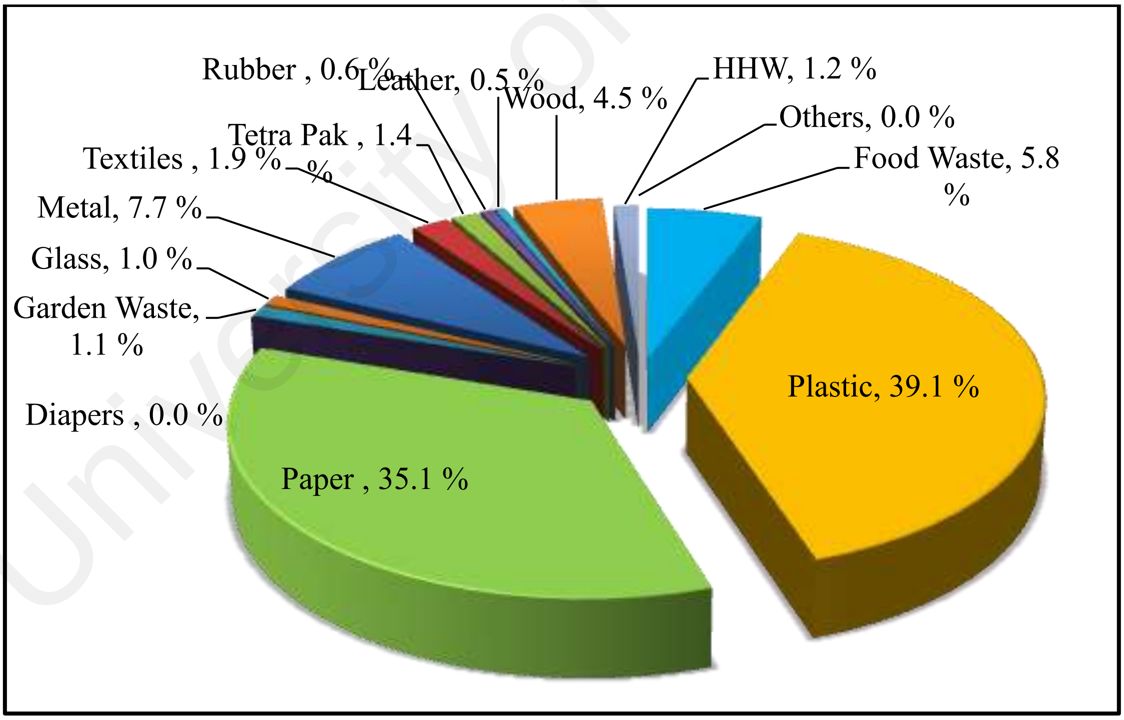

Figure 2.8: Composition of Industrial Sector Waste for Malaysia (Adapted from: JPSPN (2013)

The Industrial sectors included taking samples from food and beverages, textile apparel, chemical, petrochemical, plastic products, electrical and electronics products, fabricated metal, basic metal and non-metallic mineral products, paper and paper products, and wood and products of wood. Figure 2.8 gives the composition of the waste collected from the various industries in Malaysia. For industrial waste, the highest components were plastics at 39% and paper at 35%. Food waste comprised of only 6% of the total waste.

In contrast, Figure 2.9 and 2.10 (UNEP, 2015, 2017) provides data on waste characteristics from different parts of the world. Figure 2.9 shows that the organic component of the waste is higher in the lower income countries and compared to the higher income although India is an exception. In comparison, Malaysian waste reflects that of an upper middle income to a high-income country. This reflects the current status of Malaysia where the urban migration of population and the developed status of its citizens has changed the kind of waste generated by Malaysians.

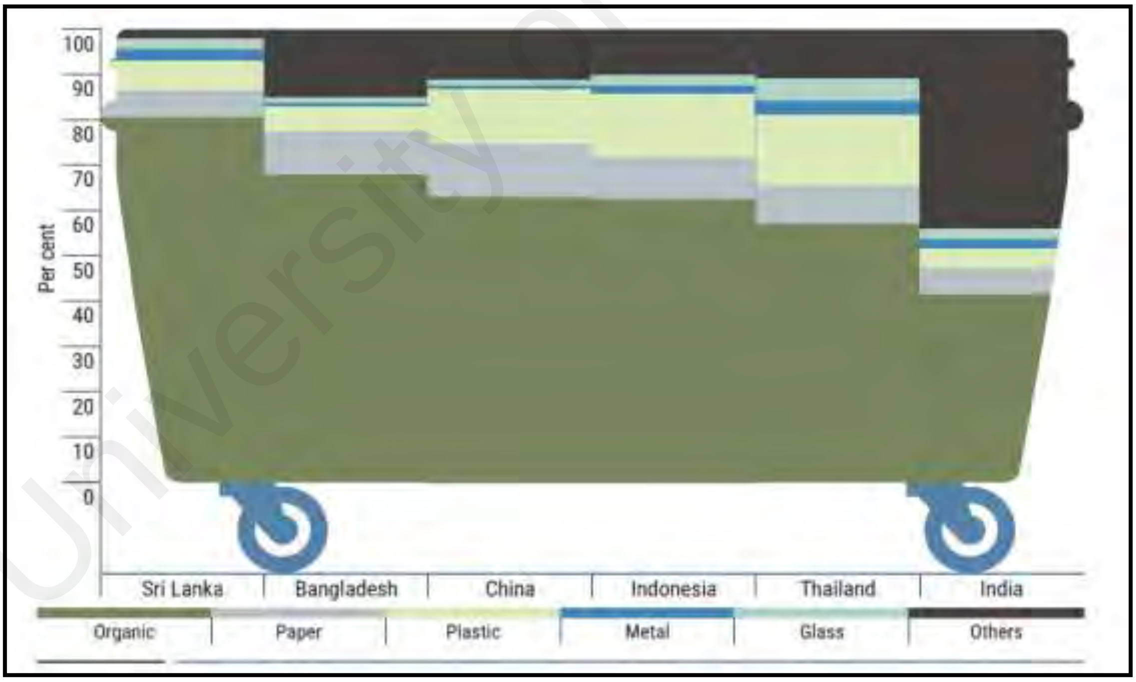

Figure 2.9: Composition of MSW grouped by country income level (Adapted from: UNEP (2017)

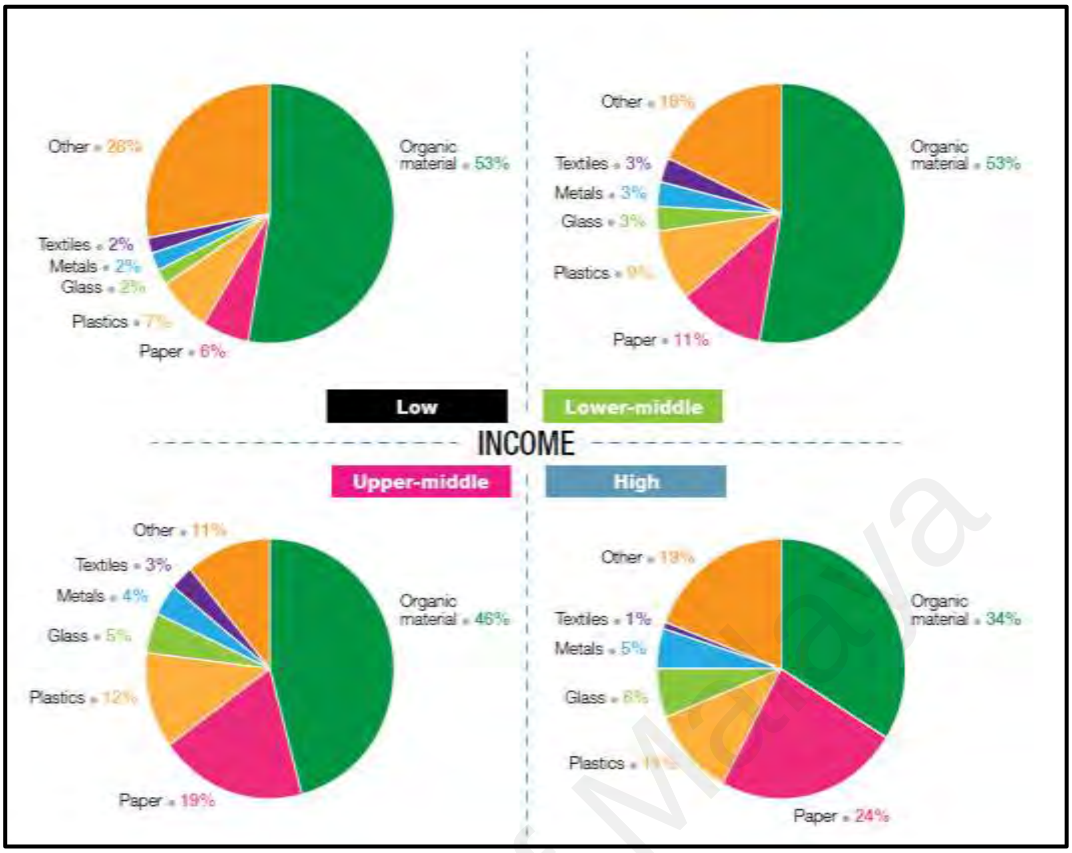

Figure 2.10: Composition of MSW grouped by country income level (Apadpted from: UNEP (2015)

2.9 Waste Analysis Protocol

After the MSW is sorted into its various components, now the components need to be analysed either individually or mixed back to form a composite sample to provide the characteristics of the MSW sample. When discussing the characteristics of the sample, parameters that come into consideration are usually;

- Bulk Density
- Proximate Analysis – Moisture content, Volatile Metter content, Fix Carbon Content and Ash Content
- Ultimate Analysis – Carbon, Hydrogen, Oxygen, Nitrogen and Sulfur content
- Heavy Metal Analysis – Mercury, Lead, Zink, Arsenic, Copper, Femur, Cobalt, Aluminium Magnesium, Nickel and many more
- Heating Value

Based on the above, analysis of the MSW has mostly been analysed for the above and reported accordingly. An important point for the success of a waste management plan is the need for accurate and up to date data on the quality and quantity of the waste that is generated in that area. With this data, proper management strategies can be planed and put into action. Notwithstanding that, this data could also be used to predict the future trends in the quantity and quality of the MSW. Unfortunately, in Malaysia, the standards for sampling of waste have just been developed in 2013 while analysis is still dependent on foreign or more established methodologies. The question is; are these methodologies suitable for the kind of waste generated in Malaysia and does it reflect the actual nature of the waste? The study would have to take into account the previous projects which have ended in failures due to the constant variation in the waste characteristics.

Currently, 'A Method for Characterization of Domestic Waste, French Agency for Environment and Energy Management' recommend that the MSW be analysed either on an individual component basis (after the MSW has be sorted to its components), or on a commingled basis (without sorting), recommended by 'Protocol of Waste Analysis, Japan Ministry of Health and Welfare'. There is also a recommendation by 'The American Society for Testing and Materials', which is to analyse the sample on an individual basis for the moisture content only, after which these individual components of the MSW is ground and mixed according to their weight % to form a commingle sample, which will be used for the further proximate analysis.

As for the reporting procedure, there is no standard reporting procedure. Generally, the results of proximate analysis, which is the moisture content, volatile matter content, fix carbon content and ash content could be delivered on a wet basis or on a dry basis. The difference here is only in the calculation where the moisture content is included in the wet basis results or otherwise; for the dry basis. It is more preferable to give the results on a wet basis as it gives a more representative result, but the dry basis also gives an indication of the amount of combustible matter in the waste. Ultimately, it could be concluded that the reporting procedure is just a formality and will not affect the results in any way.

2.10 Waste Characteristics in Malaysia

Understanding the data on the waste composition is another essential part in planning, evaluating and implementing waste management options. Data on routine waste analysis carried out on Malaysian MSW have been published and discussed in a number of articles concerning waste management. These data are reported sometimes on a wet basis and sometimes on a dry basis (Aziz, 1996; Salleh & Kathiravale, 2000). Comparison of the data is made difficult or even inappropriate due to variations in the analytical approach, omission of supporting data (e.g. waste source) and reporting basis adopted by the reports.

The data shown on Table 2.15 (Salleh & Kathiravale, 2000) reflects results of a waste study done in 1993 and 2000, which gives an indication of the characteristics of the MSW generated for Kuala Lumpur. A study of Table 2.15 in combination with Tale 2.14 shows that there was a trend where the amount of moisture in the waste has steadily increased over the years from about 40% to 55% on average. There were suggestions that this was due to rain fall into the open bins or the collection system or even the sampling and analysis method? Unfortunately, that has not been any socio-economic studies carried out to link the changes in the data on Table 2.14 and Table 2.15 to any changes in lifestyle and economic status of the country. In addition to this, as mentioned above, the method of analysis is also not documented. On the other hand, the most recent report which gives a national picture of the MSW generated in Malaysia can be found in the National Waste Characterization Report done in 2012.

Table 2.15: Characteristics of MSW generated in Kuala Lumpur (Adapted from: Salleh & Kathiravale (2000)

		1993	2000
Density	Kg/m^3	239	265
Moisture content	wt%	42.66	54.62
Combustible	wt%	42.67	33.27
Non-combustible	wt%	14.67	9.43
Carbon	wt%	23.58	14.49
Hydrogen	wt%	3.33	2.15
Nitrogen	wt%	0.28	0.49
Sulphur	wt%	0.12	0.08
Chlorine	wt%	0.26	-
Oxygen	wt%	15.10	9.58
Net Calorific Value	KJ/kg	7960	7790

2.10.1 Household Waste Characteristics in Malaysia

The average moisture content of the samples taken from the household are presented in Table 2.16 (JPSPN, 2013). The average moisture content for the generated waste varied from 52 per cent to 54 per cent for the household waste in urban areas which is in line with previous data from Table 2.14 and Table 2.15. However, the average moisture content for the generated waste varied from 42 per cent to 47 per cent for rural household waste. The moisture in the waste is clearly increasing as the waste moves from the point of generation to the point of disposal. This can be attributed to increase of food content with the reduction in recyclable material and the precipitation.

Table 2.16: Moisture Content - Malaysian Household MSW (Adapted from: JPSPN (2013)

	Urban Household			Rural Household			Malaysian Average
	Low Cost	Medium Cost	High Cost	Low Cost	Medium Cost	High Cost	
As Generated	53.84	52.30	51.95	43.92	46.96	42.03	52.10
As Discarded	56.53	59.13	58.87	48.18	50.35	47.01	57.34
As Disposed	59.65			60.55			59.45

The Proximate analysis for the samples was carried out to obtain the moisture content, volatile matter content, the fix carbon content and the ash content while the elementary components of Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur and Organic Chlorine present in the combustible fraction of the waste sample was done through the Ultimate analysis procedure. The chemical constituents of the waste are presented in Table 2.17 and 2.18 (JPSPN, 2013). These results are shown on a wet basis with the non-combustible fraction of the waste removed before analysing the sample.

Table 2.17: Average Proximate Analysis Results for Malaysian (Adapted from: JPSPN (2013)

	As Discarded	As Disposed
Moisture Content	57.34	59.45
Volatile Matter Content	22.79	20.79
Fixed Carbon Content	11.48	11.10
Ash Content	8.39	8.65

Table 2.18: Average Ultimate Analysis Results for Malaysian (Adapted from: JPSPN (2013)

	As Discarded	As Disposed
Moisture Content	57.34	59.45
Carbon Content	21.57	17.36
Sulfur Content	0.05	3.35
Hydrogen Content	4.29	5.89
Nitrogen Content	1.37	1.05
Oxygen Content	7.47	5.89
Organic Chlorine Content	0.06	0.04

Table 2.19 and 2.20 (JPSPN, 2013) goes on to show the minor chemical constituents of Metals, the average bulk density (as measured at the sampling site) the average calorific value respectively. These results have been just presented without any discussion on what was the previous trend or why such values were obtained as comparison to data from other countries; in the absences of local data.

Table 2.19: Average Heavy Metal results for Malaysia (Adapted from: JPSPN (2013)

	As Discarded	As Disposed
Mercury	0.084	0.092
Vanadium	2.859	3.590
Chromium	37. 46	46.58
Manganese	15.17	21.97
Iron	269.34	318.27
Cobalt	0.30	0.53
Copper	6.46	5.92
Zinc	18.50	19.35
Arsenic	0.18	0.66
Silver	0.41	0.66
Cadmium	0.29	2.38
Lead	1.43	1.98
Aluminium	143.65	148.23
Magnesium	56.98	88.30
Nickel	2.49	1.94

Table 2.20: Average Bulk Density measurements for Malaysia (Adapted from: JPSPN (2013)

	As Discarded	As Disposed
Bulk Density	185.33	202.54
Higher Heating Value, HHV_{dry} dry basis, kJ/kg (kcal/kg)	21,671 (5,176)	21,185 (5,060)
Lower Heating Value, LHV_{wet} wet basis, kJ/kg (Kcal/kg)	6,950 (1,660)	6,325 (1,511)

Overall, the report has presented the results of the waste characteristics analysis done on the MSW samples obtained from each state in Malaysia. Although a detailed description of the method in which the analysis was carried out and the procedure in which the samples were obtained was discussed, there are still some lingering questions like;

1. Is the adopted method of analysis the most accurate to reflect the results?
2. Can this results become the basis for future studies, thus being able to give some trend indications?

2.10.2 Institutional, Commercial and Industrial (ICI) Waste Characteristics in Malaysia

The MSW samples taken from the institutional, commercial and industrial (ICI) sources around Malaysia were analysed for its moisture content and calorific values. Apart from these, proximate and ultimate analysis was also conducted to get the various constituents in the samples. The average Moisture content of the ICI samples from various categories are presented in Table 2.21 (JPSPN, 2013). The average moisture content varies from 47 per cent to 54 per cent. The Proximate analysis was carried out to obtain the Fixed Carbon, Ash Content and Volatile Matter of the combustible fraction of the ICI waste samples and the results are presented on the same Table 2.21. Continuing on this same Table 2.21, the Ultimate analysis was carried out to obtain the elementary components of Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur and Organic Chlorine present in the combustible fraction of the ICI waste sample. Finally, Table 2.21 also highlights the bulk density and the heating value of the samples.

Table 2.21: ICI MSW Characteristics in Malaysia (Adapted from: JPSPN (2013)

	Institutional	Commercial	Industry	Overall ICI Sector
	(%, wet basis)			
Moisture Content	50.49	54.19	47.02	51.75
Volatile Matter Content	27.74	25.10	28.84	26.57
Fixed Carbon Content	13.07	12.91	14.60	13.28
Ash Content	8.70	7.80	9.55	8.40
	(%, wet basis)			
Moisture Content	50.49	54.19	47.02	51.75
Carbon Content	24.49	23.09	26.26	24.11
Hydrogen Content	5.30	4.72	5.31	5.00
Oxygen Content	9.33	8.68	9.83	9.09
Nitrogen Content	1.39	1.29	1.54	1.37
Organic Chlorine Content	0.07	0.05	0.10	0.07
Total Chlorine Content	0.16	0.13	0.31	0.17
Sulphur Content	0.12	0.05	0.09	0.08
Ash Content	8.65	7.80	9.54	8.36
	(ppm, dry basis)			
Mercury	0.127	0.112	0.174	0.127
Vanadium	1.895	1.425	0.382	1.371
Chromium	24.59	22.16	16.86	21.94
Manganese	10.80	6.77	5.71	7.71
Iron	172.02	163.17	146.73	163.17
Cobalt	0.79	0.47	0.17	0.51
Copper	6.83	3.74	3.77	4.59
Zinc	10.52	7.99	15.59	10.06
Arsenic	0.76	0.44	0.28	0.50
Silver	0.30	0.31	0.33	0.31
Cadmium	1.04	0.57	0.23	0.64
Lead	1.47	1.67	1.52	1.59
Aluminium	128.93	90.90	184.79	118.27
Magnesium	22.31	27.30	56.38	31.22
Nickel	2.80	2.22	1.71	2.29
Bulk Density (kg/M^3)	137.09	145.18	101.56	134.38
Higher Heating Value, HHV_{dry} dry basis, kJ/kg (kcal/kg)	21,192 (5,061)	20,542 (4,906)	20,757 (4,958)	20,765 (4,960)
Lower Heating Value, LHV_{wet} wet basis, kJ/kg (kcal/kg)	8,165 (1,950)	7,121 (1,701)	8,755 (2,091)	7,727 (1,846)

2.10.3 Individual Waste Component Characteristics in Malaysia

The National Waste Characterization Report can be considered as the only report that has presented the data on the individual components that make up the MSW in Malaysia. Apart from analysis of the co-mingled waste samples from the various sectors, as presented in Sections 2.10.1 and 2.10.2; the 17 individual waste components extracted from 5 disposal sites were also analysed for their major and minor chemical constituents. Components which are inert or metals by nature were not and cannot be analysed. Table 2.22 (JPSPN, 2013) presents the Proximate Analysis, Ultimate Analysis and the Calorific Value of the individual waste components while Table 2.23 (JPSPN, 2013) presents the Metal analysis of the individual waste components. Analysis will not be taken into consideration by the private sector when considering the cost and time factors in carrying out the analysis. However, are the results provided by the comingle basis accurate and how to recalculate the results from the individual components to form a single result that will give the MSW characteristics. These are some of the questions that would be taken up in this study. In general, the characteristics of MSW in Malaysia have been put forward, but the underlying questions are:

1. Is the data available to the Public and private sector comprehensive enough to go forward with planning and designing of treatment and facilities?
2. Even when the data is available, are they comparable, as to, were the sampling and analysis same or were they even reported in the first place

Table 2.22: Proximate, Ultimate analysis and Calorific Value of the Individual Components (Adapted from: JPSPN (2013)

	Moisture content	Proximate Analysis			Ultimate Analysis					Calorific Value		
	Moisture content, %	Volatile Matter, wet basis %	Fixed Carbon, wet basis %	Ash Content, wet basis %	Carbon Content, wet basis %	Hydrogen Content, wet basis %	Oxygen Content, wet basis %	Nitrogen Content, wet basis %	Sulphur Content, wet basis %	Higher Heating Value dry,kJ/kg	Lower Calorific Value wet,kJ/kg	Lower Calorific Value wet, kcal/kg
Food	82.00	14.30	1.54	2.16	7.88	1.20	5.60	1.09	0.05	12,427	229	55
Garden	30.85	50.46	11.14	7.55	30.70	3.01	26.88	0.81	0.20	17,522	11,356	2,712
Mixed Paper	54.57	34.51	3.70	7.22	21.63	3.20	12.39	0.79	0.20	20,536	7,988	1,908
Newsprint	22.73	74.33	1.03	1.90	37.78	6.50	29.50	1.35	0.23	16,209	11,953	2,855
Cardboard	12.17	72.53	7.36	7.94	37.39	7.15	33.18	1.61	0.56	16,466	14,148	3,379
Tetra Pak	14.70	71.20	7.33	6.78	38.41	6.39	32.21	1.20	0.32	14,884	12,323	2,943
PET	5.69	92.46	0.93	0.92	79.37	8.06	4.95	0.88	0.12	33,755	31,678	7,566
HDPE	5.65	91.64	1.30	1.41	76.24	9.26	6.40	0.74	0.30	34,706	32,584	7,783
PVC	7.29	79.78	3.77	9.17	69.58	7.30	4.17	1.17	1.33	32,143	29,607	7,072
LDPE	44.69	50.40	0.96	3.95	40.62	6.14	3.72	0.74	0.14	29,924	15,443	3,688
PP	24.52	61.93	6.45	7.10	49.46	7.14	9.99	1.65	0.14	30,620	22,498	5,373
PS	10.32	88.19	0.29	1.20	67.79	8.37	10.33	1.42	0.58	31,725	28,180	6,731
Diapers	76.69	19.91	1.72	1.68	9.93	2.26	9.10	0.26	0.08	25,434	4,049	967
Textile	53.80	37.86	7.31	1.03	25.39	3.19	15.83	0.56	0.21	18,185	7,079	1,691
Rubber	2.96	87.76	0.92	8.36	66.58	5.14	13.51	0.99	2.47	23,092	22,323	5,332
Leather	4.66	81.54	4.86	8.95	58.74	8.64	16.56	1.53	0.93	26,337	24,977	5,966
Wood	15.92	72.07	10.89	1.11	43.65	6.52	31.34	1.21	0.25	20,092	16,488	3,938

Table 2.23: Metal Analysis of the Individual Components, in ppm (Adapted from: JPSPN (2013)

	Mercury	Vanadium	Chromium	Manganese	Iron	Cobalt	Copper	Zinc	Arsenic	Silver	Cadmium	Lead	Aluminium	Magnesium	Nickel
Food	0.005	0.081	5.46	13.91	31	0.07	0.63	2.95	0.067	0.100	0.010	0.077	-	9.20	2.88
Garden	0.018	0.837	4.68	92.71	226	0.20	3.69	17.15	1.218	0.188	0.030	0.851	-	35.89	0.22
Mixed Paper	-	0.796	59.22	19.20	137	0.62	7.38	109.69	0.760	0.205	0.177	0.245	-	23.59	1.14
Newsprint	0.022	1.412	57.89	35.99	535	0.32	9.68	16.93	0.524	0.349	0.082	2.108	-	39.41	1.18
Cardboard	0.033	1.447	12.55	44.23	174	0.57	15.71	14.78	0.566	0.848	0.051	0.263	-	45.32	0.64
Tetra Pak	0.036	0.616	18.52	29.25	4,597	1.07	2.57	75.87	0.679	0.587	0.206	0.092	3,262	45.12	19.20
PET	0.034	0.986	134.06	6.21	2,706	0.34	6.19	200.20	1.173	0.504	0.106	2.490	-	51.17	2.90
HDPE	0.023	1.347	90.00	1.23	148	5.03	2.84	368.04	0.351	0.504	4.057	0.900	-	50.33	2.96
PVC	0.022	1.396	87.49	1.82	141	7.32	1.94	358.41	0.295	0.536	3.197	0.510	-	51.43	3.75
LDPE	0.029	0.698	108.88	4.14	1,019	0.52	2.44	149.89	1.034	0.878	0.046	3.094	-	30.31	1.77
PP	0.027	1.632	75.16	1.59	122	2.82	3.30	271.74	0.257	0.456	1.096	0.507	-	42.89	0.59
PS	-	1.322	6.78	37.56	231	1.05	3.12	33.88	1.343	0.500	0.084	0.737	-	49.12	1.45
Diapers	-	0.358	1.76	0.46	32	0.10	0.43	9.74	0.093	0.135	0.070	0.669	-	12.14	0.13
Textile	0.017	0.235	69.49	2.52	89	0.08	0.96	11.66	0.455	0.222	0.030	0.877	3,225	24.61	0.23
Rubber	0.037	6.121	-	30.89	841	1.43	227.44	1,714.35	1.432	0.398	0.670	1.461	2,069	41.79	2.68
Leather	0.048	8.345	-	35.71	1,139	2.79	278.44	2,188.07	2.059	0.473	0.040	1.770	2,541	51.19	3.04
Wood	0.044	0.281	50.84	3.13	78	0.37	3.95	13.48	0.309	0.264	0.045	1.130	3,455	44.31	0.84

From all of this MSW composition and characterization results, it can be determined that the most important parameters when looking at the management method are the percentage of the various components as reported in section 2.8 which is directly influenced by the behavioural trends of mankind who are generating this kind of waste. On the other hand, the moisture content and the heating value of the waste could also be considered as a functional parameter as the variation on these parameters will affect the management method very much. In sections 2.8 and 2.10, the various results for the moisture content and the heating value has been extensively been presented and be shown to be the most fluctuating parameters. The method in which the parameters are determined will be discussed in the following sections.

2.11 Sampling and Analysis of Waste to Determine Moisture Content

Malaysia, a tropical country by weather has abundance of rain fall, and added with a multi cultured society, where the current behaviour of the population was not to separate their waste, the moisture content of the waste becomes an essential data in defining the treatment method of the waste generated. The moisture content of Malaysian MSW is most frequently reported as the total amount of moisture in the waste. Although these reports state the various methodologies by which these data were obtained, they do not address quantitatively all the possible avenues for moisture to be lost during sampling from the MSW samples. The American Standard, which is probably the leading referral test method, requires for the waste to be air dried followed by grinding and re-drying at 107ºC to determine residual moisture. This procedure only expresses caution on moisture lost from the sample during the sampling process (Gidarakos et al., 2006; Gómez et al., 2008). Although the methods of analysing the moisture content of MSW are established, the correct protocol for analysis of the quantity of moisture lost during the sampling, sorting and transportation process has not been made known.

In a tropical country like Malaysia, drastic changes in the weather are a common phenomenon. This is an important factor to be considered with regards to the amount of moisture lost when the sampling and sorting of MSW is being carried out. Apart from various methods of sampling and weather conditions, which can both result in changes in the moisture content when analysed, another factor that contributes to the moisture loss during the sampling and sorting process is due to the length of time taken for the sampling and sorting activity. Although many sampling methods have been recommended, unfortunately these methods are only concerned on the cleanliness of the sorting area and accounting for all waste material that is sampled. The analytical procedures have remained silent on the possible moisture lost during the sampling and sorting process. There are basically four types of sorting methods that are available from literature and they are the 'Truckload Method', 'Quartering Method', 'Spot Sampling Method' and 'Laboratory Sampling Method'. In terms of time taken for each method, the 'Truckload Method' is the longest with a sampling and sorting time span of between 6 and 8 hours followed by the 'Quartering Method' and 'Spot Sampling Method' which takes about 2 to 3 hours and the fastest is the 'Laboratory Sampling Method' which takes less than 1 hour to sample and sort.

Although many literature sources have discussed the issue of moisture loss from MSW samples none have expressed or addressed the fact that moisture loss may occur during the transportation process. It is only logical that the MSW samples, once sampled, will be transported to the nearest laboratory, generally by road. In some cases, the samples have to be transported over a long distance, which could be done either by land, air or sea. However, caution is needed when transporting MSW over a long period of time, where biological activity sets in and the moisture content and other properties of the samples may be altered (Burnley, 2007; Burnley et al., 2007). With this in mind, this study did not consider the other modes of transportation but looked at transporting the waste as quick as possible by road to the laboratories for analysis.

Many methods of drying the waste have been put forward by researchers, which make the data that has been published hard to be compared. There is also the fact that sometimes the moisture content of the MSW is published for all the individual components and sometimes for the commingled waste only. This gives a wide margin for variation in the data reported on the amount of moisture that is in the MSW sample at this stage of the analysis (Agrawal, 1998; Boldrin & Christensen, 2009; Brunner, 1993). Moisture loss during oven drying process is given emphasis in literature as it accounts for the most amount of moisture that is vaporized from the MSW samples.

There is no indication of the amount of moisture that is lost during the residual drying process although most recommended methods require MSW samples which have been oven dried to be ground and further dried. The grinding is carried out to ensure that the particles of the waste are small and also homogenous so that all the residual drying process is efficient. Generally, there is only one method of carrying out the residual drying process. However, there are three methods of reporting the moisture content lost from literature.

2.12 Sampling and Analysis of Waste to Determine Calorific Value

Malaysia is a food heaven for the ASEAN region where the population brags on the fact that food is available 24 hours a day; 365 days a year. With the fact that waste is still dumped without separation at source, understanding the calorific value of the waste is essential if energy recovery is to be considered as a treatment solution. Data on the characteristics of MSW with particular interest to the calorific value have been published worldwide. A literature survey of these data shows some inconstancy in the reporting and they are:

- A major problem with the reporting of the calorific value is that, sometimes the analytical method used to get the data is not reported, i.e. by bomb calorimeter or by employing a mathematical model. Analytical method is important when determining the accuracy and validity of the data (Demirbas, 1996; Fernandez et al., 1997; Franjo et al., 1992).
- Inconsistency in the term used to report the energy content, usually being described in terms of Higher Calorific value, Lover Calorific Value, Net Heating Value or Gross Heating Value although there are relationships between these terms but inconsistent reporting causes problems in comparing the reported values (Cheremisimoff & Morresi, 1976; Demirbas, 1996; Haith, 1998; Ikeguchi et al., 1993).
- Literature also shows inconsistency in the units used to report the energy content. There are many units used such as kJ/kg, kcal/kg, Btu/lb etc. again causing inconvenience in comparing the reported values (Cheremisimoff & Morresi, 1976; Demirbas, 1996; Penner et al., 1988; Ranieri et al., 2017; Raveendran & Ganesh, 1996).
- Finally, some of the data gives the calorific value of the individual components and also the weighted average of the calorific value based on the individual weight percentage, where else some of the data only reports the calorific value of the MSW on a commingle basis (Kirklin et al., 1982; Larson et al., 1996; C. J. Lin et al., 2013; X. Lin et al., 2015; Liu et al., 1996).

To add to the problems with reporting, there are also many variations by which the HHV of the MSW could be obtained. Currently the determination of the heating value of MSW samples can be done either experimentally or by using mathematical models. Experimental determination by using a bomb calorimeter uses a sample size of 1 gram which is inadequate to account for the vast variance in MSW composition, thus requiring bigger sample size. Furthermore, the experimental method is tedious and also requires technical skills in handling the equipment and the combustion by products. As for the mathematical models, they were created to avoid over reliance on lengthy experimental techniques (Buckley, 1991; Herrmann & Berry, 1991; Lorenz & Rau, 1997). These models have been created based on data from the physical composition, proximate analysis and elemental analysis of the fuel or refuse which have limitations and are as follows:

- When a model is created, the basis used, such as the weight, in percentage or in fraction, on an ash free or moisture free basis or both, is not defined in the equation, causing inaccurate usage.
- A review also shows that sometimes the same model is reproduced based on different units causing confusion, i.e. Btu/lb, kJ/kg, Kcal/kg and etc.
- Another study clearly states that the models created, performs best in the country/locality in which it is created, while producing over or under prediction when used internationally.

Table 2.24 shows some of the more common models that have been used. The positive point is that these models do give an accurate estimation of the calorific values of the samples. Unfortunately, to obtain or to use the equations, data on the elemental, proximate or physical composition is needed, which again requires experimental analysis. At this point again questions are raised on the validity of the models and the analytical approaches.

Elemental composition-based models are the most reported with Dulong's equation being among the first available to calculate the calorific value of coal. However, further to the problems discussed in the earlier paragraph with regards to the problems associated to models, the elemental analysis itself has some queries.

Table 2.24: Some of the Models available from Literature Review for the Prediction of the Heating Value (Buckley, 1991; Cheremisimoff & Morresi, 1976; Demirbas, 1996; Haith, 1998; Herrmann & Berry, 1991; Ikeguchi et al., 1993; Lorenz & Rau, 1997)

Name	Equation	Units	Remarks	Application	Ref.
1. Models based on Ultimate Analysis					
Dulong	$HHV = 8080C + 34460H - 4308O$ $2250S$	Kcal/kg	Original (wt.fraction)	Coal	9
Dulong	$HHV = 81C + 342.5(H-O/8) + 22.5S - 6(9H-W)$	Kcal/kg	Modified (% wt)	MSW/Coal	18
Dulong	$HHV = 144.5C + 609.6H - 76.2O + 40S + 10N$	Btu/lb	Modified (% wt)	Coal	26
Dulong	$HHV = 78.31C + 359.32(H-O/8) + 22.12S + 11.87O + 5.78N$	Kcal/kg	Modified (% wt)	Coal	9
Steuer	$HHV = 81(C-3*O/8) + 57*3*O/8 + 345(H-O/10) + 25S - 6(9H+W)$	Kcal/kg	(% wt)	MSW	18
Scheurer-Kestner	$HHV = 81(C-3*O/4) + 342.5H + 22.5S + 57*3*O/4 - 6(9H+W)$	Kcal/kg	(% wt)	MSW	18
Chang	$HHV = 8561.11 + 179.72H - 63.89S - 111.17O - 91.11Cl - 66.94N$	Kcal/kg	(% wt)	MSW	24
Boie	$HHV = 83.22C + 274.3H - 25.8O + 15N + 9.4Cl + 65P$	Kcal/kg	(% wt)	Refuse	24
Vondracek	$HHV = C(89.17 - 0.0622C_1) + 270(H - O/10) + 25S$ *(C_1 - Carbon content on moisture and ash free basis)	Kcal/kg	(% wt)	Refuse	24
Wilson	$HHV = 7831C_{org} + 35932(H-O/8) + 2212S - 3545C_{inorg} + 1187O + 578N$	Kcal/kg	(wt. fraction)	MSW	24
Mott and Spooner	$HHV = 0.336C + 1.418H - .0145O + 0.0941S$	MJ/kg	(% wt)	Coal/Refuse	26
Inst. for Gas Tech., USA	$HHV = 0.3417C + 1.3221H + 0.1232S - 0.1198(O+N) - 0.0153A$	MJ/kg	(% wt)	Coal/Refuse	26
HHV = net Calorific Value; W = weight % of Water, Dry basis; A = weight % of Ash, Dry Basis					
2. Models based on Proximate Analysis					
Goutal	$HHV = 147.6*FC + K*VM$ *(K is a constant that varies with the value of VM)	Btu/lb	(% wt)	Coal/refuse	9
Bento	$HHV = 44.75*VM - 5.85*W + 21.2$	Kcal/kg	(% wt)	Refuse	18
Traditional	$HHV = 45*VM - 6*W$	Kcal/kg	(% wt)	Refuse	18
VM = % Volatile Matter; FC = % Fixed Carbon					
3. Models based on Physical Composition					
Conventional	$HHV = 88.2\,Pl + 40.5\,(Ga + Pa) - 6W$	Kcal/kg	(% wt)	Refuse	18
Tokyo	$HHV = [(100W)/100]\,\{38.8(Pa+Ga+T+Oc) + 50.9(Te+Ru) + 73.7Pl\} - 6W$	Kcal/kg	(% wt)	MSW	25
Ali Khan	$HHV = [23\,(Ga + 3.6*Pa)] + [160(Pl + Ru)]$	Btu/lb	(% wt)	MSW	9
W = total moisture; Pa = paper; Ga = garbage/food; Te = textile; Ru = rubber & leather; Pl = plastics; Oc = other combustibles; T = wood & grass					

The sample size used for elemental analysis is only 1 to 10 mg which is even smaller than that used for the conventional bomb calorimeter, thus invoking the sample size representation argument. Furthermore, elemental analysis is expensive and tedious and needs skilled workers to carry out the analysis.

In response to these comments, models were created based on proximate analysis or physical composition. Most of the equations created were used to estimate the HHV of either coal or MSW. Ideally these models were well accepted in their locality only but did not perform well against international data. Proximate analysis models created were based on the weight percentage of the volatile matter and fixed carbon in the MSW. The advantage of using proximate analysis data was that it gave results based on sample sizes which where about 1 to 5 grams. This sample size was more representative of the total MSW size when compared to the sample sizes used in the experimental method by bomb calorimeter (max. of 1gram) or in the elemental analysis (1-5 mg). A further enhancement in the sampling size was envisaged by using the physical composition, and this brought about the approach for modelling the equation from this data. Models based on the physical composition were created based on the weight percentage of the food; paper and plastic content generally but also included other components when there was a relationship.

With this in view, this research would analyse the best fit equation to calculate the calorific value of the waste. The equations in Table 2.7 would be evaluated based on data from either the physical, proximate or elemental composition of the MSW. In addition, the following questions would be answered:

1. What is the best sampling method that will address the time factor during sampling, the manpower and equipment needed for sampling and the cost

associated to the various ways for sampling – finally showing which sampling method could provide with the most accurate results?

2. Addressing the actual moisture content of the MSW from the time the sample is obtained from the source until it arrives at the laboratory for analysis
3. Finding an estimation formula that will help in reducing the cost of analysis and also provide for larger sample analysis and result accuracy.

CHAPTER 3: MATERIALS & METHODS

3.1 Introduction

MSW generated is a function of human activity which varies with time, geographical location, cultural activities, income status and many more conditions. This is further complicated by the fact that sampling to determine the composition and characteristics of this waste is done to a very small portion of the total waste generated daily. For instance, to sample the waste generated for the whole of Peninsular Malaysia which generates 35,000 tons of MSW/day is impossible, what more if it is to be done on the same day, as the cost factor and the inability to deal with such a large sample size. That is just for one day's waste, what about establishing a trend of what are the composition of the waste generated daily.

To understand the methodology better and to link the methodologies back to the objectives of the study the following table was developed to show an overall picture. The pictorial representation of this sampling flow is shown in Figure 3.1.

Figure 3.1 shows a sample flow chart for the overall collection, sorting and sample analysis procedure. This completes the sampling and sorting procedure and now the sample needs to be sent for analysis.

3.2 Standards Used for the Establishment of Sampling Plan for MSW

The methodology adopted for this part of the study was based on the existing MSW collection in any given municipality. However, doing an account of MSW at all the 144 municipalities in Malaysia will be impossible and furthermore most of the 100 over landfills catering for the 144 municipalities do not have weighbridge to give accurate data. This problem was resolved by concentrating on data from Kuala Lumpur and Penang only. As such this study only used data from the weighbridge from Kuala Lumpur and Pulau Pinang from the period of 2001 to 2014.

Table 3.1: Process flow for sampling linking back to the study objective and Methodology

Sampling Process Flow	Objective in Study	Method / Protocol	Remarks
Determining the area of study and number of samples	Contributing to Objective 1	Adopt MS 2505:2012	Data limited to Kuala Lumpur and Pulau Pinang and from 2000 to 2014
Sampling Plan	Contributing to Objective 1	Adopt MS 2505:2012	Establishing the number of samples based on geographical location and time to take the samples
Sampling Point	Contributing to Objective 1	1. As Generated 2. As Discarded 3. As Disposed	Related to the scope of the study – for facility or desk top study
Sampling Method	1	1. Truck Load 2. Cone and Quarter 3. Spot Sampling 4. Laboratory	To identify which is the best sampling method which will allow for accuracy but yet cost effective and not time consuming
Sorting	Objective 1	1. To be sorted into 10 or 25 components 2. To analyze by component or as a mixture	Sorting to as many components gives clarity to the components of the waste however not all components needs to go through the full analysis
Moisture Content	Objective 2	To monitor moisture content for the following process 1. Leachate 2. During sampling 3. During transportation 4. Oven and residual moisture analysis	Standard methods are limited to oven and residual waste analysis. This study introduces new methods to monitor moisture loss
Analysis of Samples	Contributing to Objective 2 and 3	To analyze the samples on an individual component basis or on a comingled basis or a combination of both	This process has a big impact on cost and time for analysis
Calorific Value	Objective 3	Using established equations – check the calculated value against a set of results from the experiment	To reduce analysis cost and time and can be dependent of the waste composition data

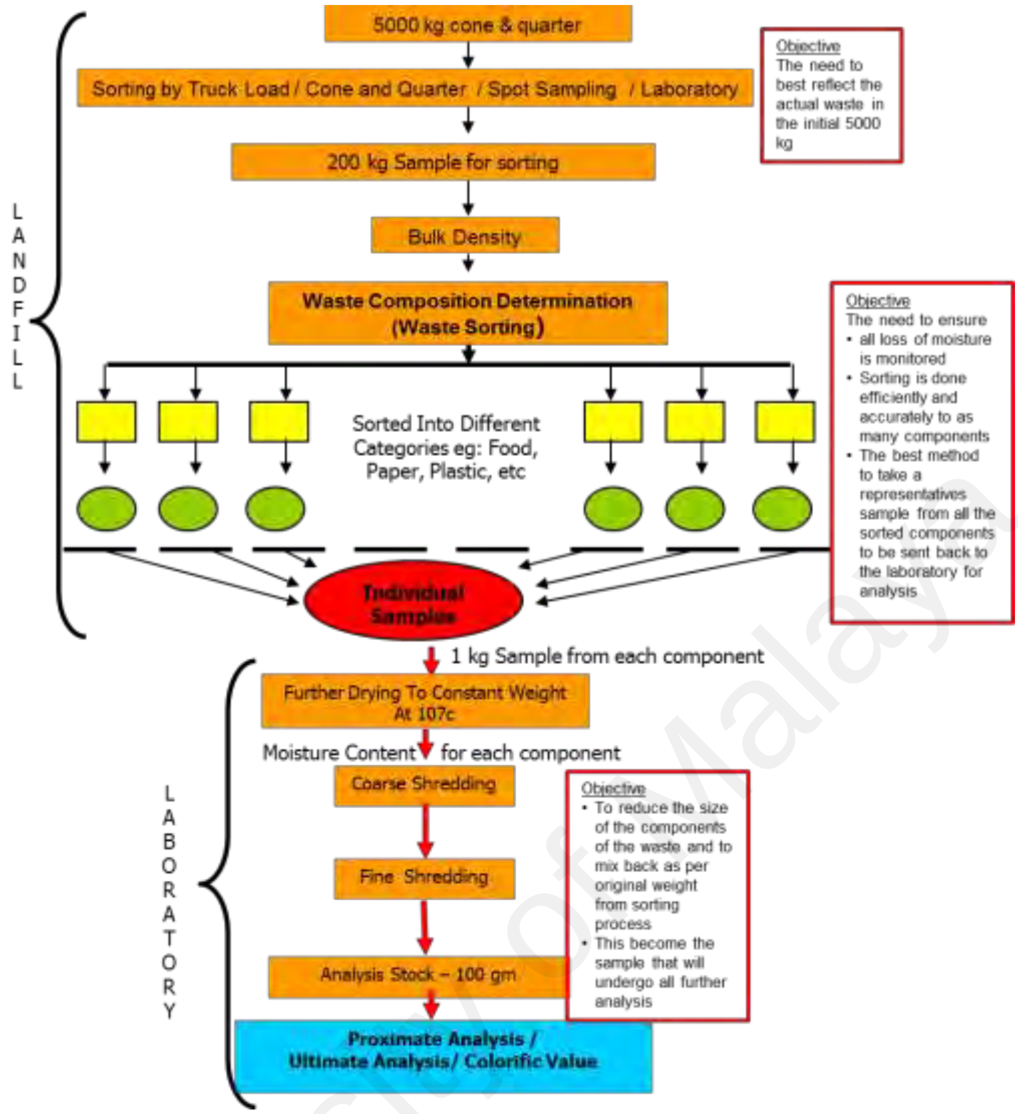

Figure 3.1: Sample flow chart from collection of samples to sorting to analysis

In 2012, the National Standards Department established a standard test method for the sampling and analysis of MSW in Malaysia; the Malaysian Standard MS 2505 – 2012 with a heading of Guidelines for sampling of household solid waste – Composition and characterisation analysis was passed and put into practice by the Malaysian Government. The Malaysian Standard specifies the sampling methodology for household solid waste composition and characterisation analysis which applies to waste As Generated, As Discarded and As Disposed; the reporting format after sampling and characterisation analysis; and the minimum number of components for household solid waste composition.

As these two guiding documents are readily available and most referred to when carrying out a MSW study, this study would adopt these documents as the base document in carrying out the sampling plan; establishing the samples and also carrying out the sampling and analysis while trying to infer the shortcomings and recommending the new procedures to better reflect the variability in the MSW being generated in Malaysia. The most recent waste analysis done on a national scale for which the author was the lead researcher will be used as the benchmark results. This sampling was done based on samples taken from each capital city or local authority (LA) in each state within Malaysia. The samples were chosen based on the activity of the local population and the trucks were targeted based on the route that it was collecting the waste. Once the identified truck has been picked out, the actual 200 kg sample is randomly picked from the pile of MSW that is dumped out of the truck when it is emptied at the landfill. The following sections will give some detailed description of the various procedures taken in the process on sampling and analysis of the MSW.

3.3 Establishment of Sampling Plan for Waste

The establishment of a sampling plan is based on the Malaysian Standard MS2505-2012 which only gives a rough guideline on how to establish the sampling plan. This was used as a basis to establish a plan and was implemented in the National Survey on Solid Waste Composition, Characteristics and Existing Practices on Solid Waste Recycling in Malaysia. The selection criteria used in identifying the locations of the samples for the Local Authorities (LAs) was based on detailed housing type information according to geographical location. The sampling plan was based as follows: -

- Areas that are geographically proximate to each other were grouped into clusters.

- Within each cluster, the households were sorted into housing types. These housing types are assumed to represent the income level of the household.
- Each cluster was then coded, after which three clusters were randomly selected within each housing type, by using the random number generator in Microsoft Excel. These housing types represented the housing type for the LA.
- The total number of samples is then divided proportionately to determine the number of sample (n) in each cluster i.e. if there were three clusters representing each housing type, $^{n}/_{3}$ samples was taken from each cluster.
- The Waste Composition Survey and the Recycling Survey collected the samples from the houses within the same clusters; however the number of houses in each cluster for these surveys differed.
- In order to compensate for all "inappropriate" cases (e.g. migrant workers' house, respondent is under 18), 50% over sampling was applied. In other words, a total of 45 households (n) were sampled per housing type in this survey. These 45 households included all households that agreed to participate, irrespective of whether they recycle or not.
- In some LAs, certain household types were not available (e.g. high-rise high income units in rural areas) or they contributed to less than 3% of the total households in that LA. In such cases, these housing types were not chosen in that LA and the 30 samples originally allocated for these housing types was reallocated to the five larger LAs namely Penang, Kuala Lumpur, Johor Bahru, Kota Kinabalu and Miri. The reason for the increase in the sample size in the more populated LAs was to capture the greater diversity and to analyse that diversity in greater detail.

Moving on to the sampling at industries and taking into account that LAs may have different types of industries; samples were selected according to industrial categories. As a general guideline, 50 samples per industrial category were sampled and a total of 11 industrial categories were identified. In other words, a total of 550 industrial establishments were sampled for this study and out of that 54 samples were collected for the waste composition study. The selection criteria ensured that at least 3 samples in each category were selected of the 54 samples.

Next was to plan for the commercial and industrial (CI) category. A total of 8 main CI categories were identified for this survey with 50-60 samples in each category. This amounts to 470 establishments as the total number of samples needed for this survey. Out of the 470 sites surveyed, a total of 108 samples were collected for the waste composition survey. The selection criteria ensured at least 3 samples in each category were selected of the 108 samples.

To integrate information collected by Waste Composition team and Recycling, a number of households, industrial and CI samples were shared. First, Recycling provided the Waste Composition with a list that were surveyed and currently practice recycling. Next, Waste Composition selected from the same list to sample and these were the shared samples. This way, the waste composition results would be able to be compared with the recycling results to establish the recycling rates for the area.

As this sampling plan was done based on the Malaysian Standard MS 2505-2012, and furthermore the sampling plan was adopted closely by the National Survey on Solid Waste Composition, Characteristics and Existing Practices on Solid Waste Recycling in Malaysia; it is deemed that this method of establishing the sampling numbers and the location in which the samples will be taken from is well established and acceptable as it follows a National Standard Method.

3.4 Procedures for Sampling of Waste

Once the number of samples and the area in which the samples to be taken from was established using the National Survey on Solid Waste Composition, Characteristics and Existing Practices on Solid Waste Recycling in Malaysia; next was to plan out the sampling time which was done taking into account for variations that would occur during festive seasons, dry and wet seasons and school holidays – the time adopted in this study was any time frame which did not include any of the above to avoid any abnormalities in the data.

The first level of stratification was the seasonal stratification. The waste composition study was conducted to include the maximum and minimum rainfall period in at least 2 sites, to account for the wet season and the dry season. Part of the study was also conducted during the festive/holiday seasons. The third level of stratification was covered by the various housing types, commercial, industrial and institutional sources of waste generators. Each LA was divided into the following different categories of sources:

- The Households in each LA was divided into 3 types based on housing types (Low, Medium & High Income). Housing type is assumed to represent the income level of the household.

- Commercials was divided into categories which included offices (office complexes, shop lots), hotels, transport hubs (railway stations, bus stations, airports), shopping areas and markets (shopping complexes, hypermarkets, supermarkets, wet markets, night markets), shop lots (restaurants), hospital and clinics, stadiums, army camps, Government complexes, police stations, Mosques, (universities, colleges, schools). Waste from at least 5 premises (if available in LA) from each of the above sources was collected to form a sample in a day for each LA.

After knowing the number of samples, location and even the time to take the samples, the study now moves to establish the various procedures that is needed to sample the MSW through the chain it takes from the source to the final disposal. That is usually divided into:-

a) As Generated Sampling – sampling at source
b) As Discarded Sampling – kerbside sampling
c) As disposed Sampling – sampling at landfill

3.4.1 As Generated Sampling

Households were divided into three housing type namely Low, Medium and High Cost households. The number of households sampled for each LA and by each category. The procedure for carrying out collection of waste for composition analysis at source in households was as follows:

- Each of the selected households was contacted and notified about the study, and their cooperation sought to participate in the survey.
- The selected households were asked to retain their wastes that are normally discarded, including the recyclable components that are kept for separate disposal with the recyclers.
- The sample representative per sampling area of selected households was at least 30 residents.
- The activity carried out in groups of 3 persons. One person (recorder) recorded the number of premises visited.

- The compositional analysis done in groups of 9 persons. One person (recorder) recorded the number of households according to the categories.
- Two persons bagged the waste, weighed the contents and recorded in the data sheets provided.
- The information on the number of newspapers and magazines was also logged.
- The recorder recorded the information of the premises and passed this information to the data analyst.
- Waste collected was placed on trucks and transported to the landfill site, where the quantity of collected waste was weighed, sorted into its components and the sorted components weighed to record the waste composition.
- Six persons conducted the sorting of the waste, weighing the sorted waste and recording of the waste composition by weight.
- A laboratory sample of about 1 kg per component was placed in a sample bag and sealed. The sample bag was weighed and marked before it was wrapped in boxes. The whole sample was boxed and couriered to the laboratory the same day.
- The survey duration covered a one-week cycle to identify the weekly trend of the waste composition and generation rate.

Figure 3.2 shows a sample flow chart based on the description in this section on how the samples were taken from the households. This gives a picture of the activities at hand and the extent of the manpower required to carry out such a survey and sampling study. This will also reflect the cost involved in carrying out the waste characterisation study. This is the reason why there are not many studies carried out and even when carried out the studies are under budget and under manpowered, limiting the number of samples and the activity of the sampling is often limited to the obtaining of samples at the landfill alone.

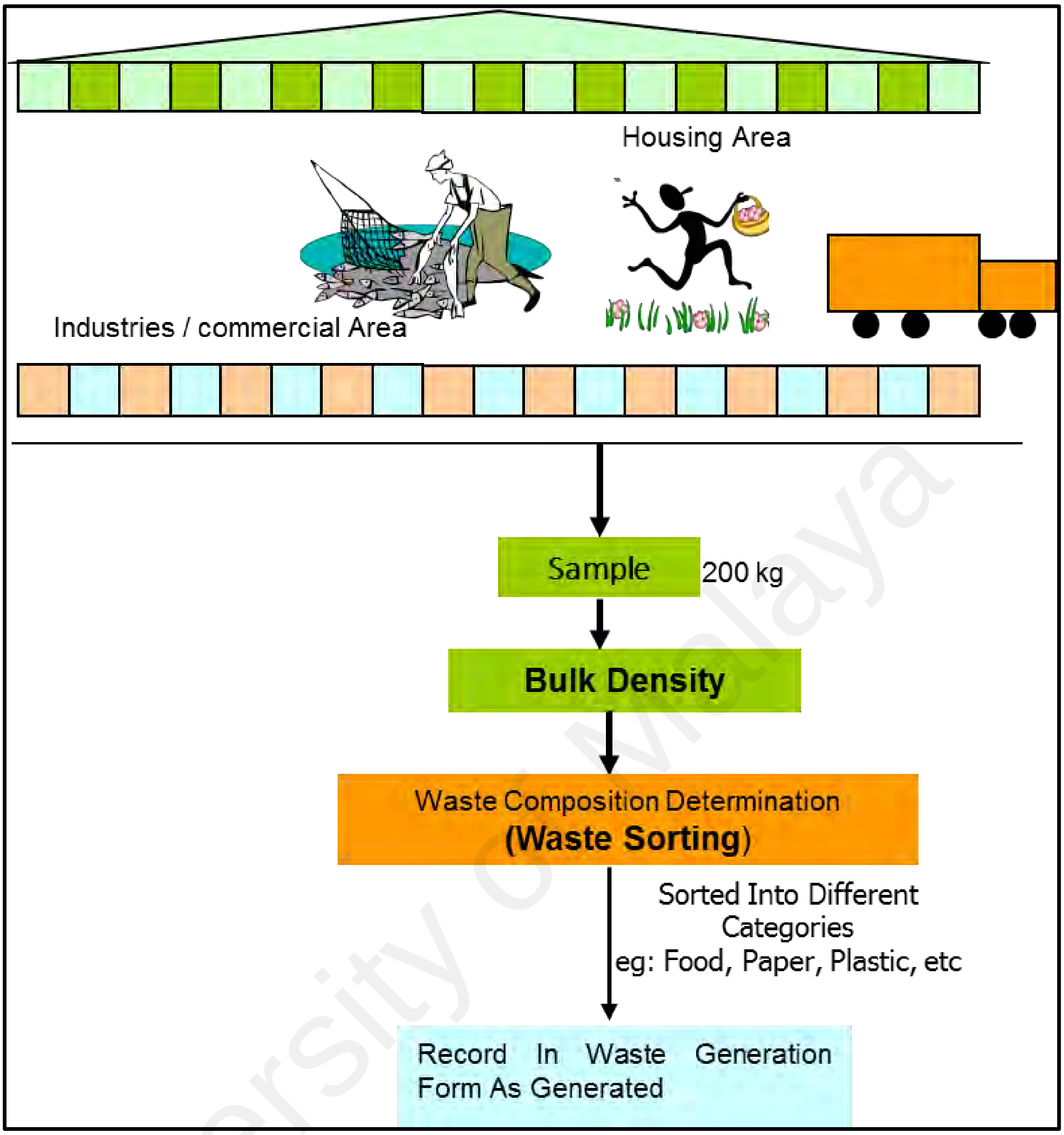

Figure 3.2: As Generated and As Disposed waste sampling flow chart for household

3.4.2 As Discarded Sampling (Kerbside sampling)

Figure 3.2 shows a sample flow chart based on the description in this section on how the samples were taken from the households on as As Discarded basis.

The locations of the households, industry, commercial and institution were determined using information obtained from the LA; collection was done based on the collection frequency of the specified area. The survey's sampling truck first collected the waste from the kerbside before the daily waste collection trucks did the normal collection. Activities that were carried out during the sampling is the same as in section 3.4.1.

3.4.3 As Disposed Sampling (Sampling at Landfill)

The composition of the waste at the landfills requires sampling of only one main landfill that receives the largest amount of waste from the predetermined LA. The quantity of waste disposed and location of illegal dumpsites were not part of the study. However, the waste collection trucks servicing these sites arriving at the landfill were randomly selected for the composite samples.

The method of "Random Sampling" was used to form the representative samples. This is where the waste was extracted from multiple waste collecting trucks that service the same areas as the samples collected for the As Generated/As Discarded waste. A grab sample of 50 to 100 kgs was taken from 10 trucks before the "cone and quarter" method for extracting sub-samples from the sample material collected was employed. The procedure for carrying out composition analysis at source at the landfill was as follows:

- Waste trucks entering the landfill site with solid waste collected from same household areas as the As Generated/As Discarded sampling was selected for the survey.
- The waste from the trucks was directed to a pre-prepared sampling site and the waste unloaded onto the tip floor.
- Bulky items, medical waste or scheduled waste found in the waste was separated from the load, weighed and logged in the datasheets.
- The remaining material was mixed by mechanical shovel, or manually using rakes or shovels, into a uniform, homogeneous pile approximately 0.8 m high.

- The pile was then divided into two equal portions by drawing a straight line through the centre of the pile. The pile was further divided by drawing a second line roughly perpendicular to the first.
- A pair of opposite quarters was removed, leaving half the original sample.
- The steps d) through f) were repeated until the required amount of sorting sample of 200kgs remained.
- The sorting sample was then sorted into the different components, weighed and each waste component's weight was recorded.
- Two persons bagged the waste, weighed the content and recorded it in the data sheet provided.
- A laboratory sample of about 1 kg per component was placed in a sample bag and sealed. The sample bag was weighed and marked before it is wrapped in boxes. The whole sample in boxes was couriered to the laboratory the same day.
- The survey duration covered a week cycle to identify the weekly trend of the waste composition and disposal rate.

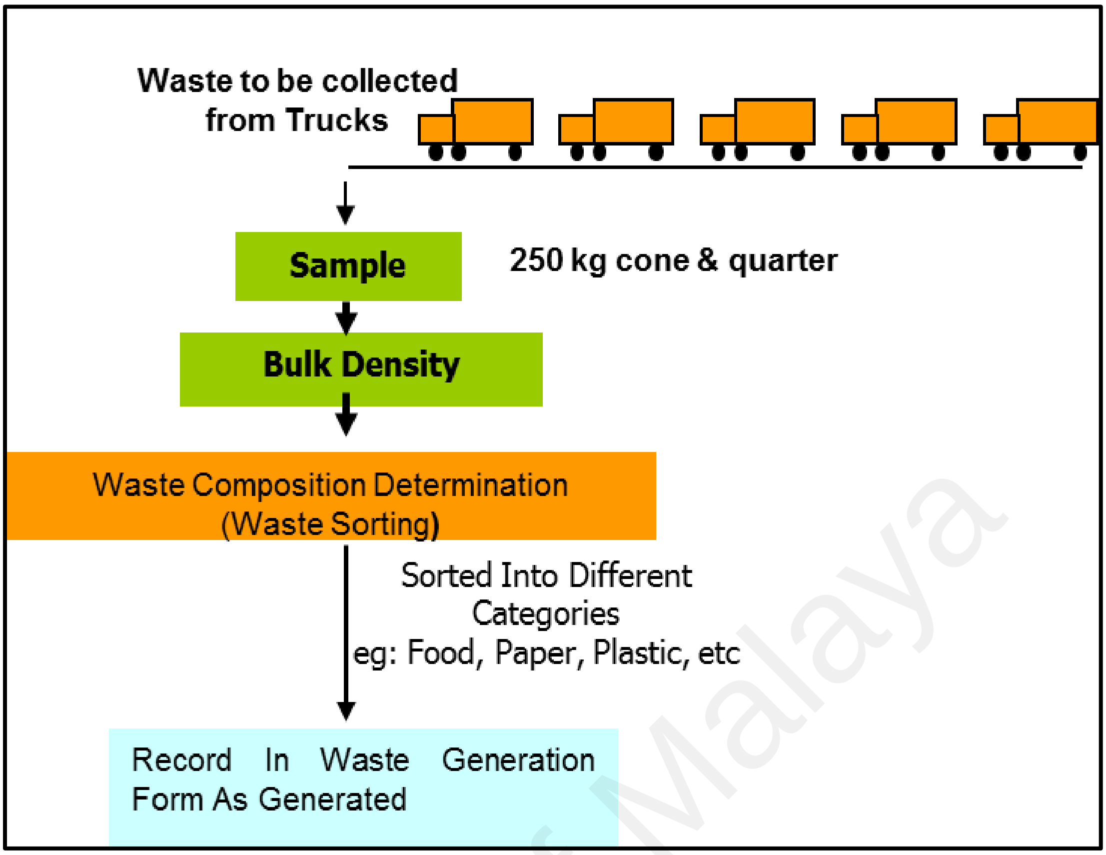

Figure 3.3: As Disposed waste sampling flow chart at landfill

Figure 3.3 shows a sample flow chart for the As Disposed sampling activity based on the description in this section on how the samples were taken at the landfill. The main difference between Figures 3.2 and 3.3 is the sample size taken from the source. In most cases, when sampling at source on an As Generated or As Discarded basis, the amount of waste collected would be between 300 to 500 kg which is an acceptable amount of waste to be sorted by a crew of 6 to 8 people. However when the sampling is done at the landfill and the sample size is usually above 500 kg or even up to 1000 kg, then the cone and quarter method is brought in to reduce the sample size so that the sorting activity will be efficient and accurate and can be achieved by a crew of between 6 to 8 people.

3.5 Procedures for Obtaining Sample Size for Sorting

In the past sections, we have established the overall quantity of waste generated, established a sampling plan and established the procedures on how these samples will be obtained from the Household, Commercial, Institutional and Industrial sources. The preceding sections have also been established based on the Malaysian Standard MS 2505-2012 and the National waste characterization study titled National Survey on Solid Waste Composition, Characteristics and Existing Practices on Solid Waste Recycling in Malaysia as the guiding example.

Moving forward, there now arises the need to establish a procedure for obtaining an appropriate sample size for sorting. In most cases the sorting is done at the landfill site and requires a large task force as the work is heavy, dirty and very smelly. The manpower cost to sort the MSW can be considered as the most expensive part in the overall costing of the waste study. As such establishing a reasonably moderate workforce that can give the necessary accuracy in the sorting procedure at the fastest time is essential. Sorting of the MSW samples can basically be carried out by four different procedures as listed below:

1. 'Truckload Method', where the whole contents of an identified truckload were sorted to account for the composition of the waste.
2. 'Quartering Method', where the contents of an identified truckload is unloaded on to a clean area and quartered until a manageable amount of waste is achieved (about 200 kg) before sorting.
3. 'Spot Sampling Method', where an amount of waste (about 30–50 kg) is taken from a few truck (about 8-10 trucks) to form a sample size of about 200 kg which is then sorted.

4. 'Laboratory Sampling Method', where the contents of a truck is unloaded, quartered and reduced until a 20 kg sample is achieved, which is parceled for laboratory sorting.

To establish the best method that will best fit the sorting of MSW in Malaysia, a simple sub study was carried out. MSW for this study was obtained mostly from the trucks, which serviced any specified area within a city. The selection of the source of MSW was predetermined randomly to accommodate for all type of sources (i.e. high, medium and low residential households, institutional, commercial and other sources). The identification of the source has been based on the majority activity or lifestyle that was practiced by the premise along the route taken by the specified truck. Samples were taken from the individual sources and at random from all sources.

Identified truckloads were weighed at the incoming weighbridge and directed to a pre cleaned flat surface where segregation of the waste to its components was carried out. The municipal workers carried out the sorting of the MSW while the researcher helped and supervised them. Segregated waste components were weighed while samples were taken for further analysis at the laboratories. Based on the results of this sub study, the results will be used to determine the most appropriate method taking into account the accuracy, cost and time fact to sort the MSW sample.

3.6 Procedures for Sorting of Waste

The waste sample was mixed, coned and quartered to get a Sorting Sample. The Sorting Sample weight for waste composition analysis was based on MS 2050-2012 that recommends sorting sample weight be a minimum of 200 kg. Before the sample can be sorted, the following has to be observed:-

- The bulk density of every waste sample was measured. The bulk density was measured by filling a 250-liter standard container/bin with the waste. The waste sample shall be put into 250-liter standard containers/bins. The container shall be lifted and dropped 3 times from a height of about 100 mm and the topped up with additional waste top before repeating the process. At least 3 or 4 containers are required to be filled. The weight of the waste divided by the volume will give the bulk density
- The As Generated and As Discarded waste material from the sampling truck carrying the waste collected from households, industry, commercial or institutional was unloaded at the working area at the landfill site.
- A bucket front-end excavator/loader removed the material longitudinally along one entire side of the discharged load in order to obtain a representative cross-section of the material.
- The sorting sample was mixed, coned, and quartered before selecting one quarter as the Sorting Sample.
- A random method of selection was used to eliminate or minimize bias of the sample.
- All bulky waste were noted of in datasheet and weighed.
- The sample was then transferred to the sorting area to start the sorting activity.

The Sorting Waste Sample was then segregated into the waste components by the Sorters at the landfill. The description of each component is as presented in Table 3.2. In the case a composite item is found in the waste, the individual materials were separated and placed into the appropriate storage containers**.** Sorting continued until the maximum particle size of the remaining waste particles was approximately 12 mm. At this point, the remaining material was apportioned into the storage containers corresponding to the waste components represented in the remaining mixture. The composition of the waste shall be sorted in the wet base as they are received.

The procedure that would be followed during each sorting activity which was carried out at the landfill was as follows:

- To prepare a sort area, a tarp/plastic sheet is placed on a level area. The tarp/plastic sheet is surrounded by containers used to hold the sorted materials (19 containers). For bulky items (corrugated cardboard, etc.), a separate area will be identified for storage.
- A sorting table is prepared for manual sorting. It has a cut-out where screens of various sizes used to allow fine materials to fall through into containers for final fine sorting.
- The sort containers are weight empty to obtain tare weights. The containers are labeled and tare weight clearly marked on each container. The containers must be cleaned periodically to ensure a consistent and accurate tare weight.
- To begin sorting operation, the first portion of the sample is placed on the main sorting table or tarp/plastic sheet. Crew members begin sorting the sample by hand. The supervisor oversees operation, checking each container for separation quality and assist in classifying questionable items. When about 90% of the first portion of the sample has been sorted, another portion of the sample is placed on the sorting table or tarp/plastic sheet and the sorting continues.
- All components will be sorted manually. After the entire sample has been sorted, the fines on the table are placed in a container. The sorting table is removed and the tarp/plastic sheet is picked up at the corners and the contents are examined and placed into appropriate containers.

- The tarp/plastic sheet will be cleaned and placed back on the ground. The filled sorting containers are weighed, and the gross weight recorded. The containers are emptied, cleaned and placed in their appropriate locations for next round of sorting.
- A laboratory sample of about 1 kg per component was placed in a sample bag and sealed. The sample bag was weighed and marked before it is wrapped in boxes. The whole sample in boxes was couriered to the laboratory the same day.

3.7 Procedures for Sample Preparation and Analysis of Waste

Generally, once the waste is sorted into the components, the components are then weighed and a sample is taken to be sent to the laboratory for analysis. From the various methodology studied, there are three main approaches in preparing the samples for analysis and they are

1. From the sorted wastes components (sorted into each waste composition category), a composite sample of about 2 kg is to be made up by weighing each waste category according to the percentage of the sorted waste and then mixing up the waste. This 2 kg sample is then put into air-tight plastic bags and weighed accurately prior to sending to the laboratory. The exact weight of the sample is recorded. This is a bit difficult to get back the exact composition mix as the original waste although it is a relatively easy and cheap way of carrying out the analysis.
2. From the sorted waste components (sorted into the individual waste composition category), each component was taken with an estimated weight of about 1 kg. This 1 kg sample was then put into air-tight plastic bags and weighed accurately prior to sending to the laboratory. The exact weight of the sample was recorded.

In this method, the analysis of the individual components is very accurate, but the time taken and the cost of analysis is just too high

3. From the sorted waste components (sorted into the individual waste composition category), each component was taken with an estimated weight of about 1 kg. This 1 kg sample was then put into air-tight plastic bags and weighed accurately prior to sending to the laboratory. Upon arriving at the laboratory, the waste components are dried first. Upon drying, the components are then mixed back according to the original weight percentage from the earlier sorting study to form the composite sample which then is used to carry out the analysis for the MSW sample. This is considered as a go between both earlier method where the accuracy is high, and the cost is low.

In order to understand the three methods above, a separate sub study was carried out to show the accuracy of these three methods and the results will be presented in the coming chapters. Samples for this study was obtained from the MSW generated in Kuala Lumpur during the months of May and Jun 2010 with a total of 30 samples collected. The selection of the source of MSW was predetermined randomly to accommodate for all type of sources (i.e. high, medium and low residential households, institutional, commercial and other sources). The MSW is sorted into 23 different components. Segregated waste components were weighed, and their weight percentage recorded while samples from both the commingled and individual components were taken for further analysis. At the laboratory, the wet waste sample was prepared by drying and size reducing before the analysis as shown in Figure 3.1.

3.7.1 Analysis of Waste Samples

Once the waste has been dried and reduced in size it is ready for analysis. The following analyses are the parameters that are carried out on any MSW sample:-

- Proximate Analysis - This analysis is carried out to obtain the Moisture Content, Fixed Carbon, Ash Content and Volatile Matter of a waste sample. This testing is performed according to MS 2505:2012.
- Ultimate Analysis - This analysis is carried out to obtain the elementary components of C, H, O, N, S, Organic Chlorine, and heavy metals present in a waste sample. This testing is in accordance to Ms2505:2012.
- Metals – The laboratory analysis for heavy metal content of the waste samples shall include Magnesium, Vanadium, Silver, Copper, Aluminium, Iron, Lead, Mercury, Zinc, Chromium, Arsenic Cobalt, Manganese and shall be tested according to MS 2505:2012.
- Calorific Value - This analysis is carried out in an apparatus known as a bomb calorimeter to obtain the heating value of a waste sample. This test is performed in accordance to MS2505:2012.
- Biodegradability is an important parameter when using treatment techniques such as composting. If a large fraction of the Solid Waste is not biodegradable, then this fraction will have to be disposed of by other means if composting is the primary mode of treatment. The potential biodegradability of the waste samples was determined using the estimated percentage of degradation of the individual components of the waste sample.

Most of the analytical methods are very well-established methods and it is a common practice. As such this study will adopt all the test methods that have been recommended in this section as the methods for analysis. However, for the moisture content and the calorific value determination, there are some varying methods.

3.8 New Procedure to Monitor Moisture Content of a Sample

Most standard methods only recommend monitoring moisture content after the sample has arrived at the laboratory. However, moisture loss in the sample happens right form the time it was taken from the source and this has never been monitored. This study recommends the following steps and methods to monitor moisture loss right from the sampling to the transportation. These steps are new and are part of the results of the study. The following sections will highlight the new methods used in this study to determine the moisture content of the samples. Basically, there are 5 avenues for moisture to be lost during a sampling process and they are as follows: -

1. Moisture loss trough Leachate – When taking samples from a truck load, very often the free water in the truck and in the receptacles to contain the leachate are not accounted for. There was a very high consequence of not accounting for this leachate/free water. These moisture content needs to be collected carefully weighed and recorded.
2. Moisture loss during sampling and sorting process - The area of sampling and sorting was pre-cleaned and dried before each sampling and sorting activity. The samples were weighed as soon as they were taken from the source. Once the sampling and sorting activity was done, all the sampled material was weighed and accounted for. The difference between the initial and the final total weight gives the amount of moisture lost. The time taken for the sampling and sorting activity and also the weather conditions during the process was noted. Care was

taken so that no component of the initial waste sample was missed from the waste pile.

3. Moisture loss during transportation - The transportation mode used was usually a van and the time taken for delivery of samples was not more than 1 hour. Packaging of the MSW samples was done consistently, whether for individual components that make up the MSW or for a commingled sample. All waste was put into plastic bags and heat sealed and then weighed before transporting. The sample size for individual components was about 1 kg and about 20 kg for the commingled style. Once the waste had reached its destination, the sample packages with their contents were weighed and the difference in weight considered as the amount of moisture loss during transportation. Care was taken to ensure that the plastic bags are not punctured by a sharp or protruding object and it did not have a visible leak.
4. Moisture loss during oven drying - The oven drying of moisture from MSW samples can be carried out at four different temperatures and their entailing methods are described below:

   a) 10 to 15°C above ambient temperature (about 45°C maximum) for 24 hrs. A commingled simulated waste sample with the size of about 2 kg was air dried in a forced air oven until less than 0.1% change in weight is observed.
   b) 85°C for 3 days. A commingled sample size of about 20 kg is air dried at 85°C for 3 days in a forced air oven and then cooled to room temperature for 1 day.
   c) 75°C for 24 hrs. A commingled sample size of about 0.1 kg is air dried at 75°C for 24 hrs.
   d) 105°C

5. Moisture loss during residual drying - The oven-dried samples were ground to pass through a 0.5 mm sieve. A sample size of 1 gram was used and the samples were put into a forced air oven to dry for 1 hour at a temperature of 107°C. The drying process was carried out for both the commingled sample and individual components.

3.8.1 Sub Study to Determine the Appropriate Temperature in Analysis for Moisture Content

This sub study was to investigate the drying of MSW samples carried out at three different temperatures, 45°C, 85°C and 105°C. The amount of sample used was about 1 kg and all the samples were air-dried in a forced air oven for the specified time frame. The weight of the samples was recorded before and after the drying process. This sub study put synthetic MSW samples through the same series of tests. The samples were synthesized in order to ensure that the material used to simulate the waste was the same for comparative reasons. This enabled the study to ascertain the variations that occur at the different recommended drying temperature. The samples were first dried for 24 hrs at the three different temperatures mentioned above, before being ground and dried again at 107°C for 1 hour, and then weighed. Finally, the samples were dried for another 23 hrs at the same temperature to ensure that all remaining moisture is lost and the final weight recorded. The sub study sample preparations were as follows:

1. Drying water – to ascertain to most efficient drying temperature.
2. Drying rice added with water at various conditions:

    a. The mixture was immediately put into the oven for drying and after the oven drying the samples was not ground. This was to see how much moisture evaporated from the sample if the water was not allowed to absorb into the waste.

b. The mixture was allowed to soak overnight and then the mixture was dried with no grinding carried out to the waste after the oven drying process. In order to determine if soaking has an effect on the amount of moisture that was vaporized at the various temperatures.

c. The mixture is allowed to soak overnight and then the mixture was dried with grinding carried out to the waste after the oven drying process. This was in order to determine if at the grinding process, moisture was lost and the effect of grinding on the mixture moisture content.

Very often, reporting is not a very big concern at the methodology stage. Most of the time, the reporting is based on the waste sample and not for the individual components. Most of the data from Chapter 2 on waste characteristics do not have the financial strength to do individual component sampling and analysis, thus the results are reflected as a single waste result. In this case the analysis was done for the individual components, and then the results are multiplied with the individual component weight fraction with the components % moisture, volatile matter, fix carbon or ash content. This will give a weighted average of the % content rather than taking a simple average.

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CHAPTER 4: PROTOCOL FOR PHYSICAL CHARACTERISTICS OF WASTE

4.1 Introduction

Chapter 4 presents the findings and analyzes that provides for the best methods and best practices for the physical characteristic of the waste whereas in Chapter 5, the establishments of the physicochemical characteristics were presented. In Chapter 4, a systematic approach based on previous studies and standard documents are presented, towards planning for a waste characterization study while executing the best practice towards establishing the physical characteristics of the waste. The extensive data base given in Appendix 1 for the various states in Malaysia by source and by components can be used as a good guide for waste characteristics in Malaysia and could also be used as an indicative figure for a typical waste disposed of in any major city in Malaysia

By following the above, the ultimate aim was to show what would be the best approach or set of procedures that would reflect the characteristics of Malaysian MSW which is heterogeneous in nature. The following sections of this chapter explores each activity during the establishment of a sampling plan, the corresponding methodology that reflect the waste generated due to the cultural diversity and the tropical nature of the MSW and its components for the benefit of future waste management.

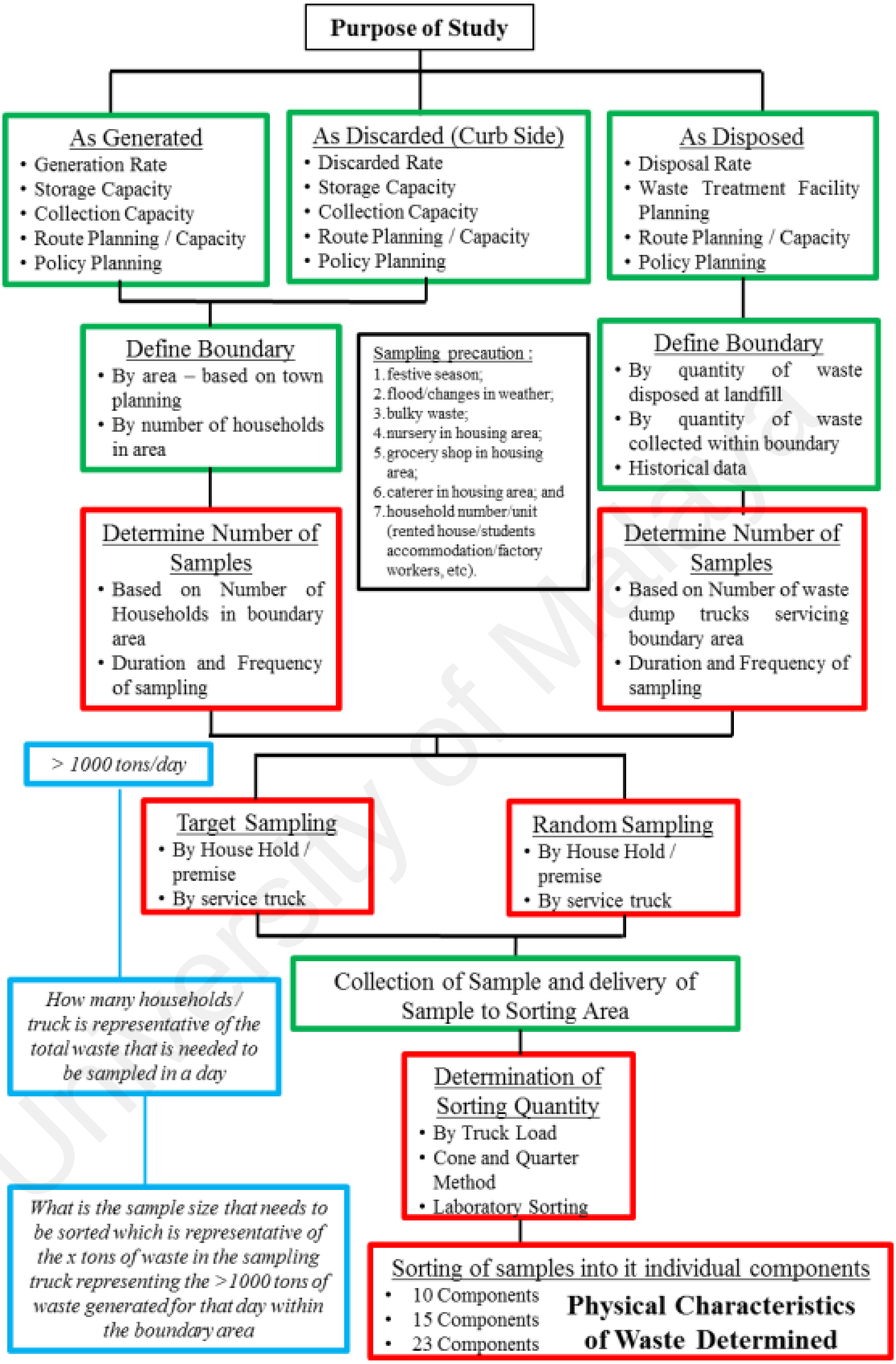
4.2 Establishing the Physical Characterization Study Plan for Malaysia

In Malaysia, the standard for waste characterization was only introduced in 2012 which is MS 2505:2012 - Guidelines for sampling of household solid waste - Composition and Characterization Analysis. As this standard is new, not many studies have been carried out using this standard. The only study done is the "Survey on SW Composition, Characteristics & Existing Practice of SW Recycling in Malaysia" in 2014 and done for the National Solid Waste Department.

After studying the MS2505:2012, Figure 4.1 shows a flow of how the standard described a waste sampling plan. The standard has stayed silent on the choice to be made in formulating a study plan. This silence can raise some questions and has been highlighted in Figure 4.1. As this study has its limitations, not all aspects within Figure 4.1 are analyzed. Only the boxes highlighted in red will be discussed. Based on Figure 4.1, the following points provide the argument on why these red box needs to be analyzed:-

1. To determine the number of samples in a study either by households or by historical weighbridge data.
   a. The “Survey on SW Composition, Characteristics & Existing Practice of SW Recycling in Malaysia” in 2014 used the number of household method to determine the number of samples for the study and as such, it will be taken as this is good approach which has been used and accepted by the Government of Malaysia. Results of this method is shown in Chapter 3, on how the samples are choses and duration of the study, which is the approach of this study.
   b. As for determination of sample by historical weighbridge data, this method has not been used as there is a lack of data. This was further elaborated in section 4.3.

2. After determining the number of samples, the quantity of samples and the frequency by which the samples must be taken, there is a need to determine on how the samples must be taken, either from random sources or from targeted sources within the boundary of the study as described in the red box in Figure 4.1.



*Green Box – Current Standard Method MS 2505: 2012
*Red Box – Proposed new methods / steps in the sampling flow
*Blue Box – Questions / Need for the improvements

Figure 4.1: Flow Chart for physical characterization based on MS 2505:2012 (Adapted from: Malaysia (2012)

3. Once the samples have been collected, there is a need to then determine if the sorting should be done on a truck load basis or any other approach which gives the most accurate results to reflect the physical composition of the waste.
4. Finally, as indicated in Figure 4.1, the sorting can be done into many components.

4.3 Analysis of Data form Weighbridge Records

For this section, the data for the weighbridge was obtained from Kuala Lumpur and Pulau Pinang, as these were the only two working weighbridges. It can be said that Kuala Lumpur and Pulau Pinang are the most populated and advanced cities in Malaysia thus can be used as an indicator to represent Malaysia waste characteristics. As pointed out, the weighbridge data can be used as the first step in knowing how much of waste is being dumped into the landfill from the collection area. This is considered by many as alternative starting point in planning for a waste characterization study. The other alternative is by using the town planning data to identify the areas and sources of waste generators, which were used to create a sampling plan.

This study gather data from Kuala Lumpur for the years 1998 to 2001 and 2007 to 2009 while as for Pulau Pinang, the data available is only for 2001. Based on these primary data, the study analyzed to see if there are any trends. The most appropriate and complete sample weighbridge data for 2001 from Kuala Lumpur is given on Table 4.1.

This table gives a very detailed account of the kind of waste coming into the landfill for every day in the whole year. However, not all records are as complete and as such, Table 4.1 can be considered as the example that should be followed by the rest of the landfills/dumpsites towards record keeping. Although, many data were collected, most of it was incomplete and in many cases in correct with a lot of missing data. Although the data is as far back as 2001, but the trends shown on Figures 4.2 to 4.4 are essential and has never been analyzed to show such rends. The results and trends can be used even to today and beyond because the collection and disposal methods in Malaysia remain the same. As such the results and trends provide relevant representation and information into the collection trends for Malaysia although the waste data is from 2001.

As Malaysia lacks the information and track record of the amount and type of waste generated, the next best thing to do is the need to know if there is a daily trend in waste collection pattern. Figure 4.2 to 4.4 gives the daily amount of domestic waste and total amount of waste disposed of at Kuala Lumpur and at Pulau Pinang. The waste disposal rate is presented on a basis for domestic waste; which indicates the amount of municipal solid waste disposed at the landfill and the total amount of waste disposed at the landfills which includes construction, industrial and other types of waste. Although the data from Table 4.1 shows many more types of waste being disposed into the landfill, but all types of waste are received daily except for domestic or municipal solid waste.

Analysis of Table 4.1 and the following Figures of 4.2 to 4.4 which are based on Table 4.1, present the following findings:-

1. It was very difficult to get any trends from the raw data in Table 4.1. However, once these data are plotted on a daily basis as in Figure 4.2, 4.3 and 4.4 there was a clear trend to indicate a weekly cycle. This can be proven by looking at the November and December 2001 graphs which shows that the weekly trend is very obvious in the KL domestic collection and the same for Pulau Pinang.
2. The category 'total amount of waste', there was no recorded cycle between both areas of collection. This can be attributed to the contribution from the other types of waste which distort the cyclic trends of domestic waste.

Table 4.1: Amount of Waste Disposed of at Taman Beringin Landfill, Kuala Lumpur in 2001 (Tons/day)

Month	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
January	Residential	1347.68	1454.85	1500.44	1626.11	1478.63	1684.85	971.7	1767.48	1754.06	1708.32	1676.68	1409.2	1566.02	941.74	1688.9	1892.02	1630.87	1615.43	1437.93	1623.91	469.48	1824.96	1971.69	1667.08	1389.13	1299.5	1406.66	880.89	1529.48	1711.84	1462.94	46390.47
	Landscape	15.88	44.03	33.75	51.93	25.55	30.02	13.84	35.91	26.84	34.45	47.14	38.87	37.1	26.58	44.39	38.04	29.75	55.19	29.72	36.55	1.24	36.32	42.67	16.65	30.78	23.8	26.9	24.47	20.28	35.62	28.26	982.52
	Industrial	16.44	13.25	28.96	19.4	21.84	32.2	17.56	21.79	20.71	20.99	20.48	23.06	21.11	8.47	36.7	19.7	29.11	19.39	104.59	35.79	8.7	24.68	19.02	12.16	2.95	12.57	14.8	1.8	36.65	49.82	53.92	768.61
	Institutional			1.29		3.72				0.41	3.39	5.31	0.48	0.66			0.17	2.31		0.49			1.99				1.21				6.33	1.13	28.89
	Commercial	162.97	263.83	250.59	310.01	222.05	254.35	196.03	251.39	246.22	274.08	255.49	296.47	289.92	209.59	317.62	280.4	348.23	297.65	329.48	334.39	212.65	245.3	275.46	211.83	167.24	180.7	208.22	163.09	229.53	331.15	284.09	7900.02
	Total	1542.97	1775.96	1815.03	2007.45	1751.79	2001.42	1199.13	2076.57	2048.24	2041.23	2005.1	1768.08	1914.81	1186.38	2087.61	2230.33	2040.27	1987.66	1902.21	2030.64	692.07	2133.25	2308.84	1907.72	1590.1	1517.78	1656.58	1070.25	1815.94	2134.76	1830.34	56070.51
February	Residential	1422.42	1262.04	1535.02	916.93	1532.12	1550.26	1270.24	1444.48	1341.56	1605.98	936.04	1677.6	1636.59	1400.85	1512.83	1254.89	1517.99	867.95	1479.53	1693.29	1476.53	1506.19	1205.88	1558.15	831.94	1616.64	1624.39	1429.67				39108
	Landscape	23.54	28.52	26.42	11.49	33.3	35.62	22.84	39.26	48.27	55.99	45.89	52.31	35.65	49.47	50	52.79	56.3	28.96	26.61	63.53	70.58	52.42	50.97	59.91	20.05	52.1	70.07	65.58				1228.44
	Industrial	33.38	45.71	26.96	8.36	30.95	40.53	18.67	19.94	129.61	34.07	6.03	48.66	32.57	41.47	71.28	32.52	34.57	14	29.11	32.08	42.99	44.33	27.98	24.75	8.59	34.05	29.61	26.83				969.6
	Institutional	0.73			0.8		0.22			1.52		1.04		2.35	0.38	0.42				0.75	1.54	0.53	0.27		1.48		0.51	1.55	1.07				15.16
	Commercial	265.1	224.56	239.9	179.74	220.87	261.88	220.88	273.41	231.25	254.99	169.46	212.49	234.59	261.03	287.46	266.49	265.62	142.69	213.97	274.98	223.96	230.5	252.89	250.67	185.5	187.81	272.21	250.49				6555.39
	Total	1745.17	1560.83	1828.3	1117.32	1817.24	1888.51	1532.63	1777.09	1752.21	1951.03	1158.46	1991.06	1941.75	1753.2	1921.99	1606.69	1874.48	1053.6	1749.97	2065.42	1814.59	1833.71	1537.72	1894.96	1046.08	1891.11	1997.83	1773.64	0	0	0	47876.59
March	Residential	1550.91	1204.74	1529.26	1040	1697.14	826.81	1388.7	1694.34	1300.56	1647.31	907.92	1656.04	1532.8	1540.88	1557.44	1250.3	1587.15	853.23	1655.2	1595.61	1539.86	1501.77	1227.73	1517.27	922.16	1457.56	1505.36	1557.53	1494.88	1213.23	1418.29	43371.98
	Landscape	44.05	31.27	48.98	24.59	33.86	3.43	22.55	31.33	38.94	36.59	13.98	27.77	52.32	53.5	56.92	35.07	62.01	27.47	38.99	48.7	47.57	88.36	51.29	53.06	21.29	25.97	45.87	49.58	56.4	35.12	57.17	1264
	Industrial	19.51	26.08	30.16	13.99	18.25	13.66	23.51	37.94	15.57	28.89	5.37	39.15	20.66	18.76	35.43	35.13	26.7	13.23	115.7	33.21	103.56	32.64	26.86	42.32	15.55	26.29	41.09	41.16	29.63	29.96	44.97	1004.93
	Institutional		2.05	0.4				10.39	7.16	1.03		1.29	0.41	8.94	2.12	5.54	3.61			0.85	0.91		7.27		2.91		1.59	0.6	6.55	4.22	4.2	3.55	75.59
	Commercial	255.89	256.5	217.43	126.79	222.08	113.12	174.5	212.41	220.77	211.33	130.03	239.66	215.32	242.02	226.7	246.03	229.45	172.07	243.32	270.56	228.33	254.66	259.65	256.7	176.62	192.97	252.94	250.9	231.09	274.64	235.79	6840.27
	Total	1870.36	1520.64	1826.23	1205.37	1971.33	957.02	1619.65	1983.18	1576.87	1924.12	1058.59	1963.03	1830.04	1857.28	1882.03	1570.14	1905.31	1066	2054.06	1948.99	1919.32	1884.7	1565.53	1872.26	1135.62	1704.38	1845.86	1905.72	1816.22	1557.15	1759.77	52556.77
April	Residential	939.52	1617.79	1740.8	1575.82	1586.08	1262.06	1610.35	911.34	1673.91	1707.64	1611.06	1629.82	1221.96	1506.22	922.68	1749.47	1704.74	1554.21	1499.81	1201.76	1551.18	944.12	1740.91	1743.44	1456.4	1417.59	1333.22	1527.97	861.13	1721.71		43524.71
	Landscape	35.63	46.26	48.35	56.23	57.61	40.8	41.85	27.14	72.17	79.71	74.05	47.22	50.47	56.58	36.31	53.91	73.26	51.12	47.51	50.92	60.46	41.97	69.82	75.71	72.1	60.84	54.24	65.55	30.7	61.34		1639.83
	Industrial	21.25	26.18	29.11	40.54	40.13	22.5	32.82	10.98	33.95	33.8	25.37	47.83	33.94	30.65	20.21	37.56	36.03	34.86	45.81	36.23	62.06	26.2	34.24	41.82	98.19	82.6	26.91	32.45	25.34	38.91		1108.47
	Institutional		0.85	1.81	3.98	1.91	4.93	1.7		3.99	0.83			0.51			1.47	2.16	0.81	0.88	0.94			1.65	1.16	0.75		0.95			1.4		32.68
	Commercial	166.9	286.74	265.45	294.11	278.6	283.63	263.93	158.79	267.14	316.97	266.44	318.16	242.76	267.76	210.52	267.54	216.93	239.02	310.12	242.32	296.7	178.28	269.48	225.01	251.42	292.4	267.22	255.26	194.48	251.77		7645.85
	Total	1163.3	1977.82	2085.52	1970.68	1964.33	1613.92	1950.65	1108.25	2051.16	2138.95	1976.92	2043.03	1549.64	1861.21	1189.72	2109.95	2033.12	1880.02	1904.13	1532.17	1970.4	1190.57	2116.1	2087.14	1878.86	1853.43	1682.54	1881.23	1111.65	2075.13	0	53951.54
May	Residential	1285.22	1562	1528.67	1259.15	1406.27	886.16	1564.15	1589.79	1473.2	1438.36	1227.74	1456.95	976.21	1657.47	1623.65	1508.76	1496.48	1221.55	1535.97	912.86	1535.73	1621.06	1440.12	1502.76	1258.5	1399.79	766.19	1628	1582.69	1510.73	1518.94	43375.12
	Landscape	51.18	42.5	50.81	35.85	74.72	16.79	35.56	51.63	38.22	48.9	44.71	37.46	24.47	60.27	51.55	39.45	57.29	52.94	55.56	18.19	57.73	53.03	45.7	41.8	53.11	56.67	23.28	43.91	57.89	61.75	43.86	1426.78
	Industrial	23.27	34.23	32.46	24.14	25.67	15.73	16.87	28.42	30.51	23.05	23.17	25.38	12.94	24.48	31.9	26.9	47.54	21.1	30.46	2.7	31.43	23.79	30.14	74.5	30.85	21.3	12.75	19.2	23.66	25.4	30.57	824.51
	Institutional			1.08					1.11	0.75	4.65	3.53	0.35		2.59	2.24	6.16		0.46			0.94		5.43	0.47						4.94	0.42	35.12
	Commercial	153.39	255.35	233.48	215.65	224.25	127.7	194.33	256.59	216.14	228.56	268.05	236.68	153.07	246.93	231.11	204.49	236.81	209.33	209.87	133.83	208.74	213.45	194.62	204.64	206.35	223.6	112.64	182.14	235.43	200.52	195.79	6413.53
	Total	1513.06	1894.08	1846.5	1534.79	1730.91	1046.38	1810.91	1927.54	1758.82	1743.52	1567.2	1756.82	1166.69	1991.74	1940.45	1785.76	1838.12	1505.38	1831.86	1067.58	1834.57	1911.33	1716.01	1824.17	1548.81	1701.36	914.86	1873.25	1899.67	1803.34	1789.58	52075.06
June	Residential	1269.57	1413.93	823.85	1461.2	1593.49	1422.5	1552.03	1340.1	1589.92	853.15	1690.97	1625.71	1446.5	1396.68	1080.14	1224.74	835.32	1534.64	1553.64	1513.37	1493.34	1239.47	1471.87	833.67	1560.35	1688.11	1403.11	1524.13	1215.1	1433.98		41084.58
	Landscape	44.4	32.23	30.04	18.7	47.33	44.66	61.99	43.42	52.53	27.35	33.93	48.61	55.22	48.38	41.11	44.57	10.84	14.47	43.32	49.33	48.51	60.99	68.52	11.16	43.43	61.65	64.48	72.07	63.54	62.2		1348.98
	Industrial	20.38	18.67	26.62	40.71	30.69	43.5	20.64	18.03	28.82	1.75	37.65	28.7	35.73	36.41	30.19	20.64	14.33	28.2	27.88	27.57	13.44	27.18	13.72	1.45	19.84	78.55	24	19.31	27.26	14.92		776.78
	Institutional	0.72			6.83	2.16	0.28		1.32					0.52		1.9			9.51	5.4	4.54	1.77	4.02	0.44			0.48	1.38	0.64	2.2	1.05		45.16
	Commercial	208.63	123.83	116.92	144.67	178.64	216.92	201.27	210.1	168.15	115.76	192.89	203.13	205.3	199.46	189.51	192.67	112.34	197.84	181.9	223.77	213.5	188.43	209.79	127.59	180.9	249.26	242.85	225.04	205.62	194.89		5621.57
	Total	1543.7	1588.66	997.43	1672.11	1852.31	1727.86	1835.93	1612.97	1839.42	998.01	1955.44	1906.15	1743.27	1680.93	1342.85	1482.62	972.83	1784.66	1812.14	1818.58	1770.56	1520.09	1764.34	973.87	1804.52	2078.05	1735.82	1841.19	1513.72	1707.04	0	48877.07
July	Residential	724.53	1639.81	1582.56	1428.47	1416.45	1132.46	1374.41	833.19	1455.33	1500.67	1451.44	1386.8	1197.01	1456.14	946.95	1624.01	1541.72	1501.12	1534.61	1309.63	1514.51	794.34	1665.32	1674.24	1519.5	1532.55	1299.35	1613	952.2	1546.31	1620.31	42768.94
	Landscape	10.46	37.52	43.77	48.55	38.3	29.5	53.03	26.35	52.37	53.46	44.17	45.23	37.86	55.25	50.95	48.74	27.67	47.22	47.8	38.79	46.29	21.27	41.48	51.81	64.34	67.43	51.62	95.51	57.38	54.98	47.17	1436.27
	Industrial	5.02	14.2	15.26	31.34	12.56	19.32	23.51	1.97	21.16	25.06	15.15	19.59	16.06	19.08	8.46	22.56	26.07	50.84	21.65	21.31	25.54		17.96	16.15	61.09	11.61	31.16	17.12	2.43	12.5	18.62	604.35
	Institutional		3.98	1.04	2.35	1.14				0.32		0.45	0.78				5.9	9.31	1.6	0.5	3.28		130.4			0.52	4.01	3.42	5.11	3.14	2.3	3.66	183.21
	Commercial	118.64	190.83	230.02	211.44	231.96	206.07	200.27	136.37	182.89	200.55	209.76	195.22	181.34	190.16	121.49	191.76	200.46	216.23	208.92	186.42	186.14		193.74	215.31	222.83	203.35	186.58	251.08	129.63	199.43	234.04	5832.93
	Total	858.65	1886.34	1872.65	1722.15	1700.41	1387.35	1651.22	997.88	1712.07	1779.74	1720.97	1647.62	1432.27	1720.63	1127.85	1892.97	1805.23	1817.01	1813.48	1559.43	1772.48	946.01	1918.5	1957.51	1868.28	1818.95	1572.13	1981.82	1144.78	1815.52	1923.8	50825.7
August	Residential	1666.41	1708.98	1526.62	1776.85	887.44	2051.04	1876.16	1850.44	1785.17	1584.85	1800	987.46	1982.95	1827.04	1782.54	1853.74	1576.61	1700.2	939.85	2006.74	1914.63	1747.93	1789.77	1537.44	1799.45	951.37	2052.13	1963.89	1710.89	1762.06	1307.36	51708.01
	Landscape	41.88	41.74	71.6	65.52	24.31	45.01	73.57	49.11	70.02	49.68	44.23	24.6	38.99	38.08	46.54	47.12	54.75	36.07	52.06	41.01	45.53	50.03	67.11	45.94	39.22	25.66	49.43	58.1	53.8	56.05	10.47	1457.23
	Industrial	34.87	98.95	71.41	33.53	4	37.97	38.29	18.88	17.29	44.11	31.52	9.5	34.74	26.43	83.68	22.29	17.39	24.94	4.75	29.05	34.4	59.18	23.41	13.42	20.34	16.95	29.39	99.63	37.21	25.95	3.09	1046.56
	Institutional			6.07			5.78	9.49	0.27	4.13							0.82			1.92	4.44	2.74		0.53			3.17	4.11				4.71	48.18
	Commercial	215.35	219.77	176.53	175.62	120.11	222.4	194.72	195.54	197.36	187.45	231.01	135.4	218.01	200.6	217.96	188.96	201.81	170.3	132.97	187.95	201.94	190.04	205.24	176.43	185.25	103.36	170.59	196.46	165.9	171.62	118.68	5675.33
	Total	1958.51	2069.44	1852.23	2051.52	1035.86	2362.2	2192.23	2114.24	2073.97	1866.09	2106.76	1156.96	2274.69	2092.15	2130.72	2112.93	1850.56	1931.51	1131.55	2269.19	2199.24	2047.18	2086.06	1773.23	2044.26	1100.51	2305.65	2318.08	1967.8	2015.68	1444.31	59935.31
September	Residential	1614.83	814.02	2019.37	2010.75	1748.18	1881.04	1559.78	1906.47	873.68	1908.9	1946.3	1682.44	1751.46	1562.97	1777.7	844.13	1946.43	1950.97	1793.49	1653.63	1430.25	1716.56	848.5	1932.15	1926.59	1717.15	1672.09	1474.89	1750.97	861.25		48576.94
	Landscape	23.05	14.89	50.01	37.78	49.53	73.1	30.49	56.42	23.21	38.87	48.11	32.43	51.32	52.08	37.47	26.24	60.07	38.62	45.88	29.82	37.53	30.68	24.68	45.01	66.59	29.86	37.5	27.87	55.82	19.22		1194.15
	Industrial	20.8	13.88	20.92	39.48	25.71	35.32	28.64	28.04		29.23	23.71	22.88	29.46	17.81	32.91	3.19	24.16	28.61	98.61	71.1	62.98	34.87	3.67	26.97	95.57	28.07	28.68	33.25	22.93			931.45
	Institutional		1.21	6.13	4.61				0.46	103.11	4.88	10.22						4.89	2	0.59	0.44	2.72		5.06	5.49	6.16							157.97
	Commercial	160.61	127.44	140.85	188.99	188.35	158.83	168.91	168.5		157.15	163.69	158.52	168.86	158.02	180.59	75.7	153.99	158.8	156.89	198.05	171.28	138.89	84.11	175.13	167.77	181.45	187.27	179.19	204.5	140.44		4662.77
	Total	1819.29	971.44	2237.28	2281.61	2011.77	2148.29	1787.82	2159.89	1000	2139.03	2192.03	1896.27	2001.1	1790.88	2028.67	949.26	2189.54	2179	2095.46	1953.04	1704.76	1921	966.02	2184.75	2262.68	1956.53	1925.54	1715.2	2034.22	1020.91	0	55523.28
Oct	Residential	2062.12	1913.46	1806.85	1781.47	1470.9	1628.3	873.35	2092.17	1940.71	1712.36	1738.6	1458.91	1742.28	826.72	1972.84	1877.3	1780.59	1833.06	1525.47	1718.15	826.5	2065.19	1925.5	1857.27	1738.43	1567.32	1789.98	877.07	1981.39	1997.98	1732.47	52114.71
	Landscape	47.64	29.66	42.16	51.03	28.97	31.18	24.96	48.78	44.85	43.19	37.14	28.37	29.79	21.21	33.55	39.58	40.45	37.45	33.73	47.83	9.02	42.66	29.05	37.11	28.58	48.29	52.32	26.98	43.09	28.51	26.69	1113.82
	Industrial	34.67	31.4	28.7	37.72	14.51	30.26		34.03	27.18	34.44	44.38	35.56	30.33	4.96	24.64	31.25	46.68	19.41	21.44		9.33	24.11	29.98	43.04	21.35	20.35	32.71	5.6	35.9	42.49	37.02	833.44
	Institutional	4.72	4.56	1.94	4.8				1.85	6.47								2.64			2.49		4.39	3.51	5.76	1.04					3.15		47.32
	Commercial	167.35	154.43	194.77	208.98	193.68	174.17	97.56	188.42	171.97	177.3	185	171.77	164.27	87.45	194.06	181.38	161.43	195.55	143.64	186.68	91.71	160.44	162.9	166.44	167.46	163.37	147.85	109.41	143.78	215.18	186.52	5114.92
	Total	2316.5	2133.51	2074.42	2084	1708.06	1863.91	995.87	2365.25	2191.18	1967.29	2005.12	1694.61	1966.67	940.34	2225.09	2129.51	2031.79	2085.47	1724.28	1955.15	936.56	2296.79	2150.94	2109.62	1956.86	1799.33	2022.86	1019.06	2204.16	2287.31	1982.7	59224.21
Nov	Residential	1925.34	1613.86	1940.3	821.06	2075.15	1982.3	1729.15	1742.24	1559.78	1891.88	995.41	2015.14	1880.17	1383.56	1610.66	1518.13	1570.99	928.04	2011.59	1939.96	1886.42	1692.49	1481.53	1965.81	1007.78	2008.45	1784.12	1644.22	1751.43	1338.23		49695.19
	Landscape	35.9	28.16	35.02	5.24	32.67	28.65	23.39	24.43	25.25	25.02	26.48	28.34	30.03	9.68	46.04	39.43	13.92	8.92	28.36	34.25	28.73	19.73	25.71	36.7	11.87	23.1	27.63	31.25	29.3	25.17		788.37
	Industrial	37.45	23.26	24.23	29.38	29.78	28.64	26.25	23.43	26.31	31.51	6.74	27.8	28.5	9.24	71.62	25.73	24.73	16.06	21.98	37.73	118.16	25.39	31.37	24.35		26.38	34.97	31.66	19.41	28.96		891.02
	Institutional						4.96		0.83					0.29		6.14	3.37								1.01								16.6
	Commercial	174.34	163.75	190.08	100.56	172.96	138.78	152.22	187.86	155.38	169.23	132.65	137.6	169.02	126.49	169.72	181.97	159.39	126.67	185.62	179.22	196.17	131.69	135.18	177.42	110.15	154.82	187.29	178.09	173.95	179.37		4797.64
	Total	2173.03	1829.03	2189.63	956.24	2310.56	2183.33	1931.01	1978.79	1766.72	2117.64	1161.28	2208.88	2108.01	1528.97	1904.18	1768.63	1769.03	1079.69	2247.55	2191.16	2229.48	1869.3	1673.79	2205.29	1129.8	2212.75	2034.01	1885.22	1974.09	1571.73	0	56188.82
Dec	Residential	1540.97	960.93	1850.67	1785.48	1555.97	1378.76	1248.68	1308.62	993.43	1617.92	1452.92	1513.43	1037.4	1359.85	1642.99	1003.28	1337.68	1439.93	1033.8	1111.84	1027.16	1158.21	1002.51	1936.11	1973.79	1871.86	1919.68	1683.34	1937.61	979.53	1971.88	44636.23
	Landscape	30.3	12.92	24.15	25.7	35.41	35.49	27.14	33.15	19.24	26.84	21.53	28.66	33.39	31.69	15.3	0.3	13.01	18.87	32.73	19.29	24.97	12.76	7.38	46.73	18.29	40.43	29.49	16.81	23.32	15.16	42.25	762.7
	Industrial	31.51	9.77	61.19	39.8	27.04	32.07	30.18	26.53	4.41	37.87	35.32	33.36	17.8	88.2	28.92	4.6	9	23.62	22.67	36.63	39.2	31.89	12.11	35.03	28.96	22.18	40.63	30.01	35.23	15.58	35.36	926.67
	Institutional	2.31				3.91																	3.01		4.1		3.55	2.41				9.61	28.9
	Commercial	162.3	108.57	179.43	137.33	190.5	158.95	155.75	179.74	110.88	190.63	168.18	183.4	149.24	193.91	205.3	61.84	91.23	98.57	88.24	123.45	148.17	136.93	89.65	161.99	140.7	165.49	185.81	143.77	188.93	94.27	152.31	4545.46
	Total	1767.39	1092.19	2115.44	1988.31	1812.83	1605.27	1461.75	1548.04	1127.96	1873.26	1677.95	1758.85	1237.83	1673.65	1892.51	1070.02	1450.92	1580.99	1177.44	1291.21	1239.5	1342.8	1111.65	2183.96	2161.74	2103.51	2178.02	1873.93	2185.09	1104.54	2211.41	50899.96

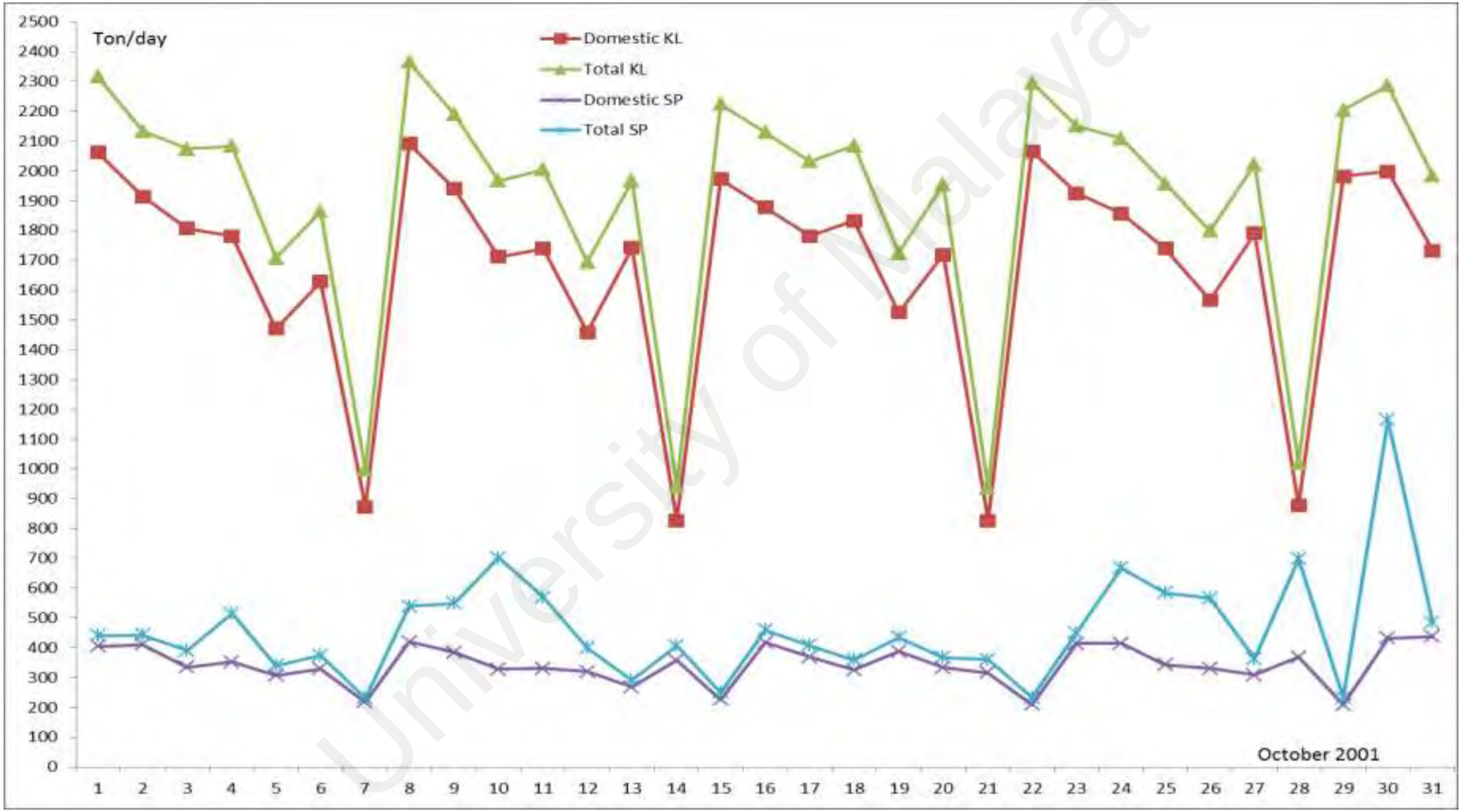


Figure 4.2: Trends in amount of waste collected in Kuala Lumpur and Pulau Pinang for the month of October 2001

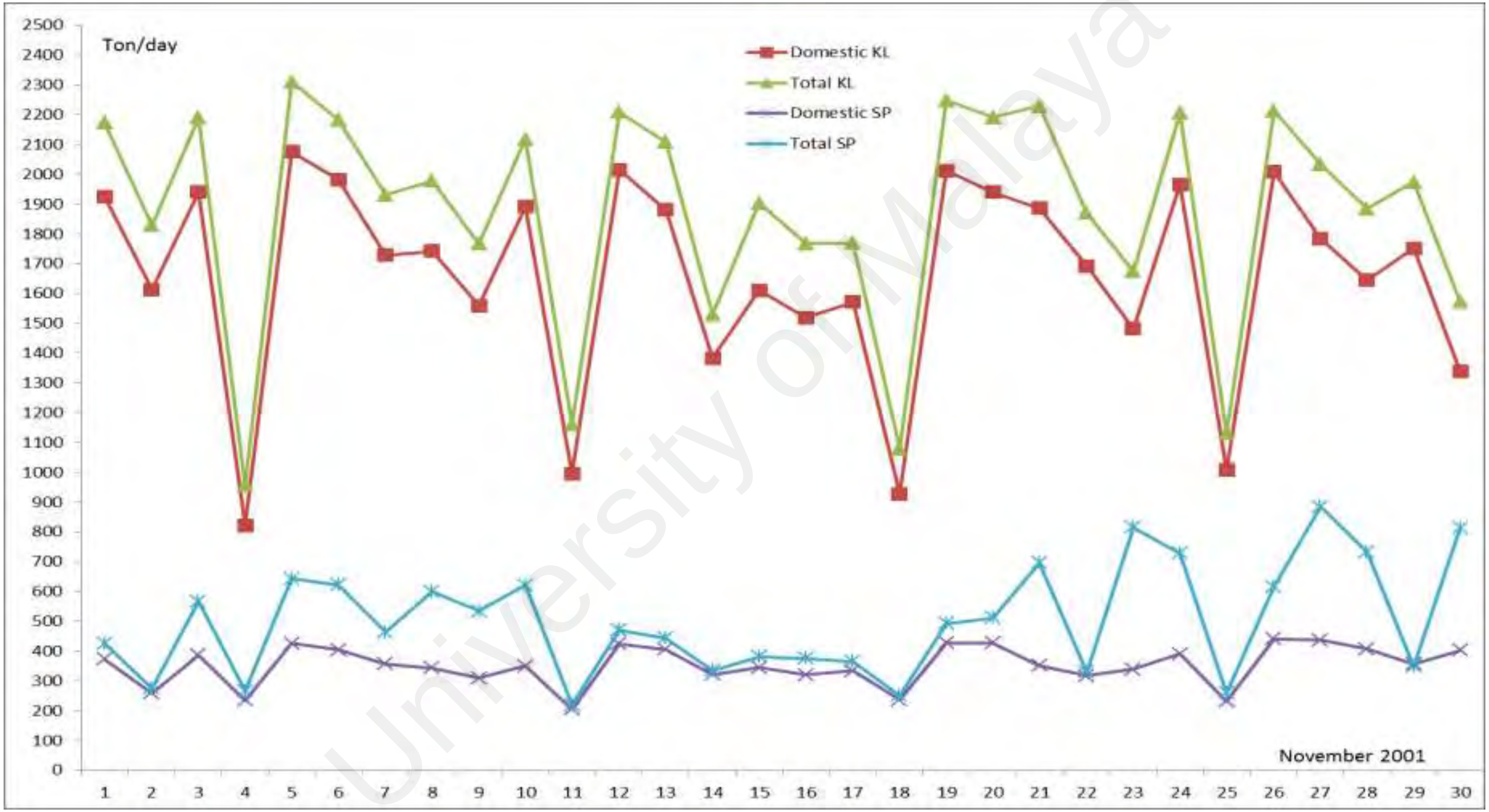


Figure 4.3: Trends in amount of waste collected in Kuala Lumpur and Pulau Pinang for the month of November 2001

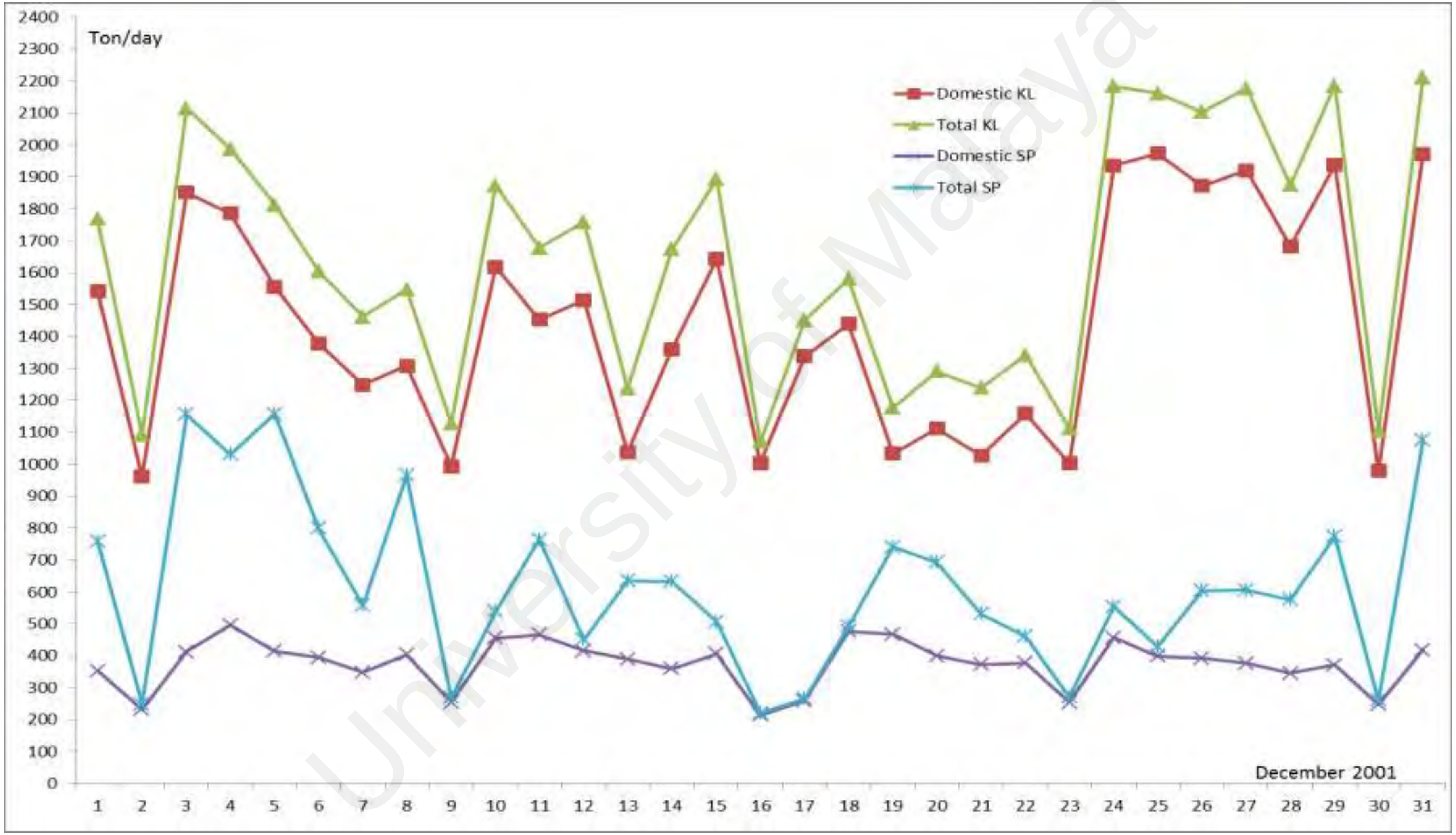


Figure 4.4: Trends in amount of waste collected in Kuala Lumpur and Pulau Pinang for the month of December 2001

3. In the months of October and November the weekly cycle for Pulau Pinang is less clear but in December, for the first 3 weeks it is clear and in the last week it becomes distorted again. However, in Kuala Lumpur the last week of December shows a huge hike in waste disposed at the landfill. This distortion in the cyclic collection behavior was directly associated to the various festivals, namely Deepavali and Christmas, in which the population in these major towns go back to their home towns or go on holidays.
4. The disposal trend of weekly cycle can be observed to have a peak on Monday, while reducing along the week day and then taking another peak on Saturday and finally have the lowest amount disposed on any Sunday.

Based on the above findings, the amount of waste disposed and the trends in disposal at the landfill which will ultimate affect the planning of characterization study are:-

1. From the study, there is surely a patent in the amount of waste disposed into the landfill on a weekly basis. This is an important point to consider during the planning stages of the characterization study. More importantly, there is also a disruption in the cycle during major holidays, as seen in December for Christmas. This shows that, carrying out sampling during these festive seasons should be avoided so as not to skew the trends in the waste composition, unless the study was specifically targeting festive type of waste
2. However, this is only a weekly trend, is there a monthly trend or even a yearly trend?. This needs to be investigated. Referring back to the National Waste Characterization study done in 2012 to 2014, there was no such analysis done prior to planning the waste study. Although the study did carry our sampling on a weekly basis, but this are just a coincidental fact and not a planned situation.
3. This is only the amount of waste disposed of to the landfill. There is no indication that this is the same trend form the generation. However, it is safe to

infer that the same is happening as the contribution by other waste is minimal as and follows the same trend as the amount of domestic waste disposed. This is only for Kuala Lumpur, an urban area. Once we have a look at Pulau Pinang which is more a sub urban area, the impact from the other types of waste (construction, garden, small industries, commercial) does change the weekly trend lines. However, due to lack of data, these findings cannot be proven for other states in Malaysia.

4. Unfortunately, the data available to further support the above findings are very scarce and in the authorities hands, who have not been forth coming in sharing data. It will be good to have a more complete data over a longer time scale to compare and predict trends.

Moving forward, apart from analyzing the waste disposal data on a daily and weekly basis as done above, this data can also be analyzed on a monthly and yearly basis. The data from Pulau Pinang cannot be used in this section as it only was available for 2001 and that too was not complete. As for Kuala Lumpur, there was available data for amount of waste disposed, from a domestic source and on a total waste disposed basis. Results from the previous paragraphs, there is no trends from the total amount of waste disposed to the landfill as the amount of waste from these sources are sporadic and inconsistent. As such Figure 4.5 and 4.6 will only look at amount of domestic waste which is Municipal Solid Waste which has been disposed in the Kuala Lumpur landfill in year 2001. Table 4.2 below shows the amount of municipal solid waste disposed of at the landfill serving KL on a yearly basis with the minimum, average and maximum amount being shown.

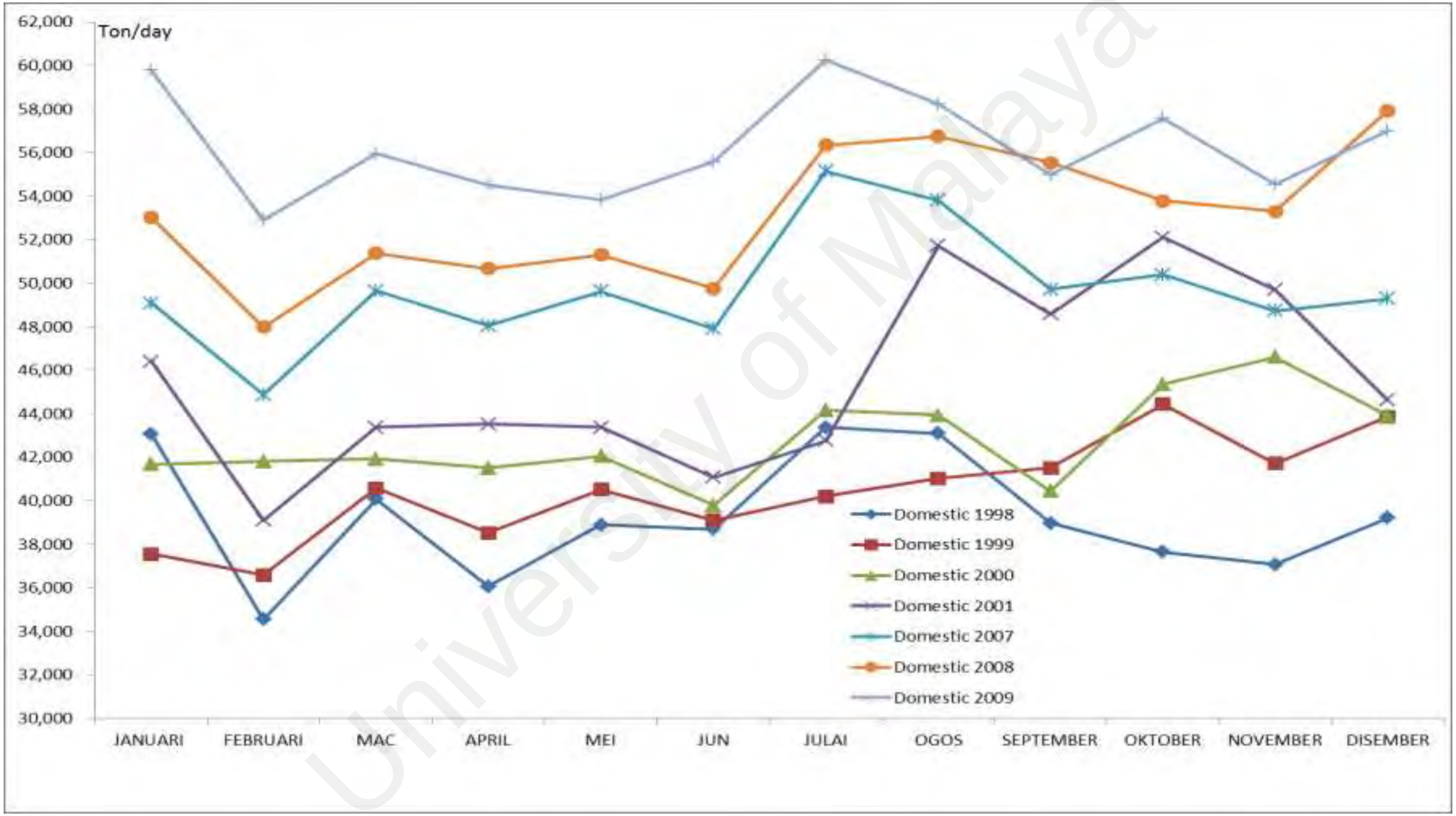


Figure 4.5: Trends in amount of municipal solid waste disposed of for Kuala Lumpur from 1999 to 2009

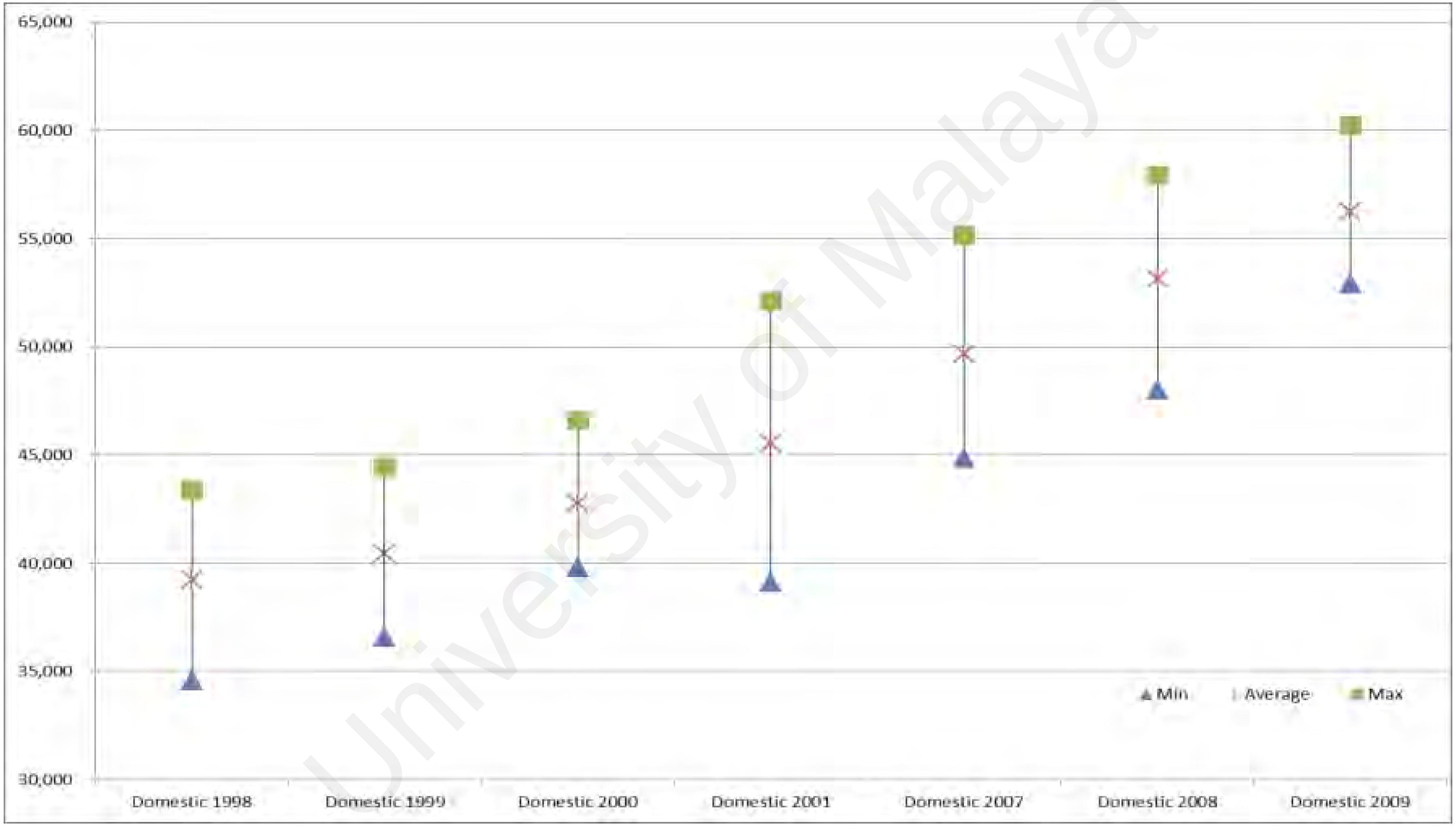


Figure 4.6: Minimum, Average and Maximum amount of municipal solid waste disposed of for Kuala Lumpur from 1999 to 2009

Table 4.2: Amount of municipal solid waste received at the Kuala Lumpur landfill

Tonns/year	Domestic 1998	Domestic 1999	Domestic 2000	Domestic 2001	Domestic 2007	Domestic 2008	Domestic 2009
Min	34,551	36,591	39,803	39,108	44,871	47,992	52,903
Average	39,230	40,469	42,764	45,530	49,688	53,150	56,260
Max	43,382	44,438	46,608	52,115	55,152	57,931	60,240
Percentage Difference		Domestic 1999	Domestic 2000	Domestic 2001	Domestic 2007	Domestic 2008	Domestic 2009
Min		5.58	8.07	(1.78)	12.84	6.50	9.28
Average		3.06	5.37	6.07	8.37	6.51	5.53
Max		2.38	4.66	10.57	5.51	4.80	3.83

From Figure 4.5 and 4.6 it could be analyzed that the minimum amount of waste received by the landfill in Taman Beringin was about 1000 tons per day and the maximum amount is about 2200 tons a day. From Table 4.2 above, there is an increase of about 3 to 8% in the annual waste disposed but it is also good to note that from year 2001 to 2007 the increase was only 8%, which averages to only about 1.2% per year. This is a very low figure, taking into account that on average the year to year growth is about 3 to 6%. Initial findings indicate that this could be due to diversion to other landfills or there was a drop in the average amount between 2002 and 2006. This will not be able to be verified as data is not available. Another finding is the minimum amount in 2001 dropped as compared to the previous year but the overall average increased the most among the three years ranging from 1999 to 2001, while the max too had overshot the norm by about 5%. The year 2001 did show a big change but there are no trends to show for 2002 to 2006.

The findings from Table 4.2, when translated to Figure 4.5 and 4.6, we find there is a huge increase in the waste amount disposed of at the landfill towards the last 5 months of the year 2001. Coincidently, the Southeast Asia Games (SEA Games) was held in Kuala Lumpur in September 2001. This could have contributed to the huge spike in the graph. However, it is also good to note the patent is still the same with the other years. Based on the results from Figure 4.5 it shows that the except for 1999, almost all other years have a peek in January, July and December, where as in the months of March to

June the disposal rates are almost constant. This is an important observation as this will indicate when a sampling plan should kick start and what the months that need more attention are. These findings cannot be done by using a simple town plan to establish a waste characterization sampling plan being the other alternative when weighbridge data is not available.

Findings on the overall monthly and yearly trends can be as follows:-

1. There is a clear need to know and understand the waste disposal patent as it does show that there are months where the waste disposal rate is high and months which shows constant disposal rates. These need to be identified when planning for a waste characterization study. Most studies do not do this because of the lack of historical data. Historically accurate and informative data is scarce in developing countries, which makes the planning for the sampling area impossible, thus making the results from the study questionable and finally leading to a wrong waste management decision. This ultimately sends the whole system back into the oldest and cheapest way of managing waste; i.e. by just dumping into open landfills.
2. In most years the waste amount does increase but there can be years where the waste amount can become a negative. This will affect the future predictions which have been made. The current yearly trend for Kuala Lumpur, an urban city in Malaysia has on average an annual waste disposal rate of about 3 to 6 percent, but it is also good to note that between the year 2002 and 2007 the amount only increases by 8 percent. There could have been a sharp increase or a drop-in disposal rate. This goes to show clearly the straight-line graph approach adopted in predicting the waste amount by linking to the predictive population increase as in Table 2.5 cannot be adopted. Most waste generation rates for a country or any locality is predicted by assuming the population increase on an

annual basis is the factor which will indicate the amount by which the waste generated will increase. However, Table 4.2 and Figure 4.5 and 4.6 clearly show that the figure can change and can vary from 3 to 6% on any given year.

3. The findings are only for one urban area which is also the capital city, this trend need to the rechecked with data from other state capitals, sub urban areas and rural areas, which could give very different indications.

This goes to show, the initial part of collecting historical data, and looking at the trends is very important in planning a sampling program. In this case, the National waste characterization study did not approach their study in this manner, which could have changed their approach in conducting the study. Another fact is that, the need to upkeep these data is very important. Currently, data is not recorded properly, and even when recorded the information, indicating from where the waste was collected, and type of waste is often not correct. Furthermore, almost all weighbridges being used to weigh these trucks are in a deplorable state which needs maintenance and have not been calibrated since they were installed.

All of the above makes this data very questionable thus giving the waste characterization sampling planning a very false start; to even begin with. In making a waste management decision, the sampling plan is to give a picture of the problem, but if the sampling plan is not started on an accurate basis, the management solution is completely wrong. Interestingly, the above data compilation can be done on a national, state, district, municipal or even project catchment basis. However, only if there are good comprehensive data at all levels can the sampling be planned properly.

4.4 Target Sampling Vs Random Sampling

Over the period of this candidature, many studies have been conducted and sampling carried out on an As Generated, As Discarded and As Disposed basis and these experiences during sampling on a target basis or random basis have been put into Table

4.3. The findings put into Table 4.3 are based on hands on working on the round in obtaining the samples from the various sources that generate waste. In putting together these findings the candidate putting forward the best options that would best fit the sampling plan for the purpose set out. It must be noted that in any sampling plan there will be times when the planed number of samples cannot and will not be able to be achieved for various reasons. In such situations, a variation in the sampling plan must be allowed to ensure the numbers of samples are achieved. This variation allowance should not be used as an excuse to deviate from the initial sampling plan.

Based on the experience put out in Table 4.3, the discussion in this section will focus on the sampling plan flow chart as pictured in Figure 4.1 which is based on the MS 2505: 2012. This document does not specify on when to do random and when to do target sampling, however based on the experienced findings on Table 4.3, it is obvious that the sampling must be planned accordingly, failing which, the sampling plan might not achieve the desired outcome. Although there are no hard data to back up the experience posted in Table 4.3, this can be taken as good practice guidance for future waste sampling plans. Even when compared to waste characterization methods as prescribed in other countries, there is no good practice guidance. As waste characterization is very tedious and requires hard work while it needs a huge budget and workforce to implement, based on results from this study, it is essential to have these best practice recommendations which will help make this work easier and more accurate.

Table 4.3: Observations for carrying out Targeted Vs Random sampling

As Generated	As Discarded	As Disposed
• Most of the time premise or household-based target sampling • Targeted sampling where premise / household are predetermined. • When predetermining the sample numbers, allow for 10% extra samples, which will compensate for houses with no occupants, and some households who do not allow for samples to be taken from their households. The 10% extra sampling can be done on any random household or premise • All households must be given sample bags for the number of days that the household will be monitored. • Collection of samples must be done on the same basis as normal collection by the sampling team truck. • Arrangements must be made so that the normal service trucks do not collect from the households which are within the sampling plan	• Most of the time premise or household-based target sampling • Targeted household is predetermined and must be the same as the As Generated target sample to ensure that the amount of waste retained can be determined. Of course, the sampling time frame will vary. • When predetermining the sample numbers, allow for 10% extra samples, which will compensate for houses with no occupants, and some households who do not allow for samples to be taken from their households. The 10% extra sampling can be done on any random household or premise • All households must be given sample bags for the number of days that the household will be monitored. • Collection of samples must be done on the same basis as normal collection by the sampling team truck. • Arrangements must be made so that the normal service trucks do not collect from the households which are within the sampling plan	<u>Policy Planning Purpose</u> • Planning for a policy matters or for determination of how much of waste is disposed from study area follow targeted sampling as described in As Generated or As Discarded • In this case, the service truck which is collecting within the area of the study needs to be identified. This truck will be targeted for sorting at the end of its collection day. <u>Waste Treatment Facility Planning Purpose</u> • For this purpose, usually the sampling is based on the trucks servicing the boundary area. • These trucks are randomly selected to achieve the predetermined quantity of waste that needs to be sorted to provide the necessary composition of the area in study • Usually random samples are easily obtained and do not need extra samples to be collected. • However, random samples have to be evenly collected over the period of time the trucks run their service. In most cases, the random samples will only be collected in the morning to achieve the predetermined quantity while disregarding the trucks that are in service in the evening.

4.5 Sampling and Sorting Method Once the samples have been identified, the question now is should the full 'truck load' of waste be sorted into its components or should it been 'Cone and Quartered' or can the sorting be done by just taking a few 'spot sampling' be taken from the back of the truck or due to cleanness and contamination of samples reasons a 'Laboratory Sampling' be taken and the sorting be done in the laboratory. This section will show data while analysis of these data and findings will be presented accordingly.

As described in Section 2.7, sorting can be done in 4 ways, which are as follows:-

1. 'Truck Load Method', where the whole contents of an identified truckload were sorted.
2. 'Cone and Quartering Method', where the contents of an identified truckload are unloaded on to a clean area, subsequently cone and quartered until a manageable amount of waste is achieved (about 200 kg) for sorting.
3. 'Spot Sampling Method', where an amount of waste (about 30–50 kg) is taken from a few truck (about 8-10 trucks) to form a sample size of about 200 kg which is then sorted.
4. 'Laboratory Sampling Method', where the contents of a truck are unloaded, quartered and reduced until a 20 kg sample is achieved, which is parceled for laboratory sorting.

During the "Survey on SW Composition, Characteristics & Existing Practice of SW Recycling in Malaysia" in 2014 for the National Solid Waste Department, a side study was carried out to clarify the above procedures. The aim of this side study was to determine if the same 'Truck Load' were to be subjected to all the 4 ways of sorting which would give the most reliable and accurate data, which than can be adopted as the way forward for Malaysia considering the heterogeneity of the waste that is generated daily. Based on this 3 'truck load' was identified, and sorted as follows:-

1. The waste from the truck was unloaded on to a clean floor. This was identified as the full truck load that will be sorted.
2. At the same time, this same truck load of waste was mixed thoroughly; Cone and Quartered to form a smaller sample about 200 kg in size.
3. From the various Quarters, a spot sample of about 20 to 30 kg was taken to form the 'Spot sampling' size of 200 kg too.
4. Finally, before all the 'Cone and Quartering' was done a small sample size of 20 kg was set aside and packed to be sent to the Laboratory for sorting in the laboratory environment.

Based on the above, the findings from the sorting process are as follows:

I. Truck Load – 4 to 5 tons of heterogeneous waste to be sorted

   a. Manpower requirement was very large with anywhere between 15 to 20 people needed to finish the full 4 to 5 tons of sample. Manpower to do such work is hard to come by and also costly. Another point is that after 5 hours of working under the sun, the accuracy and efficiency of the sorting reduced very much, with most of the workers concentrating only on macro sorting. Most contents in plastic bags were sorted based on visual inspection on the majority waste component within the bag and not opened to be sorted accordingly. As the odor is strong, long hours exposure to this waste material will reduce concentration and focus.

   b. Time needed was too long, where total sorting of the waste took anywhere between 12 to 14 hours. In addition to that, due to long hours, the problem of flies and wind blowing off some of the samples became a problem. In cases when the weather was too hot the sample started to dry up while sorting, which could lead to sample moisture reduction which is not accounted for.

c. Cost factor was just too high with payments for all 20 workers, safety equipment and overtime due to the fact that one sample cannot be finished within the 8 hours normal working time.

II. Cone and Quarter – 200 kg of heterogeneous waste to be sorted

a. Manpower requirement was reasonable where only 5 workers were required along with a supervisor to monitor the work. Moreover, the sorting of the 200 kg sample could be done with relatively good accuracy and efficiency, even when the final part where all the fines needed to be sorted.

b. The time frame for the sorting took anywhere between 2 to 3 hours. This is a very good working time frame to keep the workers fresh and alert.

c. The cost is very much manageable. However, a bit more cost is needed for the initial part where a back-hoe is needed to mix the waste and do the 'Cone and Quartering'

III. Spot Sampling - 200 kg of heterogeneous waste to be sorted

a. Manpower requirements are the same as in 'Cone and Quarter'

b. Time frame is also the same as 'Cone and Quarter'

c. Cost is cheaper as done need the extra money for the back-hoe

IV. Laboratory Sorting

a. Manpower requirement is very low, where only 2 people is required for the sorting activity, but to get the sample from the full truck load, the process still requires manpower at the landfill and sorting activity. As this sorting is done after the sample has been dried and carried out in a laboratory condition, manpower requirement is lower, however, this case needs highly skilled manpower.

b. Time frame taken for the sorting activity is relative the same as 'Cone and Quartering'

c. As this is done in a laboratory environment, the cost is much higher, but the safety of the workers is ensured in this case as compared to doing the sorting activity on the landfill site.

Based on these sorting procedures, the sorting activity was carried out with the aim to determine the time factor taken to sort the sample by the various methods, the manpower needed to carry out such a sorting activity and the related cost factor. The data of the sorting activity are provided in Table 4.4 and 4.5. Table 4.4 shows the results of the sorting process in the absolute weight of the individual components whereas Table 4.5 gives the results as a basis of percentage of the weight. It is a bit difficult to analyze the data on a weight basis but when presented on a percentage basis the findings are clearer.

Table 4.4: Components data based on various sorting methods – results in kg

	Truck Load (kg)			Cone and Quarter (kg)			Spot Sampling (kg)			Laboratory Sampling (kg)		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
Food / Organic	2,539.65	2,568.60	2,442.10	82.50	63.90	70.60	55.70	105.40	95.90	22.90	17.20	19.90
Mix Paper	27.10	56.90	48.30	1.55	7.65	2.65	1.05	2.25	5.05	0.55	0.35	0.40
News Print	94.15	190.55	162.60	9.60	8.95	8.60	11.20	16.90		1.90	3.65	2.65
High Grade Paper	96.90	52.35	59.35	8.60	8.20	7.60			18.70			1.05
Corrugated Paper	52.60	181.10	208.30	6.70	6.75	6.70	5.45	9.80	4.65	1.90	1.45	2.45
Plastic (rigid)	77.85	104.10	118.35	8.00	2.65	12.00	9.65	6.50	4.65	2.45	1.55	1.55
Plastic (film)	464.95	481.37	454.70	17.90	26.35	32.90	19.58	19.80	12.75	6.70	6.20	5.20
Plastic (foam)	45.70	40.55	51.35	2.75	2.75	7.90	1.45	3.95	1.45	0.30	0.40	1.30
Diapers	622.60	507.38	521.35	26.80	27.35	28.60	27.45	27.60	30.70	5.15	5.55	7.55
Textile	120.60	152.50	115.50	4.40	8.87	3.30	5.65	12.90	4.65	1.15	1.00	1.10
Rubber / Leather	22.80	51.05	64.90	1.10	1.50	1.00	0.80	9.45	1.05			
Wood	2.30	32.70	12.80	0.35	0.90	0.55	0.10		0.90			2.20
Yard	232.45	85.50	42.30	2.35	11.80	2.35	16.95	5.10	6.95			
Glass (clear)	52.70	108.55	98.60	8.55	3.75	6.55	4.45	5.65	7.45	1.15	3.75	2.40
Glass (colored)	10.00	39.75	79.20		1.80	1.30				0.40		
Ferrous	30.25	29.45	43.20	1.50	2.60	1.50	2.75	3.60	2.75	0.90	0.65	0.90
Non-Ferrous	3.85	11.30	12.40		1.10		5.85		5.85			
Aluminum	1.90	2.50	5.90	0.10	1.30	0.10		1.65			0.50	0.60
Batteries / Hazards	1.95	2.35	7.30					1.50				
Fine	47.65	62.15	46.20	2.60	7.75	1.60	13.50	6.00	3.50	0.95	1.20	0.50
Other Organic	32.25	51.85	76.40		5.60	5.60			5.50		7.45	5.40
Other In-Organic	21.90	8.35	12.40	4.20		1.20						
Others	30.20	12.90	9.70									
Total	4,632.30	4,833.80	4,693.20	189.55	201.52	202.60	181.58	238.05	212.45	46.40	50.90	55.15

Table 4.5: Components data based on various sorting methods – results in percentage

	Truck Load (%)			Cone and Quarter (%)			Spot Sampling (%)			Laboratory Sampling (%)		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
Food / Organic	54.82	53.14	52.03	43.52	31.71	34.85	30.68	44.28	45.14	49.35	33.79	36.08
Mix Paper	0.59	1.18	1.03	0.82	3.80	1.31	0.58	0.95	2.38	1.19	0.69	0.73
News Print	2.03	3.94	3.46	5.06	4.44	4.24	6.17	7.10		4.09	7.17	4.81
High Grade Paper	2.09	1.08	1.26	4.54	4.07	3.75			8.80			1.90
Corrugated Paper	1.14	3.75	4.44	3.53	3.35	3.31	3.00	4.12	2.19	4.09	2.85	4.44
Plastic (rigid)	1.68	2.15	2.52	4.22	1.32	5.92	5.31	2.73	2.19	5.28	3.05	2.81
Plastic (film)	10.04	9.96	9.69	9.44	13.08	16.24	10.78	8.32	6.00	14.44	12.18	9.43
Plastic (foam)	0.99	0.84	1.09	1.45	1.36	3.90	0.80	1.66	0.68	0.65	0.79	2.36
Diapers	13.44	10.50	11.11	14.14	13.57	14.12	15.12	11.59	14.45	11.10	10.90	13.69
Textile	2.60	3.15	2.46	2.32	4.40	1.63	3.11	5.42	2.19	2.48	1.96	1.99
Rubber / Leather	0.49	1.06	1.38	0.58	0.74	0.49	0.44	3.97	0.49			
Wood	0.05	0.68	0.27	0.18	0.45	0.27	0.06		0.42			3.99
Yard	5.02	1.77	0.90	1.24	5.86	1.16	9.33	2.14	3.27			
Glass (clear)	1.14	2.25	2.10	4.51	1.86	3.23	2.45	2.37	3.51	2.48	7.37	4.35
Glass (colored)	0.22	0.82	1.69		0.89	0.64				0.86		
Ferrous	0.65	0.61	0.92	0.79	1.29	0.74	1.51	1.51	1.29	1.94	1.28	1.63
Non-Ferrous	0.08	0.23	0.26		0.55		3.22		2.75			
Aluminum	0.04	0.05	0.13	0.05	0.65	0.05		0.69			0.98	1.09
Batteries / Hazards	0.04	0.05	0.16					0.63				
Fine	1.03	1.29	0.98	1.37	3.85	0.79	7.43	2.52	1.65	2.05	2.36	0.91
Other Organic	0.70	1.07	1.63		2.78	2.76			2.59		14.64	9.79
Other In-Organic	0.47	0.17	0.26	2.22		0.59						
Others	0.65	0.27	0.21									
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

The findings from the results presented on Table 4.4 and 4.5 are as follows:

1. Truck Load – yes this is the best method as all the components have been identified and are present in the waste stream. However, it is important to note that the tendency for the sorting workers to just lump all as food/organic waste, thus making the food waste component much higher than all other components. Diapers are becoming an important component in the waste stream as this material is actually very light but when mixed with all the different types of waste, it absorbs moisture and becomes very heavy.
2. Cone and Quartering method provides a fair representation from the original components, but yet there is a chance that some minor components might go missing from the sorting stock. As far as accuracy is concerned, the sorting is

done in a more micro manner due to the smaller sample size for sorting, giving more confidence in the results. Yes, food/organics and diapers are still the main components and also the trends in the weight of the components do reflect well with the 'Truck Load' method.

3. Spot sampling method does not give a very fair representation of the components as compared to that from the 'Truck Load' results. This is because, the samples are taken at random from various parts of the lorry and this can in many cases leave out many minor components. Yes, the sorting can be done with relatively good accuracy due to the smaller volume but if the component is not there in the first place, how can it be reflected in the results. The trending of the weight is almost the same with that of the Cone and Quarter method.
4. As for the Laboratory Sampling, this method of sampling and sorting cannot work for the heterogeneous nature of Malaysian waste. Many components have gone missing from the sample stream. Due to the very small size of the sample, yes very detailed sorting can be done in a very safe and clean environment. However, the sampling procedure to obtain the sample and the sample size is far too small and the trends in the compositional weight have also changed. This is obvious when analyzing Table 4.5.

Finally, based on the experience during the sorting process and the results presented in Table 4.4 and Table 4.5, the following findings can be put forward with regards to the best practice for sorting method:-

1. Truck Load is theoretically the best method to be employed for the sorting of waste, however, due to the large volume of the waste, long working hours, excessive cost for manpower, it would be not advisable, looking to the fact that if a large scale sampling is done where over 1000 samples needs to be sorted and analyzed, this method will surely not be feasible.

2. Cone and Quarter method looks to be the best method fit for the purpose of sorting heterogeneous waste. Accurate, timely and cost effective in delivering the needed results, while it is sensitive enough to ensure all components are accounted and detected during sampling and sorting.
3. Spot Sampling is a relatively good method also but the sensitivity in making sure all minor components are accounted for in the sampling and sorting process is not as good as that provided by the Cone and Quarter method. The Spot Sampling method could become the second choice behind the Cone and Quarter method.
4. The Laboratory sampling method cannot be used in Malaysia as it is not sensitive enough to provide a picture of all the components of the waste.

From the above it, the study has been able to prove that the Cone and Quarter method is the best for heterogeneous waste generated in Malaysia. The Spot Sampling can also be used for sampling and sorting purpose, but care needs to be taken on the selection of the spots for taking the sample. Thus far, this study has shown the most preferred method in selecting the sampling plan, and now the selection, shows which method can become the best method to sample and sort the heterogeneous waste generated in Malaysia.

4.6 Number of Components During Sorting Exercise

In the literature review in Chapter 2, the results that were shown are based on the national waste characteristics, which are usually done to be as complete as possible. However, this is a very time consuming and costly effort which can only be done with the funding, manpower and the equipment from the Government of Malaysia. However, in many cases, waste characterization studies are done on a very low budget and on such a scale, the next question would be, should the samples be sorted into 10, 15, 20 or even 25 components. Which give batter accuracy and clearer picture of the heterogeneous waste in Malaysia?

Again, during the “Survey on SW Composition, Characteristics & Existing Practice of SW Recycling in Malaysia” from 2012 to 2014 for the National Solid Waste Department, another side study was carried out to clarify the above. The aim of this side study was to determine if using the ‘Truck Load’ or the ‘Cone and Quarter’ method for sorting the waste into the various components, will the effect of more components or less components have an impact on the results. The waste for this side study was obtained from the various areas that were already targeted for sampling. The results presented in Table 4.6 and 4.7 are based on 5 samples, sorted separately to show if there are any significant issues that needed attention.

There are no new experience-based observations from this round of sorting as most of the experience-based observation has been put into the previous section. Based on the results shown on Table 4.6 and 4.7, the first thing is the food/organic waste, which shows a very large difference. All the other components have almost the same trend by both the 11 component and 23 component sampling. The reason behind the selection of this specific number of components; i.e. 11 and 23 components, is because the 11 components made up the basic components of the waste while the 23 components is the expanded version of the components in the waste which is found every day. Again, this is a list of components which has been stablished in Malaysia over the years and through experience.

From the results shown on Table 4.6 and 4.7, the following findings can be put forward:-

1. It is best to use the Cone and Quarter method for sampling and sorting as the truck load method giver a very wrong impression that the waste generated is predominantly made up of food/organic waste. The reason behind this is the

method in which the sorting is done, where in the 'Truck Load' method, macro sorting is done while in the 'Cone and Quarter' method the ability to micro sort waste into its components is glaring from the results.

2. It is good to have many more components, 23 components as compared to 11 components. This is because, when planning a solution to the waste management problem, having a more deep and detailed insight of the components of the waste is very important. Furthermore, Malaysian based waste is very heterogeneous, meaning, the larger the components the batter the picture.

Table 4.6: Components data based on various sorting methods – results in kg

Truck Load			
	Min	Ave	Max
Food	63.86	74.37	84.78
Rubber	1.42	0.68	0.13
Glass	1.86	0.99	0.38
Plastic	9.02	8.65	5.91
Yard	3.20	1.94	0.88
Textile	1.34	0.56	0.25
Wood	4.32	3.66	1.38
Paper	12.44	7.37	5.53
Aluminium	0.22	0.15	0.13
Ferrous	2.01	1.36	0.38
Fine	0.30	0.27	0.25

Truck Load			
	Min	Ave	Max
Food/Organic	30.08	34.33	41.13
Mix Paper	4.87	4.01	3.67
News Print	3.55	4.17	5.65
High Grade Paper	4.35	5.30	7.48
Corrugated Paper	14.04	10.90	2.46
Plastic (Rigid)	3.00	3.26	4.23
Plastic (Film)	11.50	13.55	17.67
Plastic (Foam)	0.51	0.42	0.41
Diapers	8.00	5.79	2.15
Textile	4.70	4.16	3.84
Rubber/Leather		0.97	
Wood	3.86	3.64	3.60
Yard	2.41	1.85	1.75
Glass (Clear)	2.57	1.85	1.35
Glass (Colored)	1.96	1.26	0.14
Ferrous	3.60	3.67	3.73
Non-Ferrous			
Aluminum	0.34	0.28	0.23
Batteries/Hazards	0.19	0.20	0.24
Fine	0.48	0.39	0.27
Other Organic			
Other In-Organic			
Others			

Table 4.7: Components data based on various sorting methods – results in kg

Cone and Quarter			
	Min	Ave	Max
Food	60.16	69.17	76.49
Rubber	1.17	0.54	0.28
Glass	1.33	1.26	0.71
Plastic	15.31	12.92	13.03
Yard	10.63	4.77	0.28
Textile	1.17	1.16	1.13
Wood	1.64	1.74	0.14
Paper	5.16	4.59	3.54
Aluminium		0.10	
Ferrous	2.11	2.42	2.97
Fine	1.33	1.35	1.42

Cone and Quarter			
	Min	Ave	Max
Food/Organic	32.61	35.37	39.87
Mix Paper	4.37	3.86	4.60
News Print	4.32	4.90	6.73
High Grade Paper	13.34	9.01	0.67
Corrugated Paper	5.53	4.68	4.21
Plastic (Rigid)	4.57	3.46	2.39
Plastic (Film)	11.75	12.28	14.14
Plastic (Foam)	0.95	0.79	0.81
Diapers	5.62	6.59	9.22
Textile	1.05	0.98	1.11
Rubber/Leather	0.75	0.76	0.84
Wood	3.47	3.03	2.66
Yard	0.94	0.98	1.14
Glass (Clear)	2.22	2.53	3.06
Glass (Colored)	2.15	2.16	2.36
Ferrous	4.52	4.67	5.05
Non-Ferrous			
Aluminum	0.70	0.40	0.18
Batteries/Hazards	0.25	0.22	0.19
Fine	0.43	0.38	0.31
Other Organic		2.35	
Other In-Organic	0.45	0.58	0.45
Others			

4.7 Reporting of Physical Characteristics of Heterogeneous Waste

Finally, sections 4.2 to 4.6 have made it clear on which are the best practices that should be adopted for the planning, sampling, sorting, and number of components for waste generated in Malaysia. Although the "Survey on SW Composition, Characteristics & Existing Practice of SW Recycling in Malaysia" from 2012 to 2014 for the National Solid Waste Department, did show all the results, which has been highlighted in Chapter 2, but for technical reporting purpose, the detailed results should have been shown as in Appendix 1. Analyzing the results in Appendix 1, the finding shows in detail how the waste characteristics change from As Generated to As Discarded to As Disposed. The results on Appendix 1, gives all the necessary parameters that needs to be analyzed from a waste sample representing a capital city for each state in Malaysia. Very often, waste management options or treatment methods are based on overall results, however, based on the findings of this thesis, waste management decisions can be made based on the local state waste characteristics, and even more detailed is the fact that these decisions can be made based on findings from Appendix 1 which shows how the waste changes from generated to disposed and from residential to institutional and to commercial. This thesis is not about the characteristics but on how to establish these characteristics.

An important note is that, when presenting waste characteristic data, the best and ideal way is to present the data from all sources of waste generators within the boundary of the study. At the same time, the results must also be encompassing enough to show the various components that arise from different locations and their minimum and maximum weight range. At the same time, the findings based on experience and has been to identify the best practices towards sampling and sorting heterogeneous waste generated in Malaysia, giving a clear pathway towards establishing the physical characteristics of heterogeneous waste generated in Malaysia.

Going back to the objectives set out in Chapter 1, the first objective is to establish a complete characterization of the heterogeneous waste generated in Malaysia and to recommend new best practices that will help give an accurate representation of the heterogeneous waste generated in Malaysia. Towards this, results from this chapter have been able to give the following findings:-

1. The need to have historical weighbridge data when planning for a waste characterization study is essential, where trends in the disposal rates will guide the sampling plan to achieve study objectives.
2. The need to have both target and random sampling in the waste characterization plan which will allow for more accurate sampling.
3. Sampling and sorting can be done on a ‘Cone and Quarter’ basis, as compared to doing a full truck load, which essentially provides for more reliable and accurate data. The results proved that the Cone and Quarter method was able to reduce

the time and cost for sorting while increasing the sorting efficiency. The introduction of the sorting table and ensuring that samples are individually packed for analysis are among the methods introduced by this study which can become new standard practices for future studies.

4. Sorting the waste into as many components as possible, give higher accuracy in reflecting the waste characteristics which becomes the basis for design of facilities and waste management action plans.
5. Introduction of a new step where all components are sent to the laboratory in individually sealed packaging is a new step introduced by this study. This step allows for each sample to be accurately re configured back after moisture analysis and grinding reflecting the original composition as in during sorting. This new step ensured that when the waste is analyzed, the repeatability of the results can be assured, thus increasing the validity of the data for design purpose.

CHAPTER 5: PROTOCOL FOR MOISTURE CONTENT AND CALORIFIC VALUE CHARACTERISZATION OF WASTE

5.1 Introduction

At the end of Chapter 4, the heterogeneous municipal solid waste was already sorted into its components and ready for the next phase of analysis. In this chapter, these components would now be taken to the laboratory for analysis to determine their physicochemical characteristics of the individual components which in return will provide the overall characteristics of the heterogeneous waste itself.

In this chapter, the need to provide results towards answering objective 2 and 3 of this thesis was being put forward. Among the major parameters being discussed in this section will be:-

1. The analysis can be done for all components of the waste or to take a composite sample and to carry out the analysis. The question was how to take a composite sample from 23 different components with different weight representation?
2. To determine the various factors that contributes towards determining the moisture content of a waste sample.
3. In determining the calorific value of a sample, can this be done only by experimental way or can this be obtained through predictive equations which will not only help to shorten time and cost but will also help to increase the size of the sample used to obtain the results.

Moving forward, before any analysis is done, the best is to draw out a plan for the sampling and analysis section as was done for the waste sampling and sorting in the previous chapter. This plan must show the critical areas that need to be focused on during the sampling and analysis activity, while addressing the various options that are available in sampling and analysis of waste material.

5.2 Establishing the Physicochemical Characterization Plan for Malaysia

The standard for waste characterization in Malaysia was only introduced in 2012 which is MS 2505:2012 - Guidelines for sampling of household solid waste - Composition and Characterization Analysis. This Standard Method is not only new but not many studies have been carried out using this standard. The only study done is the "Survey on SW Composition, Characteristics & Existing Practice of SW Recycling in Malaysia" in 2014 for the National Solid Waste Department.

After studying the MS 2505:2012, Figure 5.1 was derived to show a flow of how the standard described a waste sampling and analysis activity. Although the MS shows and states the various parameters to be analyzed during the sampling and analysis activity, there are many question marks on which method suits best for the Malaysian waste and which are the best approach in reducing the waste size from and catchment/boundary area which about 1000 tons/day to the various number of samples needed to represent the area, to the sampling size of 200 kg for sorting, to the 1 kg sample size to the laboratory, to the 50 grams of analysis stock for analysis and the final 1 gram which is analyzed to reflect the characteristics of the initial 1000 tons/day of heterogeneous municipal solid waste generated in Malaysia. This is a huge task with unlimited variables, for which the study is trying to narrow down the options so that the best representation can be gained. The standard has stayed silent on the choice to be made in formulating a study plan. This silence can raise some questions and has been highlighted in Figure 5.1 in red.

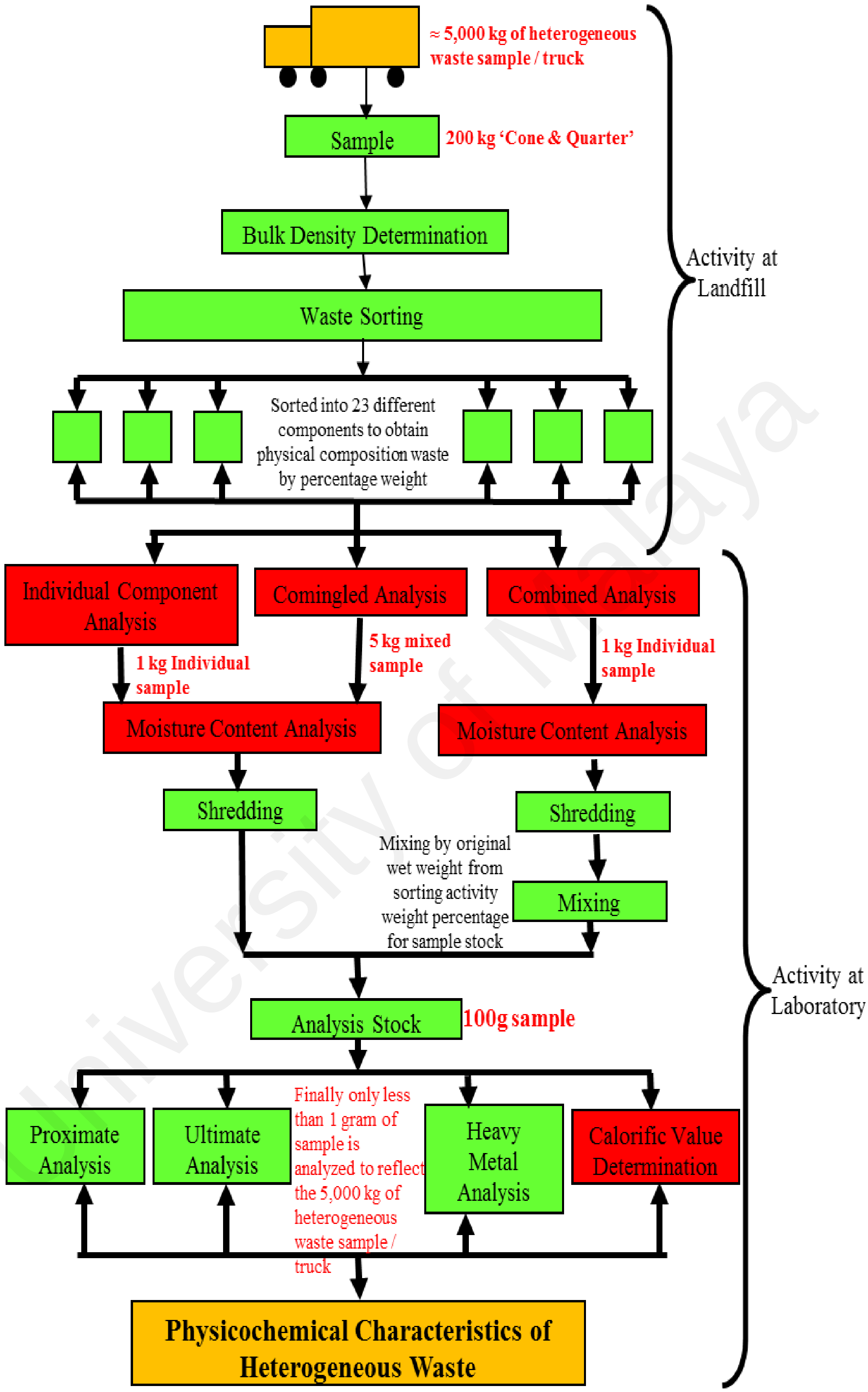


Figure 5.1: Flow Chart for physicochemical characterization based on MS 2505:2012 (Adapted from: Malaysia (2012)

As this study has its limitations, not all aspects within Figure 5.1 will be analyzed. Only the boxes in red will be discussed as it is found to have some impact on the outcome of the analysis. Based on the analysis of the MS 2505:2012 the following are highlighted in the red boxed and the findings are:-

1. To determine the best way to analyze the waste sample which could be done by either
    a. Individually conducting all the analysis for all the components of the waste.
    b. To take a mixture of all the components after the sorting process to be sent to the laboratory for analysis, or
    c. To do a combination of both, by first sending all the components to go through the moisture analysis individually followed by the shredding and grinding process. This is followed by mixing the components back according to the wet weight recorded during the sampling process. By this way an assurance is obtained that the ground sample is a close duplication of the original composition of the waste after sorting.
2. Next, is to analyze the moisture content of the waste. In Malaysia, due to the tropical nature of the country, rainfall is in abundance and due to the lack of responsibility, the accumulation of rain water and other sources or water into the waste increases the moisture content. This needs to be analyzed thoroughly.
3. Finally, the last components to be analyzed if the calorific value of the waste, which very often is one of the main parameters in converting the waste to energy. Renewable energy is a major option for waste management and how best to determine this parameter will be discussed in Chapter 5.

5.3 Individual Vs Comingle Vs Combine Analysis Results In the previous section, the results that were shown were based on the physical waste characteristics and the aim was to be as comprehensive and complete as possible. However, this is a very time consuming and costly effort which can only be done with the funding, manpower and the equipment from large multinational companies or the Government. In the case of studies for academic purpose and for even small project purpose some kind of compromise has to be found to balance the element of cost and time vs the practical aspect of reporting. This section will attempt to analyze and provide the necessary findings towards this.

After a sorting activity, it was found that most of the standard methods and including the MS 2505:2012 only required for a 1 kg sample or an appropriate amount of sample to be sent to the laboratory for analysis. In this case the question raised is how to get the accurate amount of sample size and representing all the waste components to be sent to the laboratory. For this a set of waste samples were identified during the main sampling plan to investigate these questions. As shown in Figure 5.1, there can be 3 ways of carrying out the analysis of these components, the first way is the analyze all the components for all the different parameters required, next is to take a comingled sample from all the components of the waste once the sorting activity is finished and finally, is to do a combination of both, by first taking the individual components and then mixing back after drying and grinding to form a mix of the original sample from the sorting activity by mixing the same weight basis as from the sorting waste results. All these was done to 5 sets of samples and the results for moisture content, volatile matter, fix carbon and ash are shown in the following figures.

The results for the moisture content analysis are shown on Figure 5.2. The findings based on Figure 5.2 show that the average moisture content of the MSW generated is in the range of about 45 to 70%. Generally, the weather condition in Malaysia is of tropical condition and having a moisture level of about 55% in the waste is normal considering the amount of rainfall Malaysia receives.

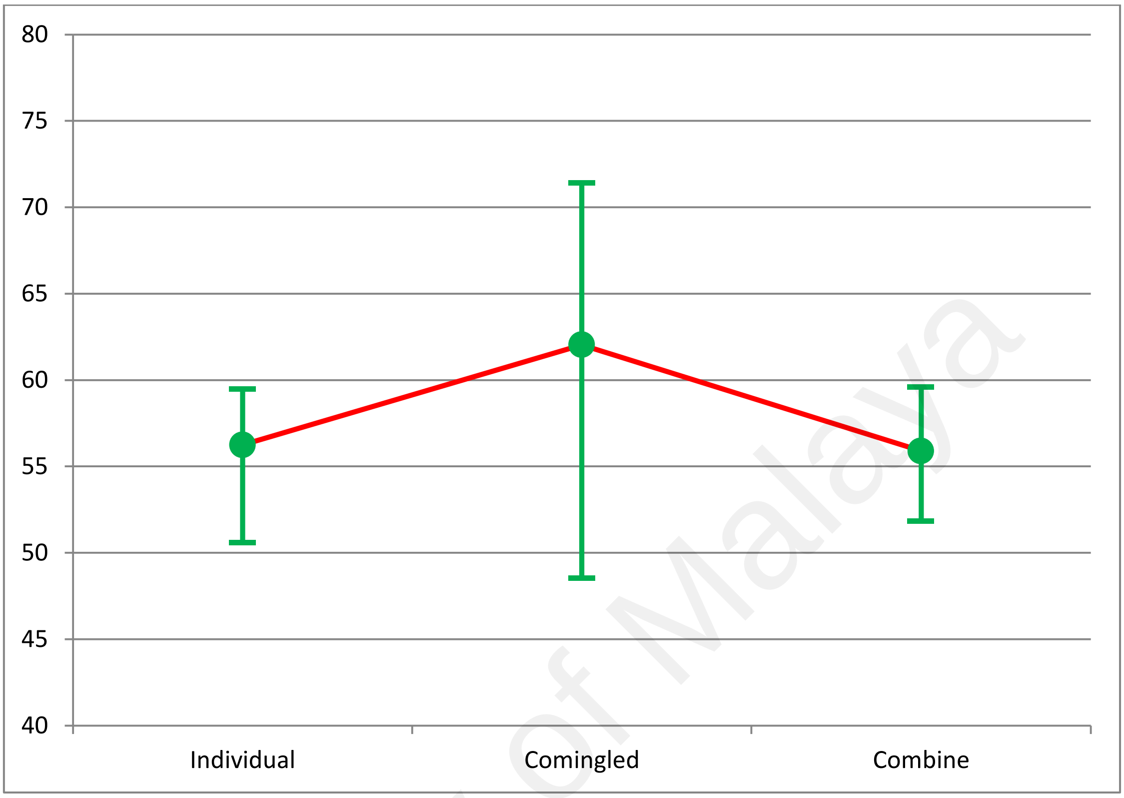


Figure 5.2: Moisture content of the MSW analyzed by the three different methods

The next factor to be considered when analyzing Figure 5.2 is the range between the maximum and the minimum values for the different method of analysis. Ideally, the waste should be analyzed based on its entire individual components (sample size of about 1 kg for every individual component) into which it has been sorted (23 components). This will give a very detailed result, which will allow for manipulation of the data to do forecasting of future trends of to look at the calorific value if there were adverse recycling carried out on the MSW generated. Unfortunately, analyzing the MSW in this manner requires a huge manpower, cost, equipment and time. The results of the moisture analysis based on the individual components in Figure 5.2 shows a small range between the maximum and minimum values. In contrast to this, by analyzing the MSW on a commingled basis, where about 5 kg of commingled sample is taken (by mixing all the waste back after sorting and taking a representative sample) to represent a truckload of MSW, the range in the moisture content was much bigger as shown in Figure 5.2, where the maximum and minimum range for the commingled sample is much bigger than that of the individual way of analysis. Although the method of analysis is much easier and also requires less cost, however the results are questionable and not repeatable. The findings show, that every time a mix is taken from the waste that has been sorted, a different range of moisture is obtained as the representation in the mix is not constant.

Finally, is to analyze the samples by a combination of both methods where the samples are first analyzed by its individual components for their moisture content and then the individual components are mixed to form a commingled sample based on their weight percentage for the volatile matter, fix carbon and ash analysis. Findings from Figure 5.2 show that the results are almost identical to that of the method of analysis for individual components. This goes to show that doing the moisture content analysis on an individual basis and then mixing the components up does not change the analysis procedure from the original method and also provides repeatability which indicated that the results obtained are accurate. Although there is a slight difference in the maximum and minimum levels, but this could be considered as a negligible factor in the analysis of the waste due to the vast variance in the individual components of the waste itself. As such, the combined method gives you the same results but at a cheaper cost, less workload and faster time frame.

Based on the findings form Figure 5.2, the results from the determination of volatile content of the samples is carried out by same the three methods mentioned above. This is shown on Figure 5.3. The results and the findings show that the same trends as Figure 5.2 have been obtained and these results are encouraging on behalf of the combined method. Figure 5.3 shows that the range for the maximum and minimum values in the figure indicating the volatile matter content for the individual component method of analysis is small, but the workload and cost is high. In contrast to this, the commingled method is low in cost and workload but the range between the maximum and minimum is much bigger making the results questionable and hard to duplicate. However, the combine method has produced a relatively batter result when compared to the commingled method with the workload and cost being relative cheaper as compared to the individual component analysis method. However, an interesting analysis of the results in Figure 5.2 and 5.3 shows that, when analyzed individually, the results are almost the same (Figure 5.2) but when the components are mixed (even when precaution is taken so that the mixture is done according to the weight percentage as in the sorting exercise) the results obtained shows a larger range and a slight shift in the average. Yes, it is effective by the variance does occur but not as bad as that by analyzing the original mixture. This is an important finding than can be verified by also analyzing the results from the fix carbon and ash content analysis.

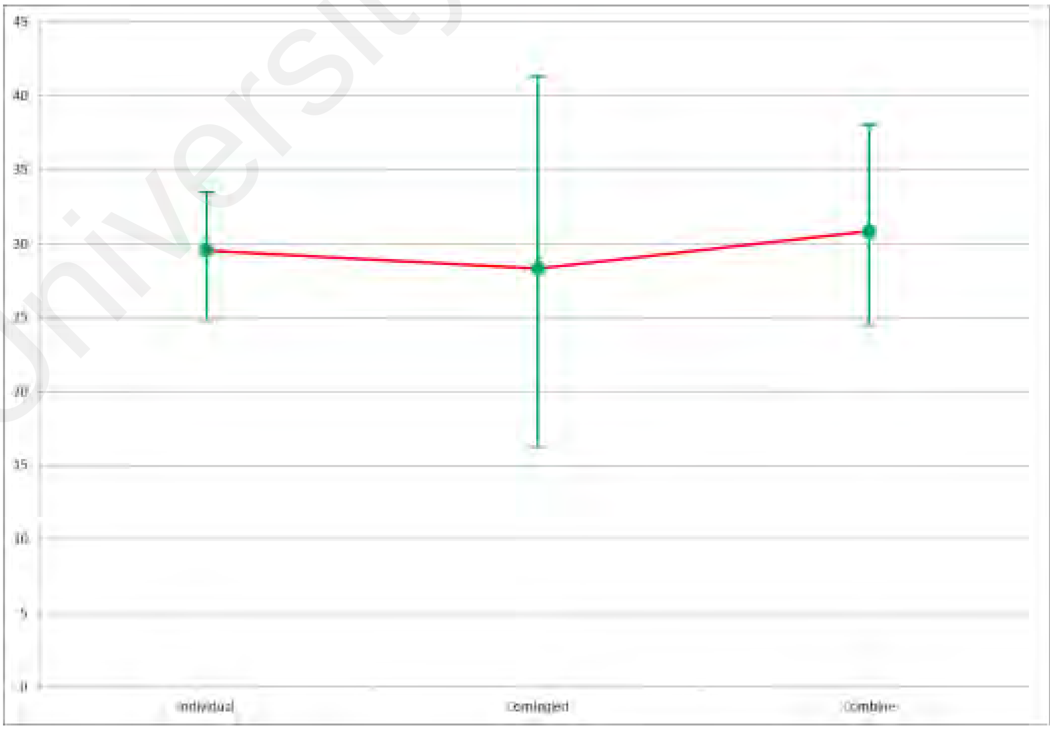


Figure 5.3: Volatile matter content of the MSW analyzed by the three different methods

Next is to analyze the results for fix carbon and ash content and this is shown on Figure 5.4 and Figure 5.5. The results further strengthen the earlier findings in Figure 5.2 and Figure 5.3, which is on the effectiveness of the combine method of analysis. Both figures comply with the argument that the combined method of analyzing the heterogeneous municipal solid waste generated in Malaysia gives relatively good results at a lower workload and cost. Again, the average has moved slightly and the maximum and the minimum values have become larger as compared to analysis by the individual components. This goes to prove that the results are consistent, and accurate. In reality, when analyzing the waste individually, surely the results will be accurate, however, this is an impossible task when there are 100 samples and each sample has 23 different components to be analyzed. Hence, the findings which allows for the waste to be mixed after the moisture analysis will reduce cost and time but with relative higher accuracy.

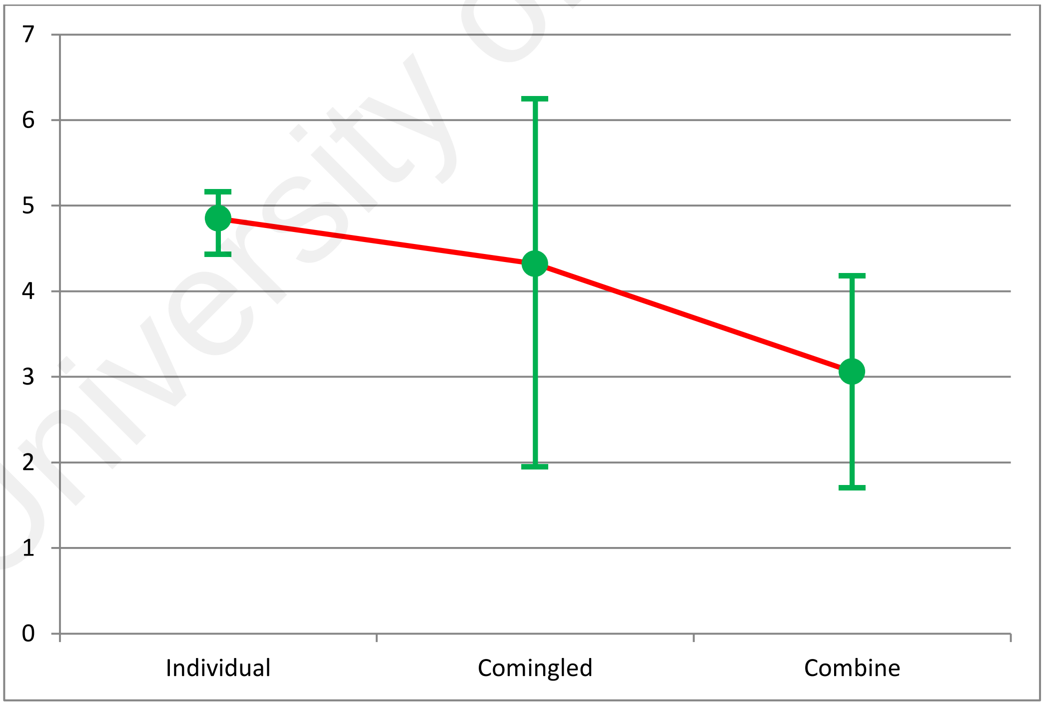


Figure 5.4: Fixed carbon content of the MSW analyzed by the three different methods

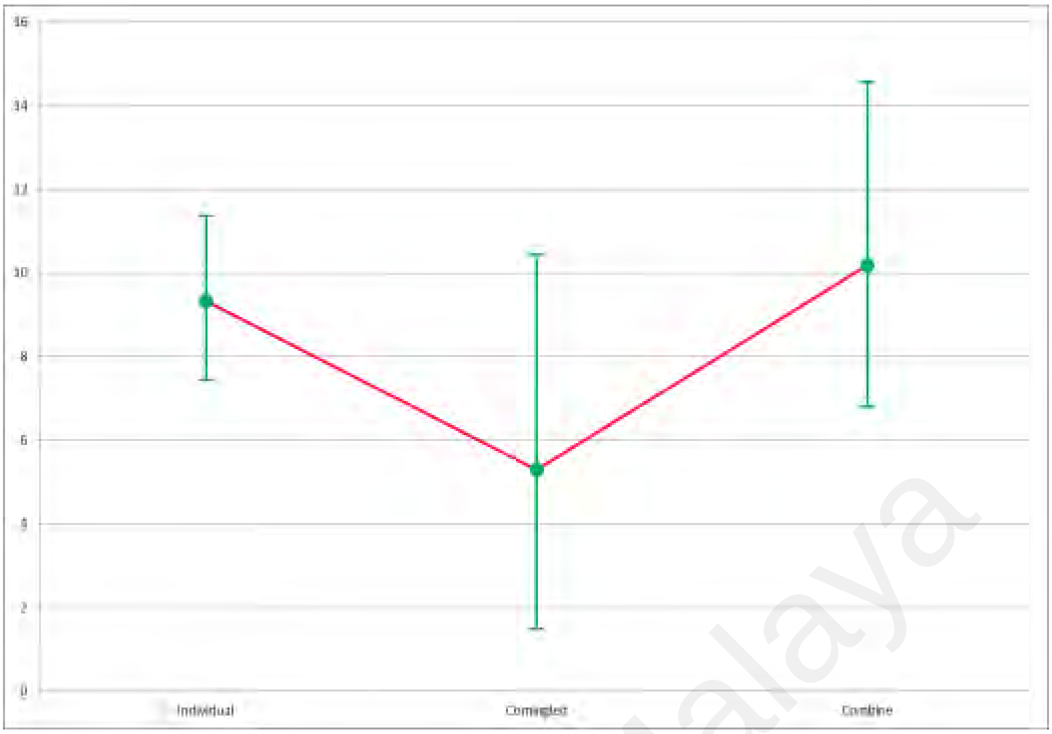


Figure 5.5: Ash content of the MSW analyzed by the three different methods

Finally, results and findings obtained from this part of the study are in good agreement with the characteristic results that have been in publication thus far. As reported in Chapter 3, the moisture content of about 55% with the volatile matter being about 30%, fix carbon of about 5% and ash content of about 10% is a typical composition content for the heterogeneous municipal solid waste generated in Malaysia. It also goes to prove that sampling and segregation into the 23 over components is necessary while the analysis can be done on a method where the individual components are dried, ground and mixed back based on the sorting weight composition and then proceed for analysis as a single sample. This is not a new method to analysis waste; it is a recommendation on best practice to achieve the most reliable result at the lowest possible cost and shortest time frame. By adopting these findings, the heterogeneous municipal waste generated in Malaysia can analyzed with greater accuracy.

5.4 Moisture Content Analysis

Going back to Figure 5.1, the first analysis that the waste sample goes through is the analysis for moisture content. Although the results and findings for moisture content analysis was discussed in the last section but that was only based on the standard method as recommended by the MS 2505:2012. As pointed out in section 1.2 of this thesis, the main problem with most of the waste treatment facilities is the unknown factor in the characteristics of the Malaysian waste and at the same time due to the high moisture content. Unfortunately, all analysis methods only point out that the sample needs to be analyzed for moisture content by drying process.

Form the experience of carrying out the many sampling exercises, a few general observations can be made as follows:-

1. All waste dump trucks in Malaysia come with 2 large containment vessels under the lorry, to cater for the water that is leached out of the waste when the waste is compacted. Most often this containment gets filled up very fast and this leachate will over flow on to the roads before reaching the landfill or point of discharge. No sampling methodology takes into account of this water content/leachate to the moisture content.
2. Once the sample has been obtained and the sorting activity is started, it has been noticed that the waste gets dried up during this process. As most sampling take between 3 to 4 hours and is carried out in open areas under the hot sun, this drying effect can contribute to the overall moisture content. Again, there are no methods that have addressed such precautions.
3. After sorting, the samples are transported to the laboratory for analysis. Moisture can be lost during this transportation process. This is another area which needs to be addressed during moisture content analysis

4. Finally, the sample arrives at the laboratory. There are a few schools of thought, with some recommending that the sample be forced dried under open air, at 85°C or even at 105°C. Which is the best temperature to reflect the desired results at the fastest time frame needs to be determined.
5. Next at the laboratory, the samples are shredded and ground to make it fine. As described in section 5.3, the combine method is the best approach forward. However, standard methods only recommend for residual moisture content analysis at this point as a precaution only and not a must.

Moving forward, each of the above parameters has been analyzed in detail and all the relevant results have been presented in the following sections.

5.4.1 Leachate quantity in a waste dump trucks

In recent years, the waste dump trucks servicing the waste collection routes are being upgraded to ensure that all leachate generated during the process of collection and compaction is contained within the truck. The good aspect of this is that the collection routes are clean, but the bad aspect of this improvement is that the trucks are now unloading all the water into the final disposal facility or landfills. This would increase the amount of water in the MSW and in evidently increase the amount of fuel and energy needed to collect and burn the waste. Pictures of the collection of the leachate from the trucks are shown on Figure 5.6.

A selection of these waste dump trucks was identified and was asked to unload all the water content in their trucks into the containers waiting in standby. The container with the leachate water was then weight and presented as a percentage of the total weight of the waste in the truck. The quantity of water recorded ranged between 3 to 8% collected from the truck (without unloading the MSW) and another 3 to 8 % once the waste is unloaded on the ground. In total the amount of free water from one truck load of waste could range between 5 to 15 % of the total weight.

Figure 5.6: Pictures of leachate being collected from dump trucks.

From the results above, a 5 to 15% increase in the moisture content is very significant and must be recoded as a procedure during sampling process in all future sampling protocols for heterogeneous municipal solid waste generated in Malaysia.

5.4.2 Moisture loss during sampling and sorting process

As described in section 4.5, there are 4 established methods for sampling and sorting the waste. Each of these methods requires a relative long time to carry out the sorting process and this is often done under very hot conditions in open areas. This will surely increase the amount of moisture loss during this process. However, prior to this, no effort has been taken to record this amount or has any standard method mentioned any extreme precaution during this activity. The following sections present the results from these sorting activities.

'Truckload Method'

It was impossible to account for the moisture loss during this sampling and sorting method due to the large volume and weight. The weight for a truckload ranged from 3 to 5 tones and sorting took between 10 to 12 hours even with a relatively large work force (up to 20 people). Furthermore, it was not possible to account for all the waste, as there was much waste stuck to the walls of the truck after unloading which could not be recovered. The amount of unaccounted weight fraction after the sorting activity was large (>10%) and this could have resulted from both moisture evaporation and loss of sample mass in the truck and sorting bins. However, it is obvious that there was some loss of moisture during this activity, but it could not be quantified.

'Cone and Quartering Method'

The time frame for sampling and sorting by this method was about 3 to 4 hours per sample. It was relatively easy to sort this amount (about 200 to 300 kg) of waste and also account for all the bits and pieces. The finding of this study shows that the amount of moisture that vaporized during this sorting activity is largely dependent on the weather when the other factors such as the time taken for sorting, sampling time frame and the sampling method and even the workforce remained constant. The results are shown on Figure 5.7 and will be discussed together with the results from the spot sampling method.

'Spot Sampling Method'

This method is almost the same as the 'cone and Quartering Method' where the sampling and sorting activity lasts for about 3 to 4 hours and all the waste could be accounted for. Thus, the amount of moisture lost during this period was more due to the climate conditions, as the other factors have been made constant. The result of this sampling method is shown in Figure 5.7.

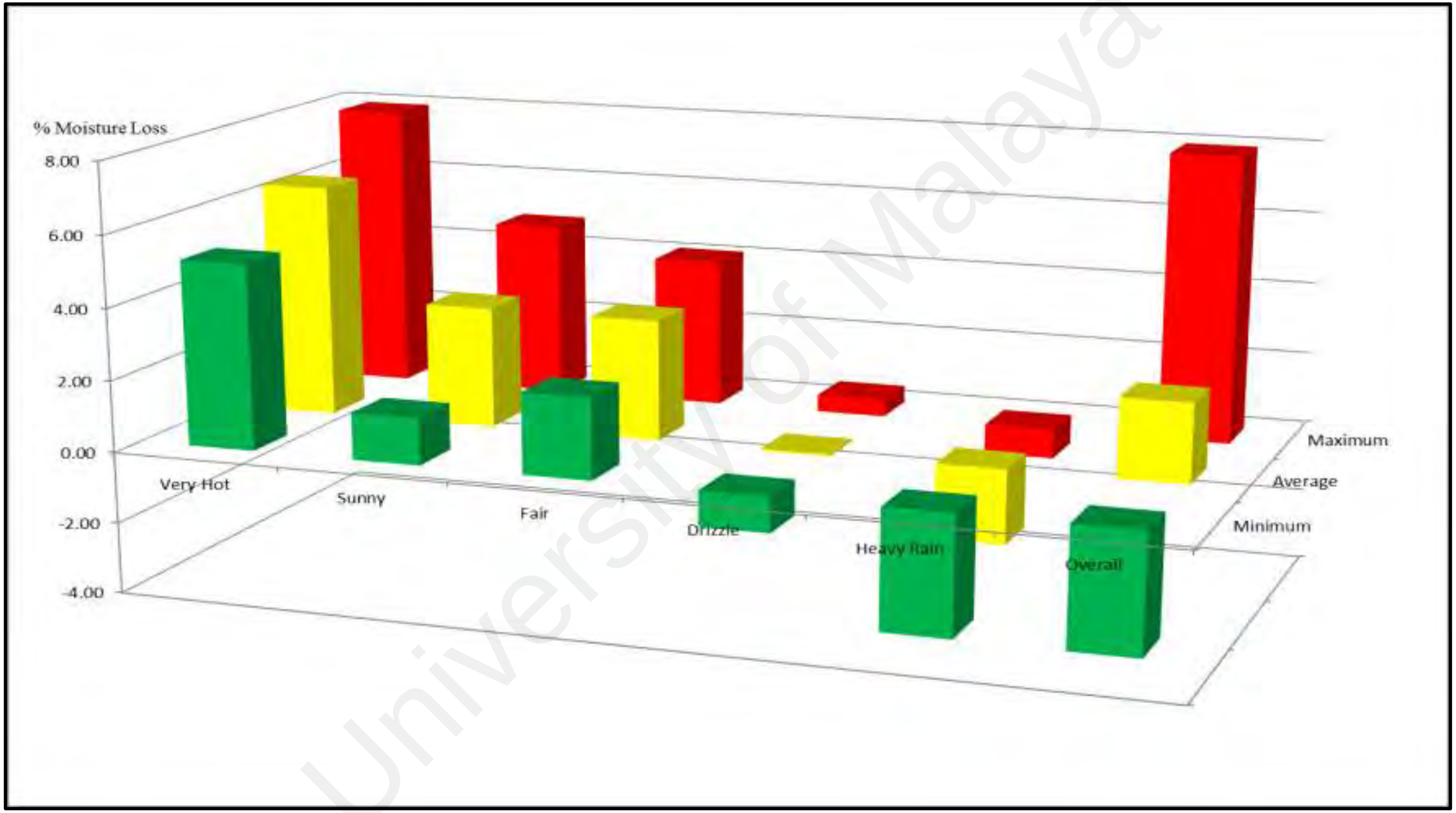


Figure 5.7: Moisture loss during sampling and sorting process based on weather condition

'Laboratory Sampling Method'

This method did not produce any moisture loss during the sorting or sampling process. This is because the sample was quartered and when the required amount (about 20 kg) was achieved, the sample was packed and sent to the laboratory. At the laboratory the sample was first dried at then sorted. Thus, it is considered that there was no moisture lost during sampling and sorting by this method.

The possible moisture losses from the various sorting methods have been identified as above. The other factors that contribute to the moisture loss during this activity are the time frame of the process which has been kept constant at 3 to 4 hours and the weather which is now the point of discussion.

Analysis of results presented on Figure 5.7 shows that the average moisture loss from a sample on a very hot day was about 6% whereas when there was heavy rain there was a moisture gain of about 2%. It also shows that overall the fluctuation in the amount of moisture lost could range from – 4% to 8% where the negative value meant that moisture gained, and the positive value meant moisture lost. The average moisture lost for every sample was about 3%. This indicated that in a tropical country typical to Malaysia, moisture loss from the sampling and sorting activity of heterogeneous municipal solid waste, due to the change in the weather condition during the sampling period is very significant, and thus should be of concern and accounted for in the total moisture content of the MSW, independent of the method used for sampling. Based on the weather condition during the sampling activity can easily contribute between -4 to 8% to the total moisture content of the waste sample. This when added with the 5 to 15% from the leachate from within the truck this can now contribute to anywhere from 1% to 23% on a maximum range. This amount is very significant and cannot be ignored.

5.4.3 Moisture loss during transportation

Results of moisture loss during transportation are shown in Figure 5.8. There seems to be not much difference between transporting the samples either individually or on a commingle basis. However, it is important to note that on average there is at least a 2% moisture loss during the transportation process and could range from 0.5% to a maximum of about 4%. Although the transportation time was limited and caution was taken to seal the plastic bags, moisture loss from the samples still occurred. This would imply that more moisture could have be lost if the time of transportation was longer. Fortunately, this did not happen, as all the sample bags are sealed and vaporization of the moisture from the samples takes place within the plastic bag space only; i.e. until the moisture content within the plastic bags becomes saturated with moisture. This becomes the limiting factor in the vaporizing of moisture from the samples.

A check with the psychometric chart indicated that at 29 to 34°C (local temperature range) and for 100% relative humidity, the amount of moisture in the air is 0.020 to 0.027 kg/kg dry air. This works out to about 2.0 to 2.7%, which is in good agreement with the moisture loss during the transportation process quoted above. There were some cases where the amount of moisture loss was more, which could be attributed to small leaks in the plastic bags, which were not noticed. It is therefore absolutely necessary for the bag sealing process to be adequately observed.

Another finding is that some objects can puncture the plastic bags and once punctured, the amount of moisture loss cannot be accounted for anymore. As such, taking into account the moisture loss from the transportation, could account for up to a maximum of 25% moisture content which has not been accounted for right from the start of identifying the sample in the truck.

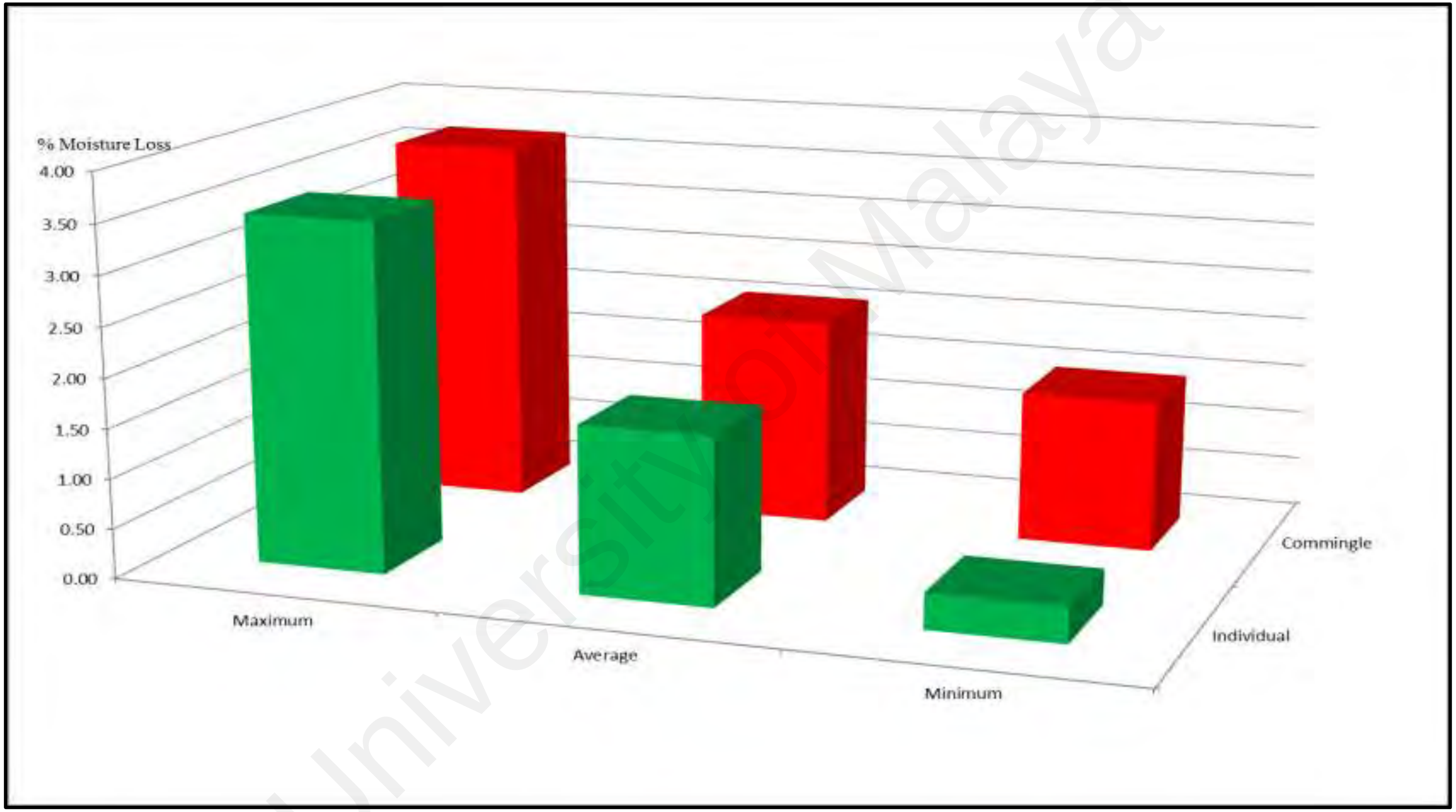


Figure 5.8: Moisture loss during transportation process

5.4.4 Moisture loss during oven drying process

Before the results are analyzed, a good understanding of the intentions of the analysis is necessary. The main intention is to determine the amount of surface moisture, on the samples. Care has to be taken for not to evaporate the volatile matter within the samples but at the same time ensuring that all surface moisture is driven off. Some standard method has indicated that at 85°C, the drying process would not drive away the volatile constituents such as ammonia and lipids, which is most likely to happen when the samples are dried at 105°C. Hence a critical point is to determine the drying temperature.

Table 5.1 shows the results of the experiments carried out as prescribed in section 3.8.2 for the simulation study done using synthetic waste. The results are summarized below:-

1. From Table 5.1 is proves that the most efficient temperature for surface moisture drying is at 105°C as indicated by the results for the tests carried out on water alone.
2. The performance of the drying at 85°C is as good as 105°C regardless of whether the food was soaked or not. At 45°C, it is obvious that the method is only for drying moisture on the surface and not that which has absorbed into the waste.
3. Next, the grinding process does not remove any moisture from the samples dried at 85°C or 105°C, and the performance of the drying process is almost the same with a very small difference in the total amount of moisture lost. As for the test at 45°C, it shows that due to the large amount of moisture still in the sample after the oven drying process, some moisture is lost during the grinding process,

as the total amount of moisture lost is much lower than that reported by the other two methods.

4. Another point to observe from Table 5.1 is that drying the samples for one hour is enough after the grinding process as the amount of moisture still inherent in the waste sample after the initial oven drying process is small and negligible.

5. Taking into consideration the argument that at 105°C there are some volatiles that are also vaporized, supported by the fact that there is a small % of difference in the amount of moisture vaporized between 85°C and 105°C, it can be concluded that oven drying a commingled sample size of about 1 kg at 85°C for 24 hrs would be the best recommended method to evaluate the moisture content of the waste.

This hypothesis can be further strengthened by analyzing Figure 5.8 and 5.9, which shows the average moisture lost for five different waste samples (actual waste). Five samples were prepared accordingly. It is clear that at 45°C the amount of moisture in the waste is under reported. In the case of 105°C and 85°C the results are almost the same; with 105°C reporting slightly higher moisture content which could be due to the volatiles evaporated. Thus, this finding shows that the best method of analyzing the moisture content of waste is oven drying the sample at 85°C for 24 hrs.

Table 5.1: Test for Moisture Lost at Different Temperatures for Simulated Waste

Type of Waste	Oven	Residual (1hr)	Residual (24hr)	Total	Remarks
	Percentage moisture loss				
45					
Water (300 g)	100.00	-	-	100.00	Close to 24 hrs
Food (300 g) + Water (100 g)	61.78	2.75	4.83	66.61	No grinding (No soaking)
Food (750 g) + Water (250 g)	39.51	10.35	27.97	67.48	No grinding (Soak overnight)
Food (750 g) + Water (250 g)	39.51	11.90	28.64	68.15	Grinding (Soak overnight)
85					
Water (300 g)	100.00	-	-	100.00	Only 18 hrs
Food (300 g) + Water (100 g)	73.44	0.02	0.62	74.06	No grinding (No soaking)
Food (750 g) + Water (250 g)	73.49	0.72	1.06	74.55	No grinding (Soak overnight)
Food (750 g) + Water (250 g)	73.49	1.19	1.25	74.74	Grinding (Soak overnight)
105					
Water (300 g)	100.00	-	-	100.00	Only 13 hrs
Food (300 g) + Water (100 g)	74.85	0.05	0.15	75.00	No grinding (No soaking)
Food (750 g) + Water (250 g)	75.02	0.71	0.89	75.91	No grinding (Soak overnight)
Food (750 g) + Water (250 g)	75.02	0.83	0.91	75.93	Grinding (Soak overnight)

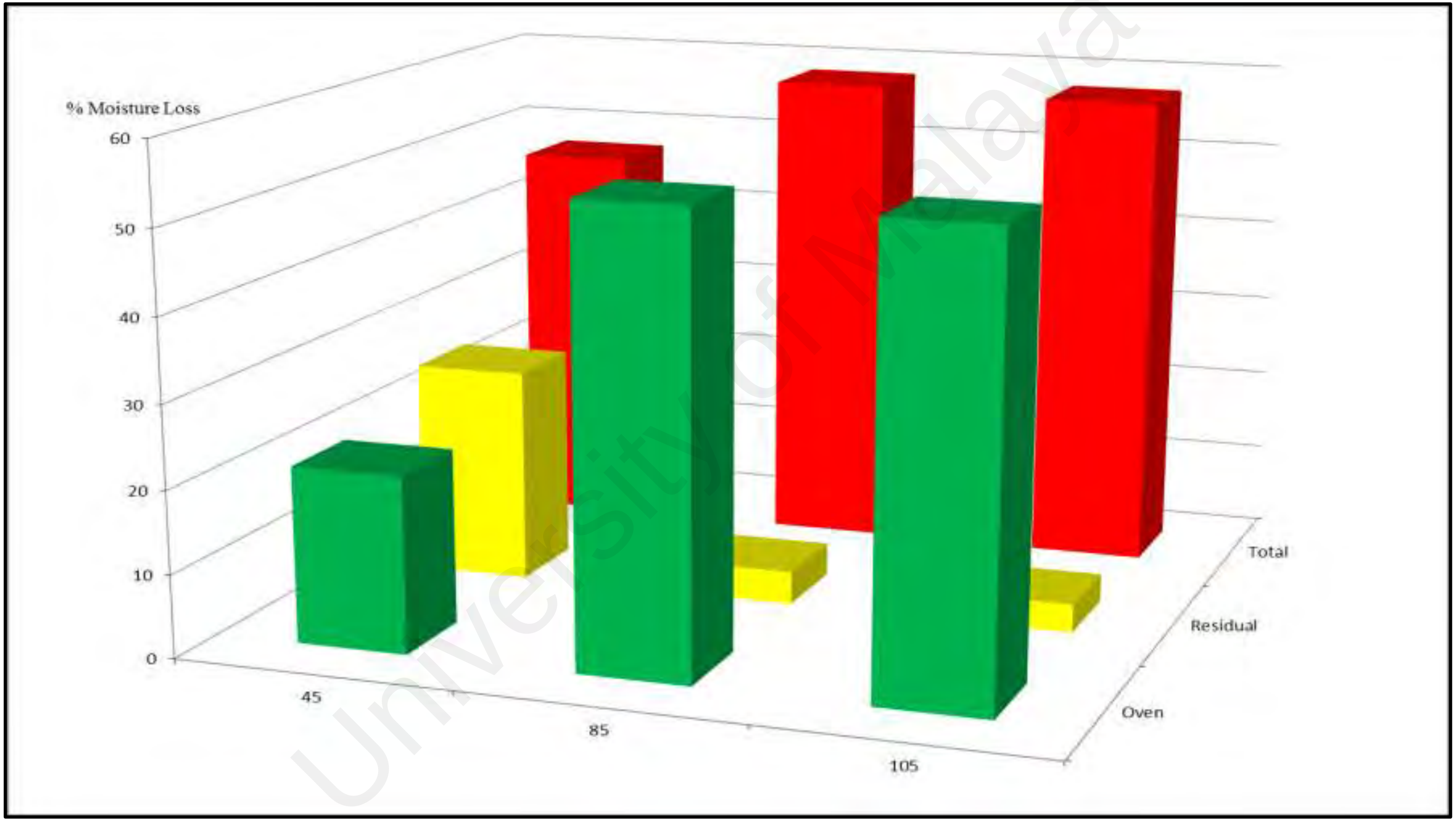


Figure 5.9: Effect of oven drying temperature on moisture content

Finally, the study would like to address the reporting procedure of the analyzed data. The results for moisture content analysis can be reported for the overall waste basis or for the individual components that make up the waste. The results presented in Figure 5.9 do not indicate any significant difference, but it should be noted that analyzing the waste on a single commingle sample gives a bigger range and higher uncertainty in the moisture content, as proved from the results in Chapter 4. In contrast to this, the moisture content reported by analyzing all the components that make up the waste shows a smaller range in the moisture content. Thus, analyzing the moisture content on an individual basis is better as it gives the moisture content of the components and also could be used to get the weighted average moisture content of the commingled waste sample.

5.4.5 Moisture loss during residual drying process

Results on the residual moisture analysis are shown on Figure 5.10. It shows that analyzing the waste by its individual components is definitely more beneficial than analyzing the waste samples based on the commingled sample alone. Another point to note is the fact that there is an average moisture loss of about 7% or each waste sample disregarding the analytical method. This is a big sum and has to be accounted for when the total moisture content of the MSW sample is to be reported.

5.4.6 Total moisture loss for heterogeneous waste its individual components

Figure 5.11 shows the moisture content of the commingled waste samples. This is an average of 30 samples taken from waste collected from Kuala Lumpur, Malaysia. The result shows that the commingled method of analysis had a bigger range, but all three methods gave almost the same averages. Generally, however, the individual method is favored as it gives a more complete picture of the moisture content and characteristics of the MSW.

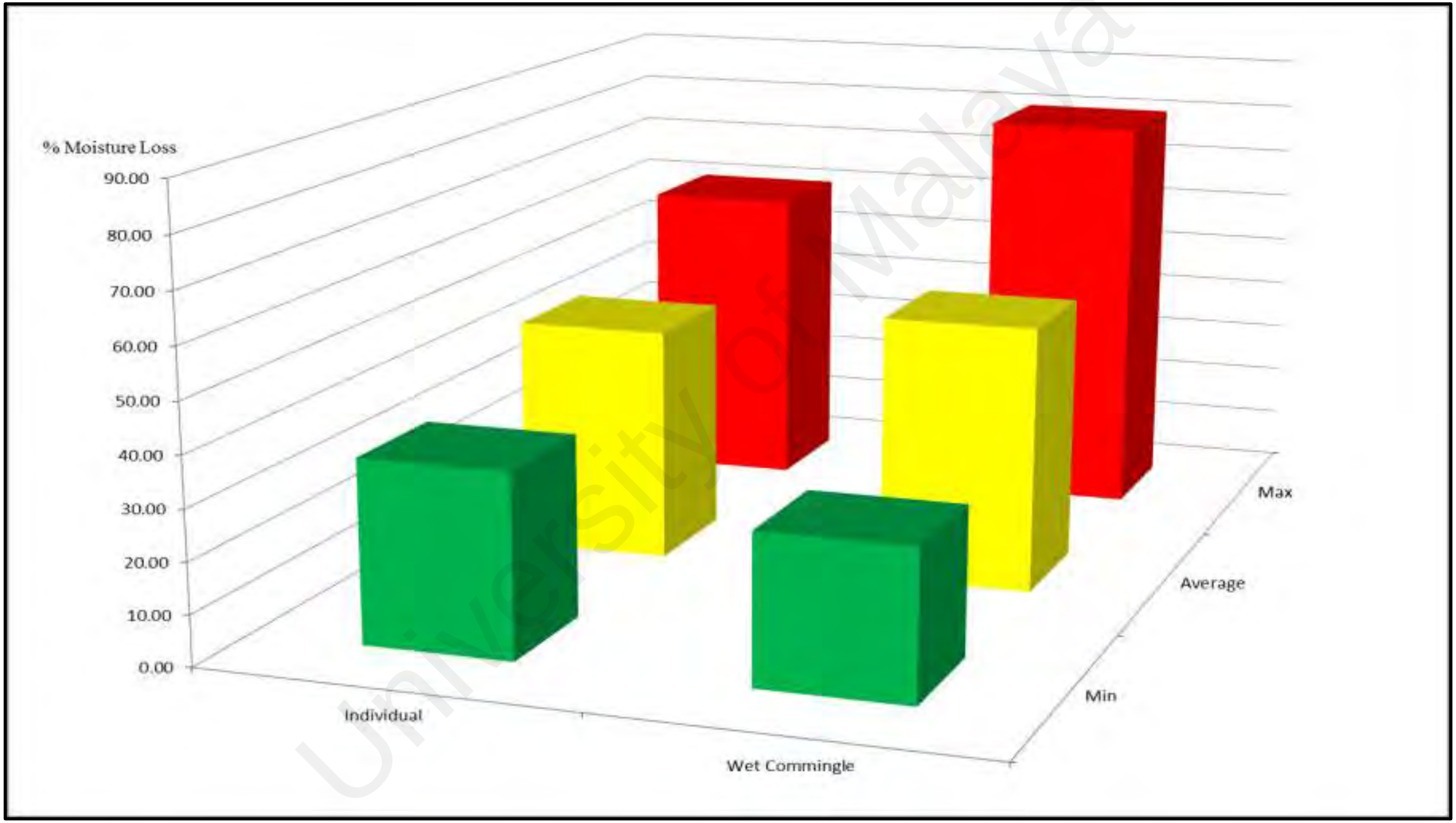


Figure 5.10: Oven moisture loss by different analytical method

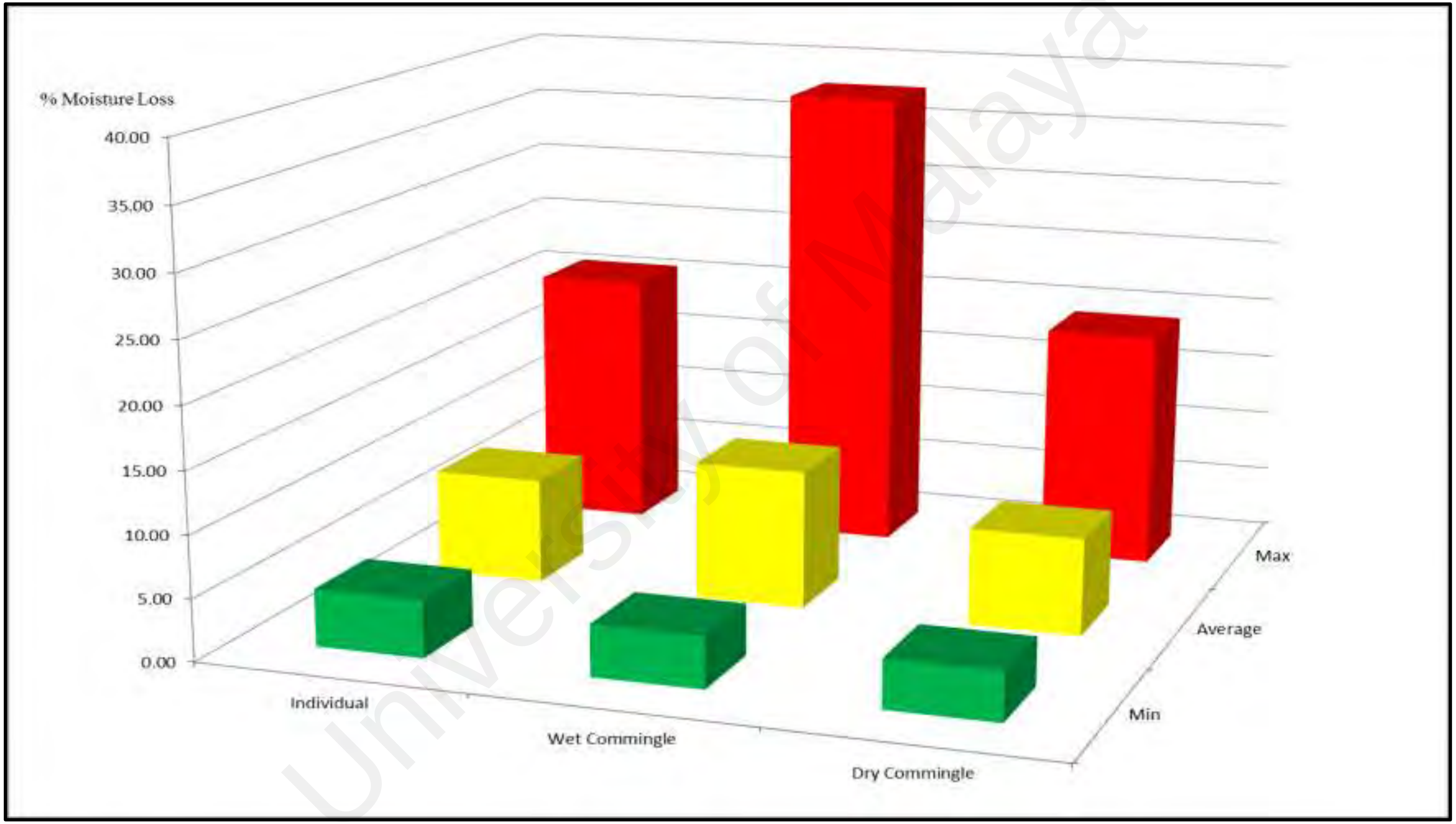


Figure 5.11: Residual moisture loss by different analytical method

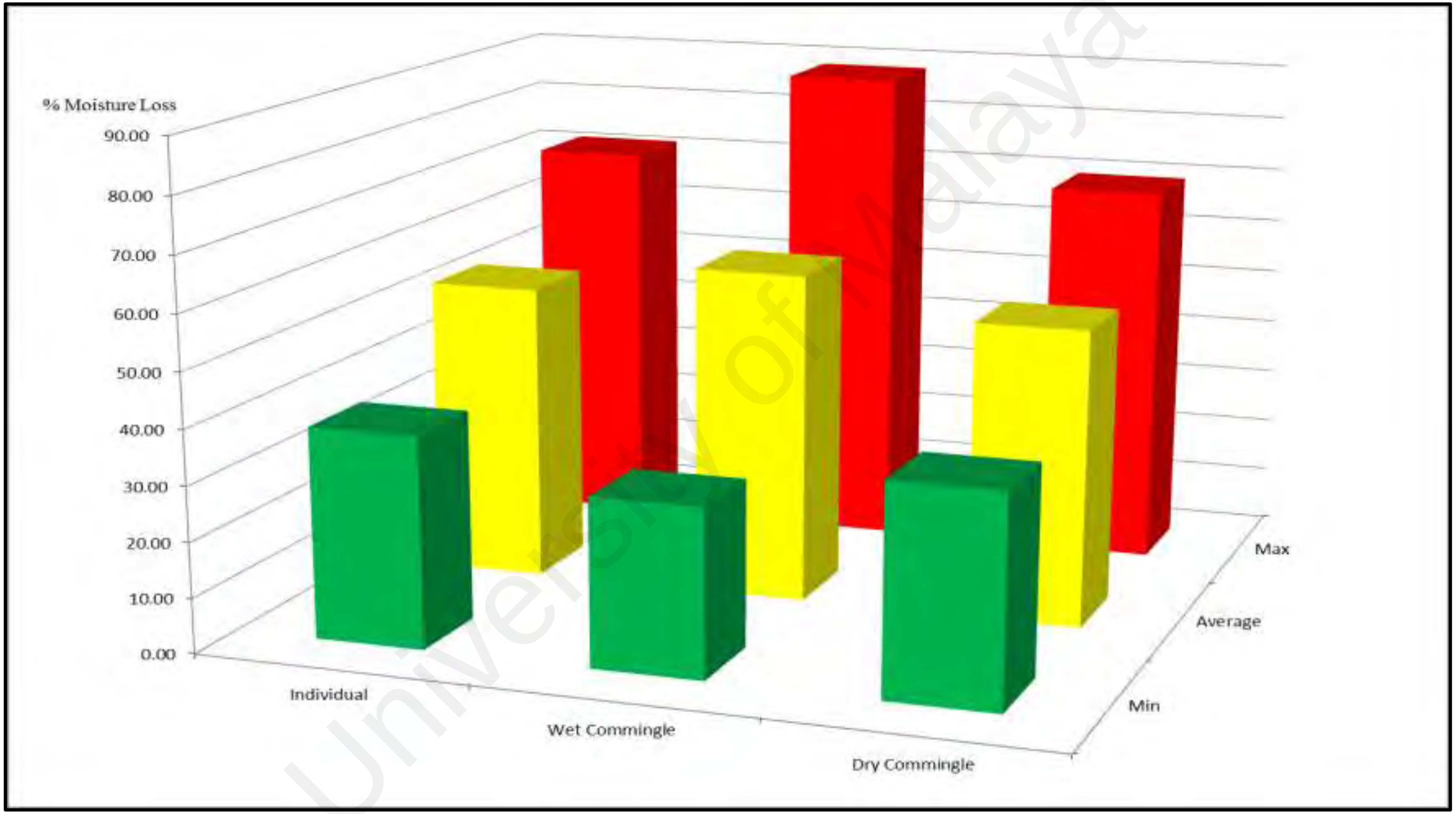


Figure 5.12: Total moisture content of waste samples analyzed by different methods

Finally, Table 5.2 indicates the total moisture content of the individual components that make up the waste. It is important to note that the average moisture content of Malaysian waste was found to be about 50 –55%. This is a high figure when compared to Europe and USA (average of 20–30%) but could be considered as normal for a country situated in the tropics and surrounded by sea. The same can also be said about the moisture contents of the individual components.

Table 5.2: Average Moisture Loss of Individual Components in MSW

	Transportation	Oven Moisture	Residual Moisture	Total Moisture
Food/Organic	1.89	62.10	12.58	68.75
Mix Paper	1.66	39.72	7.58	45.95
News Print	0.91	52.54	7.89	57.20
High Grade Paper	1.53	19.88	6.64	26.74
Corrugated Paper	2.45	45.97	7.91	52.69
Plastic (Rigid)	1.05	13.57	1.19	15.64
Plastic (Film)	1.32	39.99	2.53	42.82
Plastic (Foam)	4.68	40.19	3.86	47.18
Pampers	0.64	63.33	13.38	68.88
Textile	1.10	33.20	5.08	37.69
Rubber/Leather	1.23	11.61	1.96	14.57
Wood	0.65	34.43	9.45	41.28
Yard	0.51	57.91	10.00	62.64
Glass (Clear)	1.06	3.05	0.37	4.47
Glass (Colored)	0.88	1.83	0.31	3.02
Ferrous	1.04	9.88	0.51	11.38
Non-Ferrous	0.00	3.06	1.13	4.15
Aluminum	2.33	12.39	0.54	15.19
Batteries/Hazards	2.23	0.40	0.22	2.84
Fine	1.44	42.36	6.16	47.35
Other Organic	0.29	36.75	9.47	43.03
Other In-Organic	0.00	12.95	4.40	16.78
Others	1.26	25.80	1.31	28.04

From the results presented in this section, it is obvious that moisture content analysis is very important, and all necessary precautions needs to be taken to identify and quantify the amount of moisture the actual sample has, right from the starting of the sampling process. In this case, it can be said that about 1 to 25% of moisture can be lost and not account for, as most standard methods do not mention or prescribe such activities. However, with the conditions in Malaysia and the heterogeneity of the waste these are new precautions that need to be put in place. The sampling and sorting procedure need to have precaution clauses, while, identifying the amount of leachate in the dump truck will surely be needed to have a good picture of the waste.

5.5 Predicting the Calorific Value of MSW

After the determination of the moisture content, the next important parameter that needs to be determined is the calorific value. This is an important parameter for establishing waste management options. Calorific value can be determined through an experimental way by using a Bomb Calorimeter. However, this is a very long process, and requires some amount of skills to handle a calorimeter which operates with pure oxygen at 20 bars. As such over the years, there have been equations created to predict the calorific value of the waste. These equations were created only to reduce the problems of handling a bomb calorimeter and it must be clearly stated that these are just predictive equations for the calorific value of the waste. The ultimate result is still done by using the bomb calorimeter.

In predicting the calorific values of the waste material, the normal parameters used as variables are from the ultimate analysis of the waste itself which are the most common method. Currently the most common equation being used based on analysis results from the ultimate analysis, is called Dulong's equation and was established for calculating the calorific value of Coal as described in Table 2.7 of Section 2.12. There are many more equations for predicting the calorific value. The aim of this section is to see if these equations can actually be predicting the calorific value of the waste accurately.

To do this, this study will first need to create equations to predict the calorific value of Malaysian waste based on results from proximate analysis, ultimate analysis and from the physical characteristics of the waste. This was done based on a set of data from samples that were taken from Kuala Lumpur in 2002. The average values of the physical composition, proximate analysis and ultimate analysis for a set of 30 MSW samples analyzed in 2002 are given on Table 5.3. The calorific value or in this case the higher heating value (HHV) results obtained by using the bomb calorimeter will be used as the base line for all comparisons. Other physical, proximate and elemental data from the 30 samples were than used to create mathematical models by regression analysis. The following procedures were followed to first obtain the local equations:-

1. Results of the 30 samples were used to create equations.
2. Firstly, the main physical components of the waste such as food waste, paper and plastic content which made up about 80% of waste generated in Malaysia was used against their respective calorific value to create multi variable equations which was then simultaneously solved to get a constant value that would then be used to represent the constant for that physical parameter. These are named as physical parameter based equation and the result of such analysis is presented on Table 5.4. For the physical parameter based equation, only one new equation has been able to be created.
3. Next is to create equations based on proximate analysis, for which the same procedure as above was adopted. The result of this analysis is also presented on

Table 5.4 as proximate analysis base equations and there are two equations which gave the same results.

4. Finally, the ultimate analysis data was used to the same effect and the results are shown on Table 5.4.

Table 5.3: Municipal solid waste characteristics generated in Kuala Lumpur

Composition	**Weight %**	**Proximate Analysis (wet)**	**Weight %**
Organics/Food	51.94	Moisture content	55.01
Paper	11.23	Volatile Matter Content	31.36
Plastics	20.97	Fixed Carbon Content	4.37
Wood	1.80	Ash Content	9.26
Rubber	0.68	**Elemental Analysis (dry)**	**Weight**
Textile	1.58	Carbon Content	46.11
Yard	4.50	Hydrogen Content	6.86
Glass	2.54	Nitrogen Content	1.26
Aluminum	0.24	Oxygen Content	28.12
Ferrous	2.28	Sulfur Content	0.23
Fine	2.24	Ash Content	17.06

All possible combinations of the variables that would contribute to the energy content of the MSW were used and evaluated to produce the mathematical equations. These equations are presented in Table 5.4.

To show the accuracy of these new equations in calculating the calorific values, the results of the calculation were compared with the experimental value results of the same sample. These comparison results are given as a percentage of the accuracy in the last column in Table 5.4.

Table 5.4: List of equations short-listed from regression analysis

Name	i ***Equation***	**Units**	**Remarks**	**% Accuracy**
1. Models based on Ultimate Analysis				
Eq. (5)	$HHV = 416.638C - 570.017H + 259.031O + 598.955N - 5829.078$	kJ/kg	Dry (% wt)	62.5
2. Models based on Proximate Analysis				
Eq. (4)	$HHV = 356.248VM - 6998.497$	kJ/kg	Dry (% wt)	68.2
Eq. (3)	$HHV = 356.047VM - 118.035FC - 5600.613$	kJ/kg	Dry (% wt)	69.1
3. Models based on Physical Composition				
Eq. (1)	$HHV = 112.157Ga + 183.386Pa + 288.737Pl + 5064.701$	kJ/kg	(% wt)	77.9
Eq. (2)	$HHV = 81.209Ga + 285.035Pl + 8724.209$	kJ/kg	(% wt)	64.5

HHV = net Calorific Value;
W = weight % of Water, Dry basis;
A = weight % of Ash, Dry Basis
VM = % Volatile Matter;
FC = % Fixed Carbon
W = total moisture;
Pa = paper;
Ga = garbage/food;
Te = textile;
Ru = rubber & leather;
Pl = plastics;

Based on these results, analysis shown on Table 5.4 indicates clearly that the models obtained from the physical composition had a superior percentage in calculating back the experimental value as compared to the models obtained from the proximate and elemental analysis data. The possible explanation for this scenario could be the fact that sample size plays a big role in the accuracy of the resultant correlations. The sample size used for the physical analysis is about 200 - 300 kg where else the sample size for proximate analysis is only about 5 – 10 g and the sample size for the elemental analysis is only 1 – 5 mg. The above observation is in line with some findings in Chapter 2 where other researchers called for bigger sampling size for analysis that would give more accurate and representative results. The findings also goes to prove that, new equations can be developed to predict the calorific value of waste generated in Malaysia.

Next, is to validate these equation performances with other equations on a set of data form a more recent waste characterization study. For this purpose, the same equations were next put to test with the results from the "Survey on SW Composition, Characteristics & Existing Practice of SW Recycling in Malaysia", a study done from 2012 to 2014 for the National Solid Waste Department. Data from Appendix 1, with focus only on Kuala Lumpur, Pulau Pinang and Johor was used as comparison.

First the calorific value of each sample in the study for 2012 from the states of Kuala Lumpur, Pulau Pinang and Johor were tabulated. These three stated were identified as it represented the north, central and south section of the country while also representing the 3 major cities in the country. Next the physical characteristics, proximate analysis and the ultimate analysis results from the study for the 3 states were used to obtain the corresponding calorific values by using the equations in Table 5.4 and a few equations from Table 2.7 in section 2.12. These equations from Table 2.7 were used only to benchmark the performance of the new equations against these more established equations.

Now, after generating all the calorific values and tabulated to form a set of data, it was very difficult to infer any trends or indicators from these numbers. As it was not possible to observe the best performing model, based solely on these data, therefore some statistical evaluations of the predicted and experimentally obtained data were carried out.

The statistical evaluations on the data were namely the average and the range between the maximum and minimum error that occurred, which will indicate the performance of the model. The evaluation criteria for the said parameters should be:-

- The average should be nearest or identical to the experimental value from the bomb calorimeter
- The range (between the maximum and minimum values) shall be the same or the smallest

Appendix 2 gives an example of the calculations – based on physical composition data and how these data were used to calculate the calorific value of the samples using the various equations. The results of these evaluations are shown on Figure 5.13, 5.14 and 5.15 which show the average with the maximum and minimum value. The analysis of these figures ably shows the divergence of the averages, maximum, and minimum values from the experimental data (labeled bomb). An evaluation by the above-mentioned criteria will clearly indicate the best model, which should be similar or closest to the experimental values, without the prediction being skewed either positively or negatively.

Findings based on Figure 5.13 shows that the regression analysis on the physical composition data confirmed the predictions that food/garbage, paper and plastic would contribute positively towards the calorific value. Moisture does not play an active part in this model because the study reports the calorific value in terms of HHV. In contrast to this if the calorific value were to be reported in terms of Lower Heating Value (LHV), then the model would be moisture dependent. Plastic as an individual component accounted for about 20 % of the total weight but it contributed the most to the calorific value (based on the coefficient in the models produced) of the waste followed by paper and food/garbage.

Figure 5.13 shows that data from Equation 1 (eqn1) and Equation 2 (eqn2) is almost equivalent to the experimental data values (bomb) whereas data from the Conventional Equation (obtained from Table 2.7) have moved from the experimental value line. Although Equation 2 is one of the model created by this study, but the percentage accuracy from Table 5.4 value is much lower than that of Equation 1. This indicates the superiority of Equation 1 which is the best suited against the experimental value. These observations further strengthen Equation 1 credibility where the predicted calorific values are not skewed either positively or negatively with a small percentage error range. Validation of accuracy for Equation 2 and the Conventional Equation shows that the predicted calorific value by Equation 2 is skewed negatively whereas the Conventional Equation's prediction was skewed positively.

Thus Equation 1 determined in this study is a much superior tool for the prediction of the HHV values for MSW generated in Malaysia. Lastly, this finding also proves that models determined in foreign countries, such as that by the Conventional Equation above, are not necessarily applicable in predicting the calorific value of MSW in other countries with the same accuracy as that in their native country.

Next, when the same equations were subjected to data from the 2012 study, it gave very interesting results. Results from Figure 5.13 show that for Kuala Lumpur, the equations performed almost perfectly as it did in 2002 but when the same was done for waste sources from other states (Pulau Pinang and Johor), the performance of the equations where completely skewed. The average, maximum and minimum values deviated largely from the experimental based results.

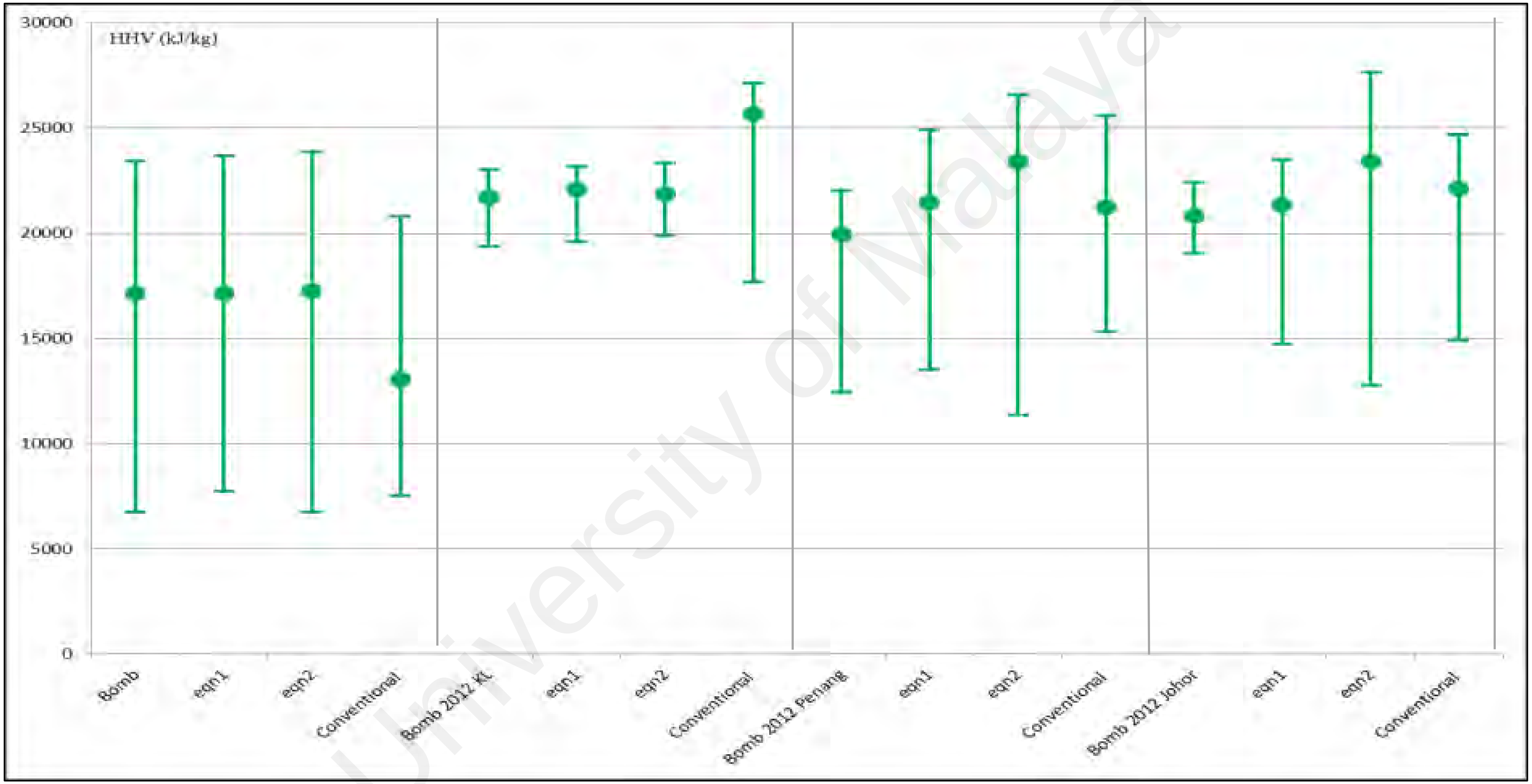


Figure 5.13: Comparison of performance of physical based equations against experimental data

The findings behind this could be that these equations are based on physical characteristics and when the area changes the composition of the waste also changes, making the equation invalid (initially these equations were based on data from Kuala Lumpur in 2002). However, based on a time frame of 10 years different between the original study and the current analysis, there is a good comparison between the experimental result and the calculated results. In this case, it can be said that the equation is localized to the area of creation.

Moving on, Figure 5.14 which shows the trends between the calorific value obtained from equations created as shown on Table 5.4 vs experimental data from this study based on data from proximate analysis. As indicated in Section 2.12, calorific value has a linear function with that of volatile matter and fixed carbon content. This can be supported by the percentage accuracy from Table 5.4, which indicate that volatile matter is a major contributor towards the calorific value.

Based on results on Table 5.4, for proximate analysis-based equations, there is a small difference in the percentage accuracy of Equation 3(eqn3) and Equation 4 (eqn4). However, when these equations are used to calculate the calorific values of the waste and compared against the experimental value (bomb) as shown on Figure 5.14, they give almost the same results, which are well distributed and almost directly on the experimental values. In contrast to this, Benton's equation (from Table 2.7) is skewed towards a positive value. This is shown well in Figure 5.14. Further analysis on the average, maximum and minimum values in Figure 5.14, strengthens the arguments that both Equation 3 and Equation 4 gave good prediction as compared to Benton Equation. This is further strengthened by the finding of the average values, which clearly show that the average value has not moved, indicating that the average for Equation 3 is

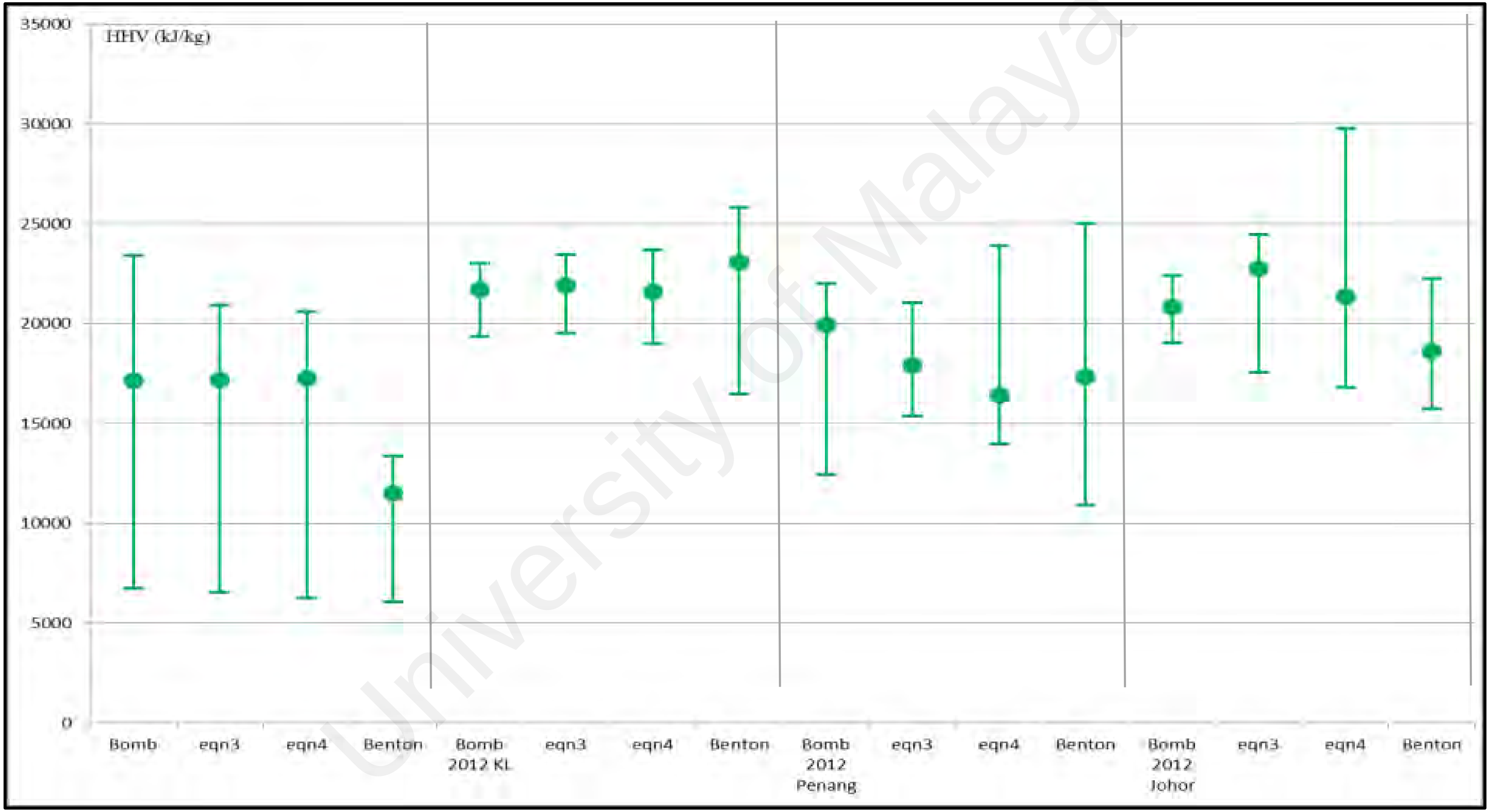


Figure 5.14: Comparison of performance of proximate analysis based equations against experimental data

almost the same with that obtained from the experimental method with a smaller range between the maximum and minimum values, as compared to Equation 4 and Benton's Equation.

Thus, Equation 3 is the best performing equation in this category. The finding of the proximate analysis results strengthens the argument that models are best suited in their own area of creation and this finding is precise and accurate in predicting the calorific value of waste in Malaysia. As done earlier, these early results were then compared to the results from the 2012 study and again almost the same results were obtained as with the physical characteristics-based equations. Findings from Figure 5.14 clearly shows that both equations performed well in Kuala Lumpur but were not able calculate the calorific values in Pulau Pinang and Johor. This firmly shows that equations are very local based.

Finally, Figure 5.15 shows the calorific value from equations that were developed using the elemental analysis data. Findings based on Table 5.4 for Equation 5(eqn5), indicate that calorific value is a positive function of Carbon, Oxygen and Nitrogen, whereas the constant in Equation 5 has a negative value for the Hydrogen. Percentage accuracy analysis from Table 5.4 also revealed that the main contributors to this model are Carbon, Oxygen and Hydrogen.

Validity of the elemental analysis model was carried out and shown in Figure 5.15. There was only one equation in this category as the other equations attempted had a low percentage accuracy value. There have been many equations predicting the calorific value of the waste in this category and from the results in Figure 5.15 it shows that there was not much difference between the calorific value calculated by the existing models such as the Dulong's, as compared to Equation 5. Again, when compared with results from the 2012 study, almost all equations performed will in all areas.

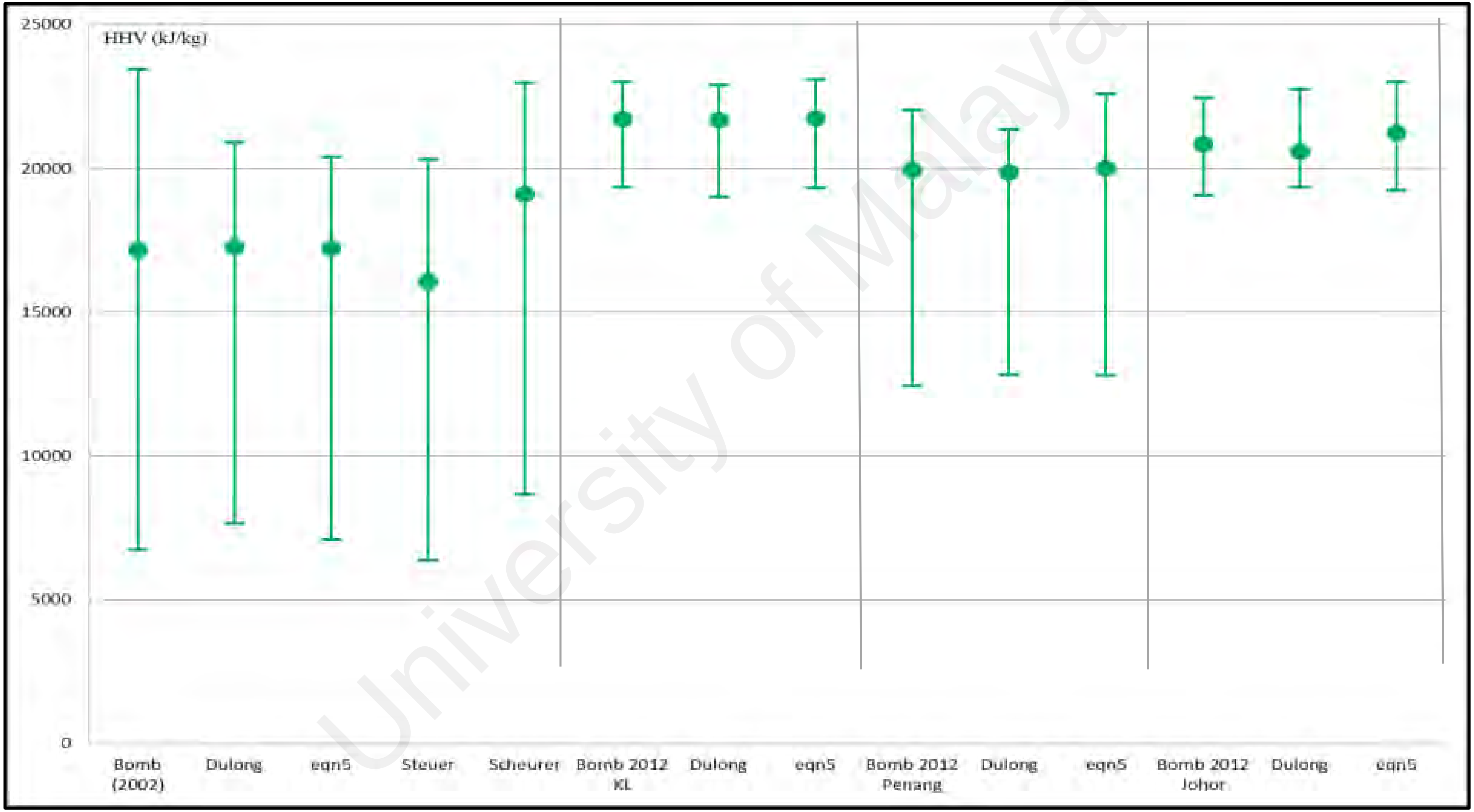


Figure 5.15: Comparison of performance of ultimate analysis based equations against experimental data

Analysis of Figure 5.15, almost all equations performed the same in all areas of the study, not only in the old study but also for the data from 2012 from the different areas in Malaysia. Based on the findings in Figure 5.15, it can be said that the ultimate analysis is a universal solution for predicting the calorific value of heterogeneous municipal solid waste generated in Malaysia. This finding can be attributed to the fact that when it comes to the ultimate analysis results of the waste, the changes in the characteristics are not as drastic when compared to the results for physical components results or from the proximate analysis results. Prior to this, most samples would have to undergo the calorific value experiment but now, these equations can provide the calorific value using the physical composition, proximate analysis and the ultimate analysis data.

Generally, the calorific value of any waste sample is a function of the physical and chemical composition of the sample and that is the basis of creating the equations to predict the calorific value. Points to note form this study on predicting the calorific value of the waste:-

1. The calorific value of the waste can be predicted using the components and the parameters in the analysis of the waste. This was useful to not only to safe cost and time, but these equations become a tool for future waste management planning.
2. From the results it is clear that the best performing equation is the equation based on the ultimate analysis – which is in line with analysis results where ultimate analysis of waste material does not change by more than 10% based on geographical location or by time.
3. In contrast the equations based on Proximate analysis and composition parameters have a tendency to only be able to predict the calorific value to an

accuracy of 10% when performing within the same area, In fact proximate analysis values and composition values do change from area to area and rightfully the equations did not perform.

5.6 Reporting of Physical Characteristics of Heterogeneous Waste

Finally, sections 5.2 to 5.6 have made it clear on which are the best practices that can be adopted for the analysis of the waste generated in Malaysia. In Chapter 5, this study has shown the importance of monitoring moisture content during sampling and sorting, accounting for the leachate in the trucks and also accounting for the moisture loss during transportation. The chapter has also shown the best practices to analyze the waste components on a cost-effective manner. The last part has shown how the calorific value of the sample can be predicted based on the proximate analysis results, ultimate analysis results and also on the physical characteristics results. All of the above have not been dealt with by most standard methods. These can be the reason why when treatment facilities designed for Malaysian waste very often fail. Very often, sampling procedure is done based on some foreign standard method, because Malaysia does not have a standard test method.

Rounding off, this chapter has shown that monitoring and analysis of moisture during sampling is essential in reflecting the actual moisture content of the waste. It can be seen as a critical method introduced in the waste cauterization procedure which will help reflect the actual moisture content of the waste which will ensure that facilities designed in the future will be able to work. Hence this study not only improved the protocol; but also introduced critical steps in the waste analysis process. Going back to the objectives set out in chapter 1, this chapter has been able to show the best methods to analyze moisture content and been able to recommend equations to calculate the calorific value of the waste.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

From the results in Chapter 4 and 5, the biggest component of the waste was the amount of food waste. Food waste can range from a low as 35% to as high as even 60% and in some cases when the truck load sampling method is used, the food waste component has been reported as high as 70%.

In summary, a waste management strategic plan would need to adopt the following:-

1. Collect data on the amount of waste disposed, based on country wide data or for a certain municipality through weighbridge measurement records.
2. Next was to compare these weighbridge data with reported generation rates multiplied with population figures to calculate for recycled and unaccounted waste.
3. Once, this quantity has been established, using the best practices recommended by this study, establish a sampling plan, including where, when and how the samples be will obtained.
4. The next step was to examine the waste generation rate on a per capita basis for the study area.
5. Next is to compare the results from the physical composition and ideally to compare this on an As Generated, As Discarded and As Disposed.
6. Next was to analyze the results from the individual component analysis and the mixed waste analysis which include the proximate analysis, ultimate analysis, calorific value analysis and heavy metal analysis.
7. Lastly was the reporting procedure for all this sampling and analysis.

6.2 Conclusions

Relating back to the objectives of this study, the following conclusions were derived:-

1. A complete analysis of the waste and the components that make up the heterogeneous municipal solid waste generated in Malaysia was presented in Appendix 1. This was the first of its kind and would form the basis for future benchmarking.
2. Moisture loss analysis must take into account the amount of moisture loss during the sampling and during the transportation of the samples to the laboratory. Additionally, the monitoring of the amount of leachate from the truck is essential to understand the amount of free water apart from the moisture content. Together, this has been shown to contribute up to an additional 15% towards the moisture content of the waste.
3. Mathematical equations that are based on the ultimate analysis of the waste was still the best way to predict the calorific value of the waste, however the proximate analysis could also be equivalently be used to predict the calorific value of the waste.
4. The protocol as shown on Figure 6.1 would be the best and improved approach for sampling, analysis and reporting of waste in Malaysia.

The complete analysis of the heterogeneous municipal solid waste generated, discarded and disposed, for the various states in Malaysia and based on the various sources that generate this waste is given in Appendix 1 of this thesis. Thus far, there is no other more complete data for the whole of Malaysia in record.

This study had established the fact that analyzing the MSW on a combined method is much better when compared to the individual component method or the commingled method of analysis. This combined method of analysis gives a relatively good result with the workload and also the cost of analysis is less. In addition to this, the proximate composition of the MSW generated is about 55% moisture, 30% volatile matter, 5% fix carbon and 10% ash could also be said a consistent with other published data. Finally, this thesis was also been able to highlight the maximum and minimum range of values for the various proximate characteristics of waste.

The next objective was to develop an accurate method to analyses the moisture content of the waste. The analysis of moisture content for MSW has been thoroughly investigated in this study and it has identified that there is significant loss of moisture from waste that is usually not reported, with a loss of about 5 to 15% of leachate in the truck which was not accounted for and another 3% on average lost during the sampling and sorting process which can vary from -4 to 8%, and another average of 2% lost during transportation. The combined moisture loss from these parts of the sampling, sorting and analysis process from about 1 to 25% by weight, thus indicating the necessity and importance for observations and recording of moisture loss to be done during these two processes. As for oven drying, it can be concluded that the best analytical approach was found to be drying a sample size of 1 kg for 24 hours at a temperature of 85°C. The oven and residual moisture process can be carried out for a commingled sample or for all the components, with the latter being preferred. Typically, the amount of moisture lost during this process is about 40 – 45 % whereas the amount of moisture lost in the residual moisture process is about 5 to 15 %. Finally, the total moisture content in the MSW, taking all possible moisture loss into account, was found to be about 50 – 55%. This was a much higher than the conventionally reported total moisture content based solely on the oven drying process, which would indicate the moisture content in the MSW to be around 40 to 45%.

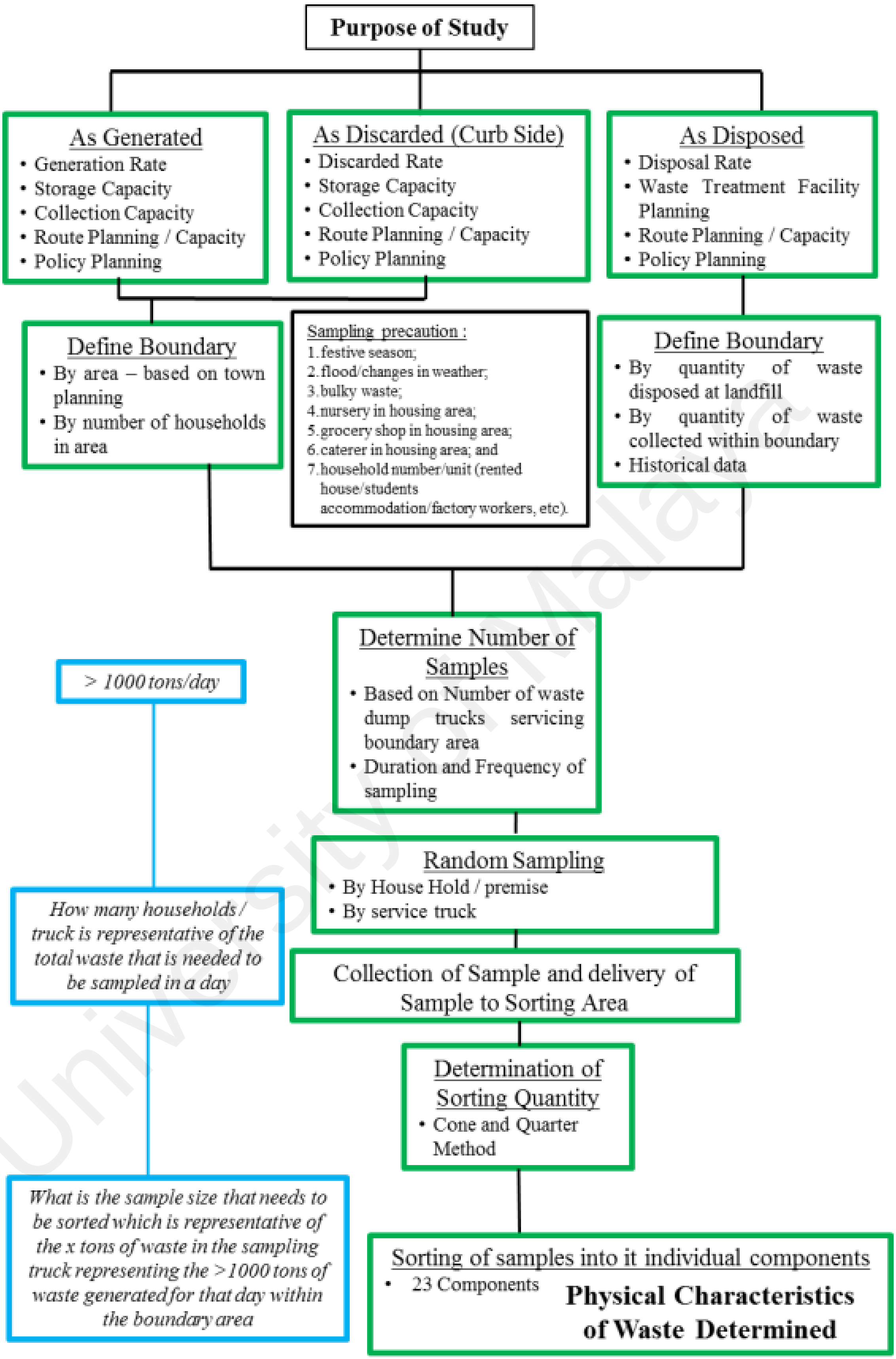


Figure 6.1: Flow Chart for physical characterization

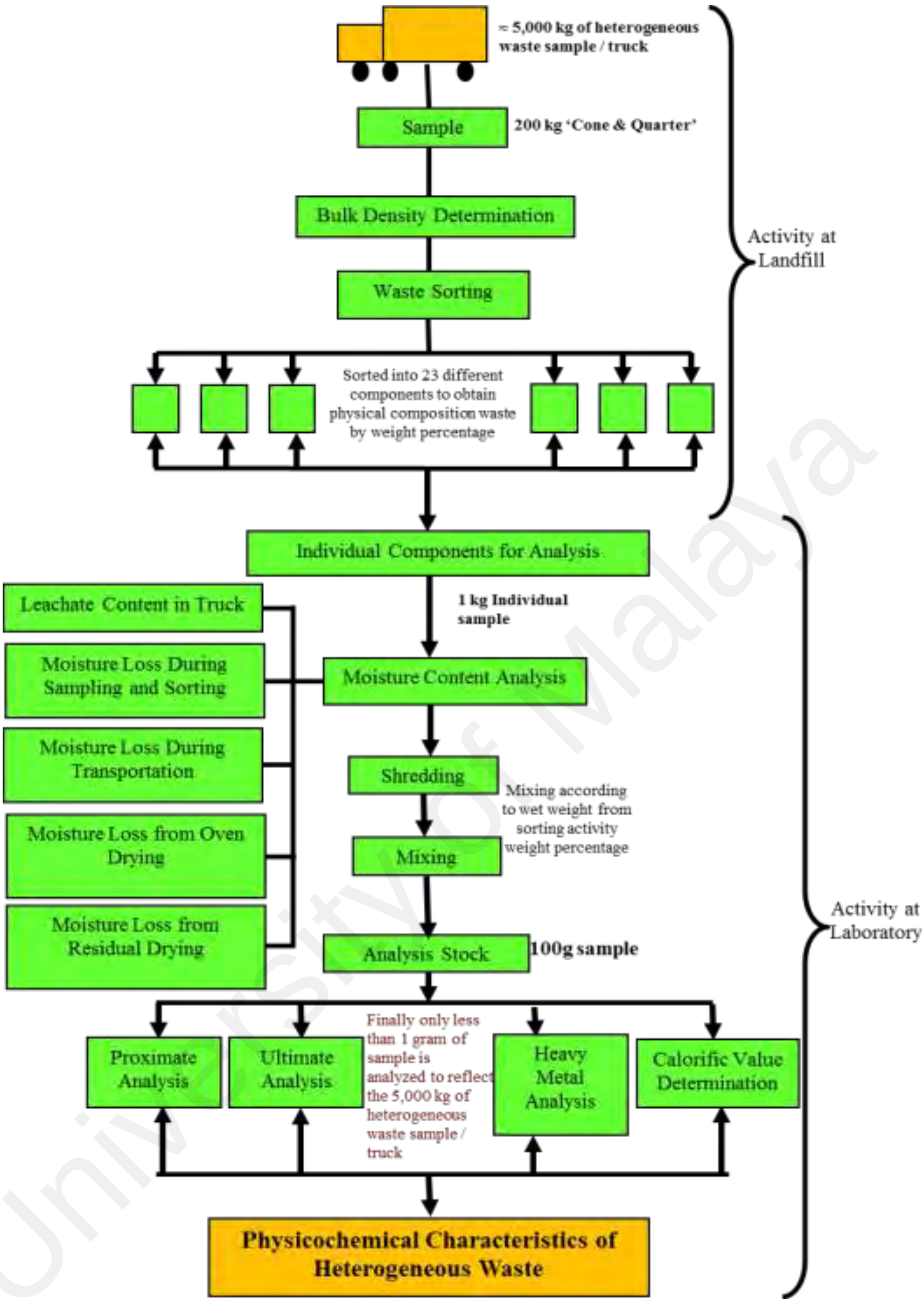


Figure 6.2: Flow Chart for physicochemical characterization

As for the determination and prediction of calorific value through the use of established equations, the following conclusions can be made: -

1. The equations create in 2002 from Malaysian waste characteristics based on the physical composition is the best predictive equation from this study. Thus, the bigger the sample size the more accurate the data, leading to a better mathematical equation and finally a more precise HHV prediction.
2. All mathematical equations created based on waste characteristics in Malaysia performed better than other equations in predicting the HHV values when compared against the HHV values obtained experimentally. This proves beyond any doubt, that an equation for the prediction of the calorific value of MSW is best suited in its own area of study.
3. There was a linear relationship between parameters that make up the physical composition, proximate analysis and elemental analysis towards the energy content of MSW. It was possible to build equations based on data from physical composition, proximate and elemental analysis using regression analysis.

The establishment of an improved protocol for waste sampling and analysis, had been clearly pictured out Figure 6.1 and 6.2. The final flow chart is based on the best practices recommended within this study. The best practice with regards to the 4 methods for doing sapling of MSW was the 'Cone and Quarter' method. The considerations for this were based on the time taken to segregate one sample, the manpower needed and also the associated cost in the sampling process. Apart for this the number of components that the sample needs to be segregate into and this was something that can only be determined based on the objectives of the sampling. However, the experience from the sampling process carried out from 2012 to 2014 shows that sorting to at least 23 components was a realistic figure to achieve in the spot sampling method. From this, it can be concluded that the flow process recommended in Figure 6.1 and 6.2 is the best that should be adopted for Malaysia.

6.3 Implications of This Research

This study has been able to develop an improved protocol for the characterization of the heterogeneous waste generated in Malaysia. For many decades, Malaysia has been relaying very heavily on Standard methods which have been developed in either Europe or United States. Although their standards are of very high credibility, unfortunately the mentality of the people who generate these wastes in Malaysia are still very low and due to this the heterogeneity of the waste generated is higher, due to the non-sorting behavior on the people in Malaysia. As such, when the waste was unsorted, and with the heavy moisture content, very often these foreign standards do not reflect the true picture of the waste material which was being generated.

This can be seen in the numerous projects which has been doomed from the start, because the waste characteristics are either not analyzed or when analyzed, reveal conditions that do not reflect the actual situation of the waste. Through this study, and the various sampling studies that have been done over the years, the results have shone a huge increase in the moisture content and the reduction in the calorific value of the waste.

The immediate impact from this study is to change the current way of sampling waste in Malaysia. This change in sampling methodology would provide a proper picture of the waste being generated and proper waste management decisions and treatment can be made. Again, all management decisions need accurate and up to date information so that the decision made can be made on an informed basis reducing the prospect of failure.

The proposed protocol has the following implications:-

- Establish an area of study with the appropriate sampling plan taking into consideration the amount of waste, the seasonal factor.
- Method of collecting the samples, sorting the samples and subsequently sending the samples for analysis. This study proposed new steps in the methodology which will give greater accuracy in defining the characteristics of the waste and the precautions.
- By employing these recommended methods, waste management in Malaysia should be able to have reliable data which can be used to accurately design facilities for the treatment of the waste.

These protocols would help address issues related to the failure of treatment technologies in Malaysia, which are related to the basic knowledge of waste characteristics.

6.4 Contributions of This Research

This research did many sub studies to help identify and research various methodologies and recommend the best methods to be adopted for the national waste characterization program. This research can now be used as a benchmark for heterogeneous waste characterization in Malaysia and the region of Asia which has similar waste problems. As such, this study has contributed the government with the ability to give the true picture of the waste generated and this allowed for more informed decision making.

As for the private sector, now embarking on privatizing the waste management industry in Malaysia, these protocols contribute very well for them which can be identified as follows:

- The development of protocol to characterize waste would lead to batter management, and data can be obtained accurately at a faster time and at a lower cost.
- The use of locally established equations to predict the calorific value will reduce cost and time in establishing the calorific value of the waste.
- Databases on waste characteristics would allow the industry players to know the current situation of the waste and be able to predict the situation in the future include the amount of investment needed.

The most important benefit and contribution to the waste industry would be, as cost become higher, the need for more simplified methods while addressing accuracy and timing was essential for waste management planning and this study has helped resolved these issues.

6.5 Recommendations for National Adaptation

This research has been successful in developing the protocol for characterization of heterogeneous waste generated in Malaysia. This protocol and the recommended methods have been highlighted in section 6.2 of the chapter. This research would like to recommend the following:

1. That Figure 6.1 and 6.2 be adopted by the National Standards committee as a national standard for sampling and analysis of Municipal Solid Waste in Malaysia.
2. Moisture content analysis was a very important analysis in Malaysia. The findings of this study have identified these precautions during sampling, and this

can be recommended to all countries worldwide to adopt these precautions during sampling and be adopted as part of the sampling and sorting process.

3. The need to understand the calorific value was important, and very often a critical component in a waste study. However, most studies don't do it extensively due to the cost and time factor. In this study, there are local equations which have been able to prove that it can be used to predict the calorific value of the waste.

6.6 Future Studies

By far, this study has been able to show a few conclusions on how sampling, analysis and reporting should be done in an industry which is still in an infancy stage in Malaysia. However, there still many more questions that needs answers, and amongst those very pertinent are:-

1. This study did not address the time factor and the seasonal variation in the analysis in obtaining sampling plan and sample size. Due to the limited data from the weigh bridge available, this is almost impossible to be done currently, however, this could be a major factor in the changes in the physical components of the MSW.
2. The social profile of the waste generators were not analyzed, which can be broken down to age profile, income profile, sex profile and even cultural profile, which if done can show a tremendous trend in the kind of waste that is generated and disposed of while also indicating the kind of programs that can be targeted towards these group of people to reduce or recycle the amount of waste generated. This could be used to show consumption pattern, and with the change in society and with the drive towards sustainable consumption, what will be the

type of waste generated in the future and how do we than make the necessary waste management decisions.

3. Due to the extent of waste generated and the scale of the sampling planning and process, it is essential, that an accurate and predictive sampling planning tool be established to ensure that when samples are taken it is representative of the area to be sampled, taking the time factor and the cost factor as these two factors very often limit the samples taken thus limiting the results and finally impacting the method in which the MSW management will be decided.
4. The call for larger samples used for analysis is very essential. As pointed out, in Chapter 5, how can a sample of 0.1 gram be able to represent heterogeneous waste in a 5 ton truck? The need to establish new ways to analyze sample in kilogram sizes are necessary and needs to be invented.

REFERENCES

Abu Qdais, H. A., Hamoda, M. F., & Newham, J. (1997). Analysis of residential solid waste at generation sites. *Waste Management Resources, 15*(4), 395-405.

Agrawal, R. K. (1998). A rapid technique for characterization and proximate analysis of refuse-derived fuels and its implications for the thermal conversion. *Waste Management and Research, 6*(1), 271-280.

Al-Khatib, I. A., Monou, M., Abu Zahra, A. S., Shaheen, H. Q., & Kassinos, D. (2010). Solid waste characterization, quantification and management practices in developing countries. A case study: Nablus district - Palestine. *Journal of Environmental Management, 91*(5), 1131-1138.

Alhumoud, J. M., Altawash, M., & Aljallal, L. (2007). Survey and evaluation of household solid waste generation and compositions in Kuwait. *International Journal of Environment and Health, 1*(4), 517-527.

Aziz, A. H. A. (1996). *Study on residential waste generation rates and composition in selected areas Perbandaran Petaling Jaya (MPPJ)* (Bachelor's dissertation). Retrieved on July17, 2012 from www.elib.upm.edu.my/sumber_eletronik/e_theses

Bandara, N. J., Hettiaratchi, J. P., Wirasinghe, S. C., & Pilapiiya, S. (2007). Relation of waste generation and composition to socio-economic factors: A case study. *Environmental Monitoring and Assessment, 135*(1-3), 31-39.

Batool, S. A., Chaudhry, N., & Majeed, K. (2008). Economic potential of recycling business in Lahore, Pakistan. *Waste Management, 28*(2), 294-298.

Beigl, P., Lebersorger, S., & Salhofer, S. (2008). Modelling municipal solid waste generation: A review. *Waste Management, 28*(1), 200-214.

Bernache, G. (2003). The environmental impact of municipal waste management: The case of Guadalajara metro area. *Resources, Conservation and Recycling, 39*, 223-237.

Boer, E. d., Jedrczak, A., Kowalski, Z., Kulczycka, J., & Szpadt, R. (2010). A review of municipal solid waste composition and quantities in Poland. *Waste Management, 30*(3), 369-377.

Bolaane, B., & Ali, M. (2004). Sampling household waste at source: Lessons learnt in Gaborone. *Waste Management & Research, 22*, 142-148.

Boldrin, A., & Christensen, T. H. (2009). Seasonal generation and composition of Danish garden waste. *Waste Management, 30*, 551-557.

Brunner, C. R. (1993). *Hazardous waste incineration* (2nd ed.). New York: McGraw-Hill.

Buckley, T. J. (1991). Calculation of higher heating value of biomass material waste component from elemental analyses. *Resources and Conservation, 5*(4), 329-341.

Buenrostro, O., Bocco, G., & Cram, S. (2001). Classification of sources of municipal solid wastes in developing countries. *Resource, Conservation and Recycling, 32*(1), 29-41.

Burnley, S. J. (2007). A review of municipal solid waste composition in the United Kingdom. *Waste Management, 27*(10), 1274-1285.

Burnley, S. J., Ellis, J. C., Flowerdewc, R., Polld, A. J., & Prosser, H. (2007). Assessing the composition of municipal solid waste in Wales. *Resource, Conservation and Recycling, 49*(3), 264-283.

Cheremisimoff, P. N., & Morresi, A. C. (1976). *Solid waste as a potential. Energy from solid waste*. New York: Marcel Dekker.

Dahlén, L., & Lagerkvist, A. (2008). Methods for household waste composition studies. *Waste Management, 28*(7), 1100-1112.

Demirbas, A. (1996). Calculation of higher heating values of biomass fuels. *Fuel, 76*(5), 431-434.

Den, B. J., Jaroszynska, J., & Szpadt, R. (2012). Monitoring of municipal waste generated in the city of Warsaw. *Waste Management Resources, 30*(8), 772-780.

Dennison, G. J., Dodd, V. A., & Whelas, B. (1996). A socioeconomic based survey of household waste characteristics in the city of Dublin Ireland. I. Waste composition. *Resource, Conservation and Recycling, 17*(3), 227-244.

Edjabou, V. M. E., Jensen, M. B., Götze, R., Pivnenko, K., Petersen, C., Scheutz, C., & Astrup, T. F. (2015). Municipal solid waste composition: Sampling methodology, statistical analyses, and case study evaluation. *Waste Management, 36*, 12-23.

Fernandez, P., Diaz, R. M., & Xiberta, J. (1997). Correlation of properties of spanish coals with their natural radionuclides contents. *Fuel, 76*(10), 951-955.

Franjo, C. F., Ledo, J. P., Anon, J. A. R., & Regueira, L. N. (1992). Caloric value of municipal solid waste. *Environmental Technology, 13*(11), 1085-1089.

Gidarakos, E., Havas, G., & Ntzamilis, P. (2006). Country report: Municipal solid waste composition determination supporting the integrated solid waste management system in the island of Crete. *Waste Management, 26*(6), 668-679.

Gómez, G., Meneses, M., Ballinas, L., & Castells, F. (2008). Characterization of urban solid waste in Chihuahua, Mexico. *Waste Management, 28*(12), 2465-2471.

Götze, R., Boldrin, A., Scheutz, C., & Astrup, T. F. (2016). Physico-chemical characterization of material fractions in household waste: Overview of data in literature. *Waste Management, 49*, 3-14.

Gu, B., Jiang, S., Wang, H., Wang, Z., Jia, R., Yang, J., . . . Cheng, R. (2017). Characterization, quantification and management of China's municipal solid waste in spatiotemporal distributions: A review. *Waste Management, 61*, 67-77.

Haith, D. A. (1998). Material balance for municipal solid waste management. *Journal of Environmental Engineering, 124*(1), 67-75.

Hassan, M. N., K., Y. M., Sulaiman, W. N. A., & Rahman, R. A. (1998). Issues and problem of solid waste management in Malaysia, *National review in environmental quality management in Malaysia towards the next two decades* (pp. 179-225). Selangor, Malaysia: Institute for Environment and Development, University Kebangsaan Malaysia.

Herrmann, R. H., & Berry, J. R. (1991). The impact of recycling and pre-combustion processing of municipal solid waste on fuel properties and steam generation, *Refused-derived fuel (RDF) quality, standard and processing* (pp. 9-15). United States: ASME.

Ikeguchi, T., Karchannawong, S., & S., K. (1993). Improvement of and empirical equation relating ash and carbon contents of municipal solid waste. *Environmental Technology, 15*, 395-399.

JPSPN. (2013). *Survey on solid waste composition, characteristics & existing practice of solid waste recycling in Malaysia*. Putrajaya, Malaysia: Jabatan Pengurusan Sisa Pepejal Negara.

Kaur, H., & Singh, K. (1995). Waste minimization through reuse and recycling: A case study in Petaling Jaya. *Proceedings of the 2nd National Seminar on Advances in Environmental Control Technology. Kuala Lumpur, Malaysia*: University of Technology Malaysia.

Kirklin, D. R., Colbert, J. C., Decker, P. H., Ledford, A. E., Ryan, R. V., & Dohalski, E. S. (1982). The variability of municipal solid waste and its relationship to the determination of the calorific value of refuse-derived fuels. *Resources and Conservation, 9*, 281-300.

Larson, E. D., Worrell, E., & Chen, J. S. (1996). Clean fuel for municipal solid waste for fuel buses in metropolitan areas. *Resources, Conservation and Recycling, 17*(4), 273-298.

Liikanen, M., Sahimaa, O., Hupponen, M., Havukainen, J., Sorvari, J., & Horttanainen, M. (2016). Updating and testing of a Finnish method for mixed municipal solid waste composition studies. *Waste Management, 52*, 25-33.

Lin, C. J., Chyan, J. M., Chen, I. M., & Wang, Y. T. (2013). Swift model for a lower heating value prediction based on wet-based physical components of municipal solid waste. *Waste Management, 33*(2), 268-276.

Lin, X., Wang, F., Chi, Y., Huang, Q., & Yan, J. (2015). A simple method for predicting the lower heating value of municipal solid waste in China based on wet physical composition. *Waste Management, 36*, 24-32.

Liu, J. I., Papde, R. D., & Holsen, T. M. (1996). Modeling the energy content of municipal solid waste using multiple regression analysis. *Journal of the Air & Waste Management Association, 46*, 650-656.

Lorenz, H., & Rau, H. (1997). A new method for investigating the combustion behavior of solid fuels in FBC. *Fuel, 77*(3), 127-134.

Malaysia, Department of Standard (2012). MS 2505: 2012 - Guidelines for sampling of household solid waste - Composition and characterization analysis. Malaysia.

Miezah, K., Obiri-Danso, K., Kádár, Z., Baffoe, B., & Mensah, M. (2015). Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. *Waste Management, 46*, 15-27.

MIGHT. (2014). *Green technology foresight 2030: Waste*. Selangor, Malaysia: Malaysian Industry Government Group for High Technology.

Ojeda-Benitez, S., Armijo, d. V. C., & Ramírez-Barreto, M. E. (2003). Characterization and quantification of household solid wastes in a Mexican city. *Resource, Conservation and Recycling, 39*(3), 211-222.

Penner, S. S., Chang, D. P. Y., Gourlard, R., & Lester, T. (1988). Waste incineration and energy recovery. *Fuel and Energy, 13*(12), 845-851.

Qu, X., Li, Z., Xie, X., Sui, Y., Yang, L., & Chen, Y. (2009). Survey of composition and generation rate of household wastes in Beijing, China. *Waste Management, 29*(10), 2618-2624.

Ranieri, E., Ionescu, G., Fedele, A., Palmieri, E., Ranieri, A. C., & Campanaro, V. (2017). Sampling, characterization and processing of solid recovered fuel production from municipal solid waste: An Italian plant case study. *Waste Management Resources, 35*(8), 890-898.

Raveendran, K., & Ganesh, A. (1996). Heating value of biomass and biomass pyrolysis products. *Fuel, 75*(15), 1715-1780.

Riber, C., Petersen, C., & Christensen, T. H. (2009). Chemical composition of material fractions in Danish household waste. *Waste Management, 29*, 1251-1257.

Rozainee, M., M., R., & Looi, S. (1999). Production of renewable energy and biomass and waste materials using fluidized bed technologies. *Proceedings of the World Renewable Energy Congress* 33, 57-61.

Saidan, M. N., Drais, A. A., & Al-Manaseer, E. (2017). Solid waste composition analysis and recycling evaluation: Zaatari syrian refugees camp, Jordan. *Waste Management, 61*, 58-66.

Salim, M. Z. (1993). Solid waste management: Materials flow and generation of solid waste, *Short course on solid and hazardous waste management*. Johor, Malaysia: University Technology Malaysia.

Salleh, M. N., & Kathiravale, S. (2000, Oct). *The characterization of Kuala Lumpur and Labuan municipal solid waste.* Paper presented at the MINT R&D Seminar 2000, Selangor, Malaysia.

Sujauddin, M. S., Huda, S. M. S., & Rafiqul, H. A. T. M. (2008). Household solid waste characteristics and management in Chittagong, Bangladesh. *Waste Management, 28*, 1688-1695.

United Nation Environmental Programme. (2015). *Global Waste Management Outlook.* Osaka, Japan: Author.

United Nation Environmental Programme. (2017). *Asia Waste Management Outlook.* Osaka, Japan: Author.

United States Environmental Protection Agency. (2002). Municipal solid waste in the United States: 2000 facts and figures (pp. 34). Washington, DC: Author.

Yunus, M. N. M., Mohamed, Z., & Kumar, R. (2000, Oct). *Progress in the treatment of MSW in TOP.* Paper presented at the MINT R&D Seminar 2000, Selangor, Malaysia.