# MATERIAL FLOW ANALYSIS OF MERCURY AND ZINC IN JERAM SANITARY LANDFILL

**NURHAWA BINTI ABDUL RASHID**

**FACULTY OF SCIENCE**
**UNIVERSITY OF MALAYA**
**KUALA LUMPUR**

**2017**

## ABSTRACT

In this research, two heavy metal (Hg and Zn) flow was identified by using Material Flow Analysis (MFA) modelling. Field sampling and heavy metal analysis were carried out for six months in a sanitary landfill located in Selangor. Interview sessions with stakeholders were done to gain additional data. All heavy metal analysis was carried out based on USEPA Method 200.8 standard, activated iodated charcoal traps and general emission equation model. STAN 2.5 software was utilized to perform MFA models in this study. Total waste received in Jeram Sanitary Landfill in 2014 was 839,500 tonne. 37.7% of waste received composed of food waste and 4% was household hazardous waste. A comparison between current waste flow analysis and estimated waste analysis under two different scenarios were generated. Results indicated that if the national recycling rate of 22% is achieved and the amount of waste to be recovered in the MRF can be increased to 400 tonne/day**,** total amount of waste that can be recovered from this landfill will increase from 10,949 tonne/year to 87,600 tonne/year. Estimation of economic value of current recyclable waste deposited in this landfill was also explored. Finding shows that total amount of potential profit was approximately RM 55 million or 12 million USD per year. Total input of material into the landfill system was 3 million tonnes per annum and total material exported from the system was 1 million tonnes per annum. Completed Hg flow revealed that the input of Hg into the landfill system was 1962 kg/year, the output was 2.3 kg/year and the stock of Hg that remained inside the landfill was 1960 kg/year. Inputs of Hg into the systems were from MSW received by the landfill (1897 kg/year), clay material which was used as the soil cover (65 kg/year) and also precipitation (0.04 kg/year). Hg was released to the environment as output through landfill gas (0.004 kg/year), working face (0.32 kg/year), treated leachate (1.54 kg/year) and surface runoff (0.42 kg/year). Meanwhile, the input of Zn into the landfill was from waste deposited (11,400 kg/year) and soil cover (7,211 kg/year). Outputs of

Zn identified in this system were surface runoff (32 kg/year) and treated leachate (3 kg/year). Thus, these MFAs can be used as a supporting tool for the authority to start implementing necessary actions to reduce heavy metal accumulation in sanitary landfill system.

**Key words**. MFA, Sanitary Landfill, Hg, Zn

## ABSTRAK

Dalam kajian ini, Analisis Aliran Bahan (MFA) telah digunakan untuk mengenalpasti dua logam berat iaitu merkuri (Hg) dan zink (Zn). Sesi temubual, kajian lapangan, proses pengambilan sampel dan pelbagai analisis makmal seperti analisis logam berat telah dijalankan selama enam bulan di sebuah tapak pelupusan sisa yang terletak di Selangor. Semua analisis logam berat telah dijalankan berdasarkan standard USEPA 200.8*, activated iodated charcoal traps* dan *general emission equation model*. Perisian STAN 2.5 telah digunakan untuk menghasilkan semua model MFA dalam kajian ini. Jumlah sisa yang diterima di Tapak Pelupusan Sanitari Jeram pada tahun 2014 ialah 839,500 tan. 37.7% adalah sisa makanan dan 4% adalah sisa berbahaya dari rumah. Satu MFA bagi sisa yang diterima di tapak pelupusan telah dibuat berdasarkan dua senario iaitu jika kadar kitar semula negara sebanyak 22% berjaya dicapai dan jumlah sisa yang diproses oleh MRF dapat ditingkatkan menjadi 400 tan sehari. MFA yang terhasil menunjukkan jumlah sisa yang boleh dikitar semula dari tapak pelupusan ini akan meningkat daripada 10,949 tan kepada 87,600 tan setahun. Anggaran nilai ekonomi bagi sisa yang boleh dikitar semula mendapati jumlah potensi keuntungan adalah RM55 juta atau 12 juta USD setahun. MFA bagi sistem tapak pelupusan menunjukkan bahawa total input ke dalam tapak pelupusan adalah 3 juta tan setahun dan jumlah bahan yang dieksport dari sistem ialah 1 juta tan setahun. MFA Hg menunjukkan bahawa input Hg ke dalam sistem tapak pelupusan adalah 1,962 kg setahun, pengeluaran Hg daripada sistem ini berjumlah 2.3 kg setahun, dan stok Hg yang kekal di dalam tapak pelupusan adalah 1,960 kg setahun. Input Hg ke dalam sistem adalah dari sisa pepejal domestik yang diterima di tapak pelupusan (1,897 kg setahun), tanah liat yang digunakan sebagai lapisan tanah (65 kg setahun) dan juga hujan (0.04 kg setahun). Manakala, Hg dilepaskan ke persekitaran melalui gas tapak pelupusan sampah (*LFG*) (0.04 kg setahun), tapak pelupusan (0.32 kg setahun), air larut resapan yang telah dirawat (1.46

kg setahun) dan larian air permukaan (0.42 kg setahun). Sementara itu, input Zn ke dalam tapak pelupusan adalah daripada sisa yang diterima (11,400 kg setahun) dan lapisan tanah (3,212 kg setahun). Output Zn yang dikenal pasti dalam sistem ini adalah larian air permukaan (32 kg setahun) dan air larut resapan yang telah dirawat (13 kg setahun). Hasil kajian ini boleh digunakan sebagai rujukan bagi pihak berkuasa dalam mengatasi masalah pencemaran logam berat di dalam tapak pelupusan sampah sanitari.

Kata kunci. Aliran bahan (MFA), Tapak Pelupusan Sampah Sanitari, Hg, Zn

## ACKNOWLEDGMENTS

First and foremost, I would like to express my gratitude to Professor Agamuthu Pariathamby and Dr. Fauziah Shahul Hamid, for their continuous guidance and encouragement throughout the whole duration of this project. I would also like to thanks IPPP, University of Malaya for providing the Postgraduate Research Grant (PO008-2014A) and MARA for providing my scholarship. Furthermore, I would like to thank the management and staff of Jeram Sanitary Landfill for giving me the permission and assistance to collect samples from their landfill.

Last but not least, I would like to thank all the Solid Waste Lab and Environmental Microbiology Lab members, Nurul Ain, Farah Aqilah, Wong Lihun, Nicole Leong, Alaribe Frank, Jayanthi Bharansathi, Lim Boon Tien, Aziz Ahmed, Afzanizam and the others who have given their utmost encouragement, support and guidance throughout the journey.

I would finally like to express my great appreciation and sincere gratitude to my precious family members and close friends for their understanding, caring, continuous and unconditional love, kindness, unfailing patience and all kind of support throughout my life.

## TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

## LIST OF PLATES

## LIST OF SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| As | Arsenic |
| ASTM | American Society for Testing and Materials |
| BOD | Biochemical oxygen demand |
| Cd | Cadmium |
| COD | Chemical oxygen demand |
| Cr | Chromium |
| DOE | Department of environment |
| EPR | Extended producer responsibility |
| e-waste | Electronic waste |
| FAU | Formazin attenuation units |
| Fl | Fluoroscent lamp |
| GHG | Greenhouse gas |
| Hg | Mercury |
| ICP-MS | Inductively coupled plasma-mass emission spectrometry |
| LFG | Landfill gas |
| MFA | Material flow analysis |
| MRF | Material recovery facility |
| MSW | Municipal solid waste |
| NSWMD | National Solid Waste Management Department |
| Pb | Lead |
| pH | Potential of hydrogen |
| STAN 2.5 | SubSTance flow ANalysis 2.5 |
| TDS | Total dissolved solid |
| TSS | Total suspended solid |
| UN | United Nations |

| | |
|---|---|
| USEPA | United States Environmental Protection Agency |
| USGS | United States Geological Survey |
| WHO | World Health Organisation |
| Zn | Zinc |

# CHAPTER 1: INTRODUCTION

## 1.1 Municipal solid waste management of Malaysia

Municipal solid waste (MSW) is commonly categorized as the combination of all community wastes except agricultural and industrial process wastes (Tchobanoglous *et al.*, 1993). In general, MSW contains various types of wastes such as food wastes, paper, plastic, metal, inorganic and hazardous wastes which are deposited from residential, commercial and institutional and industrial (Fauziah & Agamuthu, 2012). MSW generation in Malaysia has increased yearly by 3% due to many factors (Fauziah *et al*., 2009). Tremendous economic and technological transformations in recent years have stimulated the changes in Malaysians' life style and increased the per capita of wastes generated.

In 2001 the total wastes generated was 5.9 million tonnes/year with the per capita generation at 0.67 kg/capita/day and in 2005 it was 6.9 million tonnes/year and per capita generated was 0.8 kg/capita/day (Tarmudi *et al.*, 2012). These amounts are continuously increasing and by 2020 it is projected that the total wastes generated will be almost 15.6 million tonnes/year (Agamuthu & Victor, 2011). Efficient management of MSW needs to be planned and implemented urgently as continuous increase of MSW will become a serious issue not only towards health and environment but also from the socio-economic aspect (Ithnin *et al.*, 2012).

MSW composition studies that have been done in many parts of the country indicated that MSW in Malaysia are highly complex (Kalanatarifard & Yang, 2012). There are more than 20 categories of MSW deposited such as food waste, mixed paper, newsprint, phonebook, magazine, white paper, corrugated paper, rigid plastic, plastic film, polystyrene, disposable diapers, textile, rubber/leather, wood, garden waste, clear glass,

colour glass, metal, tin, non-metal, aluminum cans, other aluminum, hazardous waste, dust/sand, other organic, non-organic and bulky wastes (Noor *et al*., 2013). Figure 1.1 shows the average composition of MSW generated in Malaysia. The highest fraction of MSW was food wastes (41%), followed by plastic film (8%), garden waste (6%), rigid plastic (6%), corrugated paper (5%), and disposable diaper (5%).

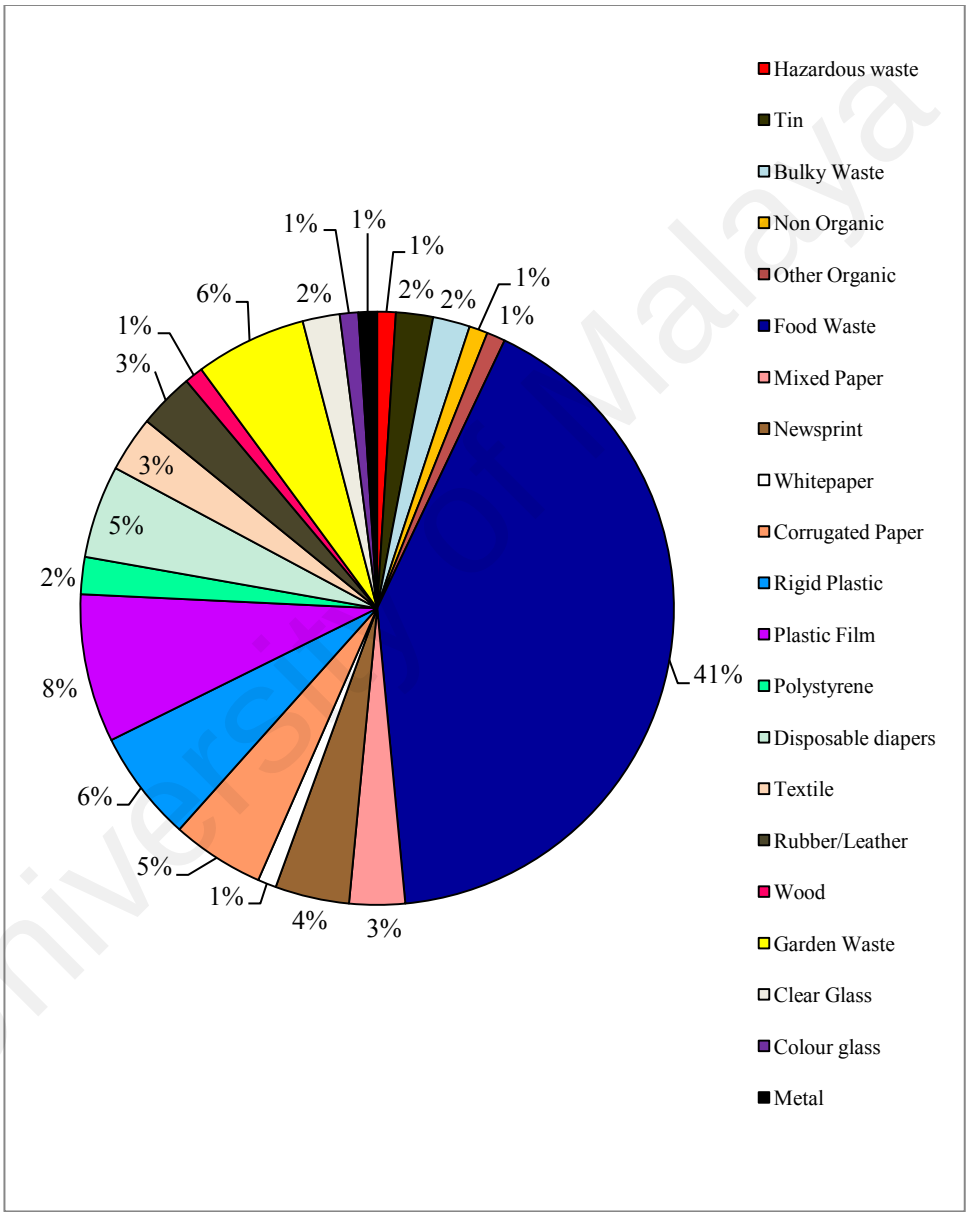


**Figure 1.1**: Average composition of MSW generated in Malaysia (Noor *et al.*, 2013).

The waste composition percentage also displayed that there is high amount of organic waste such as food and garden waste which amounted to 52.3%. There are also various types of recyclable items such as paper, aluminum, rigid plastic and glass. Integrated

waste management which emphasizes on recycling and composting should be implemented to ensure that all of these wastes can be diverted from the waste streams and more resources can be conserved.

Figure 1.1 also showed that 1% of the waste received in the landfill was categorized as hazardous waste or household hazardous waste (Noor *et al*., 2013). Household hazardous wastes are defined as MSW which possess toxic, flammable, and reactive characteristics (Gu *et al.*, 2014). According to Noor *et al*., (2013) and (HassanChaib *et al.*, 2014), examples of household hazardous waste received in Malaysia are batteries, aerosol cans, personal care products, medications and home maintenance products. Due to its perilous characteristics, presence of household hazardous wastes in the MSW needs to be emphasized.

## 1.2 Household hazardous waste

The percentage of household hazardous waste is relatively small in the MSW composition. Noor *et al*. (2013) and Agamuthu *et al*. (2009), reported the percentages of household hazardous waste to be 1% and 1.3%, respectively. According to Thanh *et al*. (2010), the percentage of household hazardous waste in a study conducted at Mekong Delta City was 0.20%. Gu *et al*. (2014) reported that 2.23% of household hazardous waste in a study conducted in Suzhou, China. Adamcová *et al*. (2016) also reported 2.05% that the percentage of household hazardous waste received in the Kuchyňky landfill in Czech Republic. Previous studies also mentioned that the amount of household hazardous waste generated is increasing over time. This is attributable to the higher affordability and accelerating number of products which are manufactured using hazardous materials (Gu *et al*., 2014).

The increasing amount of household hazardous waste needs to be disposed separately from MSW immediately, as mixed disposal of household hazardous waste and MSW might cause heavy metals contamination of MSW. The toxicity of heavy metals will inflict significant risk to the environment and human health. Heavy metals will depreciate the recycling potential of recyclable waste, and elevate the heavy metal concentration in compost made of contaminated organic waste (Page *et al*., 2014). Moreover, heavy metals contained in the waste will be released to the environment through corrosion or breakage during disposal operations, if the waste is not managed using a proper and effective system.

### 1.3 Heavy metal in the environment

According to Fernández-Luqueño *et al*. (2013), the United Nations Economic Commission for Europe has defined heavy metal as "those metals or, in some cases, metalloids which are stable and have a density greater than 4.5 g/cm3". These heavy metals are broadly dispersed in the environment through both natural and anthropogenic sources (Guo & Yang, 2016). A great amount of heavy metals are released from anthropogenic activities due to the vast usage of these metals in the facilitation of a certain human lifestyle (Vishan & Kalamdhad, 2016). Table 1.1 indicates the major utilization of heavy metals such as arsenic, cadmium, chromium and lead.

**Table1.1:** Heavy metal usage (Tchounwou *et al*., 2012).

| Metal | Usage |
|---|---|
| Arsenic(As) | Herbicides, fungicides, wood preservatives, and dye-stuffs |
| Cadmium (Cd) | Production of alloys, pigments, and batteries |
| Chromium (Cr) | Metal processing, tannery facilities, chromate production, |
| Lead (Pb) | Fossil fuels burning, mining, ammunitions, metal products (solder and pipes), and devices to shield X-ray |

The primary concern with heavy metal usage is that overexposure to heavy metals will cause perilous environmental risks, hence degradation to human health. Moreover, these metals are non-degradable, and persist for a lengthy period of time in the environment. Other heavy metals that are vastly used are mercury (Hg) and zinc (Zn). These metals can be found in many household products such as batteries, paint, pesticides, electrical devices and personal care products.

### 1.3.1 Mercury (Hg)

Hg is among the more widely used heavy metals in the world, attributable to its unique properties. Table 1.2 shows the basic properties of Hg, including its atopic number, colour and form in room temperature, weight, density, low boiling point and high boiling point. Hg is released in the environment through natural and anthropogenic activities (Zhang *et al*., 2016). Major natural sources are volcanic eruption and the degassing of the earth's crust. Meanwhile, the anthropogenic activities are the production of iron and steel, energy generation through burning of oil, wood and coal, as well as, the usage of Hg in product manufacturing (Hu & Cheng, 2012).

**Table 1.2:** Properties of Hg (Lenntech, 2017).

| Properties of Hg | Value |
|---|---|
| Atomic Number | 80 |
| Colour | Silver metallic |
| State at Room Temperature | Liquid |
| Weight | 200.59 |
| Density **(**g /cm) | 13.6 |
| Melting Point | -39 $^{o}$C |
| Boiling Point | 357 $^{o}$C |

The United States Environmental Protection Agency (2016) stated that common products containing Hg are dental amalgam, fluorescent lights and bulbs, thermometers, batteries, electronic items, cosmetic and pharmaceuticals. There is still no concrete evidence that the consumption of Hg might be beneficial to human health (Singh *et al*.,

2011). However, overexposure to this metal might cause deadly effects on humans. Singh *et al*. (2011) reported that high levels of Hg can cause spontaneous abortion, damage to the nervous system and protoplasm poisoning.

### 1.3.2 Zinc (Zn)

Basic properties of Zn are shown in Table 1.3. Zn is mainly used in the galvanization of other metals. It is also used to produce die-casting, which is very useful for the automobile and hardware industries. Various types of Zn are used for different purposes. $ZnO_2$ is mainly used to produce soap, pharmaceuticals, electrical items and batteries. Meanwhile, $Zn(SO_4)_2$ can be found in paints, x-ray screens and fluorescent lights (Periodic Table, 2017).

**Table 1.3:** Properties of Zn (Periodic Table, 2017).

| Properties of Zn | Value |
|---|---|
| Atomic Number | 30 |
| Colour | Bluish-white |
| State at Room Temperature | Solid |
| Weight | 65.38 |
| Density (g /cm) | 7.134 |
| Melting Point | 420$^{o}$C |
| Boiling Point | 907$^{o}$C |

Zn is also important as a source of nourishment for human health. Intake of Zn is important, as it is one of the major structural components of protein (Roohani *et al*., 2013). It is suggested that the dietary reference intake for Zn for adult males and females is 11mg/day and 8mg/day respectively (National Institute of Health, 2016). If a person is exposed to a higher amount than the recommended limit, he or she will experience negative health effects. According to New Jersey Department of Health (2016), if a person is exposed to more than 5 mg/m3 $ZnO_2$, the person may experience a metal fever attack. This example of over exposure to metal mainly occurs in the

welding industry, where the employees are directly exposed to high concentrations of $ZnO_2$ fumes.

Even though these metals are useful due to their unique properties, the toxicity of these metals can cause severe and intense implications to humans and the ecosystem (Jaishankar *et al*., 2014). Therefore, sustainable and proper management of waste containing heavy metals is crucial.

### 1.3.3 Impacts of heavy metal contamination

Heavy metal contamination can cause death to human. This is because heavy metal can bind with vital cellular components such as structural proteins, enzymes and mucus acids and interfere with its function (Singh *et al*., 2011). Thus, the excess exposure of these elements to human can inflict severe consequences such as, function disability and death (Jaishankar *et al*., 2014). Over exposures to heavy metal such as, Hg and Zn have threatened the health of numerous people all over the world.

Over exposure to Hg will aggravates the human health's condition by inducing various types of diseases such as hypertensions, cardiac arrhythmias, coronary heart disease and also mortalities (Houston, 2011). Minamata disease and Hg contamination in Iraq are the well-known Hg episodes which highlight the deadly impacts of Hg contamination to human and the environment (Gochfeld, 2003). Minamata disease occurred in 1953 in Minamata bay, Japan. This incident caused more than 2000 fatalities (Hachiya, 2006). Even after 50 years since the incident, there are still many victims who are suffering from the contamination of Hg in this area.

The incident occurred due to the consumption of fishes which had high level of Hg (Hachiya *et al*., 2006). The victims suffered from neurological diseases which led to their death. The high level of Hg happened because of the released of untreated waste water from acetaldehyde plant which belonged to a plastic company near the bay (Ekino *et al*., 2007). The untreated wastewater increased the bioaccumulation of Hg in the food chain of the area as most of the fishes consumed by the residents are mainly captured from the bay (Ekino *et al*., 2007). Thus, the residents who are in the top of the chain received the most detrimental impact and had the highest level of Hg in their bodies (Hachiya *et al*., 2006). Figure1.2 shows the Minamata disease victim is paralyzed and lost the ability to walk for life.

**Figure 1.2:** Health condition of Minamata Disease Victims (Tanaka, 2016)

In 1975, more than hundreds people died in Iraq due to Hg contamination of wheat cultivated on contaminated soil (Takizawa, 1979). Methylmercury fungicides which were mainly methyl mercury and phenylmercury were used to treat tons of seed wheat and barley in Iraq (Takizawa, 1979). This has caused the Hg contamination to occur when contaminated wheat was used to produce breads for citizen in rural areas (Takizawa, 1979). Ingestion of these breads was identified as the main source of the Hg poisoning. Thousands of casualties especially kids was recorded. This was due to high level of Hg in their blood and bodies.

Zn is generally not as toxic as Hg (Plum *et al*., 2010). Plum *et al*. (2010) also stated that human, plant and animal require Zn in their diet to achieve optimal growth and development. However, over exposure to Zn will also deteriorate human's health. Zn normally enters human through oral, ingestion and consumption. Researchers asserted that a person who intoxicated by high level of Zn will suffers from respiratory disorder, pancreas damage and lethargy (Plum *et al*., 2010). Eventhough it did not lead to fatalities as Hg, contamination caused by Zn will still give harmful impacts to the human's well-being in the long term.

Eventhough, heavy metal such as Hg and Zn are hazardous, there is still no regulation or legislation that demands the separation of waste containing these metal in Malaysia. Household hazardous waste are disposed together in the sanitary landfill or dumping site and not sent to the secure landfill.

## 1.4 Landfill in Malaysia

According to Johari *et al*. (2014), 90% of MSW generated in Malaysia is disposed in landfill. Landfills are favoured because the establishment cost of a landfill is much lower than that of an incinerator (Assamoi & Lawryshyn, 2012). A landfill also has the capability to cater large amounts of waste as compared to other alternatives such as composting and recycling. Landfills in Malaysia are categorized into five main levels based on the facilities provide (Ghazali *et al*., 2014). Table 1.4 indicates the technologies levels set by authority. Even for level IV sanitary landfills, removal of heavy metal to remove or contain heavy metals in the MSW before disposed in landfill sites is not compulsory. All waste received in the MSW landfill will be directly disposed without any separation or test to determine the characteristics of waste, unlike the procedures carried out in a secure landfill.

**Table 1.4:** Categories of landfill site in Malaysia (Ghazali *et al*., 2014).

| Level | Type of Landfill |
|---|---|
| Level 0 | Open Dumping |
| Level I | Controlled Tipping |
| Level II | Sanitary landfill with bund and daily cover |
| Level III | Sanitary landfill with leachate recirculation system |
| Level IV | Sanitary landfill with leachate treatment facilities |

Direct disposal of this waste will increase the amount of heavy metal in the landfill system. Previous leachate studies from various landfills in Malaysia have identified that the heavy metal content in leachate samples exceeded the limit allowed in the Environmental Quality Act 1974 Standard 2009 (Emenike *et al*., 2013; Zainol *et al*., 2012). High concentrations of heavy metals in leachate produced by landfills might be due to the presence of household hazardous waste disposed in the sanitary landfills. This waste might have released heavy metals such as Hg and Zn through corrosion or leakage.

Therefore, a comprehensive approach must be carried out to monitor the flow of these two metals in sanitary landfills in the country, in order to identify the major input and output of Hg and Zn in the sanitary landfill system. Suitable and effective measures to reduce the amount of metal in sanitary landfill systems should be proposed and implemented.

## 1.5 Material Flow Analysis

Material flow analysis (MFA) model will be employed in this study to quantify and monitor the presence and flow of Hg and Zn in a sanitary landfill system. MFA is a tool that studies inputs, outputs and stocks of a particular material or substance within a defined system boundary for a specified period of time (Brunner & Rechberger, 2004). This model is based on the law of conservation where inputs are equal to output plus

stock in a system. This analysis can also be used to trace the direct causes and origin of certain emissions and the fates of accumulated stocks. MFA is widely used in analyzing and managing environmental impacts from the use of substance or material (Jeong *et al*., 2009). Many researchers had utilized MFA in their research including for electrical and electronic waste disposal and waste management plan (Lau *et al*., 2013; Park *et al*., 2011).

## 1.6 Problem Statement

Compositions of waste in Malaysia are vastly heterogeneous where all types of waste including household hazardous waste are disposed of into the landfill. The amount of household hazardous wastes found in the landfill can be considered to be small amount but the impact of these household hazardous wastes are much more damaging (Tarmudi *et al*., 2012). These hazardous wastes are harmful as they contain heavy metal such as Hg and Zn that can endanger human health and the environment. Such instance is Minamata disease which killed thousands of life in Japan due to Hg contamination (Ekino *et al*., 2007). Besides, samples of leachate collected and analyzed from the landfills also showed presence of heavy metal elements (Fauziah *et al*., 2013).

Therefore, it is a major concern to study the existence and also the influx and outflux of these heavy metal elements to investigate the possible sources. This will enable the identification of measures to overcome it. The method that will be used to analyze this is the material flow analysis (MFA) which is a systematic assessment of the flows and stocks of materials through a region defined in space and time (Park *et al*., 2011). This study will be the first study to utilize MFA model to investigate the flow of Hg and Zinc in a Malaysia's sanitary landfill. Therefore, the objectives of this study are as follows:

## 1.7 Objectives

1. To quantify and characterize wastes received by Jeram Sanitary Landfill.
2. To identify possible inputs and outputs of Hg and Zn in a selected sanitary landfill.
3. To utilize STAN 2.5 software to produce a MFA of Hg and Zn.

# CHAPTER 2: LITERATURE REVIEW

## 2.1. Definition and types of Municipal Solid Waste (MSW)

USEPA has defined MSW as garbage or trash that are disposed everyday such as food wastes, papers, garden wastes, plastics, metals and hazardous wastes such as batteries (United States Environmental Protection Agency, 2016). These wastes come from various sources such as residential, commercial and institutions. Different countries have different categories of wastes. Germany for example, categorized all wastes from residential, institution, commercial centre, construction and industry as MSW (Berlin Senate Department for Urban Development and the Environment Communication, 2013). Meanwhile in Malaysia, MSW are categorized as wastes that originated from multiple sources such as residential, industrial, commercial, institutional, construction and demolition, municipal services and processed waste (Fauziah, 2010).

## 2.2 MSW Generation

Municipal solid waste has increased significantly in recent years especially since the expansion of industrial activities. It has been reported that in 2010, the total MSW generated was 3.5 million tonnes per day and will keep escalating fast (World Bank, 2012). It is estimated that in 2025, daily global MSW generation will be more than 6 million tonnes (World Bank, 2012). Figure 2.1 depicts the trend of the waste generated from 1960 until 2012. It can be clearly seen that MSW generated during 1960s-1970s were lower in quantity as compared to the MSW generation in the recent years (United States Environmental Protection Agency, 2012). The same trend is also observed for the per capita generation. Even though the trend is not as significant as the total waste generation, the per capita of waste generated in 2000s were higher than the previous years. World Bank (2012) reported that in 1992, a person generated 0.62 kg of MSW per day and 1.2 kg of MSW per day in 2012.

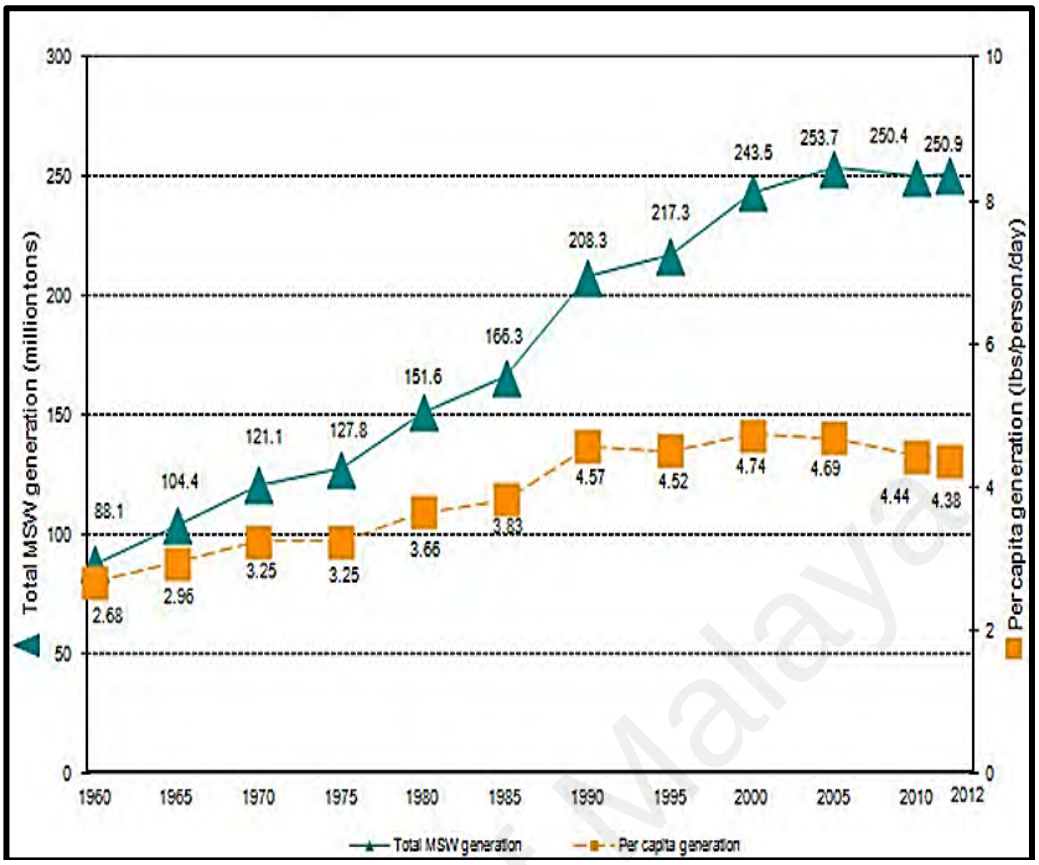


**Figure 2.1**: Worldwide MSW generation and per capita 1960-2012 (United States Environmental Protection Agency, 2012).

Asia contributes a burgeoning amount of MSW as more than 60% of the world's populations are from Asia (Ecology Global Network, 2010) Table 2.1 shows the wastes generation per capita by selected Asia Pacific Countries in 2009, 2011 and 2025 (Agamuthu & Tanaka, 2014). The per capita value of each country is on an increase. The per capita value for developed countries such as Singapore, Republic of Korea and Japan are higher than developing countries such as India, Nepal and Bangladesh (Agamuthu & Tanaka, 2014). This might be contributed by the economic performance among the developed countries which allowed the people to have more buying capability and different lifestyle that generate more waste and increase the per capita value.

**Table 2.1:** Waste generation per capita of selected Asia Pacific countries (Agamuthu & Tanaka, 2014).

| Country | Waste Generation (kg/capita/day) | | |
|---|---|---|---|
| | **2009** | **2011** | **2025** |
| Brunei | 0.66 | 0.87 | 1.3 |
| India | 0.34 | 0.5 | 0.7 |
| Indonesia | 0.76 | 0.88 | 1 |
| Laos | 0.55 | 0.7 | 1.1 |
| Malaysia | 1.3 | 1.5 | 1.9 |
| Myanmar | 0.45 | 0.44 | 0.85 |
| Philippines | 0.52 | 1.56 | 0.8 |
| Singapore | 1.1 | 1.49 | 1.8 |
| Thailand | 0.64 | 1.76 | 1.95 |
| Vietnam | 0.67 | 1.46 | 1.8 |
| Nepal | 0.4 | 0.5 | 0.7 |
| Bangladesh | 0.25 | 0.43 | 0.75 |
| Mongolia | - | 0.66 | 0.95 |
| China | 0.8 | 1.02 | 1.7 |
| Sri Lanka | 0.2-0.9 | 0.37-0.73 | 1 |
| Republic of Korea | 1 | 1.24 | 1.4 |
| Japan | 1.1 | 1.7 | 1.7 |

Table 2.1 also indicated that Malaysia is one of the developing countries which has high total and per capita of waste generation. Table 2.2 showed that the total amount of MSW in urban area had increased tremendously from 1970 to 2012. Table 2.2 also

indicates that many cities in Malaysia recorded higher amount of MSW than the previous year. Rapid generation of MSW results in accumulation of MSW but there were only minimal efforts on recycling, reducing and waste minimization.

**Table 2.2:** Generation of MSW in major urban areas in peninsular Malaysia (1970-2012) (Agamuthu & Fauziah, 2011).

| **Urban Centre** | **Solid waste generated (tonnes/day)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1970 | 1980 | 1990 | 2002 | 2006* | 2009* | 2010* | 2012* |
| Kuala Lumpur | 99 | 311 | 587 | 2754 | 3100 | 3387 | 3489 | 3701 |
| Johor Bahru | 41 | 100 | 175 | 215 | 242 | 264 | 272 | 289 |
| Ipoh | 23 | 83 | 162 | 208 | 234 | 256 | 264 | 280 |
| Georgetown | 53 | 83 | 137 | 221 | 249 | 272 | 280 | 297 |
| Klang | 18 | 65 | 123 | 478 | 538 | 588 | 606 | 643 |
| Kuala Terengganu | 9 | 62 | 121 | 137 | 154 | 168 | 173 | 184 |
| Kota Bharu | 9 | 57 | 103 | 130 | 146 | 160 | 165 | 175 |
| Kuantan | 7 | 45 | 85 | 174 | 196 | 214 | 220 | 233 |
| Seremban | 13 | 45 | 85 | 165 | 186 | 203 | 209 | 222 |
| Melaka | 14 | 29 | 47 | 562 | 632 | 691 | 712 | 755 |

*- Estimated figure

Level of per capita of MSW generated in Malaysia also rose throughout the years. In 1980s, per capita of MSW generated in Malaysia was only 0.5kg/day, and has escalated to 1.3 kg/day in 2009 (Agamuthu *et al*., 2009), the average per capita of MSW generated by a Malaysian rose again to 1.5-2.0kg/day (Agamuthu & Tanaka, 2014). Figure 2.2 illustrated the per capita generation of waste from 1985 until 2011. The acceleration of per capita MSW produced is due to urbanization which leads by higher economic performance (Noor *et al*., 2013).

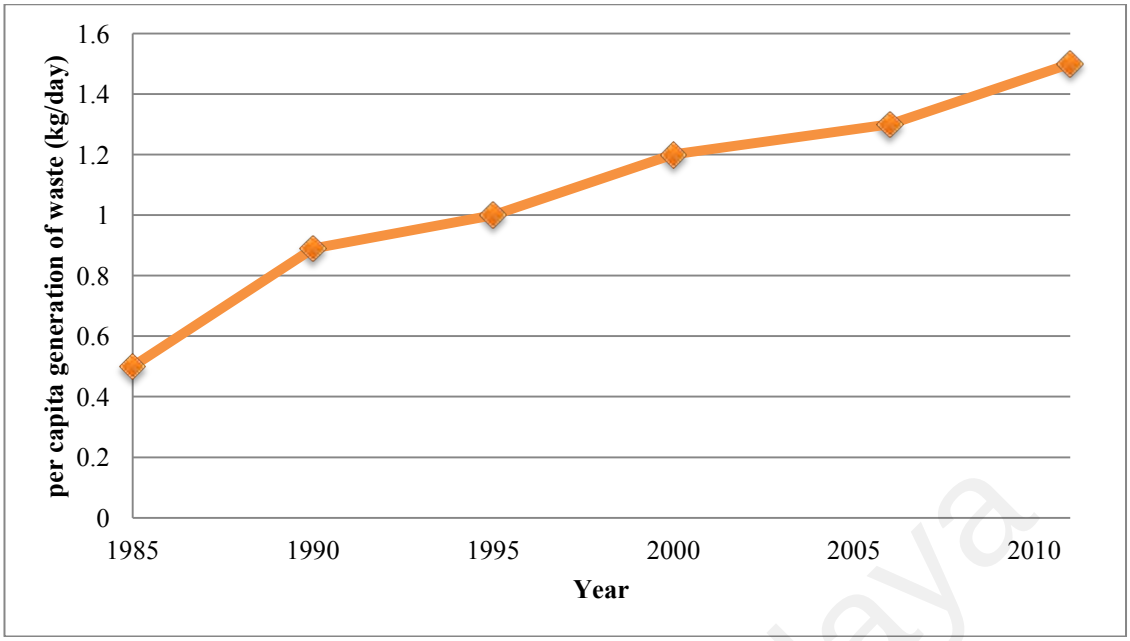


**Figure 2.2:** Per capita generation of waste from1985 until 2011(Agamuthu & Fauziah, 2011).

## 2.3 MSW Composition

Change of lifestyle also played a major role in determining the composition of MSW generated as most types of wastes produced are highly dependent on the activities carried out. MSW composition is one of the important data in MSW studies. Waste composition is used to ensure that a sound waste management technology can be employed (Bisinella *et al*., 2017). It reflects the type and percentage of selected amount of wastes. Through the composition of wastes, the characteristics of wastes such as, the calorific value and moisture can be known, and suitable waste management technology alternative can be opted. If the wastes have higher amount of organic wastes such as food waste and garden waste, composting can be opted (Hargreaves *et al*., 2008). Meanwhile, wastes with high calorific value can be recycled or used as fuel for incinerator (Wong *et al*., 2015). Waste composition also gives the insight into the awareness level of citizens in regards to environmentally-friendly practice such as recycling, waste separation at source, source reduction, and composting (Suthar & Singh, 2015).

Waste composition data have been recorded at global, regional, nationwide, and residential level. Figure 2.3 indicated the global waste composition reported in 2012. The highest percentage of waste generated was food waste followed by paper and plastic. The high percentage of organic wastes is generated by the combination of food wastes, unconsumed food, and yard wastes.

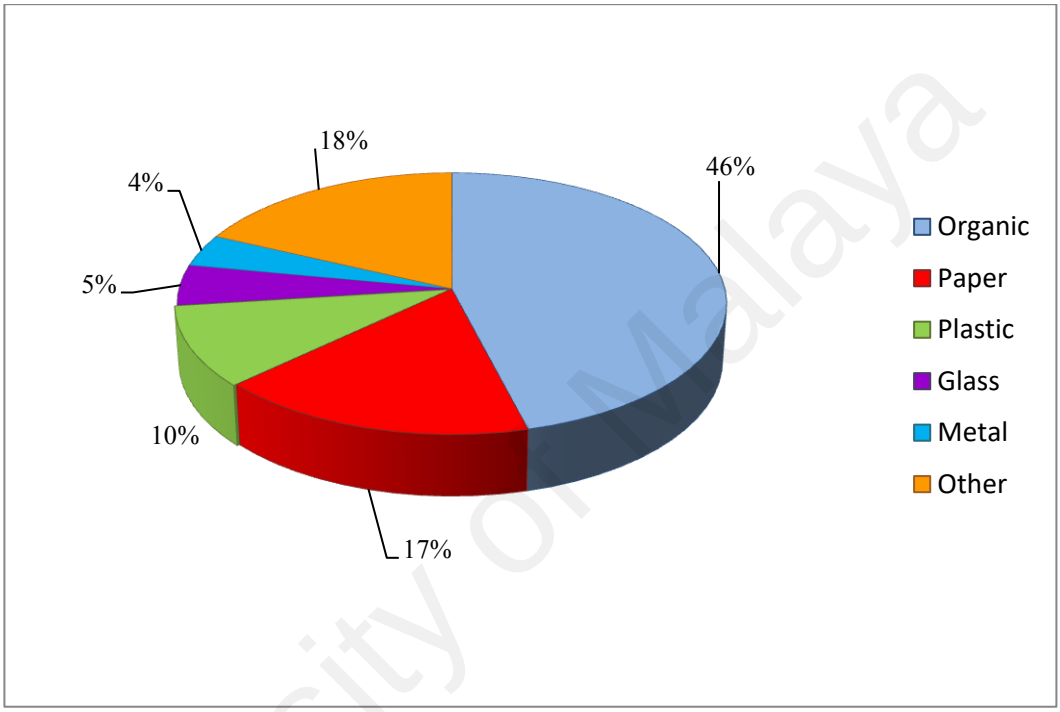


**Figure 2.3:** Global Solid Waste Composition (%) (World Bank, 2012).

The amount of food waste is expected to accelerate continuously either through food preparation process or unfinished food. Plastic and paper wastes are generated every day and it is unavoidable. Paper and plastics are widely used all around the world especially in the packaging industry. Many products come with unnecessary pamphlet and plastics which end up as wastes once the consumer starts using the product. Similar result can be seen from waste composition data in Malaysia as shown in Figure 2.4. The figure indicates that the highest percentage of waste generated in Malaysia is food waste at 44.5% of the total waste generated (Kementerian Kesejahteraan Bandar, Perumahan Dan Kerajaan Tempatan, 2012). 13.2% of the waste composition is plastic followed by 8.5% of paper, 12.1% of diaper, 5.8% of garden waste, and 3.3 % of glass, 2.7% of

metal, 3.1% of textiles, 1.6% of Tetra Pak,1.8% rubber, 0.4% leather, 1.4% wood, 1.3% of household hazardous waste and 0.5% other type of waste (Kementerian Kesejahteraan Bandar, Perumahan Dan Kerajaan Tempatan, 2012).

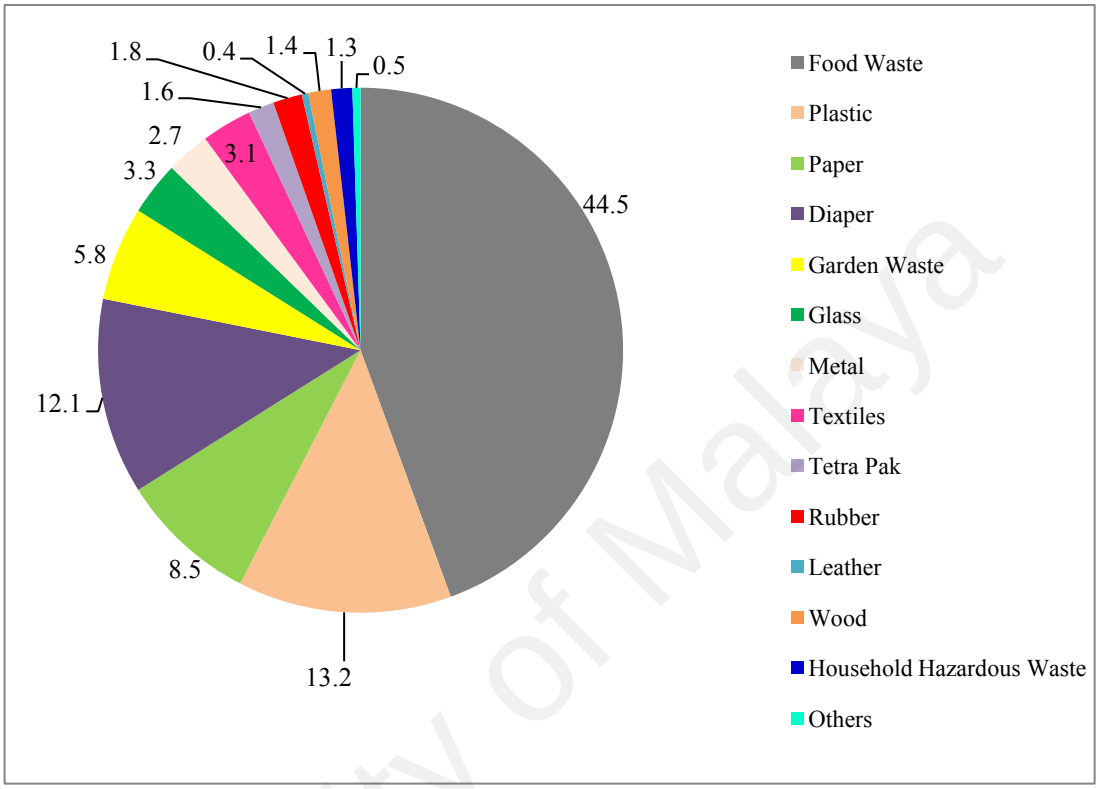


**Figure 2.4:** Average composition of MSW in Malaysia (Kementerian Kesejahteraan Bandar, Perumahan Dan Kerajaan Tempatan, 2012).

The waste composition generated shows that there are high amount of wastes which has potential to be reused or recycle. If reuse and recycling activities are extensively carried out in Malaysia, an enormous amount of wastes can be avoided from entering the waste stream. However, majority of the wastes generated in this country are disposed into landfills. This has shortened the life span of many landfills in Malaysia due to the disposal of massive amount organic wastes and various recyclable items (Fauziah & Agamuthu, 2012). It is also reported that majority of the wastes that are disposed of in Malaysia's landfills are food waste, plastics, and paper as illustrated in Figure 2.5 (Fauziah & Agamuthu, 2012).

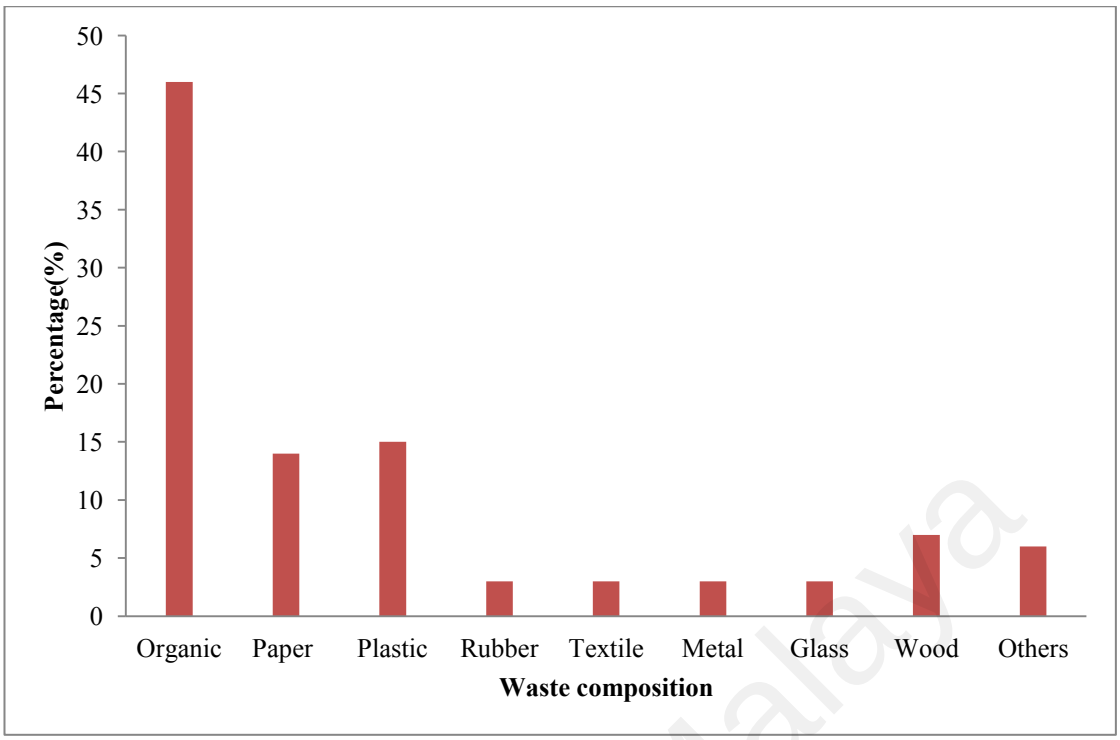


**Figure 2.5:** Average waste composition received by Malaysian landfills (Fauziah & Agamuthu, 2012).

## 2.4 Factors Affecting Solid Wastes Generation and Composition

The generation and composition of wastes are changing rapidly year by year. The changes in waste composition and waste generation are mainly caused by the same factors such as the number of population, economic status, lifestyle, climate condition, and culture (Suthar & Singh, 2015).

### 2.4.1 Population Expansion

Human population has gone through tremendous growth throughout the times. It is predicted that growth will continue and by 2050, the total world's population will be more than 9 billion people as indicated in Figure 2.6. The rapid acceleration in human population is induced by many factors such as the advancement of medical science, migration, urbanization, and better living standards (Sherbinin, 2007). Better living standard also promotes more conducive condition for population expansion. United Nations (2015) reported that global average annual rate of percentage increased 1.2%.

In 2014, it is estimated that total world's population is 7.3 billion and this amount is projected to be 8.5 billion by 2030 (United States Census Bureau, 2013).

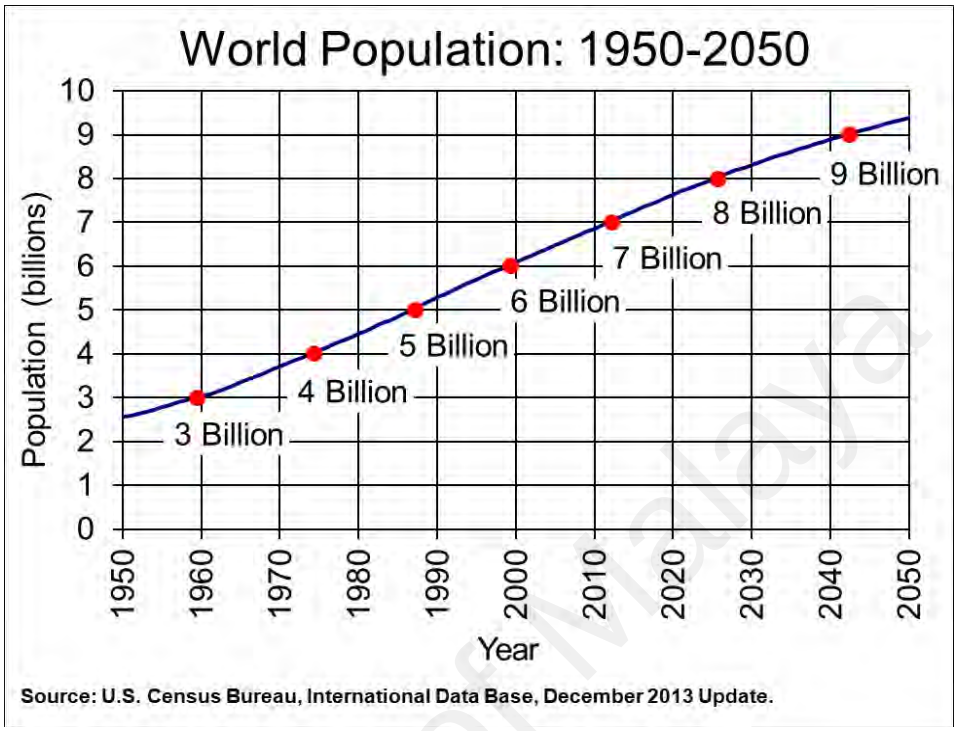


**Figure 2.6:** World population chart (United States Census Bureau, 2013).

Excessive human population has brought about more negative consequences to the ecosystem. A higher population means that more resources are required for survival. Thus, there is a high probability of environmental degradations to happen. One of the imminent problems is the generation of enormous amount of wastes (Hoornwerg *et al*., 2013). Each person undoubtedly will produce waste every day due to their activities. Activities such as eating and preparing food will create food wastes, buying ready-made products will generate plastics and paper wastes from the packaging, and industrial activities will end up producing hazardous wastes such as chemical waste. Therefore, the higher number of population in the world, the amount of wastes generated will increase accordingly.

World Bank has reported that the total global MSW generated in the year 2012 was 1.3 billion tonne while the number of world's population was more than 7.1 billion (World

Bank, 2012). Both total global MSW generation and the population of the world are estimated to undergo remarkable acceleration. It is estimated that in 2025, the world population will reach 8.1 billion and a total of 2.2 billion tonnes MSW will be produced in that year (World Bank, 2012). Besides world's population, the economic growth of economy especially in developing countries will also increase significantly which will directly influence the amount and composition of waste generated.

### 2.4.2 Economy

Economy is one of the significant elements in influencing the amount and types of wastes generated. A country with established economy will be able to provide a higher living standard and buying ability in comparison to the country with lower economic performance (Song *et al*., 2015). The citizens of developed countries such as America, Singapore, and Japan will have more affordability to buy finished product, electrical appliances, and other consumer products, as compared to the citizens from lower-income countries such as Bangladesh, Nepal, and Nigeria (Latifah *et al.*, 2009). This will result in a significant difference of waste composition between countries with different economic level as stated in Table 2.3 (World Bank, 2012).

Waste composition is different based on the level of income. Low income countries generate higher amount of organic waste compared to other types of waste while high-income countries produce fewer organic waste and generate more inorganic waste such as paper (World Bank, 2012).

**Table 2.3:** Type of waste composition based on level of income (World Bank, 2012).

| **Type of waste** | | | | | | |
|---|---|---|---|---|---|---|
| **Income level** | Organic (%) | Paper (%) | Plastic (%) | Glass (%) | Metal (%) | Other (%) |
| Low income | 64 | 5 | 8 | 3 | 3 | 17 |
| Lower middle income | 59 | 9 | 12 | 3 | 2 | 15 |
| Upper middle income | 54 | 14 | 11 | 5 | 3 | 13 |
| High Income | 28 | 31 | 11 | 7 | 6 | 17 |

Similar trend can also be seen in residential areas with different levels of income. Table 2.4 depicts the waste composition for three household of different economic status in Malaysia.

**Table 2.4:** Waste generated based on different level of residential income (Agamuthu & Tanaka, 2014).

| **Composition (%)** | **Socio- economic status** | | |
|---|---|---|---|
| | High Income | Middle Income | Low Income |
| Paper products | 19.79 | 15.73 | 13.04 |
| Plastic and rubber | 21.05 | 18.61 | 13.01 |
| Glass and ceramics | 14.99 | 9.42 | 7.57 |
| Food waste | 24.13 | 29.77 | 31.86 |
| Metals | 8.8 | 12.75 | 9.15 |
| Textiles | 1.57 | 3.87 | 3.08 |
| Garden waste | 5.5 | 6.95 | 15.56 |
| Wood | 3.45 | 2.9 | 6.72 |
| Total | 100 | 100 | 100 |

Tremendous economic improvement accelerates the urbanization process in a country (Tarmudi, 2009). However, even in an urban area, the residences can be divided into three categories based on their income. Studies showed that different financial income level will affect the type and quantity of wastes generated (Suthar & Singh, 2015).

Hectic schedule and higher financial availability have encouraged most people with higher-income to eat out or take away prepared food. On the other hand, residents of lower income normally prefer to cook at home as it is more cost-saving. Thus, a higher percentage of food waste will be generated by the lower-income residences as compared to middle and higher-income residences (Afroz *et al*., 2011).

High-income residence also recorded a high percentage of paper and plastics usage. This is due to the preference of high-income residents who prefer to buy finished products which have excessive packaging mainly made of paper and plastics (Agamuthu & Fauziah, 2008). Lower percentage of hazardous wastes can be found at low-income residential areas as most of the household hazardous products are not a necessity in the household. Hazardous waste usually comes from the products used to improve household's visual and personal items such as paint, e-waste, expired cosmetics, and medicines.

### 2.4.3 Lifestyle, climate condition, and culture

MSW generated is related closely to the lifestyle, specifically daily activities. Studies conducted have classified daily activities into three main categories which are 'maintenance', 'subsistence', and 'leisure'. 'Maintenance' which includes food and drink consumption generates more organic waste compared to the other two categories (Li *et al*., 2011). Different groups of people will have a different lifestyle. This is one of the reasons why the composition of MSW is different between urban area and rural area. The 'fast' lifestyle in urban area which prefers convenience normally opts to have their meal outside. Meanwhile, people who in the rural area will cook and have dinners with their family at home. Therefore, the probability of food waste generated in rural area is higher than urban area.

Climate condition also plays an important role in affecting the generation and composition of MSW. Many countries which experience the four season phenomenon have conducted various researches to study this factor (Nguyen & Le, 2011). In Poland, Qteishat *et al*. (2014) reported that the total MSW in Poland was higher in summer season compared to winter season. It also reported that the composition of paper in the MSW was significantly different depending on the heating system used in the residential areas. Tourist places such as islands and beaches will attract more tourists during summer thus more MSW will be generated (Mateau-Sbert *et al*., 2013).

In countries such as Malaysia, Singapore, and Indonesia which do not have various distinct seasons, the culture of the nation is another factor for MSW composition. Malaysia for example is a multi-racial country and has multiple festivals and occasions based on different cultures. Solid Waste and Public Cleansing Management Corporation Malaysia has estimated that in 2015, 9000 tonnes of food waste were disposed every day during 'Ramadhan' which is also known as the fasting month for Muslims in Malaysia. (The Star Online, 2015). These wastes were disposed directly to the landfill without any waste minimisation process such as composting or recycling.

All wastes generated in Malaysia will be managed by the authority appointed by the government. Federal government has enacted numerous regulations to ensure efficient waste management is conducted in Malaysia.

## 2.5 MSW management in Malaysia

Malaysia has undergone changes in the MSW management's system over the past 50 years. In 1970s till late 1980s, the amount of wastes generated by the country is considered low as the per capita recorded was only 0.5 kg/day/person (Agamuthu *et al*.,

2009). Thus, all collection and transportation of MSW was still manageable for local authorities such as Kuantan Municipal Council, Johor Bahru City Council, Kuala Terengganu City Council, and other municipalities (Agamuthu & Fauziah, 2011). Regulations related to the waste management at the time were the Street, Drainage and Building Act 1974, Town and Country Planning Act 1976, and Local Government Act 1976. Due to the escalated amount of wastes, the cost of waste management also has increased significantly. It has been reported that 70% of the municipalities' revenue were used to cater the waste collection process (Johari *et al*., 2014). Lack of financial capability has caused inefficient waste management and lead to public's complaints and dissatisfaction (Agamuthu & Fauziah, 2011). In order to overcome this problem the government introduced the privatisation system where four consortium were responsible to manage MSW in the region allocated for them (Sakawi, 2011).

When waste management was handled by the private entities, significant improvements were seen as these concessionaires have better expertise and skills in waste collection processes (Agamuthu & Tanaka, 2014). However, after few years, the maintenance and waste disposal cost became too high for the concessionaires to bear as the concessioners failed in getting the profitable revenue from the services they offered and this caused difficulty in buying machineries and facilities required to establish an effective waste management system (Sakawi, 2011). Thus, by the end of 2005 there were only two concessionaires in business from the total four appointed. Solid Waste and Public Cleaning Management Act, 2007 was enacted to highlight the important points and methods to achieve better solid waste management by letting the federal government to monitor all waste management matters (Latifah *et al*., 2009). Eight regulations enacted under Act 2007 were gazette on 30$^{th}$ August 2007 (Agamuthu & Tanaka, 2014). The regulations are as follows:

1. Solid Waste and Public Cleansing Management (Manner of Appeal) Regulations (2011).
2. Solid Waste and Public Cleansing Management (Prescribed Solid Waste Management Facilities and Approval for Construction, Alteration and Closure of Facilities) Regulations 2011.
3. Solid Waste and Public Cleansing Management (Compounding of Offences) Regulations 2011.
4. Solid Waste and Public Cleansing Management (Licensing) (Management and Operation of Prescribed Solid Waste Management Facilities) Regulations 2011.
5. Solid Waste and Public Cleansing Management (Licensing) (Undertaking or Provision of Collection Services for Household Solid Waste, Public Solid Waste, Public Institutional Solid Waste and Solid Waste similar to Household Solid Waste) Regulation 2011.
6. Solid Waste and Public Cleansing Management (Licensing) (Undertaking or Provision of Transportation Services by Long Haulage) Regulations 2011.
7. Solid Waste and Public Cleansing Management (Licensing) (Undertaking or Provision of Public Cleansing Management Services) Regulations 2011.
8. Solid Waste and Public Cleansing Management (Scheme for Household Solid Waste and Solid Waste Similar to Household Solid Waste) Regulations 2011.

One of the important sections of the Act 2007 is the requirement of householders to separate MSW before disposal. Currently, all wastes are collected by the general workers, despite not being separated into recyclable and non-recyclable waste. Even though there exist certain areas that implement a specific schedule of waste collection based on waste type, waste is remains to be collected, despite its characteristics. Figure 2.7 shows the most frequent method of waste collection in Malaysia which is curb, alley

and backyard collection method. Waste generated from residences will be collected by contracted workers and transferred into a garbage truck.

**Figure 2.7:** Garbage truck used to collect waste.

Once the truck arrived in a sanitary landfill, they will go through monitoring bridge and will directly dump into the waste cells. Eventhough, landfill disposal is the highest opted waste disposal method in Malaysia, this is the least preferred method in the waste management hierarchy.

## 2.6 Waste disposal options

Waste management hierarchy shows the list of options based on the preferential environmental aspect (Aja & Al- Kayiem, 2014). Figure 2.8 below listed the source reduction and reuse, recycling and composting, energy recovery and treatment and disposal. The preference of waste disposal options is similar to the waste management stated in the Solid Waste and Public Cleansing Management Act 2007. Source reduction and reuse practices are the most preferred waste management options. This is because these options will contribute to lesser amount of wastes dispose into the landfill, thus more landfill area and natural resources can be conserved (Dhokhikah *et al*., 2015). Source reduction is also widely known as waste prevention in which the same item can be used for alternative functions in order to extend the lifespan of the

item. Once the item cannot be salvaged or reused anymore, then recycling and composting (organic waste) will be the next management option (McDougall, 2008).

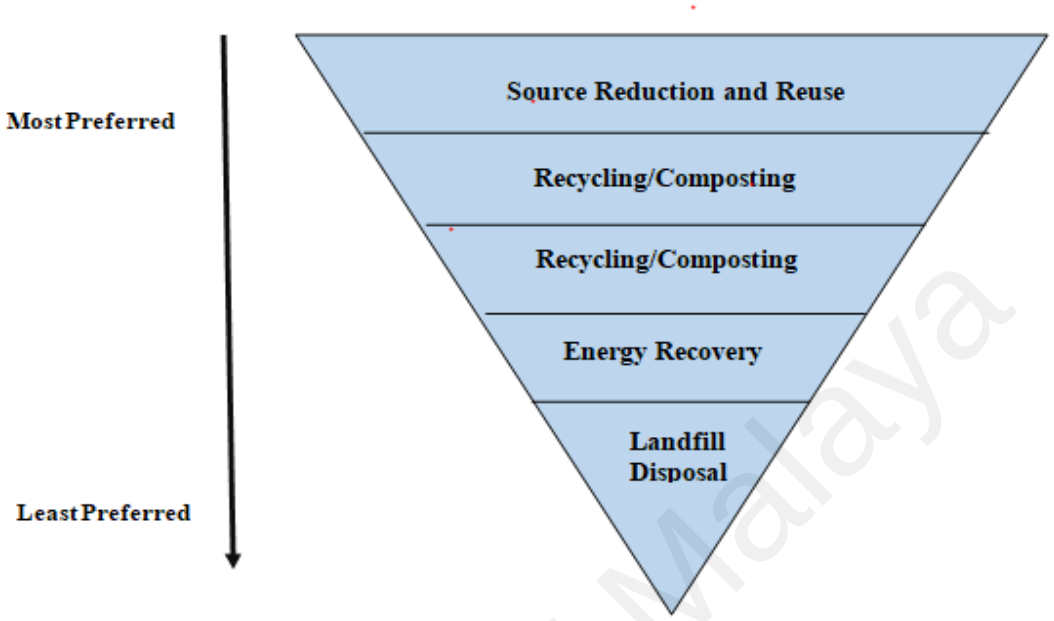


**Figure 2.8:** Waste management hierarchy.

Recycling is done to use the item to produce a totally new item or product such as recycling activity of paper waste to produce tissues or recycling activities of aluminium waste to produce a new aluminium can (Pivnenko *et al*., 2015). Composting on the other hand is an example of recycling activities which is more appropriate for organic wastes. USEPA has described composting activity as an activity that converted organic waste such as food and yard wastes into humus (Rosazlin *et al*., 2011). Humus is a material that has a high amount of essential nutrients. There are many advantages of composting such as it can improve the quality of the soil by elevating the nutrient level, increase the soil moisture, and balance the pH of the soil to the optimum level (Soobhany *et al*., 2015). Composting process is able to avert the heavy metal uptake by plants by binding to the heavy metals. It is also revealed that composting can decrease the damage caused by pest, thus increase plant's production. Besides composting, waste to energy activity is also one of sustainable waste management commonly practised.

Energy recovery is a waste management option which uses the wastes generated to produce a diverse form of energy. There are many different types of waste to energy processes such as combustion, landfill gas (LFG) recovery, gasification, pyrolisis, and anaerobic digestion (McDougall *et al*., 2008). Energy produced from waste to energy activity can be used to produce electricity for local or state usage. Thus, this will reduce the dependency on non-renewable energy resources such as petroleum, coal, and nuclear energy. One of the widely utilized waste to energy technologies is incinerator (Mc Dougall, 2008). Incinerator has been used globally because it has many advantages both in economic and environmental aspects.

An incinerator is capable of diminishing enormous amount of wastes in a short period of time compared to other waste management alternatives (McDougall *et al*., 2008). Thus, it reduced the need for landfilling and minimized the probability of environmental problems that might happen in landfilling operation. Waste incineration process is able to generate a significant amount of energy that can be employed as electricity supply. The incinerator basically combusts the wastes received and generates superheated steam. This superheated steam is later used to drive the turbo generator and thus produced electricity (McDougall *et al*., 2008). Incinerator has been used extensively in many countries especially in developed countries such as Germany, Japan and Denmark (Ismail & Manaf, 2013). There are less number of incinerators in developing countries due to the high construction and maintenance cost. In Malaysia only small size incinerators are operating. These incinerators can cater from 15 to 100 tonne of waste daily (Kementerian Kesejahteraan Bandar, Perumahan dan Kerajaan Tempatan, 2015). Generally, wastes in Malaysia have high moisture content due to high precipitation throughout the year (Ismail & Manaf, 2013). This factor have amplified the cost needed for the combustion process and caused the energy recovery activities in Malaysia's incinerator plant less profitable (Ismail & Manaf, 2013). Thus, landfilling is a cheaper way for solid waste disposal and is highly preferred by Malaysian.

## 2.7 Landfill

There are four types of landfill or disposal site in Malaysia which are open dumps, controlled-dumps, sanitary landfill, and secure landfill. Even though different types of landfill have different benefits and disadvantages such as low cost or minimal impact on the environment, many studies have reported that sanitary landfill is the most relevant disposal method in terms of economics and environmental wise (Amadi *et al*., 2012). In 2012, there were 165 active landfills in Malaysia as shown in Table 2.5 (Aja & Al-Kayiem, 2014). However, Table 2.6 indicates that only few are classified as sanitary landfills.

**Table 2.5:** Number of disposal sites in Malaysia (Aja & Al- Kayiem, 2014).

| State | Operational sites | Closed sites | Total |
|---|---|---|---|
| Johor | 14 | 23 | 37 |
| Kedah | 8 | 7 | 15 |
| Kelantan | 13 | 6 | 19 |
| Melaka | 2 | 5 | 7 |
| Negeri Sembilan | 7 | 11 | 18 |
| Pahang | 16 | 16 | 32 |
| Perak | 17 | 12 | 29 |
| Perlis | 1 | 1 | 2 |
| Pulau Pinang | 2 | 1 | 3 |
| Sabah | 19 | 2 | 21 |
| Sarawak | 49 | 14 | 63 |
| Selangor | 8 | 14 | 22 |
| Terengganu | 8 | 12 | 20 |
| Kuala Lumpur | 0 | 7 | 7 |
| Labuan | 1 | 0 | 1 |
| Total | 165 | 131 | 296 |

**Table 2.6:** Status of sanitary landfills in Malaysia (Fauziah & Agamuthu, 2012).

| Location | State | Status |
|---|---|---|
| Pulai | Kedah | In operation |
| Ampang Jajar | Penang | Closed |
| Pulau Burung | Penang | In operation |
| Jobor Jerangau | Penang | In operation |
| Air Hitam | Selangor | Closed |
| Kg. Hang Tuah | Selangor | Closed |
| Jeram | Selangor | In operation |
| Bukit Tagar | Kuala Lumpur | In operation |
| Krubong | Malacca | Closed |
| Seelong | Johor | In operation |

Malaysian government has planned to build or convert more open dumpsites or landfills into sanitary landfills as sanitary landfills, are equipped with several technologies and prevention measures to handle the by-products of landfilling operation such as leachate and landfill gas. The explanation about the functions of the technologies that are normally used in sanitary landfills such as daily cover, liner, methane gas collection system, flaring gas unit, drainage system, leachate pipe, leachate collection system, and leachate treatment plant are discussed in the following sections.

i. Daily cover

Daily cover system is introduced for few purposes which are to control pest intrusion and to avoid infiltration of rainfall into waste cell that will increase the leachate production (Qi *et al*., 2013). There are various types of cover used in a sanitary landfill such as HDPE plastic, clay or soil. After waste has been dumped and the wastes are compacted, a daily cover will be placed on top of the cell to cover the wastes (He *et al*., 2015).

ii. Liner

Due to the water infiltration through waste cell, leachate production is bound to happen (Cheremisinoff, 2003). In order to avoid leachate contamination to the precious groundwater quality, a liner must be used. In most countries, double liners consisting clay and high density polyethylene plastic are widely used (Rowe *et al*., 2012). Both materials are used as they have low permeability factor. Thus, it can prevent leachate intrusion into ground water.

iii. Methane gas collection

One of by-products of landfill operation is landfill gas (LFG). LFG contains 40%-60% of methane gas (Fei *et al*., 2016). Methane gas is widely known as one of the destructive greenhouse gas (GHG). Therefore, all gas collected are either released passively, or to be flared at the flaring gas unit or converted into energy at the LFG plant, if waste to energy technology is available at the sanitary landfill.

iv. Flaring gas unit

Most sanitary landfills in developing countries such as Malaysia are still using the gas flaring unit to burn the collected methane gas from the waste cell instead of converting it into an alternative source of power supply. High establishment cost of waste to energy activities is the main reason why there are only few number of waste to energy plant can be found in Malaysia sanitary landfills. It was reported that currently, example of landfills which are already equipped with LFG plant and electricity generator are Air Hitam Landfill and Pajam Landfill (Sustainable Energy Development Authority Malaysia, 2012 and Chan, 2013).

v. Drainage system

Drainage system is needed in a sanitary landfill in order to control the flow of surface runoff to the right drain.

vi. Leachate collection system

All leachate will flow through the pipe and is collected in the pond.

vii. Leachate treatment plant

Leachate treatment plant is built in order to treat the raw leachate collected to achieve the quality standard set by the authority. Table 2.7 lists the permissible limit of pollutants and parameters in treated leachate before discharge process. It is compulsory for the landfill management to follow the standard required by the authority. This standard is under Environmental Quality Act 1974, Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations 2009.

In order to fulfil the limitations of the standard established by the authority, a sanitary landfill needs to adopt different types of leachate treatment technologies. There are numerous types of treatment available but the choice of treatment depends on the quantity and the quality of the leachate produced by the landfill. The design and budget allocated are also important factors that need to be considered during the treatment selection process. All these treatments are basically divided into three types which are pre-treatment, chemical/physical treatment, and biological treatment (Raghab *et al*., 2013).

All leachate collected will go through a pre-treatment process before they undergo chemical/physical treatment and biological treatment. The examples of pre-treatment processes are screening, sedimentation, and pH adjustment. These treatments are used to prepare the leachate for further treatment which is the chemical/physical treatment. Chemical/physical treatment such as sedimentation with coagulation, sand filtration, activated carbon adsorption, and flocculation will facilitate the removal of heavy metal, suspended solid, and colour (Renou *et al*., 2008).

**Table 2.7:** Second schedule (Regulation 13).

| Parameter | Unit | Standard- Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations 2009 |
|---|---|---|
| Temperature | $^{o}C$ | 40 |
| pH value | N/A | 6.0-9.0 |
| $BOD_5$ at $20^{o}C$ | mg/L | 20 |
| COD | mg/L | 400 |
| Suspended Solids | mg/L | 50 |
| Ammonical Nitrogen | mg/L | 5 |
| Hg | mg/L | 0.005 |
| Cadmium | mg/L | 0.01 |
| Chromium Hexavalent | mg/L | 0.05 |
| Chromium, trivalent | mg/L | 0.2 |
| Arsenic | mg/L | 0.05 |
| Cyanide | mg/L | 0.05 |
| Lead | mg/L | 0.1 |
| Copper | mg/L | 0.2 |
| Manganese | mg/L | 0.2 |
| Nickel | mg/L | 0.2 |
| Tin | mg/L | 0.2 |
| Zn | mg/L | 2 |
| Boron | mg/L | 1 |
| Iron | mg/L | 5 |
| Silver | mg/L | 0.1 |

The last general leachate treatment is biological treatment which consists of processes such as trickling filter, activated sludge treatment, aerated lagoon treatment, and anaerobic fixed film treatment (Raghab *et al*., 2013). Biological treatment can be used to reduce or remove COD, BOD, and ammonia (Renou *et al*., 2008). High amount of heavy metal such as Hg, Zn, copper, lead and chromium are found in many raw leachate

studies. The presences of heavy metal in leachate are correlated with disposal of hazardous waste to the landfill.

## 2.8 Hazardous wastes

### 2.8.1 Definition and classification

In Malaysia, Department of Environment (2005) defined hazardous wastes as any waste listed in the first schedule under Environmental Quality (Scheduled Wastes) Regulations 2005. Table 2.8 indicate the 107 types of wastes which belong to the five major categories of hazardous waste which are SW1, SW2, SW3, SW4 and SW5. All these wastes are classified as hazardous waste if they possess one or more detrimental characteristics such as ignitability, corrosive, reactive or toxic. Hazardous characteristics of the waste can cause numerous risks to the environment and human's health such as heavy metal contamination and pollution. Managing hazardous wastes generated is one of the crucial issues as the amounts of hazardous wastes generated in Malaysia are accelerating in recent years (Jamin & Mahmood, 2015).

Rapid acceleration of industrialization and the amount of hazardous wastes generated in Malaysia have caused high risk of pollution in this country. Many industries are reported to dump their hazardous and toxic wastes directly to the adjacent river or disposal sites without treating the waste beforehand (Bavani, 2016). In order to tackle this issue, the government of Malaysia has promulgated Environmental Quality (Scheduled Wastes) Regulations 2005. This regulation is under the Environmental Quality Act 1974 [Act 127] and is used to stipulate the generation, storage, treatment, transport and disposal of hazardous waste in Malaysia.

**Table 2.8:** Scheduled wastes categories (Environmental Quality Act, 2005).

| Class | Waste Description | Example of wastes |
|---|---|---|
| **SW1** | Metal and metal-bearing wastes | -Waste containing arsenic or its compound (SW 101)<br>-Waste of lead acid batteries in whole or crushed form (SW 102)<br>-Waste of batteries containing cadmium |
| **SW2** | Wastes containing principally inorganic constituents which may contain metals and organic materials | -Asbestos wastes in sludge, dust or fiber forms (SW 201)<br>-Waste catalysts(SW202)<br>-Immobilized scheduled wastes including chemically fixed, encapsulated, solidified or stabilized sludge (SW203) |
| **SW3** | Wastes containing principally organic constituents which may contain metals and inorganic materials. | - Spent lubricating oil (SW305)<br>- Acid sludge (SW316)<br>- Rubber or latex wastes or sludge containing organic solvents or heavy metals (SW321) |
| **SW4** | Wastes containing principally organic constituents which may contain metals and inorganic materials | -Discarded drugs containing psychotropic substances or containing substances that are toxic, harmful, carcinogenic, mutagenic or teratogen (SW403)<br>-Disposed containers, bags or equipment contaminated with chemicals, pesticides, mineral oil or scheduled wastes (SW409)<br>-Waste of inks, paints, pigments, lacquer, dye or varnish (SW417)<br>-Leachate from scheduled waste landfill(SW420) |
| **SW5** | Other wastes | Any residues from treatment or recovery of scheduled wastes |

All hazardous wastes generated must be disposed of in a secure landfill. The only secure landfill in this country is under the administration of Kualiti Alam Sdn Bhd. It is located in Seremban, Negeri Sembilan and has been operating since 1998. All hazardous wastes sent to this secure landfill will undergo a thorough treatment before its final disposal. Waste received will be sent for determination of hazardous

characteristics. Suitable treatment to render heavy metal in the waste such as incineration, physical and chemical treatment and solidification will be chosen.

Only after the treatments are successfully carried out, waste will be landfilled in the secure landfill. All these procedures are carried out in order to ensure the toxic elements are sufficiently rendered to reduce the probability of any permanent damage to the surrounding environment. There are many strict regulations established for the hazardous wastes produced by industrial activities. However, there is no specific legislation on the management of hazardous wastes generated by household activities.

### 2.8.2 Household hazardous waste

United States Environmental Protection Agency has described household hazardous wastes as "*leftover household products that contain corrosive, toxic, ignitable, or reactive ingredients*" (United States Environmental Protection Agency, 2016). The increase in quality of life has caused the waste produced to become more complicated that accelerate the amount of household hazardous waste generated (Tang *et al*., 2015). Studies have reported that on worldwide scale, almost each household will generate 1% household hazardous waste (Inglezakis & Moustakas, 2015): There are several types of household hazardous waste commonly found in municipal solid waste. Tchobanoglous and Vigil (1993) have categorized household hazardous waste into five different groups which are household cleaners, personal care products, automotive products, paint products, and miscellaneous products.

Table 2.9 indicates the examples of household hazardous waste for each category. Chlorine bleach, nail polish remover, and battery have a considerably high amount of heavy metal (Ouremi & Ayodele, 2014). Meanwhile, diesel fuel has high possibility of burning, while pesticides and insecticides are toxic. Even though this

household hazardous waste is known to be harmful and able to inflict damage, there is still no proper management established for household hazardous waste disposal. In Malaysia, there is no obligation to segregate household hazardous waste from MSW during the disposal process (Yiing & Latifah, 2014). Therefore, most of the household hazardous waste will be dumped together with the non-hazardous waste in MSW.

**Table 2.9:** Categories of household hazardous wastes (Tchobanoglous & Vigil, 1993).

| Categories of household hazardous waste | Examples |
|---|---|
| Household cleaners | Chlorine bleach, out-dated medicines, shoe polish, abrasive scouring powders, spot remover |
| Personal care products | Medicated shampoos, nail polish remover, hair- |
| Automotive products | Diesel fuel, car batteries, waste oil, gasoline |
| Paint products | Paint solvents and thinners, water, latex or oil-based paints |
| Miscellaneous products | Batteries, pesticides, herbicides, chemical fertilizers |

Inefficient household hazardous waste management might not be a critical issue in the eyes of the public as household hazardous waste only constitutes a small amount of the total MSW composition (Fikri *et al*., 2015). However, studies have proven that inefficient disposal of household hazardous waste will induce accumulation of heavy metal. This will cause severe issue such as heavy metal contamination as high level of heavy metal concentration will reduce environment quality and threaten human's well-being (Tang *et al*., 2015).

## 2.9 Heavy Metal

### 2.9.1 Usage and Toxicity of Heavy Metal

Heavy metal can be referred as any metallic element which has a relatively high density and is toxic or poisonous even at low concentration. Hg, Zn, arsenic (As), copper (Cu), lead (Pb), and cadmium (Cd) are the examples of common heavy metals in the

environment. Lead has been used in industry, domestic, and agricultural industry (Huang *et al*., 2016). This heavy metal has been widely used in petrol production, lead acid batteries production, glass, sheet leads, oxides for paints, and pigments (Iyer *et al*., 2015). Arsenic has been utilized in many other industrial processes such as fossil fuel production, timber treatment and mining (Ranjan *et al*., 2009). Meanwhile, Zn is used for battery production, brass manufacture, metal plating, and plumbing activities (Ebin *et al*., 2016).

Many heavy metals not only are beneficial for industrial application but they also have bio-importance as trace elements (Iyer *et al*., 2015). Thus, they are required in recommended amount for humans to have a good physical and mental condition. Zn, for example is important for male productivity (Watson, 2015). It is also a co- factor for the production of carbonic anhydrase and dehydrogenating enzyme. Insufficient Zn intake will cause some health problems such as impaired immune function, hair loss, diarrhoea, delayed growth, and sexual maturation (National Institutes of Health, 2016). Magnesium is a vital electrolytic constituent in human body especially in the blood plasma and body fluid. Copper, chromium, iron, selenium, and nickel are examples of heavy metals which are equally important in ensuring well-balanced health for the human body.

Despite the benefits of heavy metals in human lifestyle and health, these heavy metals are toxic and harmful to human if we are exposed to the metals in a higher amount than the permissible limit (Omar *et al*., 2015). It is because heavy metals are able to magnify and accumulate inside the human's body. The heavy metal will become bio-toxic and it will interrupt the body system even at the cellular level and cause human to suffer

various chronic and acute diseases and can be fatal (Iyer *et al*., 2015). Table 2.10 summarizes the type of diseases suffered by human due to high heavy metal exposure.

**Table 2.10:** Types of heavy metals and their effect on human health (Singh *et al*., 2011).

| Heavy metal | Effects on human health |
|---|---|
| Arsenic | Bronchitis, dermatitis |
| Cadmium | Renal dysfunction, lung disease, lung cancer, bone defect, kidney damage, bone marrow |
| Lead | Congenital paralysis, gastrointestinal damage, mental retardation in children, acute or chronic damage to nervous system |
| Manganese | Damage to central nervous system |
| Hg | Tremors, gingivitis |
| Zn | Corrosive effect on skin, damage to nervous membrane |
| Chromium | Damage to the nervous system, fatigue, irriratibility |
| Copper | Anemia, liver and kidney damage, stomach and intestinal irritation |

Humans are exposed to high concentration of heavy metals resulting from inefficient and irresponsible approach of dealing, emission, and storing or disposal of wastes that contain heavy metals (Tang *et al*., 2015). This will induce the risk of heavy metal contamination. Heavy metal contains severe toxicity where it can kill thousands of people at a time. To understand the severity of heavy metal contamination, several deadly incidents reported all around the globe are been summarized in this section.

### 2.9.2 Case studies of heavy metal contamination

In the 1960s to 1970s, Japan has undergone fast economy progression through many industrial activities such as smelting, mining, and manufacturing industry. Due to the low environmental awareness of the industries at that time, many of these hazardous wastes were dumped right into the nearest river. Mitsui Mining and Smelting Company Ltd which was one of the biggest Zn mining companies also discharged their tailing slurry which is highly concentrated with Cd as its by-products into the Junzu River

Basin (Yoshida *et al*., 1999). This irresponsible action has caused severe Cd poisoning to the residents. This is because this river is used by the residents in the Toyama prefecture for their agricultural and fishery activities including the rice plantation (Nordberg *et al*., 2009).

A high amount of Cd was reported in the rice grain harvested from rice paddies in the Toyama area (Ishihara *et al*., 2001). The abundance of Cd level in the victims' body was caused by the consumption of those contaminated rice grains. These victims suffered from Itai-Itai disease which is a type of osteomalacia disease caused by renal tubular dysfunction (Inaba *et al*., 2005). This disease caused the victim to lose their ability to talk, stand or walk (Inaba *et al*., 2005). It can also cause a lot of bone fractures to the extent of 28 bone fractures in the rib alone (Yoshida *et al*., 1999).

In southern China, the biggest multi-metal mine "Dabaoshan mine site" had mined Cu and Fe ore extensively since 960–1279 AD (Zhuang *et al*., 2009). Acid mine drainage from this mine was discharged into the adjacent rivers such as Hengshi, Chuandu, Tielong, and Xitou rivers for a long period of time (Zhao *et al*., 2012). These rivers are the main water source used by the residents for personal and agricultural purposes. Studies have shown that vegetation which grew along the rivers were contaminated with high level of heavy metal concentration (Wang *et al*., 2012). High exposure of heavy metals in this vicinity has increased the number of residents suffering from serious cancer (Zhuang *et al*., 2009).

In Malaysia, similar events have occurred at Bukit Merah in Perak where the extraction of rare-earth namely ytrium and cerium were done (Furuoka, 2002). The extraction process produced sludge which has high level of radioactivity of uranium and thorium.

The improper disposal of this by-products deteriorates the health of the communities in the area (Poh, 2015). The number of people with diseases escalated and it was revealed that 39% of the children in Bukit Merah area suffered from recurrent rhinitis and mild lymphadenopathy (Poh, 2015).

Heavy metal contamination can occur in various ecosystem especially when there is no stringent regulation to control the emission of heavy metal. A sanitary landfill is one example of the system where heavy metal contamination is bound to happen.

### 2.9.3 Hg and Zn in sanitary landfill ecosystem

Hg has been recognized as one of the most lethal heavy metals in the environment (World Health Organization, 2017). Coal-fueled plants, ore processing plants, chemicals production industry and incineration of MSW were identified as main industrial activities causing an enormous amount of Hg to be released into the environment (Pirrone *et al*., 2010). Hg is hazardous, but due to its unique properties, it is still vastly used in various types of applications. Hg is used to extract gold through the amalgamation process (Veiga *et al*., 2009). It is also utilized in the production of electrical items such as switches and thermostats, because it has good electrical conductivity. Hg is also able to contract and expand uniformly with changes to temperature and pressure. Therefore, it is also used in thermometers. However, the numbers of products containing Hg such as thermometer, fluorescent lamp, batteries have depleted, due to the ban introduced by the authorities (Zhang *et al*., 2016 ; United Nation, 2017).

Zinc is a heavy metal which belongs to the IIb group periodic table, along with Hg and Cd (Plum *et al*., 2010). There are four major types of Zn, namely, $ZnCl_2$, ZnO, ZnS and

$ZnSO_4$ (United States Environmental Protection Agency, 2005). Volcanic eruptions and the rock weathering process are the natural activities that cause Zn to be released into the environment. Metal smelting and the coal industry use and produce major quantities of Zn (United States Environmental Protection Agency, 2005). Zn is profusely used, as it is very important in preventing the corrosion of steel. The usage of zinc elongates the life span of iron, and reduces the necessity of using more raw materials to produce new products (Ohio Environmental Protection Agency, 2002). This metal is also vital in rubber, alloy and brass manufacturing operations. Zn has been extensively employed in consumer products such as paint, dye, and dry cell batteries (Ohio Environmental Protection Agency, 2002). The anthropogenic activities have increased the amount of Zn into the ecosystem. The toxicity of Hg and Zn make it important to dispose waste containing these two metals carefully. This is because, if these waste were disposed together in the landfill, there will be a high probability that these hazardous metals will be dispersed into the landfill system, and thus cause adverse impacts in the long run. Previous studies show that there are concentrations of Hg and Zn in landfill components such as waste received, rainfall, leachate and landfill gas produced.

Waste is the primary component in landfill operations. Waste contributes significantly to the amount of metals released in a landfill system. Previous studies reported that there is a presence of Hg and Zn in the waste samples collected and analysed in MSW landfills. A study done by Long *et al*. (2011) suggests that the concentration of Zn in the MSW sample received was in the range of 109.3-1077.9 mg/kg. This value is higher than the value reported by Xiaoli *et al*. (2007), which was in the range of 0.002-1.36 kg/mg. Xie *et al*. (2015) stated that the maximum amount of Hg found in waste samples from his study was 6.3 mg/kg. Meanwhile, a study conducted by Lindberg *et al*. (2005) shows that the concentration of Hg in waste samples was 4mg/kg. Li *et al*. (2010) stated

that the concentration of Hg was in the range of 0.17-46.22 mg/kg. There are many factors that can induce the fluctuation of Hg and Zn found in these waste samples, such as the weather at the landfill, the moisture content of the waste and waste disposal practices (Xie *et al*., 2015). Another major reason for these differences is based on the type of household hazardous waste received in the landfill. This is because different types of household hazardous waste contain different amounts of Hg or Zn. Ullah *et al*. (2017) stated that Zn is used in the production of eye shadow, and the concentration of Zn found in the study was 270µg/g. Meanwhile, Iwegbue *et al.* (2016) mentioned that the average concentration of Zn found in hair shampoo is 30.0–69.0µg/g. Batteries also contain Zn concentrations. Karnchanawong & Limpiteeprakan (2009) reported that the concentration of Zn in a ZnO battery was 5mg/L. Meanwhile, products such as fluorescent lights, button batteries, and pesticides contain 5mg/L, 25mg/L and 0.001-8.1 ppb of Hg respectively.

Another source of Hg and Zn in the landfill system might be through the rainfall received. Even though the concentration of metal reported in rainfall is much lower than the concentration of metal found in waste, the effects are still significant. This is due to the high volume of rainfall, especially in tropical countries such as Malaysia. It was reported that the concentration of Hg in rainfall falls in the range of 1.9 ng/L and 14.8 ng/L (Siudek *et al*., 2015). This finding is in line with the result by Beldowska *et al*. (2008). Meanwhile, the average concentration of Zn in precipitation is in the range of 0.9 mg/L to 3mg/l, as mentioned by Pan and Wang (2015), and Gunawardena (2013).

Infiltration of rainfall into the waste cell will produce a by-product called leachate. Leachate is formed once precipitation infiltrates the waste cell and extracts dissolved and suspended matter from the refuse (Ye *et al*., 2014). Generally, leachate is classified as a harmful by-product due to its perilous characteristics such as high biological

oxygen demand (BOD), chemical oxygen demand (COD), and organic pollutants (Xie *et al*., 2015). Karnchanawong and Limpiteeprakan (2009) stated that leachate generated in MSW landfills also contains heavy metals such as Hg and Zn. Table 2.11 indicates the concentrations of Hg and Zn in leachate from several landfill studies carried out in various regions.

**Table 2.11:** Concentration of Hg and Zn in leachate from several landfill studies.

| **Countries** | **Hg** | **Zn** |
|---|---|---|
| Oman (Al Raisi *et al*., 2014) | NA | 0.8-1.0mg/L |
| Australia (Xie *et al*., 2015) | BDL | 0.64-10.49 mg/L |
| Malaysia (Fauziah *et al*., 2013) | 0.12 mg/L | 4.2 mg/L |
| China (Li *et al*., 2010) | 0.08 ug/L | NA |
| United States (Aucott, 2006) | 0.050 ug/L | 0.051mg/L |

NA- Not Available
BDL-Below Detection Limit

It also shows that a study conducted in Malaysia by Fauziah *et al*. (2013) has the highest concentration of Hg as compared to other studies listed. This high concentration may due to mixed waste disposal in the landfill investigated

Another by-product of landfills is the generation of landfill gas (LFG) (Das *et al*., 2016). LFG will be generated when biodegradable waste undergoes anaerobic degradation in the landfill (Lombardi & Carnevale, 2016). These gases were collected by using gas wells to reduce the risk of explosion. Gas wells are also used to ensure that a high percentage of these gases will be flared by using a gas flaring unit. By flaring LFG, methane will be converted into carbon dioxide ($CO_2$), and the green house impact can be decreased (Lombardi & Carnevale, 2016).

The composition of LFG is mainly composed of methane and $CO_2$. Table 2.12 indicates the average composition of LFG in a landfill system.

**Table 2.12:** Average composition of LFG (Damgard *et al*., 2011).

| **Substances** | **Period 1 (2 year)** | | **Period 2 (3 year)** | | **Period 3 (35 year)** | |
|---|---|---|---|---|---|---|
| | Composition | (%) | Composition | (%) | Composition | (%) |
| Methane | 25% | | 40% | | 60% | |
| Carbon Dioxide | 70% | | 60% | | 40% | |
| Benzene | 0.007 | | 0.007 | | 0.007 | |
| Carbon Monoxide | 1.00E-05 | | 1.00E-05 | 20 | 1.00E-05 | 20 |
| Carbon Tetrachloride | 3.00E-05 | 0 | 3.00E-05 | 0 | 3.00E-05 | 0 |
| CFC 11 | 0.01 | 0 | 0.01 | 90 | 0.01 | 90 |
| CFC 12 | 0.02 | 0 | 0.02 | 30 | 0.02 | 30 |
| Hydrogen Chloride | 0.006 | 0 | 0.006 | 0 | 0.006 | 0 |
| Hydrogen fluoride | 0.002 | 0 | 0.002 | 0 | 0.002 | 0 |
| Hydrogen Sulphide | 7.00E-05 | 0 | 7.00E-05 | 20 | 7.00E-05 | 20 |
| Mercury | 3.50E-06 | 0 | 3.50E-06 | 0 | 3.50E-06 | 0 |
| Toluene | 0.16 | 0 | 0.016 | 40 | 0.016 | 40 |
| VOC's | 0.23 | 0 | 0.23 | 60 | 0.23 | 60 |
| Xylenes | 0.06 | 0 | 0.06 | 30 | 0.06 | 30 |

Previous studies conducted show that the presence of Hg is recorded as one of the trace gases in the LFG, but not Zn. Aucott *et al*. (2006) reported that the concentration of Hg in LFG generated is in the range of 5-10 ug/L and Li *et al*. (2010) reported that the concentration of Hg is in the range of 0.002-1.406 ug /L.

The presence of heavy metals in landfill systems may lead to environmental risks. Heavy metal contamination will lead to the degradation of the environmental quality of the landfill. Therefore, to overcome this issue, material flow analysis (MFA) can be utilized to quantify the presence of heavy metals. This can clearly indicate the flow of heavy metals such as Zn and Hg in a landfill system.

## 2.10. Material Flow Analysis

### 2.10.1 Theory on Material Flow Analysis

The theory of MFA was identified by Santorio who was a philosopher from Greek (Brunner & Rechberger, 2004). Santorio used MFA in human metabolism study (1561-1636) by measuring the input and output of a human (Leontief, 1936). MFA is an effective methodology to identify the sources, flow, and stocks of a material in a defined system boundary for a specific period of time (Brunner & Rechberger, 2004). The system in question can be a single process or link of several processes. In MFA study, the law of matter conservation is the fundamental theory.

Through this theory, MFA can be controlled by utilizing a material balance equation which involves all inputs, stocks, and outputs of the processes in the system (Brunner & Rechberger, 2004).

MFA is widely adopted as it has numerous benefits from the environment or economic aspects. MFA has the ability to simplify the complexity of a system either at national, state, region or industry level. Table 2.13, Table 2.14 and Table 2.15 indicate some of the studies which were carried out in various areas in three different levels which are national, regional and industrial level (Bao *et al*., 2010).

**Table 2.13:** MFA studies done at national level (Bao *et al*., 2010).

| Year | The area of study |
|---|---|
| 1993 | Major material flows in Germany, Japan and Austria |
| 2000 | Austria, Germany, and the Netherlands |
| 2001 | A Preliminary material input analysis of China |
| 2009 | A material flow analysis of phosphorus in Japan |
| 2014 | Analysis of copper flows in China from 1975 to 2010 |
| 2015 | A material flow analysis: The case of the cereal supply chain in France |

**Table 2.14:** MFA studies done at regional level (Bao *et al*., 2010).

| Year | The area of study |
|---|---|
| 1986-1988 | An analysis of energy and material flow in ecosystem of Dali City |
| 2002 | Total material requirement of the Basque Country |
| 2008 | A method for regional scale material flow and decoupling analysis |
| 2009 | Design and analysis of an input output table of material flow in economic system in Beijing |

**Table 2.15:** MFA studies done at industrial level (Bao *et al*., 2010)

| Year | The area of study |
|---|---|
| 2001 | MFA in the remote tropical Island of Trinket |
| 2004 | Regional wood management in Appenzel Ausserrhoden |
| 2005 | The WEEE in the city of Delhi |
| 2005 | Stainless steel |
| 2007 | Cadmium in Australia |
| 2008 | The local household consumption in the UK |
| 2009 | Wastewater pipeline networks of Oslo |

MFA is much simpler than other assessment methods such as life cycle assessment, but it still covers all the important aspects and making the result viable for a good decision making (Baccini & Brunner, 2012). Through MFA, the insight of the system can be analyzed. This is because the analysis is capable in giving complete data about all flows and stocks of a material in the system. Any decrease or increase of a material as stock in the system and any small changes in a long-term can be clearly perceived through MFA's results.

Thus, this enables related stakeholders to do sufficient countermeasures since early recognition of accumulation of potentially harmful substances can be detected (Hongyeng & Agamuthu, 2015). MFA also produced results that can be interpreted in a transparent, reproducible, and easily understood even to laymen such as decision and policy makers.

### 2.10.2 Applications of MFA

Due to its various functions, MFA has been used in many various field of studies such as resource management, environmental management, and waste management (Bao *et al*., 2010).

### 2.10.3 Case study: MFA application of Phosphorus (P), Hg and Zn flows

#### 2.10.3.1 Material Flow Analysis of Phosphorus in Japan (Matsubae *et al*., 2009)

A study was conducted in Japan to investigate the MFA of P for the whole country. Japan requires P as it is one of the vital nutrients for its agricultural production especially to boost biofuel industry. However, there is no domestic source of P available in Japan and all the P need to be imported. Therefore, MFA was carried out to identify the potential resources of P in Japan. In this study, input, output, and total mass balance of P from 15 sectors in Japan were analysed. Matsubae *et al*., (2009) found that iron and steelmaking slag industries would be a great potential resource for P as most of the P can be recovered by the magnetic separation technology suggested in the study. Figure 2.9 shows the overall domestic flows of P in Japan. It can be clearly seen that 93.07 kilo tonnes of P was stored in slag and can be recovered using a suitable recovery technology.

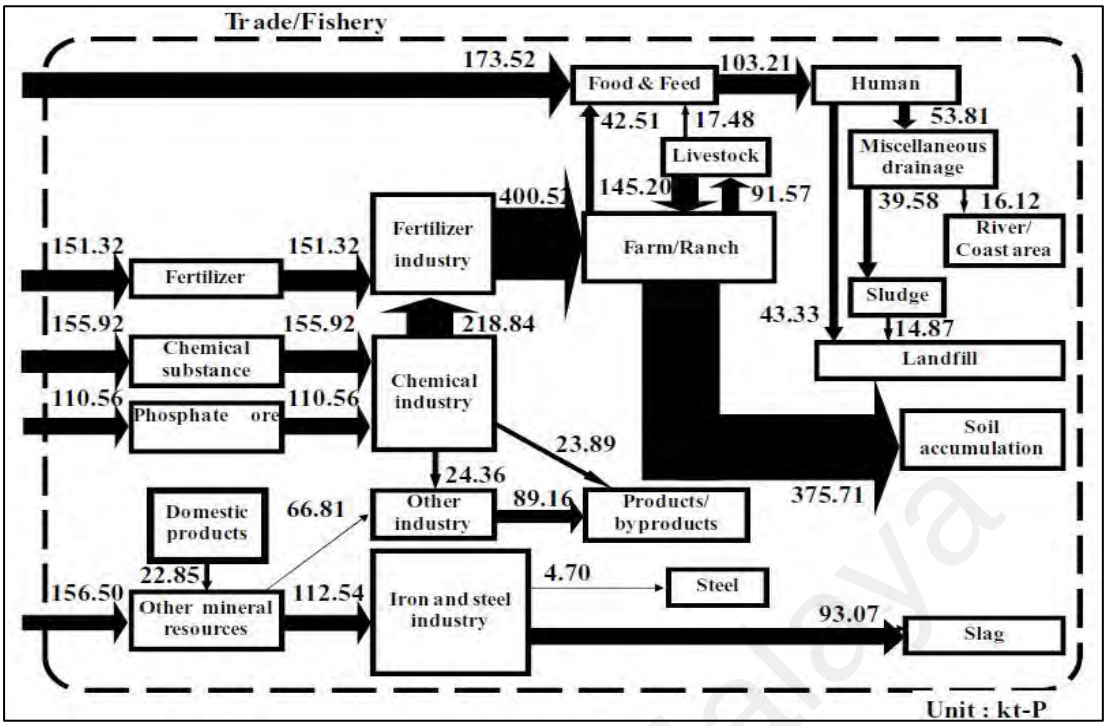


**Figure 2.9:** Overall domestic material flow of Phosphorus in Japan, in kilo tonnes (Matsubae-Yokoyama *et al*., 2009).

#### 2.10.3.2 Material Flow Analysis of Zn in Taiwan at national level (Ma *et al*., 2011)

Zn is a vital element in manufacturing industry particularly in die casting, brass production, and galvanization processes due to its distinct chemical and physical properties. Nevertheless, studies have shown that there will be a limited supply of this valuable element in the future. A substance flow analysis of Zn at national level was carried out in Taiwan (Ma *et al*., 2011). This research aimed to identify the main flow and distribution pattern of Zn in the country. The finding of the study showed that the total Zn imported into the system was 258.78 kilo tonnes, while 167.42 kilo tonnes were exported out of the system. Figure 2.10 shows that the processes are generally classified into four parts for easier monitoring procedure.

The processes are divided into production, fabrication, usage, and waste management. Figure 2.10 also shows that there were 110 kilo tonnes of Zn contained in the waste generated such as galvanizing steel, brass scrap, and Zn scrap. Even though a significant amount of Zn is sent to the landfill and stored in products, these are not suitable as it is not economically feasible. Therefore, recycling of EAF which contains 30% of Zn is highly recommended. Ma *et al*. (2011) have suggested that a better capacity and enhanced recycling facilities should be provided for waste with high potential of Zn recovery such as cement, aggregates, and MSW.

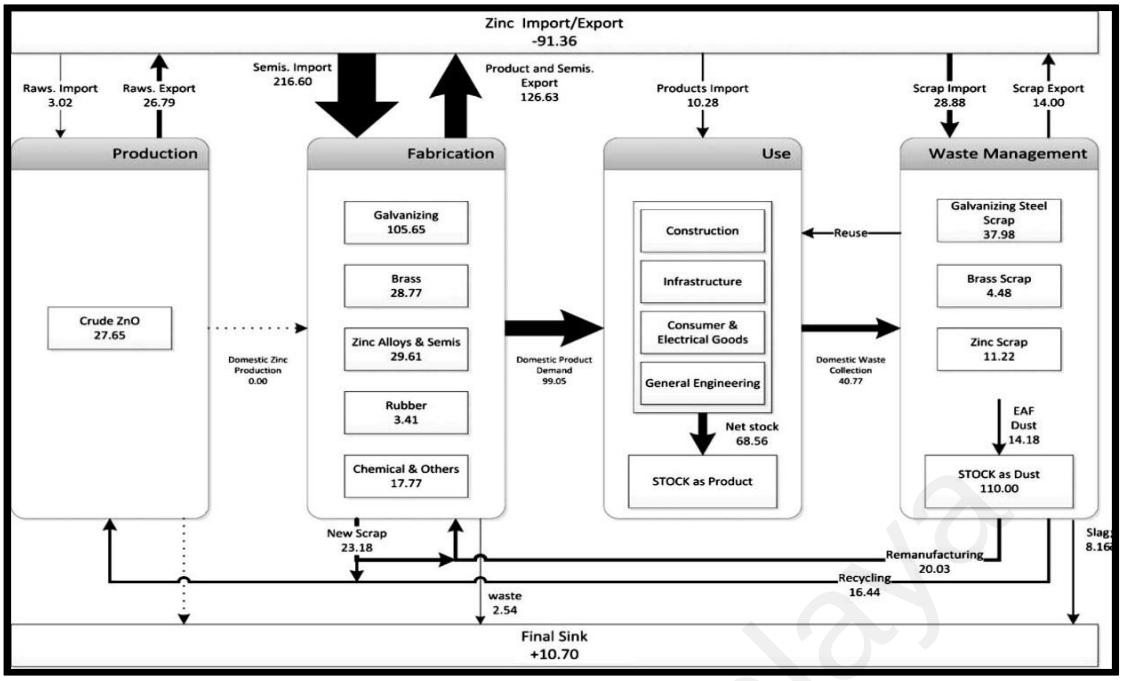


**Figure 2.10:** Four main processes in the distribution of Zn in Taiwan (Ma *et al*., 2011).

### 2.10.4 STAN 2.5

MFA is also used together with other environmental assessment tools to conduct studies in waste management. Arena and Di Gregorio (2014) have combined material and substance flow analysis together with life cycle assessment (LCA) to quantify the mass flow rates and the main chemical elements for waste management options such as recycling chain, thermal treatment, and biological treatment. The MFA studies were carried out by using various softwares. Stan 2.5 is one of the latest software used in performing material flow analysis.

SubSTance flow ANalysis 2.5 (STAN 2.5) is a free software program created by Brunner and Baccini (Brunner & Rechberger, 2004; Cencic & Rechberger, 2008). It is specifically designed to facilitate the formation of MFA. This software includes all necessary features needed to produce an MFA. STAN 2.5 has many advantages as compared to previous MFA related software. Previously, to complete an MFA, several software such as Microsoft Excel and graphical software are needed. However, by using STAN 2.5, all the design, data management, calculation, and graphs of the result can be directly accomplished using this software (Vyzinkarova & Brunner, 2013). STAN 2.5 was used in this research to determine the flow of Hg and Zn in Jeram Sanitary Landfill.

# CHAPTER 3: MATERIALS AND METHODS

## 3.1 Description of study area and time boundaries

Jeram Sanitary Landfill has been in operation since 2007 and it is under the management of Worldwide Holdings Berhad. Jeram Sanitary Landfill is located at Lot No. 1595, 2958 and 2959 in Jeram Town, Kuala Selangor District. It covers an area of 168 acres which consisted of 43 cells are divided into six phases. Jeram Sanitary Landfill is categorised as level four sanitary landfill in Malaysia as it is equipped with the leachate collection and treatment system, gas collection system (gas well), gas flaring unit and daily cover system. This landfill receives waste from seven municipalities in Selangor which include Kuala Selangor, Subang Jaya, Klang, Petaling Jaya, Shah Alam, Ampang Jaya, Selayang and it also received wastes from the private sectors. The daily average waste received was 2300 tonnes/day and consisted of heterogeneous wastes.

## 3.2 Wastes sampling

### 3.2.1 Waste characterisation

In this research, waste characterisation was carried out based on the ASTM D5231-92 standard (Dahlén & Lagerkvist, 2008). A garbage truck was randomly selected for the characterisation purpose. One to two tonnes of waste from the selected garbage truck was unloaded onto a tarpaulin at designated areas within the landfill compound.

The steps of quartering method were applied as below:

1. The pile of wastes was divided into four sections.
2. Two quarters were retained while another two were rejected.
3. Selected quarters were divided into another two sections.
4. Each section was approximately 100-250 kg.

5. 100-250 kg of wastes were sorted into ten groups according to their types namely kitchen waste, plastic, paper, wood, textile, rubber, metal, glass, hazardous and miscellaneous as listed in Table 3.1.
6. The separated wastes were weighed.
7. All data was computed and analysed to determine the waste composition.

**Table 3.1**: Detailed composition of MSW studied.

| Waste Types | Waste Groups | Examples |
|---|---|---|
| Kitchen waste | Food waste | Vegetable, fruits skin, left-over food etc. |
| | Food (not –consumed) | Expired food, rotten food etc. |
| Paper waste | Mixed paper | Coloured paper, heterogeneous paper |
| | Newsprint | Newspaper |
| | Magazine | Magazine, glossy paper |
| | White Paper | Computer paper, good quality papers |
| | Corrugated Paper | Box, cartons |
| Plastic waste | Plastic (rigid) | Plastic toys, Plastic pails |
| | Plastic (film) | Plastic bags and non-rigid, film like plastics |
| | Plastic (polystyrene) | Food containers, electrical appliances, fixing polystyrene etc. |
| | Disposable Diapers | Diapers |
| Textile waste | Textile | Clothes, rags |
| Rubber/leather | Rubber/leather | Shoes, tyres, etc. |
| Wood | Wood | Part of wooden furniture, wooden crates etc. |
| Garden waste | Garden waste | Leaves, tree branches, grass |

| 'Table 3.1, continued' | | |
|---|---|---|
| Glass | Clear glass | Non-coloured glass, window glass etc. |
| | Coloured glass | Coloured or dark glass |
| Metal | Metal | Plumbing pipes, parts of electrical appliances etc. |
| | Tin | Food can etc. |
| | Aluminium can | Drinking can |
| | Other aluminium | Aluminium foil etc. |
| Miscellaneous | Other organic | Non-food materials |
| | Other non-organic | Ceramic, inorganic materials etc. |
| | Bulky waste | Furniture etc. |
| | Hazardous wastes | Home improvement products<br>Beauty products<br>Expired medicine<br>Fluorescent lamp<br>Ink/paint<br>Automotive product<br>Miscellaneous products<br>e-waste |

### 3.2.2 MFA based on given scenario

The waste generation and composition data collected throughout the study period were utilised to generate the waste flow in the landfill system. Moreover, the estimation of profit for possible recycling activities in the landfill was done.

MFA was produced based on two different scenarios:

i. National recycling rate achieved 22% as in Vision 2020

ii. Capacity of MRF if recycling is increased to 400 tonne/day

## 3.3 Material Flow Analysis (MFA)

### 3.3.1 MFA of the sanitary landfill system

To generate MFA of a sanitary landfill, the boundary of the system to be studied must be determined. The boundary of this study included all waste cells, leachate treatment plant, gas flaring unit, landfill gas well and the Material Recovery Facility (MRF). Prominent processes identified in this study were arrival of waste to be deposited, landfilling operations, daily cover activities, material recovery operations, rainfall, evaporation, leachate and surface runoff generation, treated leachate discharges, release of landfill gas and soil-off gas from the working face area. All these processes were classified as input and output. The amount of material through each process were quantified and extrapolated to obtain the total amount per year. Data for these materials were collected through analysis or interview conducted with the landfill management. Microsoft Excel 2007 was used to organize the data before any software was used to generate the MFA of the sanitary landfill. STAN 2.5 was the chosen software to balance and illustrate the finished MFA. This software does the balancing of the MFA by utilizing four important formulas as indicated by Equation 3.1, Equation 3.2, Equation 3.3 and Equation 3.4 (Brunner & Rechberger, 2004).

*Balance equation:* $\sum inputs = \sum outputs + change\ in\ stock$ (Equation 3.1)

*Transfer coefficient equation: output x= transfer coefficient to output x* $. \sum inputs$ (Equation 3.2)

*Stock equation: stock period i + change in stock period i* (Equation 3.3)

*Concentration equation: mass substance= mass good. concentration substance* (Equation 3.4)

The balanced MFA obtained can be used to estimate the amount of input, output or stock in the landfill. Figure 3.1 depicts an example of MFA generated by STAN 2.5.

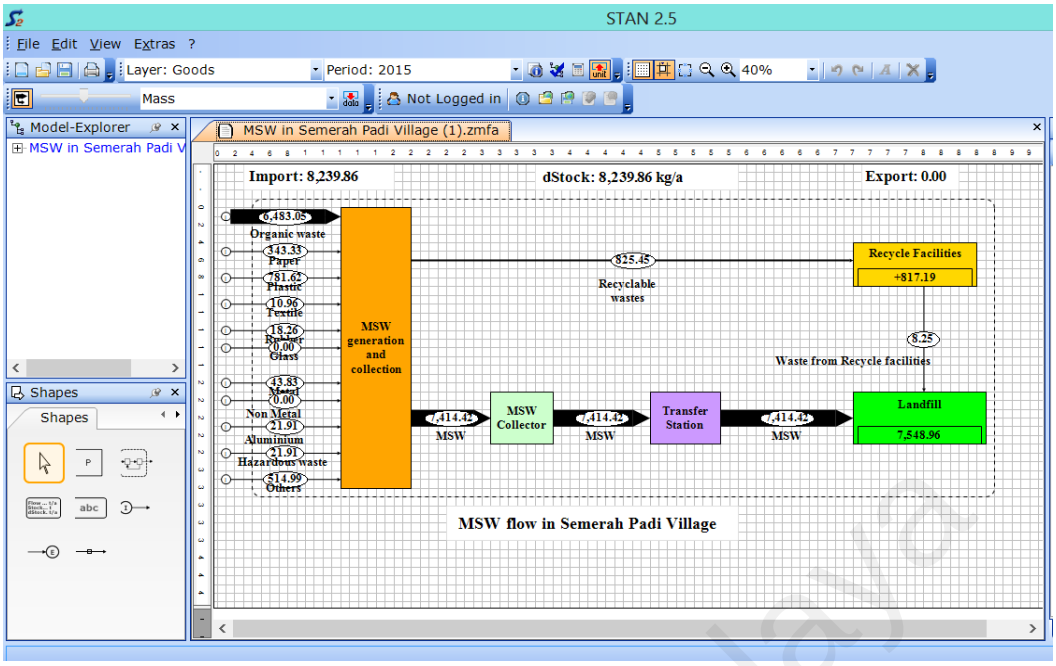


**Figure 3.1**: Example of MFA of waste in a village.

## 3.4 Waste analysis

Heavy metal analysis to determine the concentration of Hg and Zn, measurement of pH value and total moisture content of waste sample were carried out.

### 3.4.1. Heavy metal analysis

Ten kg of representative samples collected from 30 random points in active cells. Samples collected from various points to ensure that waste sample collected able to represent the average concentration of metal in the active cells. Waste samples were brought back to the laboratory for heavy metal analysis. USEPA Method 200.8 was used as the standard in this analysis (United States Environmental Protection Agency, 1994). USEPA Method 200.8 procedure is given below:

1. All volumetric ware used for the digestion was carefully acid washed and rinsed with deionised water to avoid any cross contamination prior to usage.
2. Waste samples were air-dried inside the oven at 60$^{o}$C for 14 hours to prevent any loss of elements, especially the volatile metallic compound.

3. Air-dried solid waste was then grinded, screened through a 1.0 mm sieve and subjected to further analysis.
4. 1.0 g of the dried and grinded sample was weighed and transferred to a 250 ml conical flask.
5. 4 ml of concentrated Nitric acid ($HNO_3$) and 10 ml of Hydrochloric acid (HCL) were added to the conical flask. This is conducted in a fume hood for safety purpose.
6. Elevated watch glass was used to cover the beaker in order to prevent any sample contamination.
7. Thereafter, the beaker was placed onto the hotplate set with temperature of less than 95$^{o}$C for four hours. This was done to reflux extraction of analytes.
8. After four hours, the beaker was transferred from the hot plate to let it cool to reach room temperature.
9. After cooling, the digested sample was filtered by using the Whatman No. 42 filter paper to remove any suspended solid of the sample.
10. The filtrate was decanted and diluted to 100 times dilution by using the 100 ml volumetric flask, deionised water and stopper.
11. The diluted sample was analysed by using the inductively coupled plasma-mass emission spectrometry (ICP-MS).

### 3.4.2 pH

The pH of the sample was prepared with 1:10 solid waste and water ratio and measured using the pH meter (HANNA HI 8424).

### 3.4.3 Moisture content

The moisture of MSW samples was determined by weighing 1 kg of the samples into a pre-weighed dish and drying the samples in an oven at 105°C to a constant weight by following ASTMD 3173 (ASTM, 2008). The moisture content (MC) on weight basis

was calculated as a percentage loss in weight before and after drying as stated in Equation 3.5.

Moisture content= [(Wet Weight−Dry Weight)/Wet weight] ×100%  (Equation 3.5)

## 3.5 Leachate analysis

### 3.5.1 Leachate Parameter Analysis

Two types of leachate samples were collected from the sanitary landfill which were fresh leachate and treated leachate. All leachate samples were collected using HDPE bottles. Raw leachate was collected directly from the leachate pipe connected to the waste cells. This is to ensure leachate sample collected were fresh. Plate 3.1 shows the leachate collection pond where leachate samples for further analysis were collected.

**Plate 3.1**: Leachate equalization pond in Jeram Sanitary Landfill

Treated leachate was collected from the discharged pipe of treatment plant before it enters the Sembilang River. All leachate samples collected were analysed on the same day to ensure the reliability of data obtained. If there is any need for storage, HDPE bottles were kept in a chiller at 4$^{o}$C and taken out two hours before any test carried out in order to let the samples reached room temperature. Several tests were carried out to study the characteristic of raw leachate generated from the waste cells in the landfill. All parameters measured were classified into three groups which are physical, bio-chemical

and chemical. These parameters are listed in Table 3.2. Meanwhile, Table 3.3 indicates the unit, instrument and standard used in determining the parameters of leachate.

**Table 3.2:** Leachate parameters measured.

| **Parameters of raw leachate measured** | | |
|---|---|---|
| Physical | Bio-chemical | Chemical |
| i. pH,<br>ii. TSS,<br>iii. TDS,<br>iv. Salinity,<br>v. Conductivity,<br>vi. Turbidity,<br>vii. Colour | i. Biological Oxygen Demand (BOD)<br>ii. Chemical Oxygen Demand (COD) | i. Heavy metal analysis |

**Table 3.3:** Instruments and standards used to measure parameters of leachate.

| **Parameter** | **Unit** | **Device** | **Standard** |
|---|---|---|---|
| pH | - | pH meter (HANNA HI 8424) | - |
| TSS | mg/L | Spectrophotometer HACH DR/4000 UV-VIS | HACH Method 8006 |
| TDS | mg/L | Multipurpose Hach Sension 7 | - |
| Electrical Conductivity (EC) | mS/cm | Multipurpose Hach Sension 7 | - |
| Turbidity | FAU | Spectrophotometer HACH DR/4000 UV-VIS | ASTM D7315 – 12 |
| Colour | ADMI | Spectrophotometer HACH DR/4000 UV-VIS | ADMI Weighted Ordinate Method1 |
| BOD | mg/L | Multipurpose Hach Sension 7 | Biochemical Oxygen Demand (BOD) (APHA, 1998) |
| COD | mg/L | Spectrophotometer HACH DR/4000 UV-VIS | Reactor Digestion Method DR4000 Procedure |
| Heavy metal analysis | mg/kg<br>mg/L | Inductively Coupled Plasma Mass Spectrometry 7500 Single Turbo System | USEPA 200.8 |

### 3.5.2 Heavy Metal Analysis

Heavy metal concentration was obtained by carrying out test procedure as stated in USEPA Method 200.8. This procedure has been used to determine Hg and Zn concentration in raw leachate.

USEPA Method 200.8 procedure:

1. All volumetric wares used for the digestion were carefully acid washed and rinsed with deionised water to avoid any cross contamination.
2. 100 ml of aqueous sample (leachate, rainfall, etc.) was transferred into a 250 ml Griffin beaker.
3. 2 ml of concentrated Nitric acid ($HNO_3$) and 1 ml of Hydrochloric acid (HCL) were added into the same beaker.
4. Elevated watch glass was used to cover the beaker in order to prevent any sample contamination.
5. The beaker was placed onto a hot plate with temperature <85$^{o}$C for two to three hours to reduce the volume of the sample from 100 ml to 20 ml.
6. After two hours, the beaker was removed from the hot plate and was cool down until it reached room temperature.
7. After cooling, the digested sample was filtered by using the Whatman No. 42 filter paper to remove any suspended solid of the sample.
8. The filtrate will be decanted and diluted to 100 times dilution by using the 100 ml volumetric flask, deionised water and stopper.
9. The diluted sample was analysed by using the inductively coupled plasma-mass emission spectrometry (ICP-MS).

### 3.6 Soil Sampling

Soil samples were collected from three different locations, namely:

i. Soil cover used in the Jeram Sanitary Landfill;
ii. Soil collected from palm plantation which was located 500 m away from the sanitary landfill
iii. Soil collected from Rimba Ilmu (forest in University of Malaya)

All soil samples were collected from at least 20 different points in order to get the representative sample of each location. Spade and amber glass bottles for soil samples collection. Heavy metal analysis was carried out by using USEPA 200.8 procedure.

### 3.7 Rainfall

Data on annual rainfall and evaporation were obtained from the Malaysia Meteorological Department. Data was collected from the weather station in Mardi Tanjong Karang at a height above mean sea level (MSL) of 2.4 m. Heavy metal analysis in rainfall was carried out using the same procedure for Hg and Zn determination in leachate samples (USEPA 200.8). Rainfall samples were collected around the waste cells area. Collection was done by using HDPE bottles with the assistance from landfill management staff.

### 3.8 Surface runoff

Samples of surface runoff were collected after rain episodes using HDPE bottles with the help of the landfill management staff. Samples were collected at 30 pre-determined points around the landfill drainage. All these samples underwent heavy metal analysis to determine the concentration of Hg and Zn based on USEPA 200.8.

### 3.9 LFG and gas released from working face.

#### 3.9.1 Hg (Total Gaseous Mercury) in Landfill Gas

1. The LFG flares were sampled between the flame arrester and the open flame.
2. Total gaseous mercury was collected on activated iodated charcoal traps.
3. Samples were collected at flow rates of 400 ml/min, with a backup trap.
4. Total LFG flow rates from all sampled flares were provided by continuous recording flow meters.
5. All traps were heated slightly above LFG temperatures (50$^{o}$C) to eliminate condensation.
6. The traps were analysed by acid digestion and cold vapor–atomic fluorescence spectrometry (CV–AFS)

#### 3.9.2 Hg (Total Gaseous Mercury) in the working face areas

General emission equation was used to determine the emission rate of Hg from the working face in this landfill (Schnelle & Dey, 2000). The formula for this model is listed in the Equation 3.6 below:

$$C(x, y, z): \frac{Q}{2\pi\sigma_y\sigma_z U} \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \left[\exp\left(-\frac{(z-h)^2}{(2\sigma_z^2)}\right) + \exp\left(-\frac{(2+h)^2}{(2\sigma_z^2)}\right)\right] \quad \text{(Equation 3.6)}$$

C (x, y): Atmospheric pollutant concentration at horizontal coordinates (x, y)

Q: Pollutant emission rate from the source

U: Horizontal wind speed

*h*: Effective height of pollution source

$\sigma_y$ and $\sigma_z$ :Horizontal and vertical dispersion coefficient

x,y,z: Cartesian coordinate

### 3.10 Flows of Hg and Zn

MFA of Hg and Zn was completed by following the same procedures as shown in Figure 3.2. All Hg and Zn data were obtained through sampling activities. Samplings were done twice a month for a period of seven months starting from April 2014 until October 2014. The boundary and process selected for the MFA of Hg and Zn were the same as the MFA of the sanitary landfill except for the MRF. The concentration of Zn in LFG and gas from working faces the landfill was not measured. This is because Zn does not volatilize from soil or water medium (Agency for Toxic Substances and Disease Registry, 2005). Zn also cannot be emitted to atmosphere from working face or LFG as it has high boiling point value which is 910$^{o}$C. Emissions of Hg and Zn through evaporation were also not measured due to the properties of these metal. Both metals in the rainfall will dissolve in the water more easily than being evaporated to the atmosphere (Harvey *et al*., 2002).

After the data were finalised and organised, STAN 2.5 was used to balance and generated MFA for both Hg and Zn in this sanitary landfill system. Additional parameters of these components were also measured and analysed by using statistical analysis in order to study the presence of Hg and Zn in the sanitary landfill system. Regression and correlation tests were used in this study.

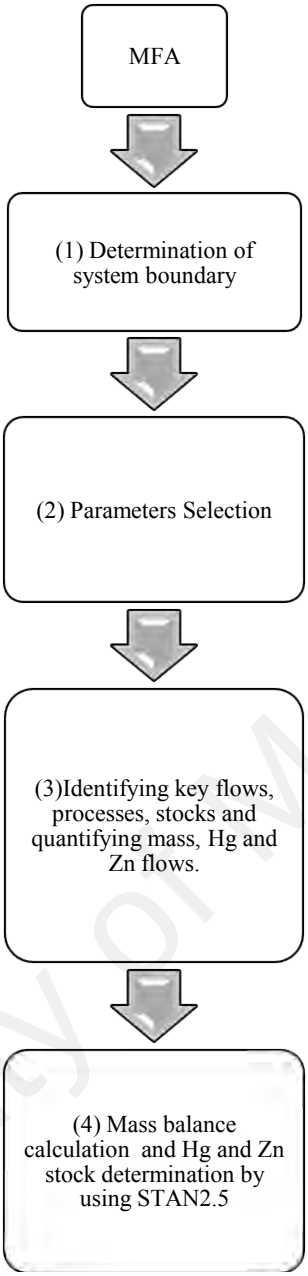


**Figure 3.2:** Steps of MFA generation (Hongyeng & Agamuthu, 2015).

Concentration of Hg and Zn were determined in various landfill components which were:

i. Waste,
ii. Rainfall,
iii. Soil cover,
iv. Landfill gas
v. Gas from working face
vi. Raw leachate,
vii. Treated leachate, and
viii. Surface runoff.

# CHAPTER 4: RESULTS AND DISCUSSION

## 4.1 Waste Study in Jeram Sanitary Landfill

### 4.1.1. Total waste received in Jeram Sanitary Landfill

The total amount of waste received increased yearly is as indicated in Figure 4.1. In 2007, the total amount of waste was 569,000 tonnes per annum (Muda, 2015). Eight years later, the total waste received in Jeram Sanitary Landfill was 842,000 tonnes per annum. This increase is due to the additional number of municipalities catered by Jeram Sanitary Landfill. The acceleration of waste received might also be contributed by the increase in human population and changes in lifestyles. Total amount of residents from seven municipals catered by Jeram Sanitary Landfill are 2,090,909 (Selangor Town and Country Planning Development, 2015).

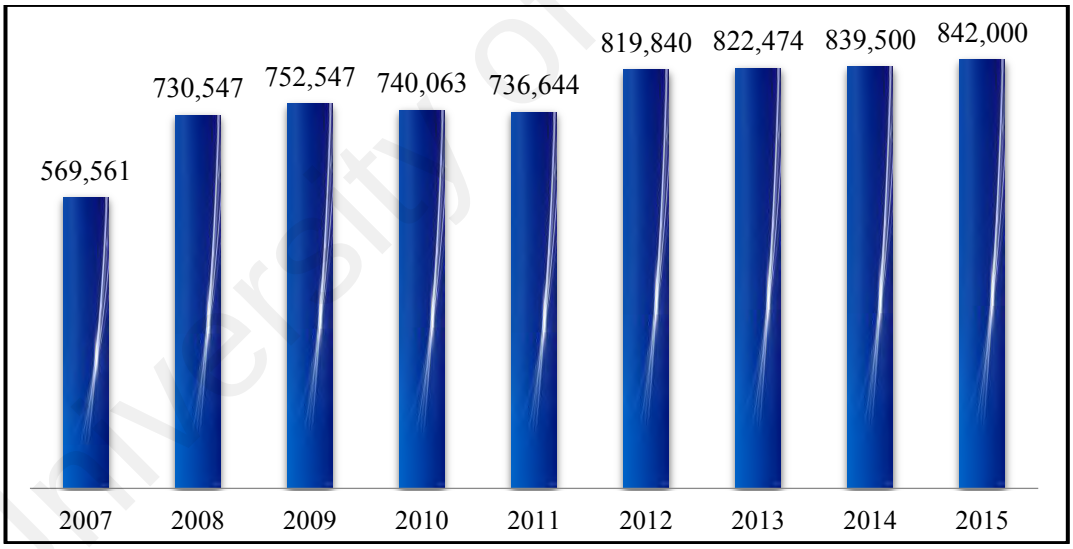


**Figure 4.1**: Total waste received in Jeram Sanitary Landfill (2007-2015).

On average, the waste generation per capita by residents from municipals catered by Jeram Sanitary Landfill is 1.1 kg/capita/day. This value is higher than the national daily per capita reported by National Solid Waste Management Department which is 0.8kg/capita/day (National Solid Waste Management Department, 2012). Higher MSW per capita generation in this study might be caused by the higher production of waste from high income residential areas such as Petaling Jaya and Shah Alam.

### 4.1.2 Waste composition studies

Results from the waste composition in Jeram Sanitary Landfill showed that food waste constituted about 37.7% of the total waste received by Jeram Sanitary Landfill Figure 4.2 indicates the composition of waste received in Jeram Sanitary Landfill. This high percentage could be attributed to the throw away habit among Malaysians. Huge amount of food waste being disposed in sanitary landfills is not a rare phenomenon especially in developing countries such as Bangladesh, Pakistan, Vietnam, Philippines, Indonesia and Cambodia (Aleluia & Ferrão 2016; Talyan *et al*., 2008). Food waste constituted about 60% in the overall waste composition at the above mentioned countries.

On the average, the percentage of food waste recorded in Jeram Sanitary Landfill was lower as compared to the data reported previously for waste composition in Malaysia (Agamuthu & Tanaka, 2014; Moh & Latifah, 2014; Zamali *et al*., 2012; Saeed *et al*., 2009). The lower food waste percentage recorded indicated that the number of residents involved in the food preparation at home was lower as compared to the number of residents who chose to dine or bought prepared meal from outside. Higher number of residents who choose not to cook their own meal might be caused by higher affordability and time constraints. Some people end up buying more processed and ready food items to save time and hassle (Mallinson *et al*., 2016). Over buying of food products has resulted in 3% of unconsumed food found in the waste received by this landfill. The habit of buying a lot of unnecessary food stocks will lead to the "buy a lot waste a lot" behaviour. As a result, food that has passed its expiry date and become non-edible will be thrown away (Mallinson *et al*., 2016). This can be avoided if the public were willing to change their purchasing behaviour by preparing plans before shopping

for food items. In addition, applying the right way to handle, cook and store food items may reduce the need to dispose food waste from households (Cicatiello *et al*., 2016).

Plastic waste contributed the second biggest waste percentage in Jeram Sanitary Landfill waste composition at 14.8%. In this study, plastic was categorised into two types, namely plastic film and rigid plastic. Plastic film recorded 9.2% while rigid plastic was 5.6%. High percentage of plastic in waste composition was due to the use of plastics in daily activities such as packaging, wiring, coating and many more (Al-Salem *et al.,* 2009). Plastics have been used in various products due to its high resistance and durability. Moreover, the low price and high accessibility of plastic have contributed to the abundance of plastic waste in the landfill.

In spite of many campaigns carried out by the government to promote recycling activities of plastic such as "No Plastic Bag Day Campaign", the response from the public has not been impressive (Asmuni *et al*., 2015). The percentage of plastic recorded was still high as there was a vast amount of recyclable items in Malaysia's waste stream. However, based on the results obtained, the percentage of plastic recorded in this study was lower than those recorded in previous studies. A study done by Saeed *et al*. (2009) reported that the percentage of plastic was 15%. This shows that even though there was no significant reduction, recycling campaigns for plastics have successfully delivered the intended message to the public.

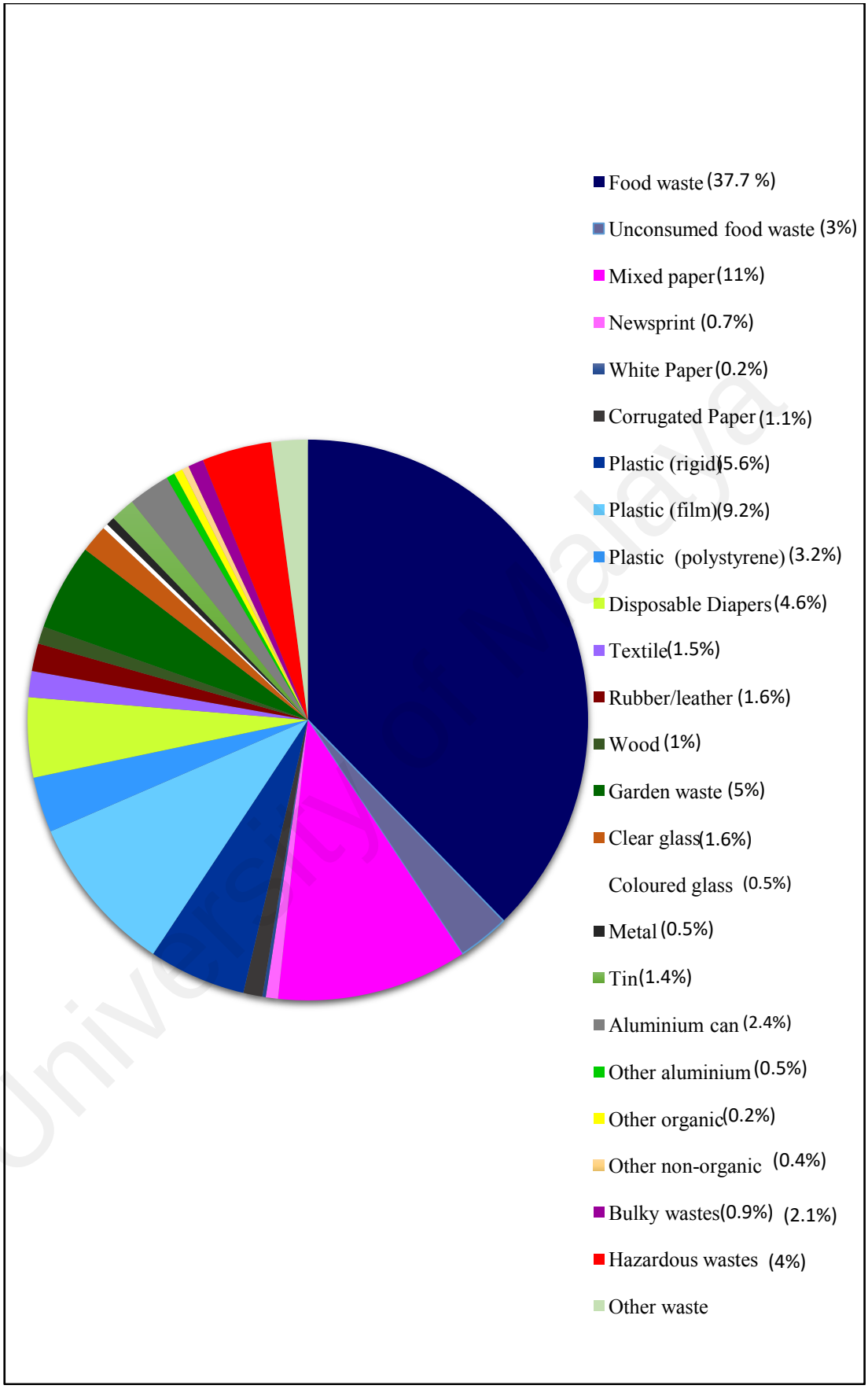


**Figure 4.2:** Composition of municipal solid waste received in Jeram Sanitary Landfill (based on wet weight) (%).

In this study, four different paper wastes were recorded, which included mixed paper, corrugated paper, newsprint and white paper. The generation of mixed paper recorded 11%, corrugated paper 1.1%, newsprint 0.7% and white paper 0.2%. The amount of mixed paper was much higher because this type of paper has the least recycling potential when compared to other types of paper waste. The purchase of products with unnecessary manuals and catalogues will eventually cause the papers to be discarded. A possible solution to reduce the amount of corrugated paper waste is to offer the 'take back program' practiced by retailers and entrepreneurs. Moreover, manufacturers can publish additional information, manuals and warranties in their respective websites instead of providing printed forms.

Newsprint and white paper waste recorded a lower percentage as compared to mixed and corrugated paper waste. The percentage of newsprint and white paper waste constituted 0.7% and 0.2%, respectively. Newsprint can be divided into magazines and newspapers. The low percentage for newsprint paper waste was because most magazine buyers will keep the magazines as their personal collections (Fauziah, 2010). The percentage for newspaper waste was also very low because newspapers were usually reused for other purposes or resold to the recycler. Daily subscription of newspaper makes it easy for the buyer to collect and sell to the recycler at one time with a price of RM0.30 per kilogram (Chen, 2015). Similar reasons were also applied to the white paper generation in the landfill. Printing and copying activities probably generated to the high amount of white papers. However, due to the attractive price of used white paper (RM0.40/kg), these papers will normally be separated from other wastes and sold directly to the informal collector.

Disposable diaper recorded 4.6% and polystyrene 3.2% because of their convenience factor and higher affordability among the public. Urbanisation has led to a fast paced lifestyle where most people would want to complete tasks in a shorter amount of time. People will opt to take away their food to save time. Hence, many premises in Malaysia are still using polystyrene as their food containers. Even though some premises may charge additional cost for the polystyrene, some customers are still willing to pay additional charges as polystyrene is convenient. A similar reason applies to disposable diapers. Despite having other alternatives such as washable cotton diaper which was more cost-effective and environmental friendly, many still chose to purchase and use disposable diapers since it was considered easier to use and less time consuming. This was definitely a worrying situation as disposable diapers are not biodegradable and will remain in the landfill for a long period of time. Waste composition study also showed that the percentage of other types of waste, such as garden waste constituted 5%, followed by rubber/leather 1.6%, textile 1.5%, wood 1%, glass 2.1%, tin 1.4% and bulky waste 0.9%. Aluminum was recorded at 2.4%, other aluminum 2.1%, other organic, other inorganic and other waste recorded 0.2% and 0.4%, 2.1% respectively. Finally 4% were categorized as hazardous and these wastes were also known as household hazardous waste.

Based on the waste generation and waste composition found in this landfill, the waste flow for the current situation in Jeram Sanitary Landfill and two different scenarios (increase of national recycling rate and capacity of the MRF) are discussed in detailed. These two scenarios are discussed as the rate of recycling and capacity of MRF will lessen the amount of waste disposed in the landfill. As waste might be main source of heavy metal input, lesser amount of waste dispose will directly reduce the probability of heavy metal release in the landfill.

### 4.1.3 Waste flow in Jeram Sanitary Landfill

The waste flow of the whole system was established (tonne/ annum) based on the data obtained from waste amount and composition study. Figure 4.3 shows that a total of 859,500 tonne of waste were received in 2014 by Jeram Sanitary Landfill.

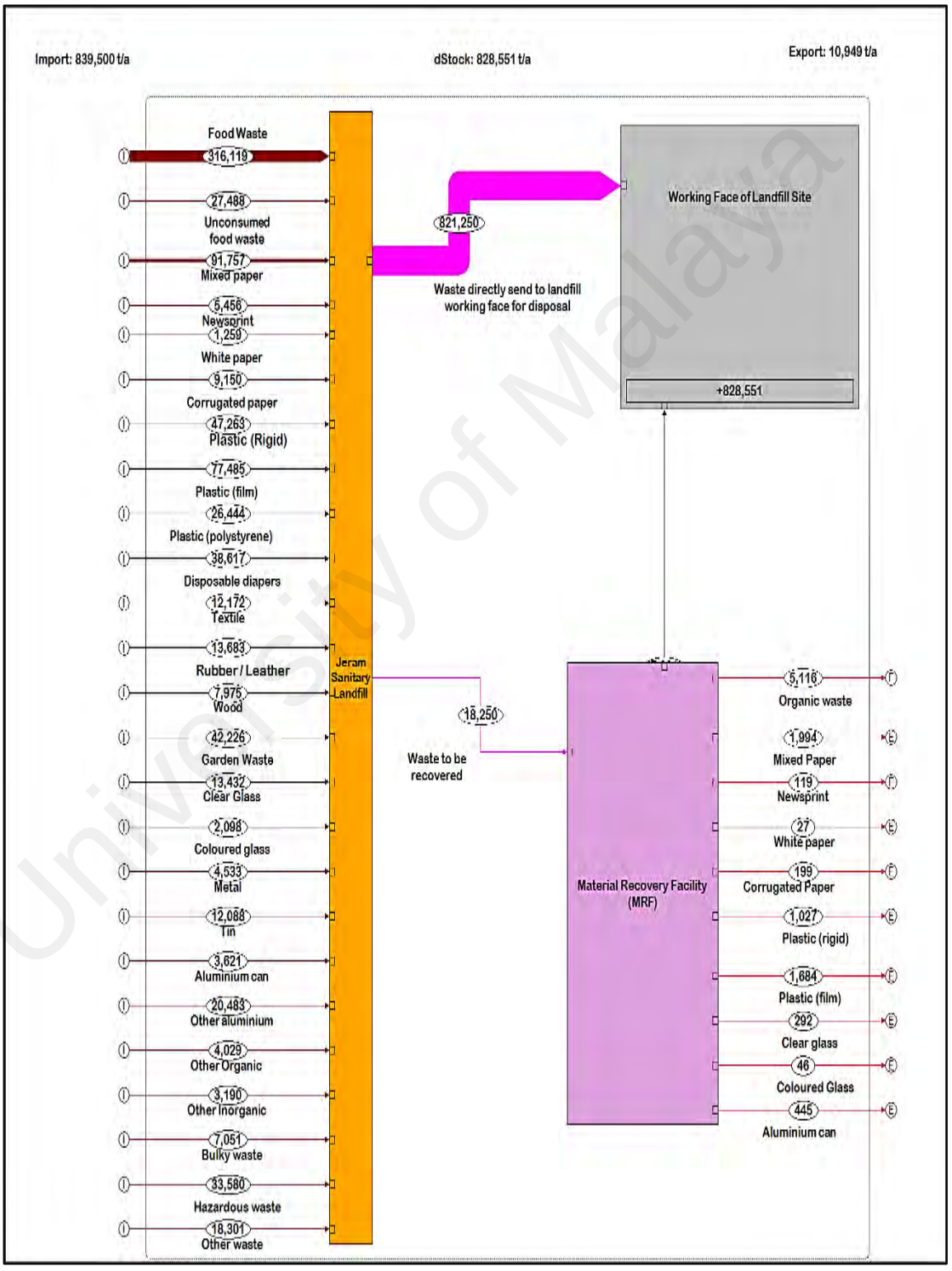


**Figure 4.3:** Waste flow of Jeram Sanitary Landfill.

Out of this amount, only 10,949 tonnes of waste were exported out from the system by material recovering activities initiated by Jeram Sanitary Landfill management. Since only small amounts of waste were exported out, the remaining waste were landfilled and remained as stock in the system amounting up to 828,551tonne per annum . The high amount of waste could be diverted out from the system, if the waste segregation and recycling activities were practiced. Moreover, if the waste were separated accordingly and sent for recycling, the amount of heavy metal released into the system could also be reduced.

This study reveals that by practising recycling, resources could be saved because significant portion of the waste can be recovered. Resource recovery can also reduce the ecological footprint. For example, the energy used to produce one aluminium can from its virgin material is equivalent to the energy needed to recycle 33 aluminium cans (Greenworks, 2017). Another main advantage if waste diversion is implemented in Jeram Sanitary Landfill is that some additional income would be obtained when the waste were sold and used by other stakeholders.

Table 4.1 indicates the market prices for a kilogram of recyclable waste and the amount of recyclable waste received in Jeram Sanitary Landfill for a year. Equation 4.1 can be used to estimate the amount of potential revenue if all the recyclable wastes received in Jeram Sanitary Landfill were collected, separated and sent for recycling (Agamuthu *et al*., 2015)

Estimated value of recyclable waste (RW) per year for waste received in Jeram Sanitary Landfill:

(Total of RW in tonne) x (1 ton/1000kg) x (Price of RW per kg)…… (Equation 4.1)

From the calculation, the total potential revenue estimated for all the waste received in Jeram Sanitary Landfill was almost RM55 million or 12.4 million USD. This value is an enormous amount of revenue and could be used to upgrade all existing facilities and technologies in Jeram Sanitary Landfill.

**Table 4.1:** Estimation of total value for the recyclable items, recycle and recovery activities are practised.

| **Type of recyclable wastes** | **Total amount of recyclable waste received by Jeram Sanitary Landfill (kg/ annum )** | **Price per kilo (RM/kg) (as at 2016)** | **Total value estimated per annum (RM)** |
|---|---|---|---|
| Plastic (rigid) | 47, 263,000 | RM0.20/ kg | RM 9,452,600 |
| Metal | 4, 533,000 | RM0.40/ kg | RM 1,813,200 |
| Clear Glass | 13,432,000 | RM0.05/ kg | RM 671,600 |
| Coloured Glass | 2,098,000 | RM0.01/kg | RM 20,980 |
| Mixed Paper/Newsprint | 91,757,000 | RM0.30/kg | RM 27,527,100 |
| White Paper | 1,259,000 | RM0.40/kg | RM 503,600 |
| Corrugated Paper | 9,150,000 | RM0.25/kg | RM 2,287,500 |
| Aluminium can | 3,621,000 | RM3.50/kg | RM 12,673,500 |
| **Total** | **121,317,000 kg/ annum** | **RM54,950,380/ annum** | |

### 4.1.4 Waste MFA based scenario/simulation

MFA can be used to illustrate the estimation of materials in the future. Figure 4.4 depicts the changes of material if the recycling rate of Malaysia increased from 10% to 22% which is the target of national recycling rate (Johari *et al*., 2014).

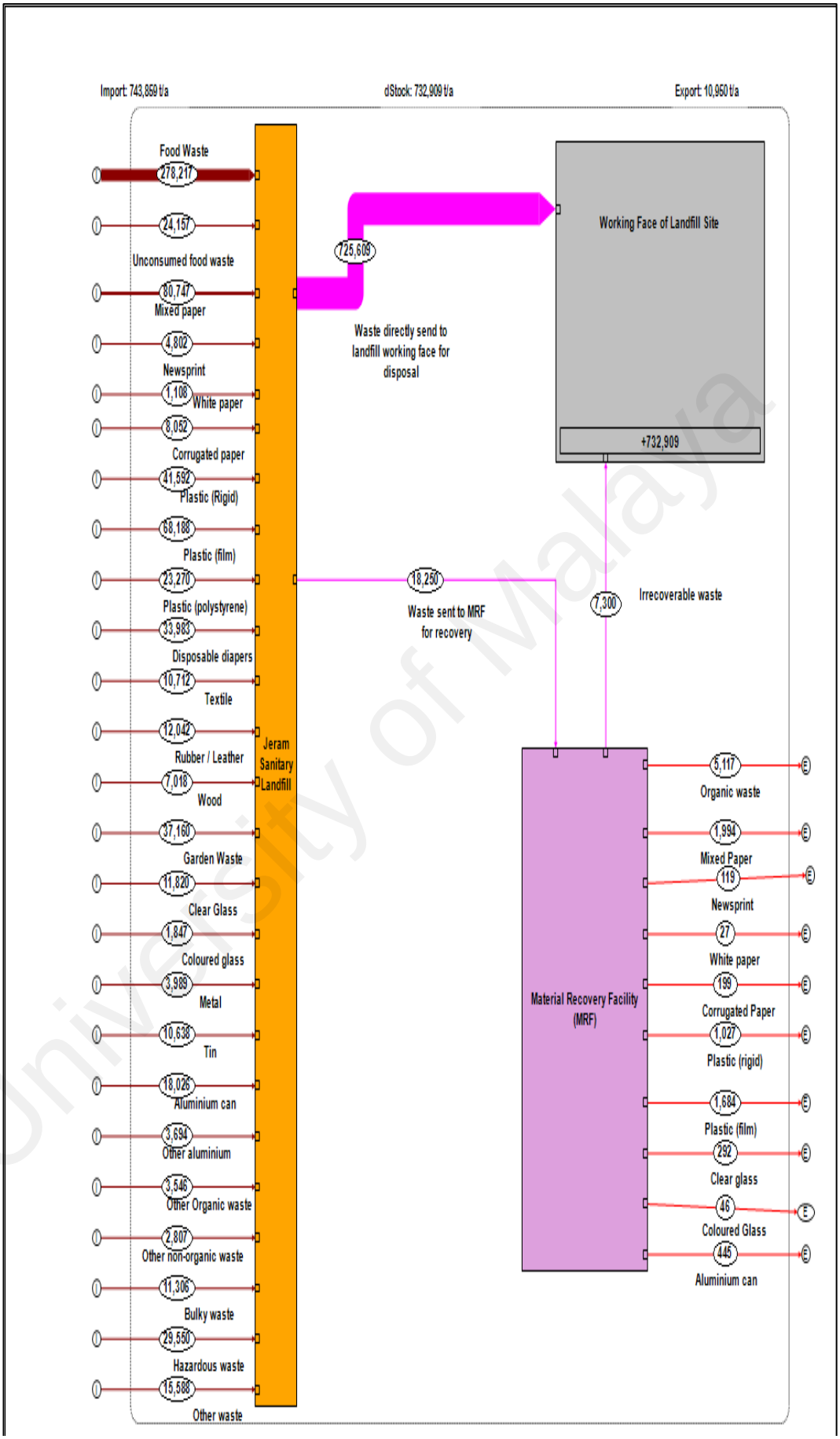


**Figure 4.4:** Hypothetical simulated waste flow of Jeram Sanitary Landfill with national recycling rate of 22% is achieved.

The waste flow indicates that if the new recycling rate is achieved, the total amount of waste will be deposited in Jeram Sanitary Landfill will decrease from 8395,500 tonnes per annum to 743,859 tonnes per annum. The reduction of waste disposed to the landfill will minimize the waste management cost. It will also lengthen the span of the landfill and indirectly reduce the potential risk of heavy metal contamination. Moreover, the amount of waste recovered and recycled will also increase.

Another scenario is if the current capacity of MRF is increased. Currently, MRF in Jeram Sanitary Landfill only has the capacity of processing 50 tonnes per day. If this amount can be increased to 400 tonnes per day with the help of the authority fund and technologies, the total waste that could be exported and sold from waste recovering activities will increase the output from 10,949 tonnes per annum to 87,600 tonne per annum as depicts in Figure 4.5.

Figure 4.6 shows the waste flow in Jeram Sanitary Landfill if both scenarios are successfully carried out. Total amount of waste landfilled and total amount of waste recovered and export out from the landfill has significantly changed. Total waste reduced by 95,641 tonne per annum. Meanwhile, total waste recovered increased by 76, 651 tonne per annum. The management of this sanitary landfill and the authority should worked hard towards these changes because implementations of waste minimisation, separation and recycling, there are numerous benefits that can be obtained for the sake of environmental protection and the economic development.

Another advantage of waste minimisation, separation and recycling activities is the reduction of household hazardous waste in the landfill. Figure 4.2 depicted that the waste composition of Jeram Sanitary Landfill is composed by 4% of household

hazardous waste. In next topic, the household hazardous waste received in Jeram Sanitary Landfill will be discussed.

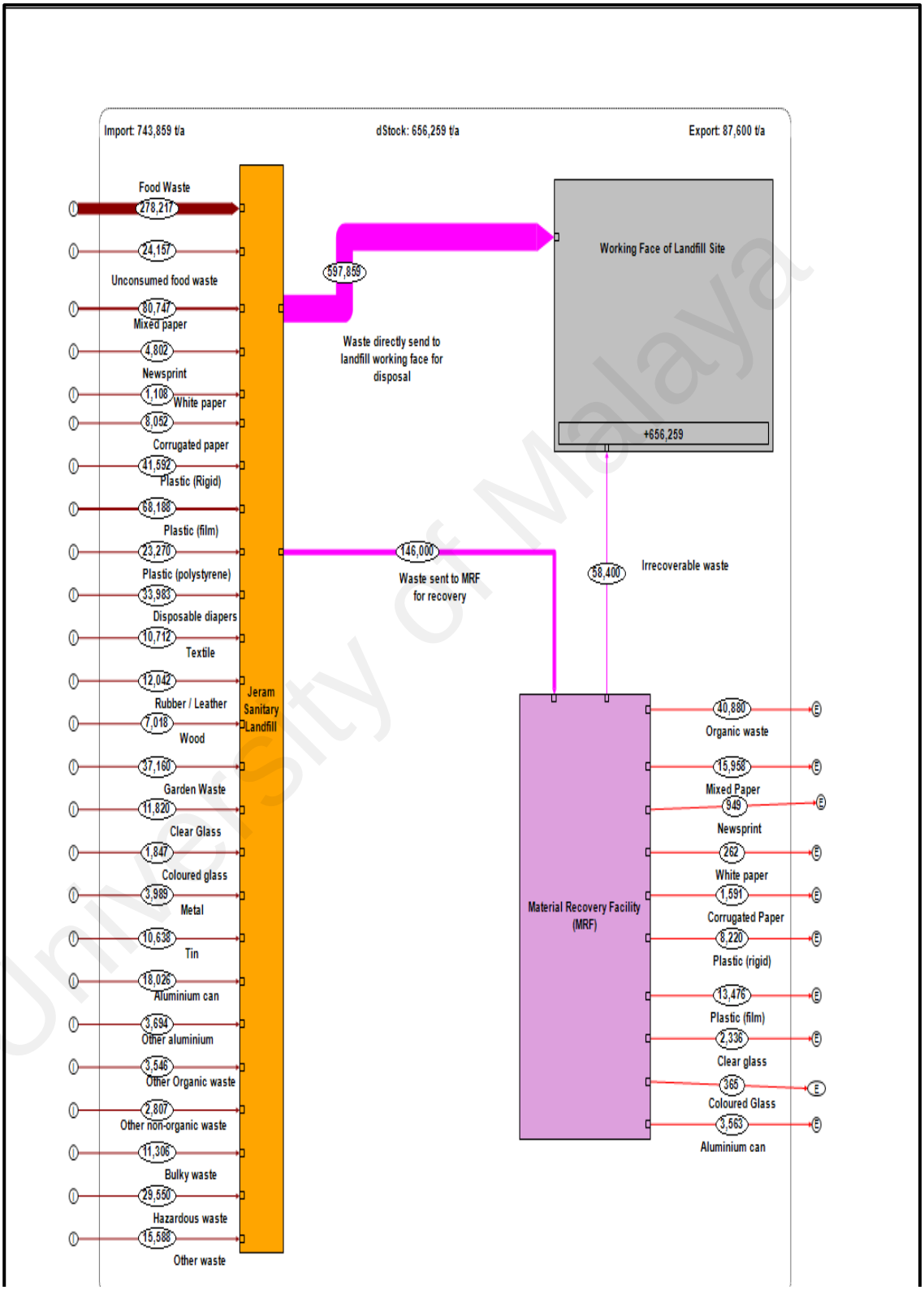


**Figure 4.5:** Hypothetical simulated waste flow of Jeram Sanitary Landfill with MRF's capacity of 400 tonne per day.

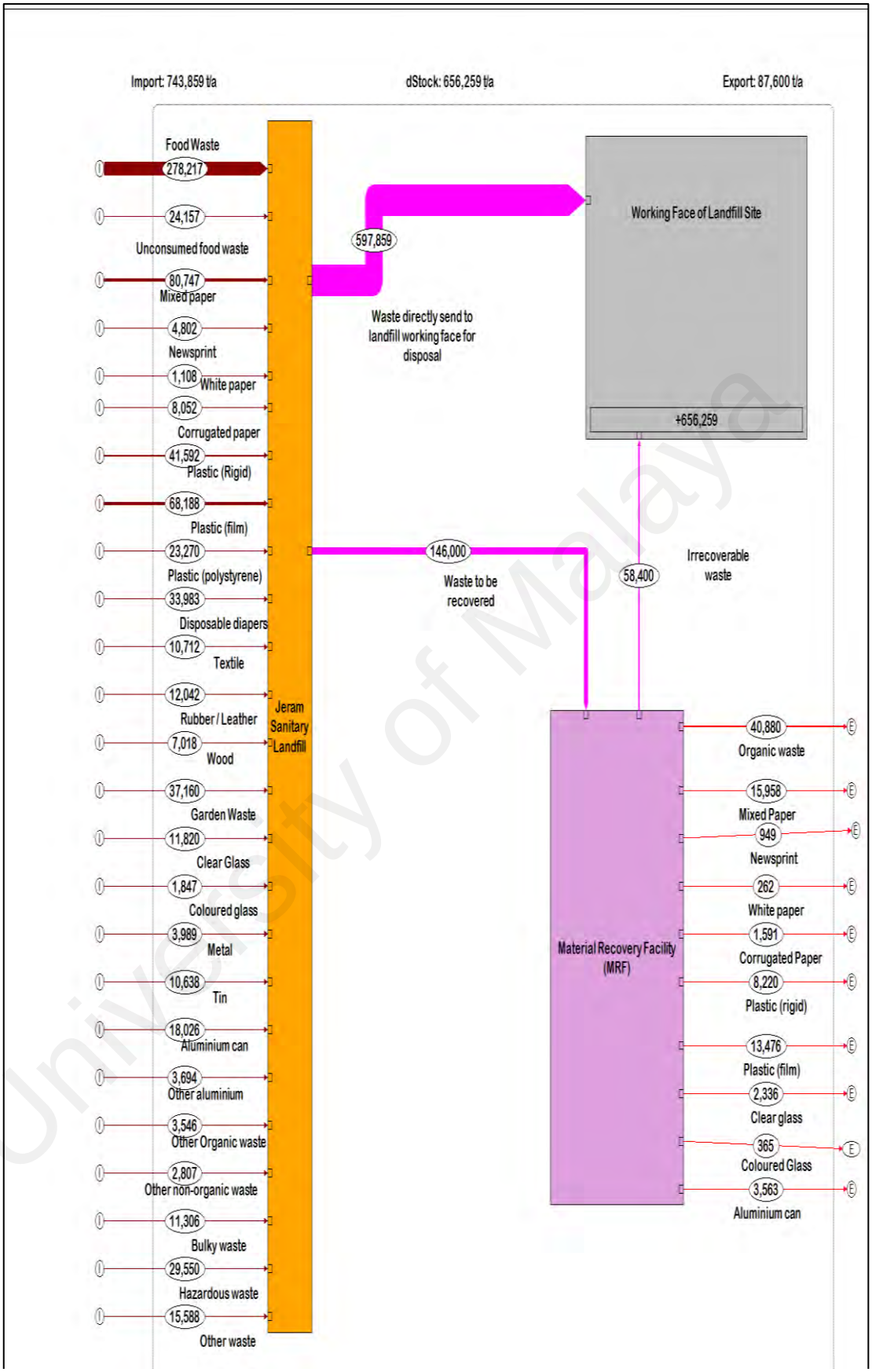


**Figure 4.6:** Hypothetical of simulated waste flow of Jeram Sanitary Landfill with recycling rate of 22% and capacity of MRF is increased to 400 tonne per day.

### 4.1.5 Composition of hazardous waste (%)

Four percent of the total waste composition in Jeram Sanitary Landfill consisted of household hazardous waste. National Solid Waste Management Department (2012) reported household hazardous waste composition was 1.3% and Noor *et al*., (2013) stated household hazardous waste attributed 1.3% of the total MSW composition in their study. According to United States Environmental Protection Agency (2016), household hazardous waste was described as "*leftover household products that contained corrosive, toxic, ignitable or reactive ingredients*".

Therefore, due to these characteristics, such waste needs to be treated before they are landfilled. Even though Jeram Sanitary Landfill was classified as a level IV sanitary landfill, current technologies available were not designed to cater the disposal of specific waste (Turner *et al*., 2017). Therefore, all household hazardous waste must be separated at the source and sent to a secure landfill. This is because all waste received in a secure landfill will undergo waste characterization and suitable treatments (i.e., solidification and stabilization) before landfilled (Malaysia Productivity Corporation, 2014). Figure 4.7 indicates the categories of household hazardous waste found in this study.

The wastes were categorized into eight groups. Figure 4.7 shows the household hazardous waste composition which consist of 28% home improvement products with, 23% e-waste, 15% miscellaneous products, 12% of automotive products, 8% fluorescent lamp, 8% ink/paint, 3% medicine and also 3% beauty products. The highest household hazardous waste was home improvement products such as chlorine bleach, shoe polish, abrasive scouring powders and spot removal. This result was also similar to the result reported by Delgado *et al*. (2007). Home improvement products were the

regular household hazardous waste found due to their high accessibility and used by most households. Moreover, there were very little recycling demands for these home improvement products.

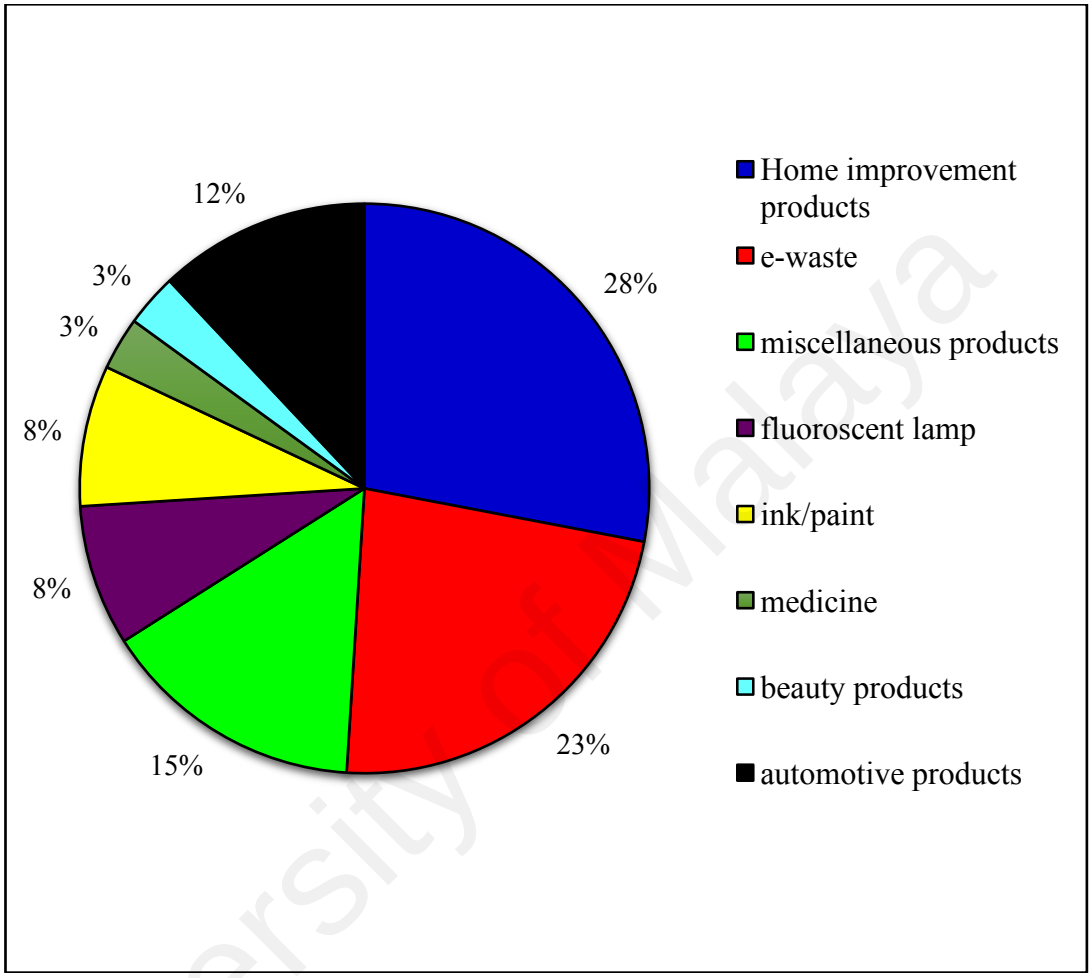


**Figure 4.7:** Composition of household hazardous waste received in Jeram Sanitary Landfill (%).

E-waste found in the landfill included computer monitors, television and electrical switches. According to Islam *et al*. (2016), this type of e-waste can also be found in the landfill investigated in their studies. The number of e-waste item was small but due to the high weight, e-waste recorded the second highest percentage based on weight. E-waste was found in the landfill since e-waste will normally be separated by the owner or the waste collector and then sold to the recyclers. This was because the price offered for e-waste especially television, computers and laptops was much more attractive than other types of waste (Duan *et al*., 2011; Chen, 2015).

In this study, pesticides, herbicides, chemical fertilisers and batteries were categorised as miscellaneous products. The increase of agricultural activities has increased the demand for these products over the years. These products have been extensively used for pest control and to ensure the plant's growth (Sankoh, 2016). However, there was very little awareness among the users about the correct disposal of these products containers. There were many initiatives carried out by the government and non-governmental organizations to reduce the usage of batteries that contain Hg and Zn (Terazono *et al*., 2015). However, the response is quite disappointing as these batteries were still vastly used and can be found in many landfill sites including Jeram Sanitary Landfill.

Serious action must be taken to overcome the increasing amount of hazardous waste in sanitary landfill. This is because even though the quantity of household hazardous waste is low in MSW, household hazardous waste can inflict more severe impacts to the environment due to the release of heavy metal such as Hg and Zn. In this study, Material Flow Analysis (MFA) model has been used to produce the flow of Hg and Zn in Jeram Sanitary Landfill system to showcase the impacts of these metals.

## 4.2 Material Flow Analysis of Jeram Sanitary Landfill

The management of Jeram Sanitary Landfill was required to abide by Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations 2009 (Emenike, 2013). In this research, a material flow analysis was established in Jeram Sanitary Landfill with the objective to assist the landfill management and the related stakeholders to monitor the environmental performance of this sanitary landfill. It was to ensure that the operation of this landfill will not cause

any severe environmental consequences with regards to heavy metal pollution. STAN 2.5 was utilised to generate the MFA in this study.

Figure 4.8 shows that there were many different processes and components that need to be taken into account to establish the MFA. All these processes and components could be divided into inputs and outputs. The inputs were all materials that enter the system boundary (Cencic & Rechberger, 2008) including waste received in the landfill, rainfall event and clay used by the management as the daily cover of active waste cells. On the other hand, outputs were materials that are being exported out from the system (Cencic & Rechberger, 2008). The outputs in the MFA were surface runoff (from rainfall), soil-off gas and landfill gas (LFG), treated leachate and recovered waste which was exported to the recyclers as recyclable materials.

Materials which remained in the system is stock balance (Brunner & Rechberger, 2004). Landfilled wastes, remaining waste from material recovery process, soil cover and sludge from the water treatment plant are considered as stock in this study. Data on weight and volume of all these components were collected from the landfill's management to calculate the mass. All values in the MFA were done based on annual generation in total (tonne per annum). Results showed that the total input for the material flow of Jeram Sanitary Landfill was 3,061,489 tonne/ annum while the output was 1,006,110 tonne/ annum. The output value was much smaller than the input because the major input of this system remained in the landfill and it became stock. Total stock was 2,055,379 tonne per annum.

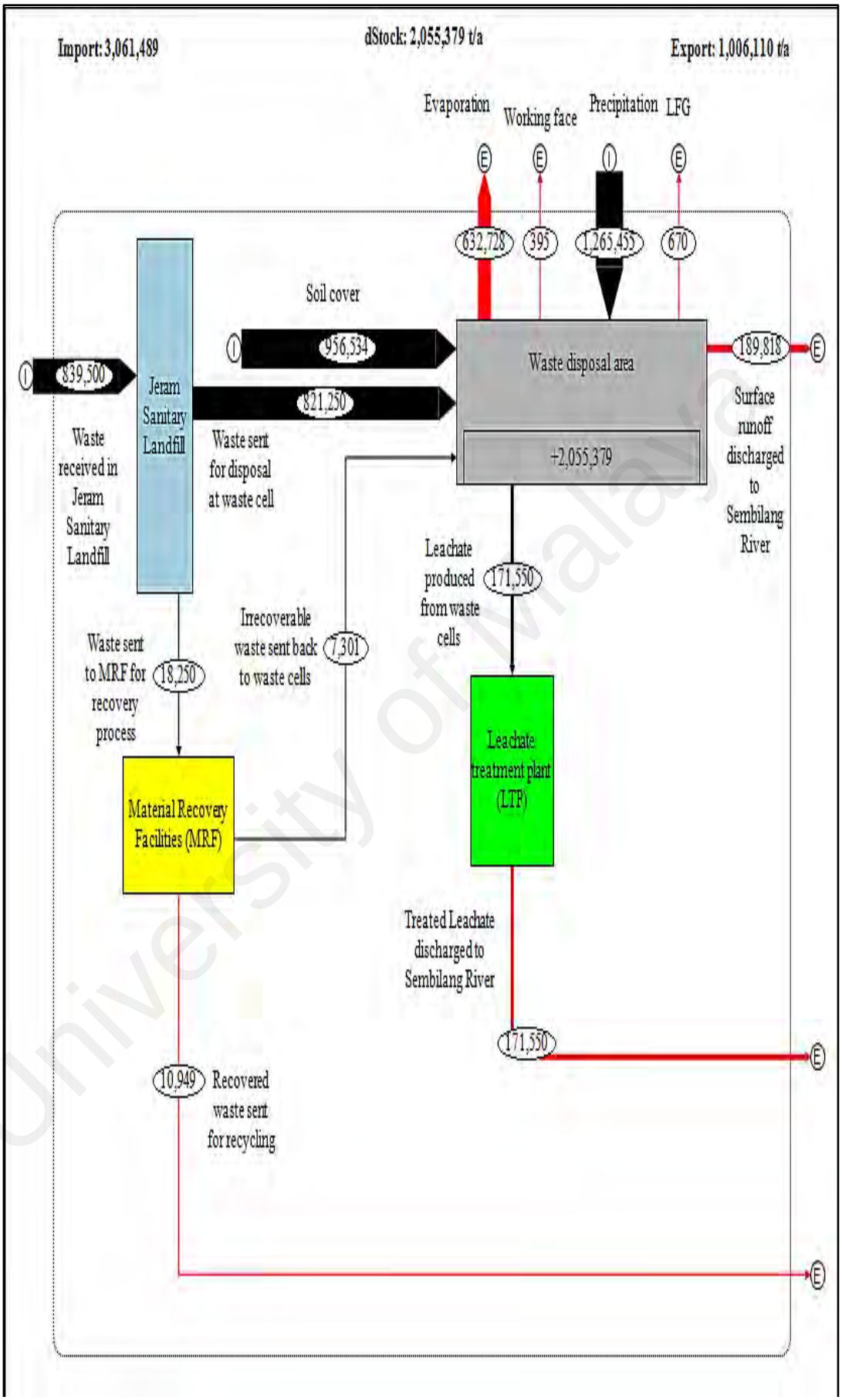


**Figure 4.8:** Material flow in Jeram Sanitary Landfill.

The highest amount of material received in the system was wastes. Jeram Sanitary Landfill receives average of 2300 tonnes of waste daily from multiple municipals of Selangor state. The amount of waste received in this landfill is lower to amount of waste received in Bukit Tagar Landfill (2500-3000 tonne of waste daily) but higher than waste received in Matang Landfill which is 250-300 tonne per day (Ghazali *et al*., 2014).

Jeram Sanitary Landfill has made an initiative with Tetra Pak to establish the first Material Recovery Facility (MRF) (Tetra Park, 2012). This MRF was established to separate and recover recyclable waste. Then, recovered wastes were exported to the recyclers. This was done to minimise the amount of waste to be landfilled, with the aim of generating additional income to the landfill management. However, the amount of waste received in this MRF is 50 tonne per day. This value is lower than the average amount of waste processed in MRF located in Norfolk of United States (110 tonne per day) (Letsrecycle.com, 2013). The amount of waste received in MRF of Jeram Sanitary Landfill is lesser because this MRF is still at an experimental stage. Plate 4.1 illustrates the separation of waste into organic waste, mixed paper, newsprint, white paper, plastic (rigid), plastic (film), clear glass, coloured glass and aluminium can.

The separation processes were carried out using the rotary kiln machine and manual separation by the workers in the facility. On average, 60% of the 50 tonne waste could be diverted away from the landfill. Meanwhile, the remaining waste will be sent to the waste cell for disposal. An average of 2,250 tonne/day or 821,500 tonne/ annum of waste will be sent to the landfill's waste cells for direct disposal without undergoing separation at the MRF.

**Plate 4.1:** Contract workers are separating waste in MRF

Once the wastes were dumped into the waste cell in Jeram Sanitary Landfill, clay will be used as a soil cover. The soil cover was applied to minimise the odour, disturbance from pests, birds and flies and also to ensure minimum amount of rainfall infiltrated into waste cells (United States Environmental Protection Agency, 2014). This practise of soil cover is important in preventing infiltration of rain into waste cells to reduce the amount of leachate generated (Li *et al*., 2016). The mass of clay used in Jeram Sanitary Landfill was estimated to be 956,534 tonne/ annum.

Another input identified for MFA of Jeram Sanitary Landfill was rainfall. Rainfall played a very important role in a sanitary landfill operation because the amount of rainfall received by the landfill could directly influence the quality and quantity of leachate produced by the landfill (Bhalla *et al*., 2013). Malaysia is a humid country and regularly receives about 3000mm/ annum of rainfall. The total mass of rainfall entering into this landfill was 1,265,455 tonne per annum. Even though this is an enormous value to the whole MFA system, half of the value will be evaporated back to the atmosphere (632,728 tonne per annum). This was due to the high evaporation rate in Jeram Sanitary Landfill which was about 50%, and is influenced by the high ambient temperature which ranged between 29$^{o}$C-34$^{o}$C. The rest of the rainfall will infiltrate

into the waste cells, and hence turned into surface runoff if not controlled (Jia *et al*., 2010).

Surface runoff will directly flow through the drainage around the working area and passed through the silt trap before being discharged to the nearest river. Based on the data received from the management, it is estimated that 189,818 tonne of surface runoff were discharged in a year. The rest of the rainfall, which did not evaporated or converted into surface runoff, were considered to infiltrate into the soil, and become leachate.

Leachate is produced through excessive infiltration of rainfall into the waste cells (Talalaj *et al*., 2015). On average, Jeram Sanitary Landfill produced 470 $m^3$ of fresh leachate per day. This amount is higher than the leachate produced in Bukit Tagar Sanitary Landfill which is 180$m^3$/day (Kortegast *et al*., 2007) The difference of leachate volume recorded in both landfills might be caused by various factors such landfill age, soil properties, weathering conditions, waste composition, landfill operation and facilities installed in these landfills (Tang *et al*., 2015). The leachate produced in Jeram Sanitary Landfill underwent various treatments in the leachate treatment plant before being discharged to the nearest river. The treated leachate was discharged into the Sembilang River through a drainage system connected from the discharge point of leachate treatment plant. This river was located only 70 meters from the discharging point. At the discharge point, a small sampling station was set-up by the landfill management, to monitor the parameters of treated leachate.

Another route of material exportation from Jeram Sanitary Landfill system was through the gases compounds generated during the waste disposal processes. There are two types of gases which are landfill gas (LFG) and gas emitted from the working face.

Biodegradation of waste in the landfill will lead to the production of landfill gas (LFG) (Ahmed *et al*., 2015). These gases compounds were collected by using the gas well installed strategically around the sanitary landfill. The installation of gas wells were done in order to reduce the risk of explosion and to ensure that high percentages of these gasses are flared (US Army Corps of Engineers, 2014). LFG produced in Jeram Sanitary Landfill were 670 tonne per annum and total emitted gas from the working face were 395 tonne per annum.

Based on the data collected and MFA established, the total input of materials into Jeram Sanitary Landfill system was 3,061,489 tonne per annum. These materials were waste, clay cover and rainfall. The completed MFA also implicated that total export of material from this system was 1,006,110 tonne per annum. This showed that most of the materials were retained in the landfill as stock. Total stock deposited in the sanitary landfill every year was estimated to be 2,055,379 tonne. In this study, the average concentration of Hg and Zn in the landfill's components which are waste, soil cover, rainfall, landfill gas, gas from working face, fresh leachate, treated leachate and surface runoff were also examined.

## 4.3 Hg and Zn in Jeram Sanitary Landfill's components

### 4.3.1 Hg and Zn in waste

Waste is one of the important components in a sanitary landfill system. This is because the existence of a sanitary landfill was to store waste deposited by taking all considerations to minimise detrimental impacts to the environment (Raghab *et al*., 2013). According to Gu *et al*. (2014) the characteristics of disposed waste were played a major role in determining the quality of by-products generated and the future environmental threats. The two heavy metals studied, Hg and Zn, were detected in the

waste sample analysed. Concentrations of Hg averaged at 2.27 mg/kg while concentration of Zn was 13.6 mg/kg. Meanwhile, Talalaj *et al*. (2015) reported the concentration of Hg in waste sample studied is 0.04-1.54 mg/kg and the concentration of Zn in waste was 52-1143mg/kg.

High concentration of these metals in the waste is due to the presence of household hazardous waste. According to Fikri *et al*. (2015) and Talalaj *et al*. (2015), there are many household products contained heavy metal such as Hg and Zn. These products such as home maintenance, personal care and automobile products are highly accessible and can be found almost in every household. Once these products were fully discarded as waste, improper disposal will lead to the release of Hg and Zn to the landfill system. It was also assumed that the concentration of Hg and Zn in the household products varies, based on the composition. It is reported that there were many cosmetic products for skin lightening which possess high concentration of Hg, perhaps as high as 33,000 mg/kg (Pan American Health Organization, 2012). Vermont Department of Environmental Conservation (2004) reported that a button battery cell could contain up to 25 ppm of Hg. This type of battery was mostly used in calculators, cameras and hearing aids. Hg may also be found in detergent products with concentration ranging from 0.001 ppb until 8.1 ppb. The concentration of Hg in fluorescent lights may also range between 4-8 mg/kg. Meanwhile, Zn was mainly used in zinc galvanising process as a shield to avoid rusting of steel (United States Geological Survey, 2011). Concentration of Zn can also be found in household products such as detergent, pesticide, motor oil, e-waste and paint (Gergely *et al*., 2011; Kszos *et al*., 2004; Pant *et al*., 2012).

In this research, the concentration of heavy metal and pH value of the wastes were measured and statistically analysed. The pH of waste measured in this study averaged at 5.84-5.9. This pH value indicated that the condition of waste is acidic, probably due to the waste degradation by microorganisms within the waste itself (Fauziah, 2010). Figure 4.9 shows the correlation between the pH value of waste and the corresponding concentration for Hg and Zn in the waste sample.

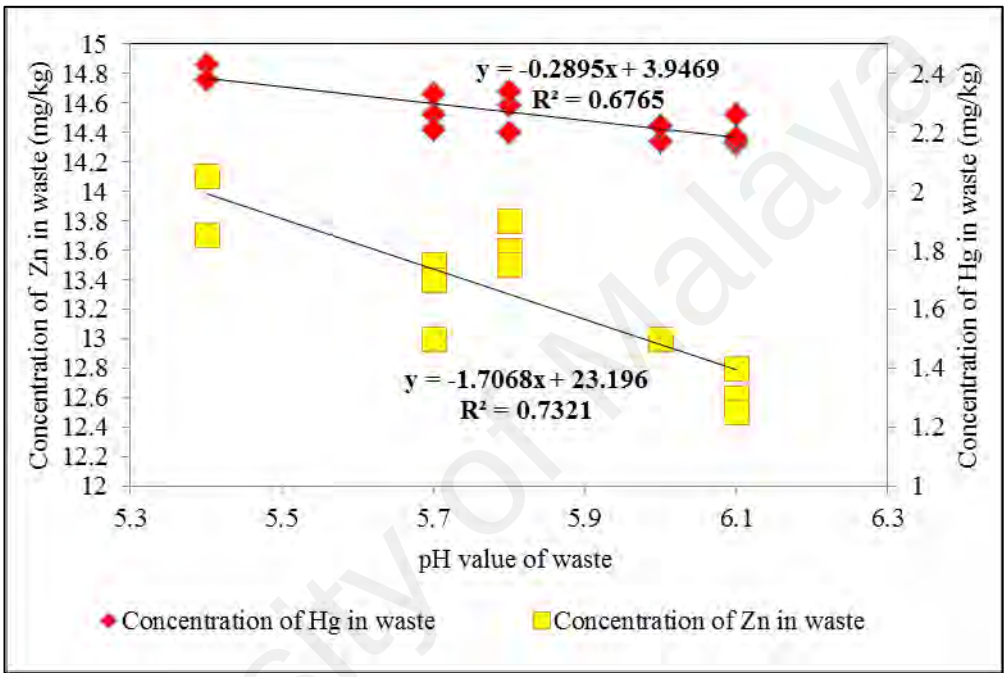


**Figure 4.9:** Concentration of Hg and Zn versus pH in waste.

This indicated a negative linear correlation between pH value and both heavy metal concentrations in the waste composition. This showed that when the pH value decreased, the concentration of Hg and Zn increased. A negative linear correlation coefficient of $R^2$= 0.68 was obtained between pH and Hg concentration of waste, while $R^2$= 0.73 was obtained from the correlation of pH and Zn concentration. Lo *et al*. (2009) also reported similar result of which the concentration of metal increased when the pH of waste decreased. Thus, it can be concluded that the lower the pH value of waste the higher the amount of metal will be released from the waste.

The moisture level of waste averaged at 56%. This result is agreeable with some results from previous landfills study in Malaysia as posited by Tan *et al*. (2014) and Johari *et al*. (2012). It is reported by Latifah *et al*. (2009) that the moisture content of 55%. Generally, waste in Malaysia has high moisture content, due to both dry and wet wastes were mixed and disposed together (Fauziah, 2010). Moreover, Malaysia receives high amount of rainfall and this definitely affected the moisture level of wastes analysed (Aziz *et al*., 2015). High amount of moisture may increase the release of Hg and Zn from waste. This was because the high moisture content in the waste will accelerate the acid fermentation, thus causing a drop in the pH value. This indirectly affected the concentration of Hg and Zn in the leachate produced (Renou *et al*., 2008).

### 4.3. 2 Hg and Zn in soil cover

Results showed that the concentration of Zn from soil cover used in the landfill (11.3 mg/kg) was higher than the concentration of Zn in the control soils collected from Rimba Ilmu (2.9 mg/kg). The concentration of Zn in Rimba Ilmu was low due to the absence of anthropogenic activities in the area. Therefore, the concentration of Zn detected was mainly from the natural composition of the soil (Zarcinas *et al*., 2004). Meanwhile, the concentration of Zn in the soil from the palm plantation (7.2 mg/kg) was higher than the concentration of Zn in Rimba Ilmu and closer to the concentration of Zn in the soil cover. This might be caused by the frequent usage of fertiliser in the plantation which may have significant concentration of Zn (Rehman *et al*., 2015). Results from the heavy metal analysis carried out also indicated that the concentration of Hg in soil cover was higher than both control soil samples and soil samples from the palm plantation. The concentration of Hg in soil cover averaged at 0.12 mg/kg. Meanwhile the concentration of Hg in control soil from Rimba Ilmu averaged at 0.003 mg/kg and concentration of Hg in palm plantation averaged at 0.08 mg/kg. Higher

concentration of Hg might be attributed by the release of Hg from household hazardous waste during waste disposal operations in the landfill (Smith, 2009).

Previous studies reported that the concentration of heavy metal in the soil cover could increase when certain properties of soil such as pH changed (Chibuike & Oboira, 2014; Yanai *et al*., 2006). Another factor which influenced the release of heavy metal in soil is the pH value of soil. Boechat *et al*. (2016) stated that the lower the pH value of soil, the higher the level of heavy metal will be found. This is because the acidic condition of soil will increase the metal solubilisation process (Boechat *et al*., 2016).

### 4.3.3 Hg and Zn in rainfall

The result of heavy metal analysis in rainfall samples collected indicated traces of Hg was at 0.006 µg/L. According to Guentzel *et al*. (2001), traces of Hg in rainfall were caused by the oxidation of elemental gases Hg. Meanwhile, Zn was not detected in the same rainfall samples. The absence of Zn in the rainfall samples is due to the low evaporation rate of Zn as compared to Hg (Tidblad, 2001). Eventhough the metal concentration found is extremely small, it is advisable for the landfill management to monitor the quality of rainfall even though the heavy metal concentration might be insignificant. This is because various studies had reported that characteristics of rainfall played an important role in affluencing the quality of leachate produced from the landfill system (Mangimbulude *et al*., 2012; Bhalla *et al*., 2012; Salleh *et al*., 2013).

### 4.3.4 Hg in landfill gas (LFG)

Landfill gases produced in this landfill are flared before released to the atmosphere. In this study, the concentration of Hg found in this landfill is 4200 ng/m$^3$. This result is lower than amount of Hg reported in LFG studied by Linberg *et al*. (2005). It is reported

that the concentration of Hg in the LFG was 6850-8600 ng/$m^{3.}$ This value is higher than study carried out in Jeram Sanitary Landfill and also concentration of Hg found in LFG from study conducted by Zhu *et al*. (2013) which is 1130 ng/$m^3$. Significant variability of Hg concentration found in these landfills are due to the different volume of gas flared and differences of Hg content in the waste received in these landfills.

### 4.3.5 Hg release from working face

General emission equation is used to compute the total Hg release from the working face of the landfill. Total amount of Hg released from the working face in Jeram Sanitary Landfill is 200 mg /hour. This result is comparable to the study conducted in Laogang and Brevard County Landfill. These studies reported that Hg concentration emitted from the working face were 369mg/hour and 300-600 mg/hour (Li *et al*., 2010; Lindberg *et al*., 2005). Jeram Sanitary has lower Hg released compared to the studies conducted by Li *et al*. (2010) and Lindberg *et al*., 2005). Lower emission of Hg might be caused by lower concentration of Hg in the waste, and installation of better soil cover compared to the other two landfills. According to Linberg *et al*. (2005) physical mixing of Hg bearing household hazardous waste such as fluorescent lamp with MSW will also influence the Hg emission from working faces. This is because the volatile Hg will be released to atmosphere whenever these waste are exposed in the landfill.

### 4.3.6 Hg and Zn in Leachate

#### 4.3.6.1 Fresh Leachate quality

Leachate is a complex refractory wastewater as it contained various compounds. Leachate is considered harmful to human and the environment as it generally contained high amount of organic, heavy metals and/or inorganic salt (Shehzad *et al*., 2015).

Therefore, fresh leachate must undergo suitable treatment before being released out from the landfill system and abide the standard regulated by the authority as listed in Table 4.2. Jeram Sanitary Landfill (Level IV) must abide to the standard of Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations 2009. This standard indicates the parameters of fresh leachate measured in this study which were colour, pH, $BOD_5$, COD, turbidity, electrical conductivity (EC), total suspended solid (TSS) and total dissolved solid (TDS).

Table 4.2 shows the results of treated leachate with parameters mentioned above. In addition to the result obtained from this study, Table 4.2 indicates the result from three different landfill studies. These studies were conducted in Matang Landfill, Pulau Burung Landfill and also Jeram Sanitary Landfill in 2010 (Nur Shaylinda *et al*., 2013; Shukor *et al*., 2010 and Emenike, 2010).

Leachate collected in Jeram Sanitary Landfill recorded pH of 8.45. The leachate from the other two landfills also has a similar pH value which ranged from 8.05-8.35. According to Umar *et al*. (2010) and Nur Shaylinda *et al*. (2013), high pH values were recorded from these landfills because of the age of the landfill. All three landfills were considered as old landfills as they had operated for more than seven years. Thus, the leachate produced was more stable than the leachate produced from a new landfill.

**Table 4.2:** Characteristics of fresh leachate.

| Parameter | Unit | Jeram Sanitary Landfill (2014) | Matang Landfill (Nur Shaylinda *et al*., 2013) | Pulau Burung Landfill (Shukor *et al*., 2010) | Jeram Sanitary Landfill (Emenike *et al*., 2010) | *Std |
|---|---|---|---|---|---|---|
| Location | | Selangor | Perak | Penang | Selangor | |
| Age of landfill | | 7 years | 14 years | 10 years | 3 years | |
| pH | - | 8.45 | 8.1 | 8.05-8.35 | 7.35 | 5.5-9.0 |
| Temperature | $^{o}$C | 28.5 | 29 | - | 27.5 | - |
| Colour | | Black | | | Black | - |
| $BOD_5$ | mg/L | 1532 | 109 | 67-93 | 27,000 | 50 |
| COD | mg/L | 10112 | 770 | 600-1300 | 51,200 | 100 |
| BOD/COD | - | 0.15 | 0.14 | 0.051-0.12 | 0.53 | |
| Turbidity | FAU | 1532 | 28 | 600 | 4,150 | - |
| Electrical Conductivity | mS/cm | 30.1 | - | 10.14-13.630 | 10.04 | - |
| TSS | mg/L | 511 | - | - | 688 | 100 |
| TDS | mg/L | 1620 | - | - | 1730 | - |

*Std- Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations 2009

This was because the older landfill (Matang Landfill and Pulau Burung Landfill) were in methagonic phase where lesser strong decomposition and leaching took place in the landfill (Kulikowska & Klimiuk, 2008). Thus, the pH of leachate generated became less acidic. Study conducted by Emenike *et al*. (2010) indicates that pH of leachate was only

7.35. The value recorded is is because this study was conducted 3 years after the landfill operation and still undergoing the acidogenic phase.

Colour is another characteristic of leachate analysed in this study. Both studies conducted in leachate sample from Jeram Sanitary Landfill displayed a black colour characteristic with slightly ammoniac odour. Colour is used to see the reflection of dissolved component and organic content in the leachate (Shukor *et al*., 2010). The darker colour of leachate showed higher concentration of dissolved component and organic content. Colour is highly related to the turbidity value of leachate studied. Leachate sample analysed from Jeram Sanitary Landfill recorded turbidity value of 1,532 mg/L FAU. Meanwhile, turbidity value reported from the same landfill in 2010 was 4150 FAU. These values are higher than the turbidity values reported in PBL and Matang Landfill Differences of turbidity values might be attributed by landfill age and stabilization of leachate (Zainol *et al*., 2012). High turbidity values in leachate implied that chemical treatment must be done to reduce the turbidity level before the leachate could be discharged (Raghab *et al*., 2013). This was to avoid any discharge of leachate with a high turbidity value. The release of leachate with high turbidity in river ecosystem will inhibit the photosynthesis process and dissolved oxygen production, as lesser sunlight could penetrate into the river system (Sackey *et al*., 2015). Increase of turbidity value is influenced by other leachate's parameter such as total suspended solid (TSS). According to Sackey *et al*. (2015), the higher the amount of TSS in leachate, the higher the value of turbidity recorded. TSS of leachate collected from Jeram Sanitary Landfill was reported to be 511 mg/L.

Another important measure in leachate characterisation is $BOD_5$. It is used to identify the concentration of organic pollution in the leachate. This was done by measuring

dissolved oxygen used up by microorganisms in the biochemical oxidation of organic matter (Li *et al*., 2010). $BOD_5$ value of leachate in Jeram Sanitary Landfill in 2014 was 1532 mg/L and 27,000mg/L in 2010, 109 mg/L in Matang landfill and the least value was in Pulau Burung landfill was 67-93 mg/L. Higher $BOD_5$ value indicated that the leachate was more polluted. Leachate sampled from Jeram Sanitary Landfill in 2010 had much higher $BOD_5$ value as compared to the other three leachate studies. Higher value of $BOD_5$ in leachate produced from Jeram Sanitary Landfill in 2010 is because it was a new landfill and only operated for three years. During this time, the landfill was in aerobic phase and was undergoing more acetogenic fermentation compared to the older landfills (Kuusik *et al*., 2016).

COD value of Jeram Sanitary Landfill in this study was 10,112 mg/L. Meanwhile, studies in PBL, Matang Landfill and Jeram Sanitary Landfill in 2010 reported COD values of 109 mg/L, 67-93mg/L and 27,000 mg/L. It can be seen that study conducted by Emenike (2010) in Jeram Sanitary Landfill has much higher COD value as compared to the COD values recorded in three other studies. The high value of COD recorded is highly related to the age of the landfill when the leachate was studied.

The study conducted by Emenike (2010) was done when the landfill is still in young phase while the other three studies were conducted when the landfills were in intermediate and mature phases. According to Adhikari and Khanal (2015), in general the younger a landfill is, the leachate will record higher COD value. This is because leachate from the young landfill is still in acidic condition and contain high amount of biodegradable organic contents that will shoot up the COD value. BOD/COD ratio reflected the biodegradability of leachate and also the degradation of organic matter in the landfill (Lee & Nikraz, 2014). Based on the results shown in Table 4.2, Jeram

Sanitary Landfill in 2014, had BOD/ COD ratio of 0.15 and 0.53 in 2010, 0.14 for Matang Landfill and 0.12 for Pulau Burung Landfill. According to Pi *et al*. (2009), if the ratio of BOD/COD is <0.1, the leachate will be categorised as stabilised. If BOD/COD ratio is 0.1-0.5, the leachate will be categorised as intermediate leachate. Meanwhile, if the record ratio of BOD/COD is more than 0.5, leachate will be classified as fresh leachate. Therefore, leachate produced in study conducted by Emenike (2010) is considered as fresh leachate and the other three landfills were considered as intermediate leachate.

Leachate at Jeram Sanitary Landfill in 2014 had a conductivity of 30.1 mS/cm in 2014 and 10.04 mS/cm in 2010, while PBL had conductivity value ranging from 10.14-13.630 mS/cm. These values were within the range of values reported by Ogata *et al*. (2016) which was 3–41 mS/cm. Electrical conductivity may come from dissolved salt and inorganic material. The electrical conductivity value is important to be measured and recorded, as higher electrical conductivity depicted higher concentration of ionic constituent could be found (Ohwoghere-Asuma & Aweto, 2013). The electrical conductivity could highly affect another important leachate parameter which is TDS. Higher amount of electrical conductivity may indicate higher amount of TDS as the concentration of dissolved salts were increasing (Aderemi *et al*., 2011). In this study, TDS value of leachate analysed averaged at 1,620 mg/L.

**4.3.6.2Hg and Zn in Fresh Leachate**

Heavy metal analysis conducted in raw leachate samples collected from this landfill indicated that the concentration of Hg averaged at 0.002 mg/L, while Zn averaged at 0.48 mg/L. Hg concentration in the sample leachate was lower than the limit allowed in the standard, which was 0.005mg/L. On the other hand, concentration of Zn obtained

was higher than the standard limit by the DOE, which is 0.2 mg/L. Correlation between the concentration of Hg and Zn in raw leachate and waste resulted with a weak positive linear correlation. $R^2$ obtained for the Hg correlation between raw leachate and waste was only 0.0025 as indicates in Figure 4.10.

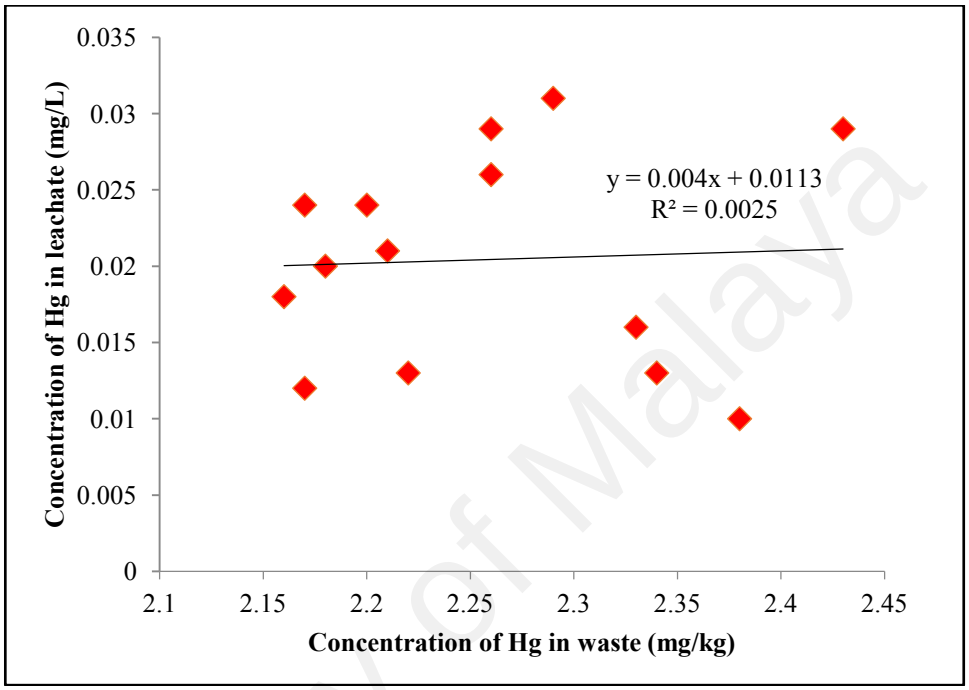


**Figure 4.10:** Correlation test of Hg in waste versus Hg in leachate.

Correlation test between raw leachate and waste for Zn concentration also shows similar trend. Figure 4.11 shows that $R^2$ obtained for the Zn correlation between raw leachate and waste was 0.0064. Result of these analyses indicated that even though the waste did affected the concentration of leachate but not all metals contained in the waste will be dissolved and transferred into the leachate generation. This finding is agreeable to study conducted by Li *et al*. (2010).

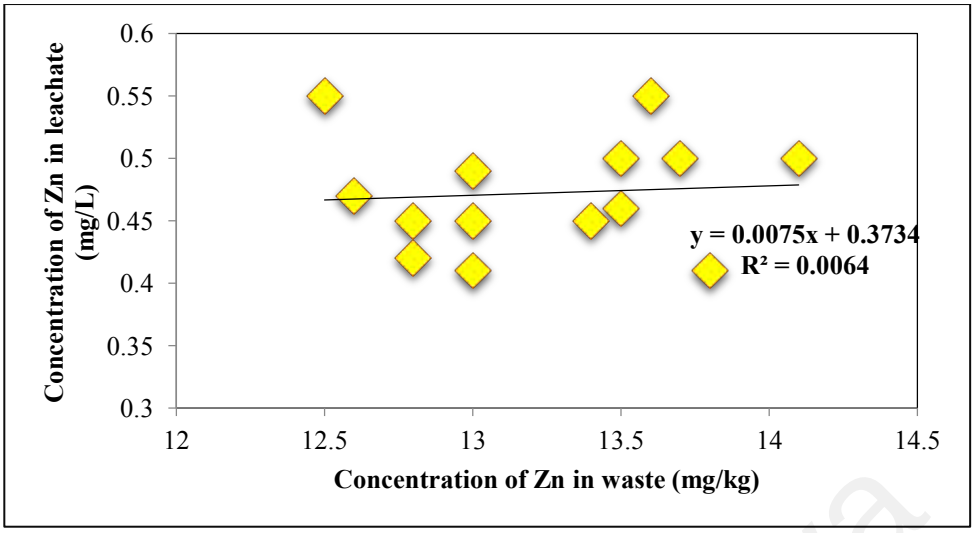


**Figure 4.11**: Correlation test of Zn in waste versus Zn in leachate.

### 4.3.7 Hg and Zn in Treated Leachate

Analysis on the treated leachate samples revealed that concentration of Hg was below the detection limit while the concentration of Zn averaged at 0.18 mg/L. Even though the concentration of Zn found in the treated leachate was below the standard, significant amount of Zn will be released into the river after a long period of time. There will be probability that the Zn will accumulate and kill the organisms which have low tolerance of this heavy metal (McRae *et al*., 2016). The concentration of Hg and Zn in the treated leachate showed that the existing treatment technologies such as physical, biological and chemical treatments in Jeram Sanitary Landfill are efficient enough to remove the Hg and Zn inside the treated leachate to be lower than the amount required by the standard. However, in the long run, more advanced technologies, such as reverse osmosis must be considered by the landfill management to ensure that lesser or no Hg and Zn will be released to the environment through treated leachate from this landfill (Labiadh *et al*., 2016).

### 4.3.8 Hg and Zn in Surface Runoff

All surface runoff produced in this landfill were channelled to the drainage around each cell and were directly discharged to the river. There was no treatment provided for surface runoff generated since the landfill management had justified that all these water were excess rainfall and do not have direct contact with deposited waste. However, analysis conducted on the surface runoff sample showed the presence of Hg and Zn. The amount of Hg in surface runoff averaged at 0.002 mg/L while the concentration of Zn averaged at 0.52 mg/L. The concentration of Hg was lower than the limit allowed in the Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations 2009, which is 0.005 mg/L. The concentration of Zn in surface runoff was 0.2 mg/L, which was slightly higher from the limit. High concentration of Zn, as compared to leachate, might be due to the natural occurring Zn in the soil (Alfaro *et al*., 2015).

## 4.4 Flows of Hg and Zn

Flows of Hg and Zn were established with the objective to identify the presence, route, and amount of these hazardous metals in the sanitary landfill system. Figure 4.8 indicates the amount of yearly input and output material in this system. The data of landfill's materials and average concentration of Hg and Zn in the landfill components were used to determine the amount of both metals in the landfill boundary for a one year period (kg/ annum).

### 4.4.1 Flow of Hg

Figure 4.12 shows that the highest contributor of Hg in this landfill is from the waste received. The total estimated amount of Hg in a year was 1,962.51 kg/ annum.

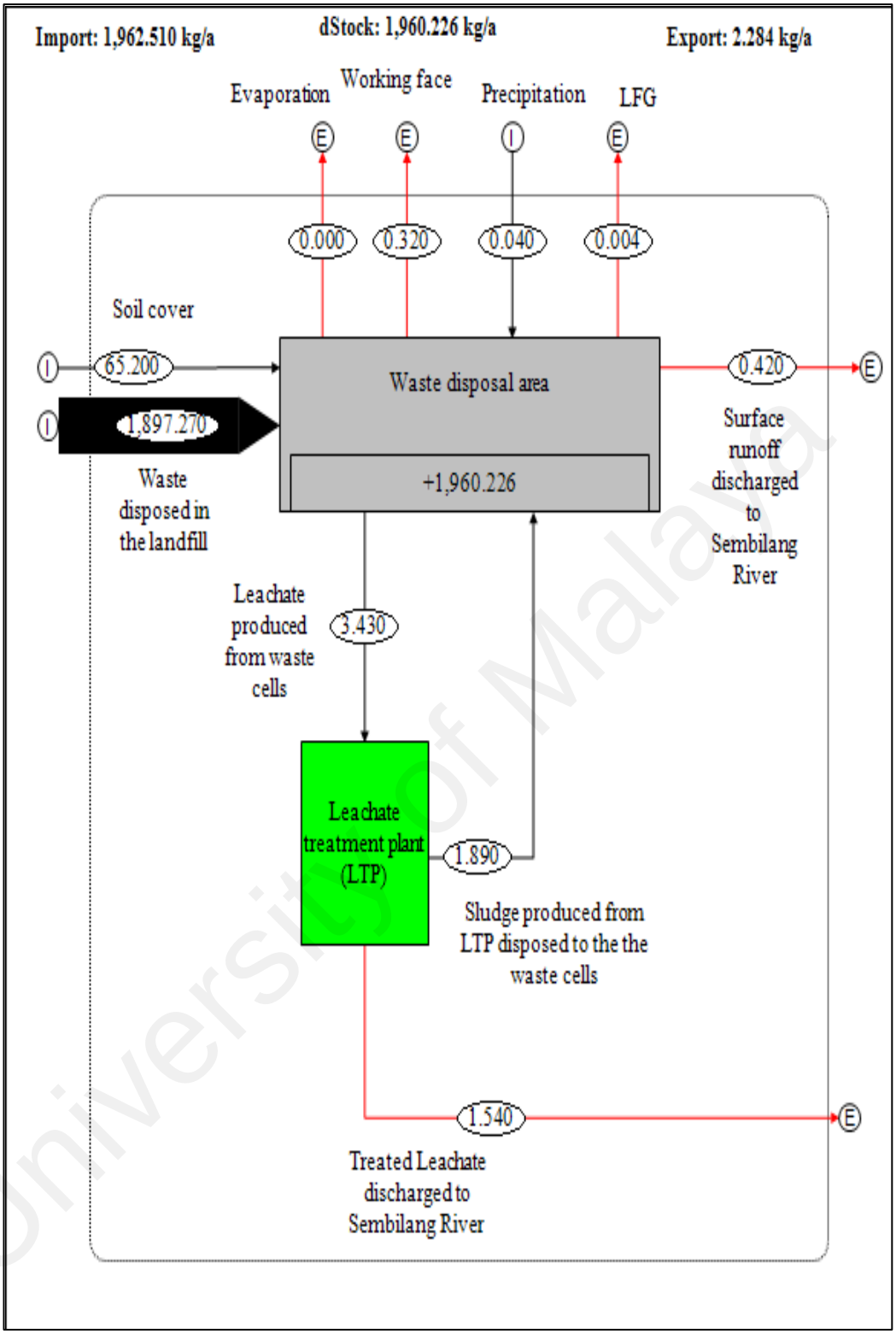


**Figure 4.12:** Hg flow in Jeram Sanitary Landfill.

The amount of Hg was due to the high quantity of waste received in this landfill over the years. In Malaysia, there is no efficient waste separation system. Thus, all waste are mixed together despite their characteristics. This leads to the disposal of household hazardous wastes, which has increased the probability of metal leakage in the landfill.

Hg concentration found in waste sample collected from Jeram Sanitary Landfill averaged at 2.56 mg/kg. This concentration is still in range with the concentration of Hg found in previous studies. Zhu *et al*. (2013) reported that the concentration of Hg in the wastes analysed was 0.19 to 1.68 mg/kg. Meanwhile, Li *et al*. (2010) reported the concentration of Hg in the wastes analysed from its landfill was 0.170 - 46.22 mg/kg. The presence of Hg in the municipal solid wastes (MSW) analysed in these studies might be caused by no stringent waste segregation practices in both countries.

The background concentration of Hg in the cover soil before being used is 0.007 mg/kg. Meanwhile, the concentration of Hg in the soil cover which was used was averaged at 0.12 mg/kg. This amount is higher than the concentration of Hg recorded in soil cover reported by Zhu *et al*. (2013), which was 0.0525 mg/kg. The differences of Hg concentration in soil cover from Jeram Sanitary Landfill and landfill studied by Zhu *et al*. (2013) might be caused by the differences of Hg concentration in the wastes disposed in both landfills. According to Smith *et al*. (2009), a higher amount of Hg in waste will lead to a higher amount of Hg in soil cover. Total Hg released into the landfill system was 65.2 kg/annum.

Rainfall, on the other hand, only brings 0.04 kg/ annum of Hg in the landfill system. This is lower compared to the amount of Hg accumulated from the wastes disposed and the used soil cover used. According to Li *et al*. (2010), the concentration of Hg in the rainfall is generally much smaller as compared to waste received and soil cover used in the landfill. The presence of Hg in the rainfall collected from Jeram Sanitary Landfill indicates that there are depositions of Hg in the landfill's atmosphere. However, the source of Hg cannot be determined as Hg deposited may also originate from other sources. This is due to Hg's properties, in which it can evaporate more easily than most

metal and can travel long distances in the atmosphere (Drevnick *et al*., 2016). Even though the concentration of Hg in the rainfall was only 0.04 kg/ annum in this landfill system. It is still significant as it is able to affect the quality of other landfill components such as leachate and surface runoff.

The concentration of Hg in leachate was 3.43 kg/ annum. The concentration of Hg in leachate is not only influenced by Hg concentration in rainfall. It is also affected by the concentration of Hg in waste. This is because leachate is generated by the infiltration of rainfall into the waste cell (Brennan *et al*., 2016). During the flow of rainfall through the waste, Hg generated in the waste deposits might get dissolved in the leachate flow (Sharifah & Latifah, 2013).

The concentration of Hg released from the landfill through the treated leachate is averaged at 0.009 mg/L with yearly amount of 1.54 kg/annum. This value is definitely lower than the concentration of Hg permitted in the Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations 2009 which is 0.05 mg/L. However, due to the volume of treated leachate discharge every year from this landfill and the bio-accumulative and persistent properties of Hg, the presence of Hg in the discharged leachate is still a concern to the environment. Kortegast *et al*. (2007) reported that treated leachate released from Bukit Tagar Sanitary Landfill has lesser than 0.001 mg/L. Therefore, this shows that with appropriate technologies, it is possible to reduce the amount of Hg released through treated leachate from Jeram Sanitary Landfill.

On average, concentration of Hg found in surface runoff is 0.002 mg/L. The concentration of Hg found in surface runoff is higher than the concentration found in

the rainfall (0.006 ug/L). This is because the concentration of Hg in surface runoff not only is influenced by the rainfall, but also the concentration of Hg in the soil around the landfill. During heavy rainfall events, oversaturated soil cover may have produced leachates that are spilled out from the waste cell areas. Then, overflow of these leachate may seep into the soil around the landfill. Thus, surface runoff that flows through the soil become contaminated and has higher presence of Hg. Talalaj *et al*. (2013) and Tang *et al*. (2003) also reported presence of Hg in the surface runoff studied which is 0.0001 mg/L and 0.05 to 0.27 μg/L. Higher value of Hg found in Jeram Sanitary Landfill's surface runoff may attributed by higher amount of Hg presence in the leachate sample and amount of rainfall received.

Figure 4.12 shows total release of Hg to from landfill system to the atmosphere from LFG and also the working face. Total amount of Hg released from LFG is 0.004 kg/annum per year. Meanwhile, the amount of Hg released through the working face is 0.32 kg/annum. The amount of Hg released from the working face is higher than Hg released from the LFG. Lee *et al*. (2016) stated that this scenario is a common situation in most landfills. Higher emission of Hg from working face than LFG is because there is no barrier between the Hg released from working face to the atmosphere. Emission of Hg at the working face is elevated especially with the compaction of waste such as fluorescent lamp (Linberg *et al*., 2005). Breakage of these wastes will cause immediate emission of volatile Hg to the atmosphere.

Overall, the input of Hg in the sanitary landfill system was from the wastes received in the landfill, rainfall, and soil cover used in the landfill. Meanwhile, the outputs identified are surface runoff and discharged treated leachates. The total import amount of Hg into the landfill for a year is 1,962.51kg/ annum and the estimated export of Hg

is 2.28 kg/ annum. Meanwhile, the amount of Hg stock in the landfill is 1,960.23 kg/ annum. This amount shows that most of Hg in the landfill will remain within the landfill system.

### 4.4.2 Flow of Zn

Figure 4.13 shows the MFA of Zn in the sanitary landfill system in kg/ annum unit. The MFA recorded the amount of Zn released or discharged from the landfill system throughout the study period. Input of Zn in the landfill system is recorded at 18,611 kg/ annum.The output was 35 kg/ annum and the stock of Zn inside the landfill was 18,576 kg/ annum. Wastes disposed and clay utilised as the soil cover are the two main Zn inputs in this sanitary landfill system. Meanwhile, the output sources of Zn are surface runoff and treated leachate. The highest amount of Zn was contributed by the wastes disposed in the landfill. The heterogeneity of waste received in this landfill highly affects the concentration of Zn (Alimba *et al*., 2016). Li *et al*. (2010) reported that heavy metal analysis done to MSW collected contain 41.2 mg/kg to 1643mg/kg of Zn. In this study, the concentration of Zn in the waste sample averaged at 13.6 mg/kg. Meanwhile, the estimated amount of Zn in waste deposited for a whole year was 11,400 kg/annum.

Heavy metals from household hazardous waste might be released to the waste through breakage or leakage during collection, landfilling or daily waste compaction (Nnorom *et al*., 2010; United States Environmental Protection Agency, 2016) The aerobic and anaerobic microbial decomposition activities in waste deposits are also the processes that attribute to the increase of Zn in the wastes (Brennan *et al*., 2016). Another input of Zn is the soil cover namely clay. The application of clay as soil cover increases the

concentration of Zn in the landfill system. This is because the background concentration of Zn in the landfill system is 7.5 mg/kg.

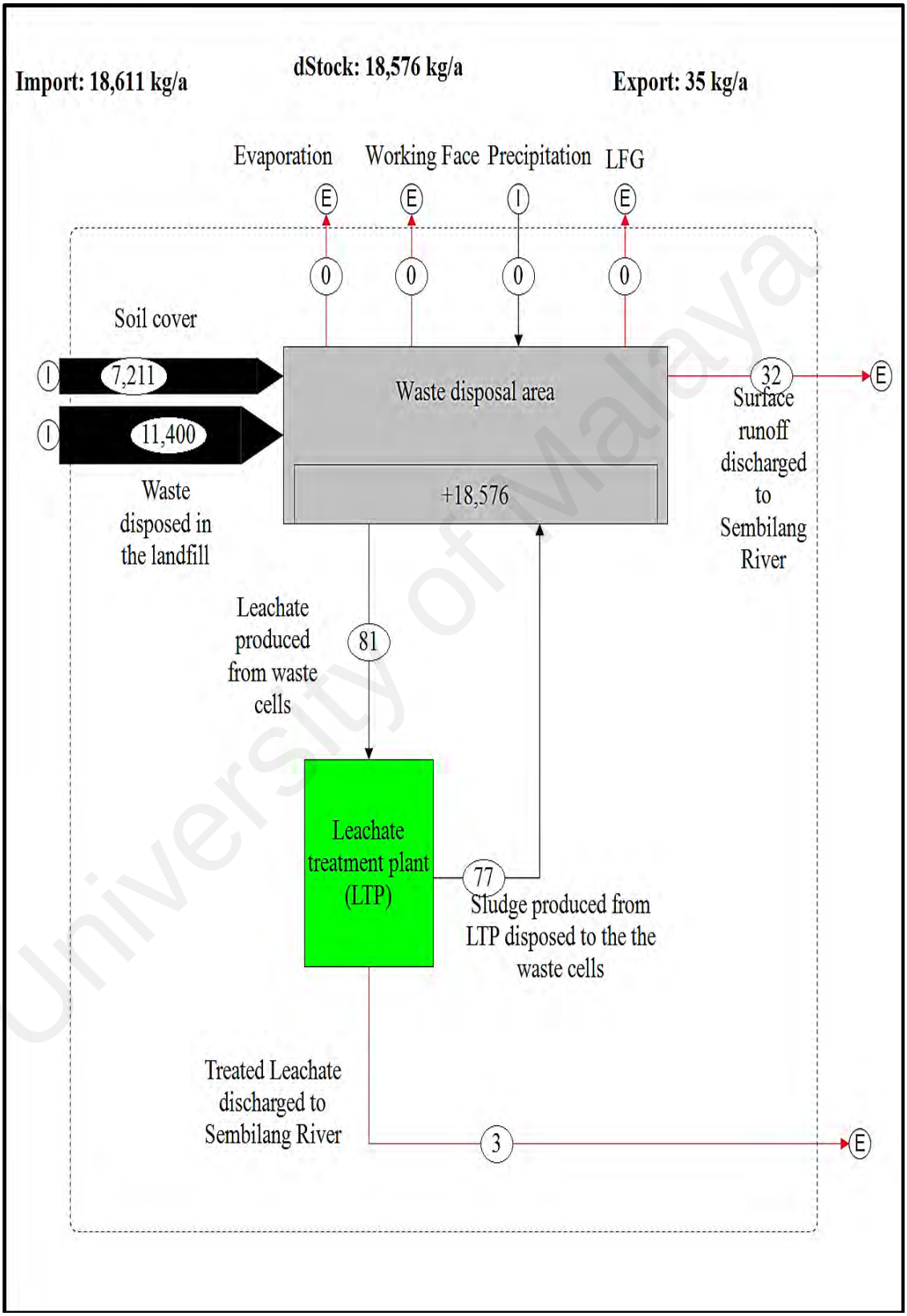


**Figure 4.13:** Zn flow in Jeram Sanitary Landfill.

This value increased to 11.3mg/kg after the soil cover is used in the landfill. Figure 4.13 shows the concentration of Zn in soil cover was 7,211 kg/ annum. The amount of Zn in leachate of this study averaged at 0.48mg/L. Studies showed that Zn presence in leachate is common observation. Alimba *et al*. (2016) stated that the Aba-Eku landfill recorded a Zn concentration of 17.36 mg/L and Bhandewadi Nagpur Landfill in India had a concentration of 0.0210 mg/L. Karnchanawong and Limpiteeprakan (2009) also reported that the concentration of Zn in the leachate from their study was 3.93–49.30 mg/L. This signifies that the amount of Zn in the leachate is widely diversified as the concentration of Zn is influenced by various factors such as type of waste, climate, and amount of rainfall received (Mangimbulude *et al*., 2012; Xie *et al*., 2015). Total of Zn produced in fresh leachate was 81 kg/annum.

The discharged treated leachates still contains detectable concentration of Zn which is 0.18 mg/L. Azim *et al*. (2011) also reported presence of Zn in the treated leachate samples from Matuail Landfill in Dhaka which is 0.04 mg/L. Meanwhile, Kortegast *et al*. (2007) reported that 0.18 mg/L of Zn is also detected from the treated leachate discharged from Bukit Tagar Sanitary Landfill.

Another output of Zn from the landfill is through surface runoff. The estimated amount of Zn in surface runoff was 0.2 mg/L or total of 32 kg Zn per annum. This value is comparable to values reported by Azim *et al*. (2011) which are 0.27 mg/L. Meanwhile, Talalaj *et al*. (2013) reported the value of Zn in surface runoff was averaged at 0.03 mg/L. Therefore, it is important to note that the discharge of treated leachate and surface runoff without completely removing the Zn concentration will bring impacts to the aquatic system (Mavakala *et al*., 2016).

## 4.5 Recommendations

Based on the result obtained in this study, recommendations are proposed as initiatives to reduce the potential release of Hg and Zn into the sanitary landfill and environment. Analysis indicate that mixed disposal of household hazardous waste and MSW will increase the release of the metals in the sanitary landfill. This is due to breaking, evaporation or corrosion of household hazardous waste while being disposed together with MSW in the landfill. Therefore, separation at source of household hazardous waste and MSW from residential area is highly recommended. Separation at source will deviate the recyclable and hazardous wastes from the waste stream. Waste separation will help to reduce the moisture content which will directly reduce risk of heavy metal leaching into the waste.

Malaysian authorities have passed the Solid Waste and Public Cleansing Management Act 2007 (Act 672) in 2007 while the implementation of the waste segregation was carried out among public starting September 2015 (Edward, 2015). However, the current situation does not show any progressive improvement and the method of imposing fines have been used as the last resort to ensure waste segregation is carried out (Edward, 2015). The awareness on the importance of separating wastes based on their classification is still low even in urban areas. According to an article published by Clean Malaysia (2016), the public community in Malaysia lacks the knowledge on household hazardous waste. There are many Malaysians who are still not aware towards the impact of improper disposal of household hazardous waste.

In order to increase public knowledge and awareness on these issues, the government may need to be more aggressive in spreading information on household hazardous waste, especially on its characteristic, type, and how damaging it can be if not

managed properly. Campaigns and advertisements emphasising on the health effects of heavy metal released from household hazardous waste should be done to gain public attention to this issue. Furthermore, the government can provide more promotion on environmental friendly products that avoid heavy metal addition. This information can also be highlighted in the information label attached on the products. Indirectly, this will enlighten the consumers and increase the probability of consumers to buy more environmental friendly products.

It is vital for a proper household hazardous waste collection centre to be established. Eventhough, more recycling centres have been established, facilities to collect household hazardous waste such as fluorescent lamps, paints, batteries or e-waste is still lacking. It is recommendable if the collection point of these household hazardous wastes are increased and located in accessible places, for instance in shopping malls or educational institutions to encourage proper disposal options to the consumers.

Increase in collection facilities will also encourage consumers to contribute more toward the recovery and recycling of household hazardous waste. It is also important to note that all household hazardous wastes collected from the collection points must be accumulated and sent to legalised recycling/recovery centres. Therefore, the government must have specific methods to supervise and control the collection of household hazardous waste to ensure the recovery and recycling of household hazardous waste are according to the required regulation. Proper regulation will ensure less risk of heavy metal released such as Hg and Zn from wastes to the environment. Another effective way to reduce the amount of wastes that contain Hg and Zn from landfill is by controlling the amount of products that contain these heavy metals. It is difficult to be accomplished since this issue deals with the industry. However, it is

possible to be implemented with the support and intervention by the Malaysian government.

Various actions can be initiated by the government in ensuring fewer products with Hg and Zn are available in the public market. Financial help such as subsidies and tax exemptions are considered as good and attractive incentives for the manufacturers to support heavy metal free concept in their products. In addition, more researches and collaboration projects can be carried out aggressively between the manufacturers, higher education institutions, as well as government bodies to study the alternatives to replace heavy metal such as Hg and Zn from household products. The government can also adopt extended producer responsibility (EPR) for products containing Hg and Zn. This is to guarantee that each household product bought will be disposed properly once it is used up or discarded. Thus, the government can start applying mandatory EPR to products such as laptops, mobile phones and television sets.

There are many improvements that can be implemented in Jeram Sanitary Landfill to reduce the concentration of heavy metal in and out of the landfill system. One of the significant changes that need to be done is to completely remove the use of clay as soil cover. The soil cover should be substituted with HDPE liner as temporary cover before final cover material. This is because the properties of clay accelerate the accumulation of heavy metal, especially when there are other inducing factors such as rainfall and high waste moisture content. The installation of the HDPE liner can also intercept rainfall from entering the waste cell.

Both amount of Hg and Zn detected in the treated leachate from this study are below the standard limit required by authority. However, the treated leachate are discharged

on daily basis for 16 years. Therefore, it is highly possible for these metals to accumulate over time in the near river ecosystem. Thus, it is advisable for the landfill management to improve the existing leachate treatment technologies. This is in order to minimize the amount of Hg and Zn release trough the treated leachate and reduce the risk of heavy metal contamination in the future.

In order to reduce the amount of wastes disposed in this landfill the management can consider is to increase the size and capacity of the existing MRF in the Jeram Sanitary Landfill. This will allow the recovery of more wastes and reduce the amount of wastes sent to the waste cells. Another way to recover and reduce wastes in this landfill is by hiring waste pickers to recover valuable material. This will not only open up opportunities for employment for the people, but also increases additional income and save more landfill space.

# CHAPTER 5: CONCLUSION

## 5.1 Conclusion

In 2014, total waste received in Jeram Sanitary Landfill was 839,500 tonne. The waste composition study in Jeram Sanitary Landfill showed that the highest contribution of waste received is food waste (37.7%). Waste composition also indicated that 4% of the total waste composition consisted of household hazardous waste. Percentages of household hazardous waste classified were home improvement products (28%), e-waste (23%), miscellaneous products (15%), automotive products (12%), ink and paint (8%), medicine (3%) and beauty products (3%). The presence of these household hazardous waste contribute to the increased concentration of Hg and Zn in Jeram Sanitary Landfill. This research has managed to gain insight on the flow of Hg and Zn in Jeram Sanitary Landfill Input of Hg concentration in the system are waste (1,962.51 kg/ annum), soil cover (65.20 kg/ annum) and rainfall (0.004 kg/ annum), while the output of Hg are treated leachate (1.54 kg/ annum) and surface runoff (0.4 2 kg/ annum). Meanwhile, the input of Zn in this landfill system are waste (11,400 kg/ annum) and soil cover (7211 kg/ annum), whereas the output channel are surface runoff (32 kg annum) and treated leachate (3 kg/ annum). Waste has been identified as the largest contributor of Hg and Zn in this study. In order to reduce the concentration of both heavy metals, precautionary steps such as “from cradle to grave” concept must be implemented at the national level.

## 5.2 Areas for Future Research

The focus of this research is the material flow analysis of Hg and Zn in the sanitary landfill. Future research can include the specification of the Hg and Zn elements in landfill components specifically on different types of household hazardous wastes. Moreover, with the presence of advanced instruments and additional funds, the

concentration of metal in the groundwater system and speciation of Hg and Zn in landfill's components which are not studied in this research, can also be carried out.

## REFERENCES


Adamcová, D., Vaverková, M. D., Stejskal, B., & Břoušková, E. (2016). Household solid waste composition focusing on hazardous waste. *Polish Journal of Environmental Studies*, *25*(2), 487-493.

Aderemi, A. O., Oriaku, A. V., Adewumi, G. A., & Otitoloju, A. A. (2011). Assessment of groundwater contamination by leachate near a municipal solid waste landfill. *African Journal of Environmental Science and Technology, 5*(11), 933-940.

Adhikari, B., & Khanal, S. N. (2015). Qualitative study of landfill leachate from different ages of landfill sites of various countries including Nepal. *Journal of Environmental Science, Toxicology and Food Technology, 9*(1), 23-26.

Afroz, R., Hanaki, K., & Tudin, R. (2011). Factors affecting waste generation: a study in a waste management program in Dhaka City, Bangladesh. *Environmental Monitoring and Assessment*, *179*(1), 509-519.

Agamuthu, P., & Fauziah, S. H. (2008, October). *Solid waste: Environmental factors and health*. Paper presented at the EU-Asia Solid Waste Management Conference, Perak, Malaysia.

Agamuthu, P., & Fauziah, S. H. (2011). Challenges and issues in moving towards sustainable landfilling in a transitory country-Malaysia. *Waste Management & Research, 29*(1), 13-19.

Agamuthu, P., & Tanaka, M. (2014). *Municipal solid waste management in Asia and the Pacific Islands*. Singapore: Springer

Agamuthu, P., & Victor, D. (2011). Policy trends of extended producer responsibility in Malaysia. *Waste Management & Research*, *29*(9), 945-953.

Agamuthu, P., Fauziah, S. H., & Khidzir, K. (2009). Evolution of solid waste management in Malaysia: Impacts and implications of the solid waste bill, 2007. *Journal of Material Cycles and Waste Management*, *11*(2), 96-103.

Agamuthu, P., Milow, P., Nurul, A. M., Nurhawa, A. R., & Fauziah, S. H. (2015). Impact of flood on waste generation and composition in Kelantan. *Malaysian Journal of Science, 34*(2), 130-140.

Agency for Toxic Substances and Disease Registry (2005). *Toxicological profile for zinc*. Retrieved August 1, 2016 from https://www.atsdr.cdc.gov

Ahmed, S. I., Johari, A., Hashim, H., Mat, R., Lim, J. S., Ngadi, N., & Ali, A. (2015). Optimal landfill gas utilization for renewable energy production. *Environmental Progress & Sustainable Energy, 34*(1), 289-296.

Aja, O. C., & Al-Kayiem, H. H. (2014). Review of municipal solid waste management options in Malaysia, with an emphasis on sustainable waste-to-energy options. *Journal of Material Cycles and Waste Management, 16*(4), 693-710.

Aleluia, J., & Ferrão, P. (2016). Characterization of urban waste management practices in developing Asian countries: A new analytical framework based on waste characteristics and urban dimension. *Waste Management, 58*, 415-429.

Alfaro, M. R., Montero, A., Ugarte, O. M., do Nascimento, C. W. A., de Aguiar Accioly, A. M.,…. da Silva, Y. J. A. B. (2015). Background concentrations and reference values for heavy metals in soils of Cuba. *Environmental Monitoring and Assessment, 187*(1), 4198.

Alimba, C. G., Gandhi, D., Sivanesan, S., Bhanarkar, M. D., Naoghare, P. K., Bakare, A. A., & Krishnamurthi, K. (2016). Chemical characterization of simulated landfill soil leachates from Nigeria and India and their cytotoxicity and DNA damage inductions on three human cell lines. *Chemosphere, 164*, 469-479.

Al Raisi, S. A. H., Sulaiman, H., Abdallah, O., & Suliman, F. (2014). Landfill suitablity analysis using ahp method and state of heavy metals pollution in selected landfills in Oman. *European Scientific Journal*, *10*(17).

Al-Salem, S. M., Lettieri, P., & Baeyens, J. (2009). Recycling and recovery routes of plastic solid waste (PSW): A review. *Waste Management, 29*(10), 2625-2643.

Amadi, A. N., Olasehinde, P. I., Okosun, E. A., Okoye, N. O., Okunlola, I. A., Alkali, Y. B., & Dan-Hassan, M. A. (2012). A comparative study on the impact of Avu and Ihie dumpsites on soil quality in Southeastern Nigeria. *American Journal of Chemistry, 2*(1), 17-23.

Arena, U., & Di Gregorio, F. (2014). A waste management planning based on substance flow analysis. *Resources, Conservation and Recycling, 85*, 54-66.

Asmuni, S., Hussin, N. B., Khalili, J. M., & Zain, Z. M. (2015). Public participation and effectiveness of the No Plastic Bag Day Program in Malaysia. *Procedia-Social and Behavioral Sciences, 168*, 328-340.

Assamoi, B., & Lawryshyn, Y. (2012). The environmental comparison of landfilling vs. incineration of MSW accounting for waste diversion. *Waste Management*, *32*(5), 1019-1030.

Aucott, M. (2006). *The fate of heavy metals in landfills: A review*. Retrieved August 11, 2015 from https://cfpub.epa.gov/

ASTM. (2008). *Standard method for determination of moisture content in biomass*. (ASTM E790-08). Retrieved June 12, 2015 from *https://www.astm.org/*

Azim, M. D., Rahman, M. M., Khan, R. H., & Kamal, A. T. M. M. (2011). Characteristics of leachate generated at landfill sites and probable risks of surface and groundwater pollution in the surrounding areas: A case study of Matuail Landfill site, Dhaka. *Journal of Bangladesh Academy of Sciences, 35*(2), 153-160.

Aziz, S. Q., Aziz, H. A., Bashir, M. J. K., & Mojiri, A. (2015). Assessment of various tropical municipal landfill leachate characteristics and treatment opportunities. *Global NEST Journal, 17*(3), 439-450.

Baccini, P., & Brunner, P. H. (2012). *Metabolism of the anthroposphere: Analysis, evaluation, design*. Massachusetts, United States: MIT Press.

Bao, Z., Zhang, S., Chen, Y., Liu, S., Zhang, Y., & Wang, H. (2010). A review of material flow analysis. *Proceeding of 2010 International Conference on Management and Service Science*, 1-8.

Bavani. M. (2016, March 14). *Rapid urbanisation leads to pollution*. *The Star Online*. Retrieved July 11, 2015 from http://www.thestar.com.my/

Bełdowska, M., Zawalich, K., Falkowska, L., Siudek, P., & Magulski, R. (2008). Total gaseous mercury in the area of southern Baltic and in the coastal zone of the Gulf of Gdansk, during spring and autumn. *Environment Protection Engineering, 4*, 130-139.

Berlin Senate Department for Urban Development and the Environment Communication (2013). *Municipal waste management in Berlin*. Retrieved April

3, 2015 from https://www.cleanenergywire.org/experts/senate-department-urban-development-and-environment-state-berlin

Bhalla, B., Saini, M. S., & Jha, M. K. (2013). Effect of age and seasonal variations on leachate characteristics of municipal solid waste landfill. *International Journal of Research in Engineering and Technology, 2*, 223-232.

Bisinella, V., Götze, R., Conradsen, K., Damgaard, A., Christensen, T. H., & Astrup, T. F. (2017). Importance of waste composition for life cycle assessment of waste management solutions. *Journal of Cleaner Production*, *164*, 1180-1191.

Boechat, C. L., Pistóia, V. C., Ludtke, A. C., Gianello, C., & Camargo, FAO. (2016). Solubility of heavy metals/metalloid on multi-metal contaminated soil samples from a gold ore processing area: Effects of humic substances. *Revista Brasileira de Ciência do Solo, 40*, 1-10.

Brennan, R. B., Healy, M. G., Morrison, L., Hynes, S., Norton, D., & Clifford, E. (2016). Management of landfill leachate: The legacy of European Union directives. *Waste Management, 55*, 355-363.

Brunner, P. H., & Rechberger, H. (2004). Practical handbook of material flow analysis. *The International Journal of Life Cycle Assessment*, *9*(5), 337-338.

Cencic, O., & Rechberger, H. (2008). Material flow analysis with software STAN. *Journal of Environmental Engineering and Management, 18*(1), 3.

Chan, J. (2013, November 7). Given new lease of life. *The Star Online*. Retrieved April 5, 2015 from http://www.thestar.com.my/

Chen, G. (2015, December 2). Recycling for earth and cash, *The Star Online*. Retrieved July 29, 2015 from http://www.thestar.com.my/

Cheremisinoff, N. P. (2003). *Handbook of solid waste management and waste minimization technologies*. Oxford, United Kingdom: Butterworth-Heinemann.

Chibuike, G. I., & Obiora, S. C. (2014). Heavy Metal Polluted Soils: Effect on plants and bioremediation methods. *Applied and Environmental Soil Science*, 2014, 1-12.

Cicatiello, C., Franco, S., Pancino, B., & Blasi, E. (2016). The value of food waste: An exploratory study on retailing. *Journal of Retailing and Consumer Services, 30*, 96-104.

Clean Malaysia. (2016). *Waste management in Malaysia: In the dumps*. Retrieved July 1, 2015 from http://cleanMalaysia.com/2015/09/04/waste-management-in-Malaysia-in-the-dumps/

Damgaard, A., Manfredi, S., Merrild, H. K., Stensøe, S., & Christensen, T. H. (2011). LCA and economic evaluation of landfill leachate and gas technologies. *Waste Management, 31*(7), 1532-1541.

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

Das, D., Majhi, B. K., Pal, S., & Jash, T. (2016). Estimation of land-fill gas generation from municipal solid waste in Indian cities. *Energy Procedia, 90*, 50-56.

Delgado, O. B., Ojeda-Benítez, S., & Márquez-Benavides, L. (2007). Comparative analysis of hazardous household waste in two Mexican regions. *Waste Management, 27*(6), 792-801.

Department of Environment. (2005). *Environmental quality (Scheduled Wastes) regulations 2005*. Retrieved February 18, 2015 from https://www.doe.gov.my

Department of Environment. (2009). *Environmental quality (Control of pollution from solid waste transfer station and landfill regulations 2009*). Retrieved March 2, 2015 from https://www.doe.gov.my

Dhokhikah, Y., Trihadiningrum, Y., & Sunaryo, S. (2015). Community participation in household solid waste reduction in Surabaya, Indonesia. *Resources, Conservation and Recycling, 102*, 153-162.

Drevnick, P. E., Cooke, C. A., Barraza, D., Blais, J. M., Coale, K. H., Cumming, B. F., ... & Engstrom, D. R. (2016). Spatio temporal patterns of mercury accumulation in lake sediments of western North America. *Science of The Total Environment, 568*, 1157-1170.

Duan, H., Hou, K., Li, J., & Zhu, X. (2011). Examining the technology acceptance for dismantling of waste printed circuit boards in light of recycling and environmental concerns. *Journal of Environmental Management, 92*(3), 392-399.

Ebin, B., Petranikova, M., Steenari, B. M., & Ekberg, C. (2016). Production of zinc and manganese oxide particles by pyrolysis of alkaline and Zn–C battery waste. *Waste Management, 51*, 157-167.

Ecology Global Network. (2010). *Current world population by continent*. Retrieved April 3, 2015 from http://www.ecology.com/world-population-continent/l/

Edward, J. (2015, December 2). Waste segregation enforcement starts today. *Malay Mail Online*. Retrieved August 11, 2016 from http://www.themalaymailonline.com/

Ekino, S., Susa, M., Ninomiya, T., Imamura, K., & Kitamura, T. (2007). Minamata disease revisited: An update on the acute and chronic manifestations of methyl mercury poisoning. *Journal of the Neurological Sciences*, *262*(1), 131-144.

Emenike, E. C. (2010). *Landfill leachate toxicity studies on fish (Pangasius Sutchi and Clarias Batrachus) and soil microbes*. (Master's thesis). Retrieved July 11, 2016 from http://www.diglib.um.edu.my/umtheses/

Emenike, E. C. (2013). *Leachate toxicity assessment and bioremediation of leachate contaminated soil*. (Doctoral thesis) University of Malaya, Kuala Lumpur, Malaysia. Retrieved July 12, 2016 from http://www.diglib.um.edu.my/umtheses

Fauziah, S. H. (2010). *Municipal solid waste management : A comprehensive study in Selangor*. (Doctoral thesis) University Malaya, Kuala Lumpur, Malaysia. Retrieved July 11, 2016 from http://www.diglib.um.edu.my/umtheses

Fauziah, S. H., & Agamuthu, P. (2012). Trends in sustainable landfilling in Malaysia, a developing country. *Waste Management & Research, 30*(7), 656-663.

Fauziah, S. H., Emenike, C. U., & Agamuthu, P. (2013). Leachate risk and identification of accumulated heavy metals in *Pangasius Sutchi*. *Waste Management & Research, 31*(10), 75-80.

Fauziah, S. H., Khairunnisa, A. K., Siti Zubaidah, B., & Agamuthu, P. (2009, Oct). *Public perception on solid waste and public cleansing management bill 2007 towards sustainable waste management in Malaysia*. Paper presented at the ISWA/APESB World Congress, Lisbon, Portugal.

Fei, X., Zekkos, D., & Raskin, L. (2016). Quantification of parameters influencing methane generation due to biodegradation of municipal solid waste in landfills and laboratory experiments. *Waste Management, 55*, 276-287.

Fernández-Luqueño, F., López-Valdez, F., Gamero-Melo, P., Luna-Suárez, S., Aguilera-González, E. N., Martínez, A. I., ... Pérez-Velázquez, I. R. (2013). Heavy metal pollution in drinking water-a global risk for human health: A review. *African Journal of Environmental Science and Technology*, *7*(7), 567-584.

Fikri, E., Purwanto, P., & Sunoko, H. R. (2015). Modelling of household hazardous waste management in Semarang city (Indonesia) by using life cycle assessment approach to reduce greenhouse gas emissions. *Procedia Environmental Sciences, 23*, 123-129.

Furuoka, F. (2002). *Japanese multinational corporations and the export of pollution: The case of Bukit Merah*. Paper presented at the Third International Conference on Disaster Management, Kuching, Malaysia.

Gergely, A., Pfeifer, É., Bertóti, I., Török, T., & Kálmán, E. (2011). Corrosion protection of cold-rolled steel by zinc-rich epoxy paint coatings loaded with nano-size alumina supported polypyrrole. *Corrosion Science, 53*(11), 3486-3499.

Ghazali, F. M., Syafalni, S., & Noor, S. M. (2014). Public perception on the current solid waste management system in Malaysia: A comparative study of Matang Landfill and Bukit Tagar Sanitary Landfill (BTSL). *World Applied Sciences Journal, 32*(5), 872-883.

Gochfeld, M. (2003). Cases of mercury exposure, bioavailability, and absorption. *Ecotoxicology and Environmental Safety*, *56*(1), 174-179.

Greenworks. (2017). *Recycle*. Retrieved January 12, 2017 from http://www.greenworks.co.za/recyclepage.html#tins

Gu, B., Zhu, W., Wang, H., Zhang, R., Liu, M., Chen, Y., ... Yang, J. (2014). Household hazardous waste quantification, characterization and management in China's cities: A case study of Suzhou. *Waste Management*, *34*(11), 2414-2423.

Guentzel, J. L., Landing, W. M., Gill, G. A., & Pollman, C. D. (2001). Processes influencing rainfall deposition of mercury in Florida. *Environmental Science & Technology, 35*(5), 863-873.

Gunawardena, J., Egodawatta, P., Ayoko, G. A., & Goonetilleke, A. (2013). Atmospheric deposition as a source of heavy metals in urban stormwater. *Atmospheric Environment, 68*, 235-242.

Guo, Y., & Yang, S. (2016). Heavy metal enrichments in the Changjiang (Yangtze River) catchment and on the inner shelf of the East China Sea over the last 150 years. *Science of the Total Environment*, *543*, 105-115.

Hachiya, N. (2006). The history and the present of Minamata disease. *Japan Medical Association Journal*, *49*, 112-118.

Hargreaves, J. C., Adl, M. S., & Warman, P. R. (2008). A review of the use of composted municipal solid waste in agriculture. *Agriculture, Ecosystems & Environment, 123*(1), 1-14.

Harvey, J. W., Krupa, S. L., Gefvert, C., Mooney, R. H., Choi, J., King, S. A., & Giddings, J. B. (2002). *Interactions between surface water and ground water and effects on mercury transport in the north-central*. Retrieved March 30, 2016 from https://pubs.er.usgs.gov

HassanChaib, Hamouda, A., & M.A, M. (2014). Household hazardous waste management in Malaysia. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, *3* (12), 13516-13523.

He, J., Li, F., Li, Y., & Cui, X. L. (2015). Modified sewage sludge as temporary landfill cover material. *Water Science and Engineering, 8*(3), 257-262.

HongYeng, L., & Agamuthu, P. (2015). Nitrogen flow in organic and conventional vegetable farming systems: a case study of Malaysia. *Nutrient Cycling in Agroecosystems, 103*(2), 131-151.

Hoornweg, D., Bhada-Tata, P., & Kennedy, C. (2013). Environment: Waste production must peak this century. *Nature, 502*(7473), 615-617.

Houston, M. C. (2011). Role of mercury toxicity in hypertension, cardiovascular disease, and stroke. *The Journal of Clinical Hypertension*, *13*(8), 621-627.

Hu, Y., & Cheng, H. (2012). Mercury risk from fluorescent lamps in China: Current status and future perspective. *Environment International*, *44*, 141-150.

Huang, Y., Zhang, M., Xia, Y., Hu, Y., & Son, S. W. (2016). Is there a stratospheric radiative feedback in global warming simulations? *Climate Dynamics, 46*(1-2), 177-186.

Inaba, T., Kobayashi, E., Suwazono, Y., Uetani, M., Oishi, M., Nakagawa, H., & Nogawa, K. (2005). Estimation of cumulative cadmium intake causing Itai–itai disease. *Toxicology Letters, 159*(2), 192-201.

Inglezakis, V. J., & Moustakas, K. (2015). Household hazardous waste management: A review. *Journal of Environmental Management*, *150*, 310-321.

Ishihara, T., Kobayashi, E., Okubo, Y., Suwazono, Y., Kido, T., Nishijyo, M., ... & Nogawa, K. (2001). Association between cadmium concentration in rice and mortality in the Jinzu River basin, Japan. *Toxicology*, *163*(1), 23-28.

Islam, M. N. (2016). E-waste Management of Bangladesh. *International Journal of Innovative Human Ecology& Nature Studies 4*(2), 1-12.

Ismail, S. N. S., & Manaf, L. A. (2013). The challenge of future landfill: A case study of Malaysia. *Journal of Toxicology and Environmental Health Sciences, 5*(6), 86-96.

Ithnin, A., Awang, N., Aimie, A. N., Aizam, A. S., & Ariffin, F. D. (2012). Studies of health effect among the Taman Wahyu II Building, Kuala Lumpur residents at the former Landfill. *Middle East Journal of Scientific Research*, *11*(11), 1524-1529.

Iwegbue, C. M., Emakunu, O. S., Nwajei, G. E., Bassey, F. I., & Martincigh, B. S. (2017). Evaluation of human exposure to metals from some commonly used bathing soaps and shower gels in Nigeria. *Regulatory Toxicology and Pharmacology*, *83*, 38-45.

Iyer, S., Sengupta, C., & Velumani, A. (2015). Lead toxicity: An overview of prevalence in Indians. *Clinica Chimica Acta, 451*, 161-164.

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., & Beeregowda, K. N. (2014). Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary Toxicology*, *7*(2), 60-72.

Jamin, N. C., & Mahmood, N. Z. (2015). Scheduled waste management in Malaysia: An overview. *Advanced Materials Research*, *1113*, 841-846.

Jeong, Y. S., Matsubae-Yokoyama, K., Kubo, H., Pak, J. J., & Nagasaka, T. (2009). Substance flow analysis of phosphorus and manganese correlated with South Korean steel industry. *Resources, Conservation and Recycling, 53*(9), 479-489.

Jia, G. W., Zhan, T. L., Chen, Y. M., & Fredlund, D. G. (2010). Influence of rainfall pattern on the infiltration into landfill earthen final cover. In *Advances in environmental geotechnics*. Proceedings of the International Symposium on Geoenvironmental Engineering (pp. 641-645). Hangzhou, China.

Johari, A., Alkali, H., Hashim, H., Ahmed, S. I., & Mat, R. (2014). Municipal solid waste management and potential revenue from recycling in Malaysia. *Modern Applied Science, 8*(4), 37.

Johari, A., Hashim, H., Mat, R., Alias, H., Hassim, M., & Rozzainee, M. (2012). Generalization, formulation and heat contents of simulated MSW with high moisture content. *Journal of Engineering Science and Technology, 7*(6), 701-710.

Kalanatarifard, A., & Yang, G. S. (2012). Identification of the municipal solid waste characteristics and potential of plastic recovery at Bakri Landfill, Muar, Malaysia. *Journal of Sustainable Development*, *5*(7), 11.

Karnchanawong, S., & Limpiteeprakan, P. (2009). Evaluation of heavy metal leaching from spent household batteries disposed in municipal solid waste. *Waste Management, 29*(2), 550-558.

Kementerian Kesejahteraan Bandar, Perumahan Dan Kerajaan Tempatan. (2012). *Survey on solid waste composition, characteristics & existing practice of solid waste recycling in Malaysia.* Retrieved June 25, 2015 from http://www.kpkt.gov.my/.

Kementerian Kesejahteraan Bandar, Perumahan dan Kerajaan Tempatan. (2015). *Solid waste management lab 2015*. Retrieved July 14, 2016 from http://www.kpkt.gov.my/resources/

Kortegast, A. P., Eldridge, S. F., Richards, B. A., Yong, S., Chock, E. T., Bryce, A., ... Carville, M. (2007). *Leachate generation and treatment at the Bukit Tagar landfill, Malaysia.* Paper presented at the Eleventh International Waste Management and Landfill Symposium, Cagliari, Italy.

Kszos, L. A., Morris, G. W., & Konetsky, B. K. (2004). Source of toxicity in storm water: Zinc from commonly used paint. *Environmental Toxicology and Chemistry, 23*(1), 12-16.

Kulikowska, D., & Klimiuk, E. (2008). The effect of landfill age on municipal leachate composition. *Bioresource Technology*, *99*(13), 5981-5985.

Kuusik, A., Pachel, K., Kuusik, A., & Loigu, E. (2016). Assessment of landfill wastewater pollutants and efficiency of different treatment methods. *Proceedings of the Estonian Academy of Sciences, 65*(4), 452.

Labiadh, L., Fernandes, A., Ciríaco, L., Pacheco, M. J., Gadri, A., Ammar, S., & Lopes, A. (2016). Electrochemical treatment of concentrate from reverse osmosis of sanitary landfill leachate. *Journal of Environmental Management, 181*, 515-521.

Latifah, A. M., Samah, M. A. A., & Zukki, N. I. M. (2009). Municipal solid waste management in Malaysia: Practices and challenges. *Waste Management, 29*(11), 2902-2906.

Lau, W. K. Y., Chung, S. S., & Zhang, C. (2013). A material flow analysis on current electrical and electronic waste disposal from Hong Kong households. *Waste Management, 33*(3), 714-721.

Lee, A. H., & Nikraz, H. (2014). BOD: COD ratio as an indicator for pollutants leaching from landfill. *Journal of Clean Energy Technologies, 2*(3), 263-266.

Lee, S. W., Lowry, G. V., & Hsu-Kim, H. (2016). Biogeochemical transformations of mercury in solid waste landfills and pathways for release. *Environmental Science: Processes & Impacts, 18*(2), 176-189.

Lenntech. (2017). *Mercury - Hg*. Retrieved July 1, 2017 from http://www.lenntech.com/periodic/elements/hg.htm

Leontief, W. W. (1936). Quantitative input and output relations in the economic systems of the United States. *The Review of Economics and Statistics, 18*(3), 105-125.

Letsrecycle.com. (2013). *Norfolk councils set to agree 10-year MRF deal*. Retrieved August 14, 2015 from http://www.letsrecycle.com/news/latest-news/norfolk-councils-set-to-agree-10-year-mrf-deal/

Li, J. H., Li, L., Chen, R., & Li, D. Q. (2016). Cracking and vertical preferential flow through landfill clay liners. *Engineering Geology, 206*, 33-41.

Li, Z. G., Feng, X., Li, P., Liang, L., Tang, S. L., Wang, S. F., ... Shang, L. H. (2010). Emissions of air-borne mercury from five municipal solid waste landfills in Guiyang and Wuhan, China. *Atmospheric Chemistry and Physics, 10*(7), 3353-3364.

Li, Z. S., Fu, H. Z., & Qu, X. Y. (2011). Estimating municipal solid waste generation by different activities and various resident groups: A case study of Beijing. *Science of the Total Environment, 409*(20), 4406-4414.

Lindberg, S. E., Southworth, G. R., Bogle, M. A., Blasing, T. J., Owens, J., Roy, K., ... & Sfeir, H. (2005). Airborne emissions of mercury from municipal solid waste. I: New measurements from six operating landfills in Florida. *Journal of the Air & Waste Management Association, 55*(7), 859-869.

Lo, H. M., Lin, K. C., Liu, M. H., Pai, T. Z., Lin, C. Y., Liu, W. F., ... & Chen, P. H. (2009). Solubility of heavy metals added to MSW. *Journal of Hazardous Materials, 161*(1), 294-299.

Lombardi, L., & Carnevale, E. A. (2016). Analysis of an innovative process for landfill gas quality improvement. *Energy, 109*, 1107-1117.

Long, Y. Y., Shen, D. S., Wang, H. T., Lu, W. J., & Zhao, Y. (2011). Heavy metal source analysis in municipal solid waste (MSW): Case study on Cu and Zn. *Journal of Hazardous Materials, 186*(2), 1082-1087.

Ma, H. W., Matsubae, K., Nakajima, K., Tsai, M. S., Shao, K. H., Chen, P. C., ... & Nagasaka, T. (2011). Substance flow analysis of zinc cycle and current status of electric arc furnace dust management for zinc recovery in Taiwan. *Resources, Conservation and Recycling, 56*(1), 134-140.

Malaysia Productivity Corporation. (2014). *Report on best practices visit to Kualiti Alam Sdn. Bhd.on Solid Waste Managemen*t. Retrieved July 6, 2015 from http://www.mpc.gov.my

Mallinson, L. J., Russell, J. M., & Barker, M. E. (2016). Attitudes and behaviour towards convenience food and food waste in the United Kingdom. *Appetite, 103*, 17-28.

Mangimbulude, J. C., van Straalen, N. M., & Röling, W. F. (2012). Microbial nitrogen transformation potential in surface run-off leachate from a tropical landfill. *Waste Management, 32*(1), 77-87.

Mateu-Sbert, J., Ricci-Cabello, I., Villalonga-Olives, E., & Cabeza-Irigoyen, E. (2013). The impact of tourism on municipal solid waste generation: The case of Menorca Island (Spain). *Waste Management, 33*(12), 2589-2593.

Matsubae-Yokoyama, K., Kubo, H., Nakajima, K., & Nagasaka, T. (2009). A material flow analysis of phosphorus in Japan. *Journal of Industrial Ecology, 13*(5), 687-705

Mavakala, B. K., Le Faucheur, S., Mulaji, C. K., Laffite, A., Devarajan, N., Biey, E. M., ... Poté, J. (2016). Leachates draining from controlled municipal solid waste landfill: Detailed geochemical characterization and toxicity tests. *Waste Management, 55*, 238-248.

McDougall, F. R., White, P. R., Franke, M., & Hindle, P. (2008). *Integrated solid waste management: A life cycle inventory* (2nd ed.).New Jersey, United States : Blackwell Science.

McRae, N. K., Gaw, S., & Glover, C. N. (2016). Mechanisms of zinc toxicity in the galaxiid fish, *Galaxias Maculatus*. *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology, 179*, 184-190.

Moh, Y. C., & Latifah, A. M. (2014). Overview of household solid waste recycling policy status and challenges in Malaysia. *Resources, Conservation and Recycling, 82*, 50-61.

Muda, M. A. (2015). *Carbon and nitrogen flow in Jeram Sanitary Landfill Selangor Malaysia*. (Master's thesis) University of Malaya. Retrieved December 2, 2016 from http://www.diglib.um.edu.my/umtheses

National Institute of Health. (2016*). Zinc Fact Sheet for Health Professionals*.Retrieved July 15, 2016 from https://ods.od.nih.gov/factsheets/Zinc-HealthProfessional/

National Solid Waste Management Department. (2012). *Survey on solid waste composition, characteristics & existing practice of solid waste recycling in Malaysia*. Retrieved July 17, 2016 from http://jpspn.kpkt.gov.my

New Jersey Department of Health. (February, 2016). *Hazardous Substance Fact Sheet*. Retrieved November 11, 2016 from http://www.nj.gov/health/

Nguyen, X. H., & Le, H. V. (2011). Solid waste management in Mekong Delta. *Journal of Vietnamese Environment, 1*(1), 27-33.

Nnorom, I. C., Osibanjo, O., Okechukwu, K., & Nkwachukwu, O. (2010). Evaluation of heavy metal release from the disposal of waste computer monitors at an open dump. *International Journal of Environmental Science and Development, 1*(3), 227.

Noor, Z. Z., Yusuf, R. O., Abba, A. H., Hassan, M. A. A., & Din, M. F. M. (2013). An overview for energy recovery from municipal solid wastes in Malaysia scenario. *Renewable and Sustainable Energy Reviews*, *20*, 378-384.

Nordberg, G. F. (2009). Historical perspectives on cadmium toxicology. *Toxicology and Applied Pharmacology, 238*(3), 192-200.

Nur Shaylinda, M. Z., Abdul Aziz, H., Adlan, M. N., Ariffin, A., Yusoff, M. S., & Dahlan, I. (2013). A comparative study of Matang and Kuala Sembeling Landfills leachate characteristics. *Applied Mechanics and Materials 361*,776-781.

Ogata, Y., Ishigaki, T., Nakagawa, M., & Yamada, M. (2016). Effect of increasing salinity on biogas production in waste landfills with leachate recirculation: A lab-scale model study. *Biotechnology Reports, 10*, 111-116.

Ohio Environmental Protection Agency. (2002). *Zinc and zinc compounds*. Retrieved December 8, 2014 from http://www.epa.state.oh.us/

Ohwoghere–Asuma, O., & Aweto, K. E. (2013). Leachate characterization and assessment of groundwater and surface water qualities near municipal solid waste dump site in Effurun, Delta State, Nigeria. *Journal of Environment and Earth Science, 3*(9), 126-134.

Omar, W. A., Mikhail, W. Z., Abdo, H. M., Abou El Defan, T. A., & Poraas, M. M. (2015). Ecological risk assessment of metal pollution along greater Cairo sector of the river Nile, Egypt, using nile tilapia, *Oreochromis Niloticus*, as bioindicator. *Journal of Toxicology.* 1-11.

Ouremi, O. I., & Ayodele, O. E. (2014). Lipsticks and nail polishes: Potential sources of heavy metal in human body. *International Journal*, *3*(4), 45-51.

Page, K., Harbottle, M. J., Cleall, P. J., & Hutchings, T. R. (2014). Heavy metal leaching and environmental risk from the use of compost-like output as an energy crop growth substrate. *Science of the Total Environment*, *487*, 260-271.

Pan American Health Organization. (2012). *Epidemiological alerts and updates 2012*. Retrieved December 18, 2015 from http://www.paho.org/hq/index.php?option=com_docman&task=doc_download&gid=24886&Itemid=270.

Pan, Y. P., & Wang, Y. S. (2015). Atmospheric wet and dry deposition of trace elements at 10 sites in Northern China. *Atmospheric Chemistry and Physics*, *15*(2), 951-972.

Pant, D., Joshi, D., Upreti, M. K., & Kotnala, R. K. (2012). Chemical and biological extraction of metals present in e-waste: A hybrid technology. *Waste Management, 32*(5), 979-990.

Park, J. A., Hong, S. J., Kim, I., Lee, J. Y., & Hur, T. (2011). Dynamic material flow analysis of steel resources in Korea. *Resources, Conservation and Recycling, 55*(4), 456-462.

Periodic Table. (2017). *Zinc*. Retrieved January 3, 2017 from http://www.rsc.org/periodic-table/element/30/zinc

Pi, K. W., Li, Z., Wan, D. J., & Gao, L. X. (2009). Pretreatment of municipal landfill leachate by a combined process. *Process Safety and Environmental Protection, 87*(3), 191-196.

Pirrone, N., Cinnirella, S., Feng, X., Finkelman, R. B., Friedli, H. R., Leaner, J., ... Telmer, K. (2010). Global mercury emissions to the atmosphere from anthropogenic and natural sources. *Atmospheric Chemistry and Physics, 10*(13), 5951-5964.

Pivnenko, K., Eriksson, E., & Astrup, T. F. (2015). Waste paper for recycling: Overview and identification of potentially critical substances. *Waste Management, 45*, 134-142.

Plum, L. M., Rink, L., & Haase, H. (2010). The essential toxin: Impact of zinc on human health. *International Journal of Environmental Research and Public Health*, *7*(4), 1342-1365.

Poh, L. K. (2015*). In search of environmental justice in Malaysia: the cases of Broga and Bukit Merah* (Doctoral thesis) University of Brighton, Hastings, England. Retrieved July 6, 2016 from http://eprints.brighton.ac.uk/

Qi, L. S., Larson, M. H., Gilbert, L. A., Doudna, J. A., Weissman, J. S., Arkin, A. P., & Lim, W. A. (2013). Repurposing CRISPR as an RNA-guided platform for sequence-specific control of gene expression. *Cell, 152*(5), 1173-1183.

Qteishat, O. Comparison of Municipal solid waste in the Hashemite Jordanian Kingdom and Poland - A Case Study. *World Applied Sciences Journal, 33* (2), 303-311.

Raghab, S. M., El Meguid, A. M. A., & Hegazi, H. A. (2013). Treatment of leachate from municipal solid waste landfill. *HBRC Journal, 9*(2), 187-192.

Ranjan, D., Talat, M., & Hasan, S. H. (2009). Biosorption of arsenic from aqueous solution using agricultural residue 'rice polish'. *Journal of Hazardous Materials, 166*(2), 1050-1059.

Rehman, A., Farooq, M., Ahmad, R., & Basra, S. M. A. (2015). Seed priming with zinc improves the germination and early seedling growth of wheat. *Seed Science and Technology, 43*(2), 262-268.

Renou, S., Givaudan, J. G., Poulain, S., Dirassouyan, F., & Moulin, P. (2008). Landfill leachate treatment: Review and opportunity. *Journal of Hazardous Materials, 150*(3), 468-493.

Roohani, N., Hurrell, R., Kelishadi, R., & Schulin, R. (2013). Zinc and its importance for human health: An integrative review. *Journal of Research in Medical Sciences*, *18*(2), 144.

Rosazlin, A., Fauziah, C. I., Wan Rasidah, K., Rosenani, A. B., & Kala, D. R. (2011). Assessment on the quality of recycled paper mill sludge mixed with oil palm empty fruit bunch compost. *Malaysian Journal of Soil Science, 15*, 49-62.

Rowe, R. K. (2012). Short-and long-term leakage through composite liners. *Canadian Geotechnical Journal*, *49*(2), 141-169.

Sackey, L. N. A., & Meizah, K. (2015). Assesement of the quality of leachate at Sarbah landfill site at Weija in Accra. *Journal of Environmental Chemistry and Ecotoxicology, 7*(6), 56-61.

Saeed, M. O., Hassan, M. N., & Mujeebu, M. A. (2009). Assessment of municipal solid waste generation and recyclable materials potential in Kuala Lumpur, Malaysia. *Waste Management, 29*(7), 2209-2213.

Sakawi, Z. (2011). Municipal solid waste management in Malaysia: Solution for sustainable waste management. *Journal of Applied Sciences in Environmental Sanitation, 6*(1), 29-38.

Salleh, N. F. D. M., & Hamid, K. H. K. (2013). Leachate characterization from a closed landfill in Air Hitam, Puchong, Malaysia. *Malaysian Journal of Analytical Sciences, 17*(1), 24-29.

Sankoh, A. I. (2016). *An assessment of pesticide use, contamination and impact on the environment and the health of people in Sierra Leone* (Doctoral thesis) Lancaster University, Lancashire, England. Retrieved April 22, 2015 from http://eprints.lancs.ac.uk

Selangor Town and Country Planning Development. (2015). *Draf rancangan struktur negeri Selangor 2035.* Retrieved July 7, 2016 from http://jpbdselangor.gov.my.

Schnelle, K. B., & Dey, P. R. (2000). *Atmospheric dispersion modeling compliance guide*. New York, United States: McGraw-Hill Professional Publishing.

Sharifah, N. S. I., & Latifah, A. M. (2013). The challenge of future landfill: A case study of Malaysia. *Journal of Toxicology and Environmental Health Sciences, 5*(6), 86-96.

Shehzad, A., Bashir, M. J., Sethupathi, S., & Lim, J. W. (2015). An overview of heavily polluted landfill leachate treatment using food waste as an alternative and renewable source of activated carbon. *Process Safety and Environmental Protection, 98*, 309-318.

Sherbinin, A. D., Carr, D., Cassels, S., & Jiang, L. (2007). Population and environment. *Annual Review of Environment and Resources, 32*, 345-373.

Shukor, Q. A., Aziz, H. A., Yusoff, M. S., Bashir, M. J., & Umar, M. (2010). Leachate characterization in semi-aerobic and anaerobic sanitary landfills: A comparative study. *Journal of Environmental Management, 91*(12), 2608-2614.

Singh, R., Gautam, N., Mishra, A., & Gupta, R. (2011). Heavy metals and living systems: An overview. *Indian Journal of Pharmacology*, *43*(3), 246.

Siudek, P., Falkowska, L., Brodecka, A., Kowalski, A., Frankowski, M., & Siepak, J. (2015). Mercury in precipitation over the coastal zone of the southern Baltic Sea, Poland. *Environmental Science and Pollution Research, 22*(4), 2546-2557.

Smith, S. R. (2009). A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge. *Environment International, 35*(1), 142-156.

Song, Q., Li, J., & Zeng, X. (2015). Minimizing the increasing solid waste through zero waste strategy. *Journal of Cleaner Production, 104*, 199-210.

Soobhany, N., Mohee, R., & Garg, V. K. (2015). Comparative assessment of heavy metals content during the composting and vermicomposting of municipal solid waste employing *Eudrilus eugeniae*. *Waste Management, 39*, 130-145.

Stan2web. (2014). *Material flow analysis*. Retrieved February 20, 2015 from http://www.stan2web.net/NetHelp/default.htm?turl=HTMLDocuments%2FBuildupMFAsystem.htm

Sustainable Energy Development Authority Malaysia. (2012). *Banking on the right power*. Retrieved August 21, 2015 from http://seda.gov.my/

Suthar, S., & Singh, P. (2015). Household solid waste generation and composition in different family size and socio-economic groups: A case study. *Sustainable Cities and Society, 14*, 56-63.

Takizawa, Y. (1979). Minamata Disease in Japan. *Environmental Toxicology and Human Health*, *1*, 1-25.

Talalaj, I. A. (2013). Groundwater and surface water quality assessment near the closed municipal landfill. *Journal of Ecological Engineering, 14*(3), 89-98.

Talalaj, I. A. (2015). Mineral and organic compounds in leachate from landfill with concentrate recirculation. *Environmental Science and Pollution Research, 22*(4), 2622-2633.

Talyan, V., Dahiya, R. P., & Sreekrishnan, T. R. (2008). State of municipal solid waste management in Delhi, the capital of India. *Waste Management, 28*(7), 1276-1287.

Tan, S. T., Hashim, H., Lim, J. S., Ho, W. S., Lee, C. T., & Yan, J. (2014). Energy and emissions benefits of renewable energy derived from municipal solid waste: Analysis of a low carbon scenario in Malaysia. *Applied Energy, 136*, 797-804.

Tanaka H. (2016, May 1). One Minamata disease patients still suffering. *The Asahi Shinbun*. Retrieved November 21, 2016 from http://www.asahi.com/ajw/

Tang, Q. H., Ding, Z. H., Huang, R. H., Wang, H. J., & Wang, W. H. (2003). Mercury pollution of water system in landfill site. *Urban Environment & Urban Ecology, 16*(6), 15-17.

Tang, W., Cheng, J., Zhao, W., & Wang, W. (2015). Mercury levels and estimated total daily intakes for children and adults from an electronic waste recycling area in Taizhou, China: Key role of rice and fish consumption. *Journal of Environmental Sciences*, *34*, 107-115.

Tang, Y., Ma, X., Yu, Q., Zhang, C., Lai, Z., & Zhang, X. (2015). Heavy metal enrichment characteristics in ash of municipal solid waste combustion in $CO^2/O^2$ atmosphere. *Waste Management, 43*, 247-254.

Tarmudi, Z., Abdullah, M. L., Tap, M., & Osman, A. (2009). An overview of municipal solid wastes generation in Malaysia. *Jurnal Teknologi, 51*(F), 1-15.

Tarmudi, Z., Abdullah, M. L., Tap, M., & Osman, A. (2012). A review of municipal solid waste management in Malaysia. *Jurnal Teknologi*, *57*, 41-56.

Tchobanoglous, G., Theisen, H., & Vigil, S. A. (1993). *Integrated solid waste management: Engineering principles and management issues*. New York, N.Y., U.S.A. : MacGraw-Hill Book Co.

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012). Heavy metal toxicity and the environment. In A.Luch (Ed), *Molecular, clinical and environmental toxicology* (pp. 133-164). Basel, Switzerland:Springer Basel.

Terazono, A., Oguchi, M., Iino, S., & Mogi, S. (2015). Battery collection in municipal waste management in Japan: Challenges for hazardous substance control and safety. *Waste Management, 39*, 246-257.

Tetra Park (2012). *Tetra Pak Malaysia hands over Malaysia's first small scale materials recovery facility (MRF) to Government of Malaysia*. Retrieved April 7, 2015 from http://www.tetrapak.com/my/about/newsarchive/mrf-innovation

Thanh, N. P., Matsui, Y., & Fujiwara, T. (2010). Household solid waste generation and characteristic in a Mekong Delta City, Vietnam. *Journal of Environmental Management*, *91*(11), 2307-2321.

The Star Online. (2015, June 19). Up to 270,000 tonnes of food go to waste during Ramadan. *The Star Online*. Retrieved August 17, 2016 from http://www.thestar.com.my/

Tidblad, J., Kucera, V., & Mikhailov, A. A. (2001). Mapping of acid deposition effects and calculation of corrosion costs on zinc in China. *Water, Air, and Soil Pollution*, *130*(1-4), 1469-1474.

Turner, D. A., Beaven, R. P., & Woodman, N. D. (2017). Evaluating landfill aftercare strategies: A life cycle assessment approach. *Waste Management*, *63*, 417-431.

Ullah, H., Noreen, S., Rehman, A., Waseem, A., Zubair, S., Adnan, M., & Ahmad, I. (2017). Comparative study of heavy metals content in cosmetic products of different countries marketed in Khyber Pakhtunkhwa, Pakistan. *Arabian Journal of Chemistry, 10*(1), 10-18.

Umar, M., Aziz, H. A., & Yusoff, M. S. (2010). Variability of parameters involved in leachate pollution index and determination of LPI from four landfills in Malaysia. *International Journal of Chemical Engineering*. 1-6. doi: org/10.1155/2010/747953

United States Environmental Protection Agency (1994). *Fluorescent lamp recycling*. Retrieved January 16, 2014 from https://www.epa.gov/homeland-security-research/epa-method-2008-determination-trace-elements-waters-and-wastes

United Nation. (2017). *Mercury reduction in products*. Retrieved January, 18 from http://www.unep.org/chemicalsandwaste/global-mercury-partnership/mercury-reduction-products

United Nations. (2015). *World population prospects the 2015 revision*. Retrieved December 14, 2016 from https://www.un.org/development/desa/en/.

United States Census Bureau. (2013). *International data base world population: 1950-2050*. Retrieved July 4, 2015 from https://www.census.gov/en.html.

United States Environmental Protection Agency (2005). *Toxicological review of zinc and compounds*. Retrieved August 8, 2014 from https://nepis.epa.gov/

United States Environmental Protection Agency (2009). *Fluorescent lamp recycling*. Retrieved September 16, 2015 from https://archive.epa.gov/

United States Environmental Protection Agency (2014). *Guidance note on daily and intermediate cover at landfills*. Retrieved October 18, 2015 from https://www.epa.ie

United States Environmental Protection Agency (2016). *Defining hazardous waste: listed, characteristic and mixed radiological wastes*. Retrieved July 24, 2016 from https://www.epa.gov/hw/defining-hazardous-waste-listed-characteristic-and-mixed-radiological-wastes

United States Environmental Protection Agency. (2012). *Municipal solid waste generation, recycling,and disposal in the United States: Facts and figures for 2012*. Retrieved April 10, 2015 from https://www.epa.gov/

United States Environmental Protection Agency. (2016). *Household hazardous waste*. Retrieved November 26, 2014 from https://www.epa.gov/hw/household-hazardous-waste-hhw

United States Environmental Protection Agency. (2016). *Municipal solid waste* Retrieved from November 25, 2014 from https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/

United States Geological Survey. (2011). *Zinc—The key to preventing corrosion*. Retrieved November 25, 2014 from https://pubs.usgs.gov/

US Army Corps of Engineers (2014). *Landfill gas collection and treatment systems*. Retrieved January 13, 2015 from http://www.publications.usace.army.mil/

Veiga, M. M., Nunes, D., Klein, B., Shandro, J. A., Velasquez, P. C., & Sousa, R. N. (2009). Mill leaching: A viable substitute for mercury amalgamation in the artisanal gold mining sector? *Journal of Cleaner Production, 17*(15), 1373-1381.

Vermont Department of Environmental Conservation. (2004). *Proper management of household batteries*. Retrieved November 11, 2015 from https://anrweb.vt.gov/dec/mercury/PDF/fs_batteries_ea.pdf

Vishan, I., & Kalamdhad, A. S. (2016). Heavy metal removal through bacterial biomass isolated from various contaminated sites. *International Journal of Environmental Sciences*, *7*(1) 1-18.

Vyzinkarova, D., & Brunner, P. H. (2013). Substance flow analysis of wastes containing polybrominated diphenyl ethers. *Journal of Industrial Ecology, 17*(6), 900-911.

Wang, Y., Qiao, M., Liu, Y., & Zhu, Y. (2012). Health risk assessment of heavy metals in soils and vegetables from wastewater irrigated area, Beijing-Tianjin city cluster, China. *Journal of Environmental Sciences*, *24*(4), 690-698.

Watson, R. R. (Ed.). (2015). *Handbook of fertility: Nutrition, diet, lifestyle and reproductive health*. Massachusetts, United States: Academic Press.

Wong, S. L., Ngadi, N., Abdullah, T. A. T., & Inuwa, I. M. (2015). Current state and future prospects of plastic waste as source of fuel: A review. *Renewable and Sustainable Energy Reviews, 50*, 1167-1180.

World Bank. (2012). *What a waste 2012*. Retrieved August 2015 from http://www.worldbank.org/

World Health Organization. (2017). *Learn the basics of hazardous waste.* Retrieved January 10, 2017 from https://www.epa.gov/hw/learn-basics-hazardous-waste

Xiaoli, C., Shimaoka, T., Xianyan, C., Qiang, G., & Youcai, Z. (2007). Characteristics and mobility of heavy metals in an MSW landfill: Implications in risk assessment and reclamation. *Journal of Hazardous Materials, 144*(1), 485-491.

Xie, S., Ma, Y., Strong, P. J., & Clarke, W. P. (2015). Fluctuation of dissolved heavy metal concentrations in the leachate from anaerobic digestion of municipal solid waste in commercial scale landfill bioreactors: The effect of pH and associated mechanisms. *Journal of Hazardous Materials, 299*, 577-583.

Yanai, J., Zhao, F. J., McGrath, S. P., & Kosaki, T. (2006). Effect of soil characteristics on Cd uptake by the hyperaccumulator Thlaspi caerulescens. *Environmental Pollution, 139*(1), 167-175.

Ye, Z. L., Xie, X., Dai, L., Wang, Z., Wu, W., Zhao, F., ... Chen, S. (2014). Full-scale blending treatment of fresh MSWI leachate with municipal wastewater in a wastewater treatment plant. *Waste Management, 34*(11), 2305-2311.

Yiing, M. C., & Latifah, M. A. (2014). Overview of household solid waste recycling policy status and challenges in Malaysia. *Resources, Conservation and Recycling, 82*, 50-61.

Yoshida, F., Hata, A., & Tonegawa, H. (1999). Itai-Itai disease and the countermeasures against cadmium pollution by the Kamioka mine. *Environmental Economics and Policy Studies*, *2*(3), 215-229.

Zainol, N. A., Aziz, H. A., & Yusoff, M. S. (2012). Characterization of leachate from Kuala Sepetang and Kulim Landfills: A comparative study. *Energy and Environment Research*, *2*(2), 45.

Zamali, T., Abdullah, M. L., & Tap, A. O. M. (2012). A review of municipal solid waste management in Malaysia. *Jurnal Teknologi*, *57*(1).

Zarcinas, B. A., Pongsakul, P., McLaughlin, M. J., & Cozens, G. (2004). Heavy metals in soils and crops in Southeast Asia 2. Thailand. *Environmental Geochemistry and Health, 26*(4), 359-371.

Zhang, J., Chen, S., Kim, J., & Cheng, S. (2016). Mercury flow analysis and reduction pathways for fluorescent lamps in mainland China. *Journal of Cleaner Production*, *133*, 451-458.

Zhao, H., Xia, B., Fan, C., Zhao, P., & Shen, S. (2012). Human health risk from soil heavy metal contamination under different land uses near Dabaoshan Mine, Southern China. *Science of the Total Environment*, *417*, 45-54.

Zhu, W., Li, Z., Chai, X., Hao, Y., Lin, C. J., Sommar, J., & Feng, X. (2013). Emission characteristics and air–surface exchange of gaseous mercury at the largest active landfill in Asia. *Atmospheric Environment, 79*, 188-197.

Zhuang, P., Zou, B., Li, N. Y., & Li, Z. A. (2009). Heavy metal contamination in soils and food crops around Dabaoshan mine in Guangdong, China: Implication for human health. *Environmental Geochemistry and Health, 31*(6), 707-715.