APPLICATION OF MATERIAL FLOW ANALYSIS AND WATER QUALITY MODELLING TO FACILITATE THE EFFICIENCY OF LEACHATE MANAGEMENT SYSTEM

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APPLICATION OF MATERIAL FLOW ANALYSIS AND WATER QUALITY MODELLING TO FACILITATE THE EFFICIENCY OF LEACHATE MANAGEMENT SYSTEM

ABSTRACT

Leachate from landfills is known to be one of the major environmental impacts, particularly those constructed near rivers. Therefore, this study is conducted to assess the impact of discharged leachate, using SL Landfill and Sembilang River as the case study. Solid waste generated from 2015-2016 served as input data on volume and composition of the solid waste that was sent to SL Landfill. A material flow analysis (MFA) is employed to trace the fate of solid waste that has been disposed and leachate that is produced at SL Landfill using STAN software. Six parameters in Water Quality Index (WQI), *viz.* DO, pH, BOD, COD, NH_3N, TSS were used to define the quality of the river water. A total of 80 water samples were collected monthly for 1 year from 10 sampling stations. In order to predict and assess the pollutant transport in Sembilang River basin, QUAL2K was used as a simulation model. Water quality parameters (DO, BOD and NH_3-N) were chosen to model the impact from the SL landfill effluent towards Sembilang River. The findings showed that the highest composition of waste that was present at the landfill can be categorized as food waste with 32% of the total waste input. Results from the MFA model showed that the amount of leachate generated from SL landfill was 123,386 m^3/year. The finding had also successfully identified the input and output flow of SL Landfill, with an overall input values of 948,505 ton per year and the output at 393,292 ton per year. From 3 different possible scenarios that were chosen, results from the MFA showed that composting was the most effective method in terms of reducing leachate production in SL Landfill which expected to reduce leachate production by up to 92%. The Sembilang River water quality results show that it falls in Class III of the WQI, which ranges from 43.46 to 68.03 mg/L.

Different water quality model scenarios were simulated in order to assess the pollutant transport on the Sembilang River water quality and it was found that the effects of different scenarios for water quality parameters were particularly noticeable for DO and BOD. However, for the NH_3N parameters there were no significant change and had remained in Class IV and V. This was due to the high NH_3N concentration from a few points along the river. These findings showed that the MFA, water quality assessment and modeling were found to be the best methods to predict and analyzed the composition of waste to the leachate production and the effect to the river water pollution.

Key words: solid waste, leachate, water quality, material flow analysis, water quality index, QUAL2K

APLIKASI ANALISIS ALIRAN BAHAN DAN PEMODELAN KUALITI AIR BAGI KECEKAPAN SISTEM PENGURUSAN AIR LARUT RESAP

ABSTRAK

Air larut resap yang dihasilkan dari tapak pelupusan dikenali sebagai salah satu faktor utama kesan alam sekitar, terutamanya kepada sungai yang hampir dengan tapak pelupusan. Oleh itu, kajian ini dijalankan untuk menilai kesan air larut resap, menggunakan SL Landfill dan Sungai Sembilang sebagai kajian kes. Sisa pepejal yang dihasilkan dari 2015-2016 berfungsi sebagai input data bagi jumlah, ciri-ciri dan komposisi sisa pepejal yang dihantar ke SL. Analisis aliran material (MFA) digunakan untuk mengesan nasib sisa pepejal yang telah dilupuskan dan larut resapan yang terhasil di tapak pelupusan SL menggunakan perisian STAN. Enam parameter dalam Indeks Kualiti Air (WQI), iaitu DO, pH, BOD, COD, NH_3N, TSS digunakan untuk menentukan kualiti air sungai. Sebanyak 80 sampel air dikumpulkan dari 10 stesen persampelan secara bulanan untuk satu tahun. Untuk meramalkan dan menilai status kualiti air di Sungai Sembilang, QUAL2K digunakan sebagai model simulasi. Parameter kualiti air (DO, BOD dan NH_3-N) telah dipilih untuk memodelkan kesan daripada efluen SL ke atas Sungai Sembilang. Hasil menunjukkan komposisi tertinggi sisa yang terdapat di SL adalah sisa makanan dengan 32% daripada jumlah input sisa. Dari model MFA, menunjukkan bahawa jumlah air larut resap di SL adalah 123,386 m^3/tahun. Penemuan ini juga berjaya mengenal pasti aliran input dan output SL, dengan nilai keseluruhan inputnya ialah 948,505 tan/tahun dan pengeluaran 197,825 tan/tahun. Daridapa 3 senario yang telah dipilih, hasil daripada MFA menunjukkan pekomposan merupakan kaedah pengurusan yang paling berkesan dari segi jumlah pengurangan penghasilan air larut resap dalam SL yang mana ia dijangka dapat mengurangkan pengeluaran larut resapan sehingga 92%. Kualiti air Sungai Sembilang berada di bawah Kelas III WQI pada lingkungan antara 43.46 hingga 68.03 mg/L. Senario model kualiti

air yang berbeza telah disimulasikan untuk menilai impak punca pencemaran ke atas Sungai Sembilang dan didapati bahawa kesan senario yang berbeza bagi parameter kualiti air dapat dilihat terutama bagi DO dan BOD. Namun begitu bagi parameter NH_3N tiada perubahan yang ketara dan masih kekal di Kelas IV dan V. Ini disebabkan oleh kepekatan NH_3N yang tinggi di beberapa titik persampelan di sepanjang sungai. Penemuan ini menunjukkan bahawa MFA, penilaian kualiti air dan pemodelan didapati sebagai kaedah terbaik untuk meramalkan dan menganalisis jenis utama sisa kepada pengeluaran air larut resap dan kesan pencemaran air sungai.

Kata kunci: sisa pepejal, air larut resap, kualiti air, material flow analysis, indeks kualiti air, QUAL2K

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LIST OF SYMBOLS AND ABBREVIATIONS

0C	:	Degree Celsius
ab	:	Bottom algae biomass
ap	:	Phytoplankton
cs	:	Slowly reacting CBOD
cf	:	Fast reacting CBOD
cT	:	Total inorganic carbon
mg	:	milligram
mi	:	Inorganic suspended solids
mo	:	Detritus
no	:	Organic nitrogen
na	:	Ammonia nitrogen
nn	:	Nitrate nitrogen
o	:	Dissolved oxygen
po	:	Organic phosphorus
pi	:	Inorganic phosphorus
s	:	Conductivity
µg	:	Micro gram
Ag	:	Silver
Al	:	Aluminum
Alk	:	Alkalinity
AN	:	Ammonical Nitrogen
As	:	Arsenic
BOD	:	Bio-chemical Oxygen demand
Ca2+	:	Calcium ion

CBOD	:	Carbonaceous Bio-chemical Oxygen demand
Cd	:	Cadmium
COD	:	Chemical Oxygen demand
Co	:	Cobalt
Cr	:	Chromium
Cu	:	Copper
DO	:	Dissolve Oxygen
D/S	:	Downstream
E.coli	:	Escherichia coli
EC	:	Electric conductivity
EQA	:	Environmental quality act
Fe	:	Iron
GIS	:	Geographic Information System
HCA	:	Hierarchal cluster analysis
HPI	:	Heavy metal pollution index
HW	:	Head water
ICP-OES	:	Inductively coupled plasma optical emission spectroscopy
INb	:	Bottom algae nitrogen
INp	:	Phytoplankton nitrogen
IPp	:	Phytoplankton phosphorus
IPb	:	Bottom algae phosphorus
IWK	:	Indah Water Konsortium
K+	:	Potassium ion
L	:	Liter
LOD	:	Limit of detection
LOQ	:	Limit of quantitation

Mg	:	Magnesium
Mn	:	Manganese
MPN	:	Most probable number
MWA	:	Malaysian Water Association's
Na+	:	Sodium ion
ND	:	Not detected
NH_3-N	:	Ammonical Nitrogen
Ni	:	Nickel
NO^{3-}	:	Nitrate ion
NPS	:	Non-point source
NTU	:	Nephelometric Turbidity Units
NWQS	:	National water quality standard
Pb	:	Lead
PE	:	Population Equivalent
PS	:	Point source
Q	:	Discharge/ Flow
R	:	Reach
SC	:	Scenario
SI	:	Sub index
St.	:	Station
TCU	:	True color unit
TDS	:	Total dissolved solid
U/P	:	Upstream
WQI	:	Water Quality Index
WQ	:	Water Quality
X	:	Pathogen

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CHAPTER 1: INTRODUCTION

1.1 Background of study

At present, the world's total urban population is approximately 4.028 billion and is increasing tremendously at a rate of 2.035% yearly. This whopping increase in population leads to rapid industrialization, urbanization and economic growth, which are the main factors of increased municipal solid waste (MSW) generation worldwide. The waste that is generated by urban residents is expected to get almost doubled from 3.5 million metric tons/day in 2002 to 6.1 million metric tons/day in 2025 (Khandelwal et al., 2019). Improper management of MSW through open burning, open dumping and unsanitary landfilling contributes to many environmental problems, such as global warming, ozone depletion, human health hazards, ecosystem damages, abiotic resource depletion, and etcetera. In developing countries, where the management of MSW is worsened by unsustainable practices that increase environmental contamination and the spread of diseases. Over 90% of all waste disposal sites in South and Southeast Asia is non- engineered (Tra¨nkler et al., 2005). In Cambodia, in the capital city of Phnom Penh, where the MSW management system lacks regulation, in 2008 households commonly burned, buried, or dumped about 361,000 tons of MSW and in 2015 it was 635,000 tons. In Thailand, more than 60% of the MSW final disposal was carried out by open dumping. In Maputo, the administrative center of Mozambique, with about 1,200,000 inhabitants about 0.5 kg of waste per inhabitants is generated daily, the MSW is transported to the official dumpsite of the city, which is in operation for more than 40 years. The area is of about 17 ha, with heights that achieved 15m; open fires and auto ignition of the waste are common issues, exacerbated by more than 500 waste pickers collecting recyclables waste at the dumpsite. Therefore, SWM issues are common worldwide, posing environmental burdens and hazard for the population (Ferronato & Torretta, 2019).

Great amounts of waste that have resulted from speedy urbanization, high commercial and industrial activities contribute towards the significant increase of municipal solid waste (MSW) in Malaysia (Tan et al., 2014; Zen et al., 2013). MSW can be defined as waste that is generated from residential, commercial, institution and public parks (Tan et al., 2014). In Malaysia, the amount of waste that was generated in 2012 was approximately 33,000 tonnes per day, and this number had increased by 18% in 2016 to 40,566 tonnes per day (Choong et al., 2019; Zulkifli et al., 2019). Hence, the amount of land that is available for solid waste disposed is becoming limited for an expanding population (Moh & Abd. Manaf, 2014).

In developing countries, rapidly growing cities and the cities management of solid waste are a serious challenge (Johari et al., 2012). Solid Waste Management was under the Local Government Act, 1976; Street, Drainage and Building Act 1974 and now it is under the National Solid Waste Management Department and Solid Waste and Public Cleansing Management Corporation Act 2007. For this reason, after the adoption of the Solid Waste and Public Cleansing Management Act 2007, the National Solid Waste Management Department (NSWD) has been established to integrate the solid waste management system in Malaysia nationally. In relation to that, some of the open dumping sites were closed due to the negative impacts on the surrounding area (Fauziah et al., 2013). According to the statistics that have been released by NSWD, as of June 2019 the total number of non-sanitary landfills currently operating is 120 with 18 sanitary landfills across Malaysia.

Waste that cannot be recycled, reduced, reused or recovered will be disposed of in the landfill which is the main waste disposal method in Malaysia where 80% is sent to the landfill. However, this amount is only 65% of the total solid waste that has been produced in Malaysia in 2020 (Ismail & Manaf, 2013; Sreenivasan et al., 2012).

Malaysia's municipal solid waste has an enormous percentage of food waste (45-60%), which generates a lot of organic waste (MAEKO, 2013). In Malaysia, factors effecting the volume and composition of solid waste include socio-economic development of the area, as well as the degree of industrilization. The higher the economic and urbanization growth, the greater the quantity of solid waste that is generated (Mohd Yatim & Arshad, 2010). In Malaysia, another factor that is affecting waste generation includes the season where Malaysia has two main seasons– the dry and rainy season. According to Mohd Yatim et al. (2019), the daily solid waste that was generated during the rainy season was higher than dry season. This is also supported by Wahab & Ola's (2018) study which states that the seasonal variation has been affected by the volume and type of waste generated. Besides, the rainy season coincides with the festive season, during which extra waste is generated as a result of the procurements that are related to the festive season. The ethnic diversity in Malaysia that is comprised of more than 32 ethnic groups may have also contributed to waste generation. The different races have different cultures, custom and different holidays. Due to these differences in customs, for certain period of the year the solid waste that is generated will sharply increase because the different ethnic groups celebrate their own festivities. This is supported by a study that has been done by Zahari et al. (2018) and Mohd Yatim & Arshad (2010) where the increase in the amount of certain types of waste has been observed during the fasting month for Muslims.

Most of the landfills in Malaysia are in a poor condition, and are operated without appropriate securing measures, for instance the lining systems, leachate treatment and gas ventilation (Ismail & Manaf, 2013). Open dumping can highly pollute surface water bodies and will penetrate the groundwater system through the soil layers, and the mixture of waste that is deposited in landfills which is the result of the penetration of different substances, including leachates, which contain a huge number of compounds that can be expected to pose health and nature threat (Fauziah et al., 2013; Melynk et al., 2014; Oman & Junestedt 2008). Landfill leachate is high in pH value, biochemical oxygen demand (BOD), chemical oxygen demand (COD), inorganic salts and also toxicity. The leachate characteristic relies on various aspects including waste composition, moisture and oxygen availability, landfill design and operation, hydrogeological factors at the site and the age of the landfill (Syafalni et al., 2012). The quality of a leachate demonstrates the type of landfill it originates from, therefore, the variety of contamination varies tremendously among the different types of leachates (Zawierucha et al., 2013). However, leachate is changing over time and the fluctuating production rate is due to the interaction of water input from the outside- primarily through rainwater infiltration, apart from the water which is already present as moisture in the deposited waste and a small fraction that could be produced from the multiple reactions inside the landfill (Banch et al., 2019; Zahari et al., 2016), all of which make leachate management one of the major challenges for landfill operators (Singh et al., 2017).

One of the significant environmental impacts that is associated with landfill leachate is the ground and surface water pollution. Surface water pollution can hapened especially for the river that is located near to the landfill and received effluent from the landfill. The risk of groundwater pollution is probably the most severe environmental impact from landfills because historically most landfills have been built without liners and leachate collection facilities. This will allows the leachate to penetrate the soil beneath the waste and later penetrates into the groundwater or runs off into the river (Ahmad et al., 2019; Karaca & Ozkaya, 2006; Mayakaduwa et al., 2012). Further information on level of sanitary landfill system in Malaysia have been discussed in Chapter 2. Studies show that if landfill leachate is not collected, treated and discharged safely, small quantities of leachate could pollute large quantities of water, making it unusable and toxic for domestic or commercial use. Thus, the accelerated generation of waste that is caused by a growing population, urbanization and industrialization, makes leachate a critical environmental problem and the proper treatment and risk assessment and management are considered essential (Butt et al., 2014; Trankler et al., 2005; White et al., 2013).

Waste management covers various technologies and regulations are implemented in accordance with current rules, social and environmental regulations, which are economically acceptable and safe to the community and the environment. Thus, material flow analysis (MFA) is the best tool to meet this requirement (Font Vivanco et al., 2012). MFA studies the flows of resources that are used and transformed through a single process or through a combination of various processes as they flow through a region. This method has proven to be an appropriate tool for the early identification of environmental issues and for environmental planning through the analysis of various pollutants (Aramaki & Thuy, 2010).

A few studies have been conducted on the material flow analysis of landfill leachate and have proposed mathematical programming models using the MFA technique to track pollutants through the watersheds and to prevent hazardous accumulation in the final disposal (Lopez-Villarreal et al., 2014). Moreover, Schaffner et al. (2005) and Do & Nishida (2014) have also mentioned that MFA can be used to address the entire river basin in terms of substance flow and the effect to the water quality of the river. In a study reported by Kwonpongsagoon et al. (2007) on the cadmium flow in Australia's economy using MFA as a framework, it has been shown that MFA can present a holistic portrayal of the use and loss of resources in a geographical area in a given year, allowing the examination of all material or substance flows, outflows and stocks in each sub-compartment. MFA is also used to identify and quantify parabens (available in personal care, pharmaceuticals, food, industrial and domestic products) sources, transport routes and to map and understand the flow of substances in the urban environment (Eriksson et al., 2008).

Considering that river water supplies approximately 98% of Malaysia's water demand, it can be very challenging to manage water resources due to the increased in water demand and environmental degradation (Leong et al., 2007; Shamsuddin et al., 2014). The Department of Environment (DOE) Malaysia is the body that is responsible for monitoring the river's water quality and has been recognized Water Quality Index (WQI) as an instrument for defining surface water quality condition in Malaysia (Fulazzaky et al., 2010). Selangor which is one of the seven states in Malaysia is the fastest growing and densely populated state with 6.53 million people with an average annual population growth rate of 2.1% for the period 2015 to 2019, which creates the demands for clean water resource. However, most of the landfill in Selangor is located along the Selangor River basin which can contribute the most to potential future problems for water supply in Selangor.

To identify the surface water quality of Selangor River that might be polluted by the landfill leachate, many researchers have used water quality assessment to determine the degree of river pollution characteristics and the changes of surface water quality, in accordance with the standards that are set by the National Water Quality Standard. Next, on finding transportation of pollution along the river, the best method is water modelling to quickly assess the transportation of the pollution in the river. One of the models that can be used is QUAL2K. QUAL2K indicates the values of variable water quality due to the flow, quantity and quality of waste loads and discharges or to increase the capacity of the receiving systems to assimilate waste. QUAL2 K is an updated version of the QUAL2E model with a one-dimensional water quality model for rivers and streams. The QUAL2K framework, which has been developed by the United States Environmental Protection Agency, can mimic the migration and transformation of conventional pollutants. The model contemplates the river to be a one-dimensional channel with a constant flow that is not consistent and contemplate the impact of pollution from point and non-point sources (Idris et al., 2016).

1.2 Problem Statement

Urbanization, industrialization, population and economic growth contributed to the increase in waste, thus, the waste that is generated today comes from various sources, which are environmentally damaging and costly to manage sustainably (dos Muchangos et al., 2015; Zaman, 2015). Unfortunately, economic growth, which has been given higher priority than the concept of sustainable waste management, has resulted in the environment being sacrificed for the sake of economic aspirations. The variety of different wastes compromises decision-makers (government department, pollution control agencies, regulatory bodies and public) with no other choice than to select incompetent and environmentally contaminating solution for waste management (Agamuthu & Fauziah, 2010; Khajuria et al., 2010; Zaman, 2015).

One of the popular methods of municipal solid waste is landfill, which has benefits such as simple disposal procedures, low costs and the effect of landscape restoration on holes in mineral works and technical restrictions on landfills, which are favored in some countries for waste disposal (Aziz et al., 2010; Yusof et al., 2009). Furthermore, problems that are related to the management of solid waste in Malaysia have become more concerning especially when there is no suitable space to build new landfill sites in order to accommodate the generation of solid waste that is ever increasing. The problems start with the diversity of solid waste composition that is disposed at the landfill site which produces leachate without the knowledge as to which solid waste has the most potential to produce the highest quantity of leachate. This problem persists when the effluent from the landfill is channeled to the nearby river and will further pollute the water body. With a certain amount of solid waste which will generate a certain amount of effluent that will travel along the river and eventually contaminate the river. So, it is of great importance to determine the most appropriate treatment option as well as the optimal operating conditions in order to achieve minimal waste that is disposed and the effluent discharged to the environment.

Therefore, the main objective of this study is to determine the leachate movement along the stream that is receiving the effluent, by identifying the sources of pollution from the initial stage of characteristic of the solid waste. By starting with the characteristics of the solid waste, certain types of solid waste that should not be disposed of on the landfill site can be identified, as well as certain types of solid waste that could cause high leachate production and ultimately how far this leachate will move to pollute the nearby rivers.

1.3 Research Objectives

The general objective of this study is to examine the performance of the sanitary landfill in Selangor with a view of solid waste and leachate flow. A further aim is to study the leachate flow and application of water modelling system of the effect of the leachate to the river. The following objectives have been set in order to achieve the objectives and to answer the research question and are achieved in the thesis as follows:

i. to determine waste composition that contribute to the leachate generation in SL Landfill
ii. to determine all relevant input and output flows of waste and leachate flow using Material Flow model to provide suitable strategies in leachate management in SL Landfill
iii. to assess the river water quality and pollutant transport along Sembilang River
iv. to propose modelling improvement using scenario

1.4 Research flow

In the light of the research objectives, and the content of this thesis falls into five chapters that begin with (1) Introduction of thesis (this chapter), (2) literature review, (3) general methodology, (4) result and discussion, and (5) Conclusion. A list of cited references for more information about theory, methodology and data is provided at the end of this thesis.

This first chapter describes a short history of the situation of solid waste in Malaysia, especially in Selangor. Material flow analysis (MFA), water quality parameters and water modelling system are introduced as an evaluation tool to measure the solid waste and leachate flow in the studied area. Chapter 2 provides the background information about waste management in Malaysia. The focus then shifts to the waste management in Selangor, landfills, leachate generation that is related to the river water quality along the Selangor River Basin. Sembilang River and SL Landfill, are located within Kuala Selangor, Selangor is used as a case study for the evaluation of the solid waste and leachate flow in Chapter 3. This chapter describes the general methodology for MFA, water quality standard procedure, as well as water modelling to identify the future of leachate flow along the Sembilang River. The results are presented and analyzed in Chapter 4. Finally, Chapter 5 emphasizes the importance of the study provides recommendations for improving local solid waste management practices using the results.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Considering that the low process and maintenance costs compared to others, most countries prefer landfills for the disposal of municipal solid waste (Aziz et al. 2007). Likewise, in Malaysia almost 80% of the municipal solid wastes are disposed at landfill or dumpsite and only 3% goes into the incinerators (Chua et al., 2011; Pariatamby & Bhatti, 2020). In comparison with incinerators, landfills need more in-depth monitoring during design, operation and long-term post-closure due to the leachate that is generated which, if left untreated, may potentially pollute the surface and ground water (Ahmed & Lan 2012). This is mainly because degradation products in the leachate (ammonium, dissolved organic carbon) which are developed over a long period of time have represented critical issues in Malaysia. With so many effects that can result from post-disposal, there are various ways of treatment in reducing the environmental effect of pollution from the landfill. (Lenz et al., 2016).

Not only in Malaysia, but most places around the world are also facing the problem of overflow solid waste generation. Malaysia alone has produced over 38, 142 tonnes of MSW daily in 2018. In capita terms, there was a relatively large increase in the daily waste that had been generated per capita in 2018 compared to previous years at 1.18 kg, and there is an urgent need for a more effective waste management system and more sustainable landfill practices to reduce the environmental impacts. Various campaigns and efforts such as recycling has been carried out to lessen the influx of solid waste into the landfill, but in solid waste management landfills will remain to be the most favorable ways of waste treatment. (Al-Jarrah & Abu-Qadis, 2006). Victor & Agamuthu (2013) reported that just as the total number of clean rivers in Malaysia had been reduced, at the same time the number of landfills and illegal dumpsites had also increased day by day. Selangor alone have 22 landfills (8 active and 14 non-actives) and most of them are non-sanitary landfills. Only 4 are sanitary landfills and all of them are situated along the Selangor River which is the main river that supply water throughout Selangor. This is very worrying because even with a small amount of leachate being discharged into the river, it will take several years to be cleaned again. The high concentration of organic substance and ammonium nitrogen in leachate which is the result from the decomposition of disposed solid waste can be influenced by the age of the landfill, waste composition, decay rate and physical conversion of the waste (Hossain et al., 2014; Islam et al., 2013). It is also different for each landfill and also within a particular landfill cell (Islam et al., 2013).

2.2 MSW Management in Malaysia

The Ministry of Housing and Local Government is in charge of handling solid waste in Malaysia under the Solid Waste and Public Cleansing Management Act 2007 (Act 672). After privatization in 1993, the collection and transport of waste from residential and commercial sites to the final disposal centers is carried out by four concessionaires. But after a few years of concession, only two concessionaires remain- Alam Flora Sdn. Bhd. and Southern Waste Management Sdn. Bhd. (Abd Kadir et al., 2013). Since the 1st of September 2011, the government had appointed three concessionaires for the management of solid waste, they are Alam Flora Sdn. Bhd. (Central and Eastern Zone- Kuala Lumpur, Putrajaya, Pahang), E-Idaman Sdn. Bhd. (North Zone- Perlis, Kedah) and SWM environment Sdn. Bhd. (South Zone- Johor, Melaka, Negeri Sembilan).

Various measures have been undertaken by the government to lessen the quantity of solid waste to the landfill. This includes the separation of waste initiative which is formulated from the Solid Waste and Cleansing Management Act 2007 (Act 672). The states that are initially involved in this program include the Federal Territory of Putrajaya, Kuala Lumpur, Pahang, Johor, Melaka, Negeri Sembilan, Kedah, and Perlis.

Table 2.1: Waste treatment method in Malaysia (Sin et al., 2013)

Treatment method	**Percentage of Waste Disposed**		
	2002	**2006**	**Target 2020**
Recycling	5.0	5.5	22.0
Composting	0.0	1.0	8.0
Incineration	0.0	0.0	16.8
Inert landfill	0.0	3.2	9.1
Sanitary landfill	5.0	30.9	44.1
Other disposal sites	90	59.4	0.0
Total	100	100.0	100.0

Table 2.1 shows the waste treatment method in Malaysia. These targets were set out by Malaysia's National Strategic Plan for Solid Waste Management. Sin et al., (2013) reported that the targeted recycling and incineration of waste in 2020 are 22% and 16.8%, respectively. He also reported that waste to be sent to the sanitary landfill reduced to 44.1%. This is in line with the waste hierarchy which is aims to have effective intermediate treatment of the waste in order to reduce the waste amount and at the same time recover the value of the waste through composting or waste to energy. Besides, this is also effective in reducing the amount of waste to be disposed of by the sanitary landfill. However, according to the most recent statistics available, in year 2021 almost 90% of waste was reportedly disposed to sanitary landfills, while only 10.5% was recycled and this is mostly for construction and demolition waste. For MSW specifically, the recycling rate remains largely unknown but could be very low, as domestic segregation of recyclables in Malaysia is not common practice. The government have also introduced the Reduce, Reuse and Recycle (3R) practice which is also to reduce the production and transmission of solid waste to the landfill (Badgie et al., 2012). This not only reduces waste generation but can also contribute to a significant reduction on the cost management of solid waste, where in 2016 the

government has spent a total of RM1.86 billion on SWM with RM74 million for the operation and maintenance of the disposal facilities (Zainal, 2018).

In January 2011, The Ministry of Domestic Trade, Cooperative and Consumerism (MDTCC) has also started the 'No Plastic Bag Campaign' nationwide at the customer-end level. The objective is to save the environment and at the same time to reduce the consumption of plastic bags which take forever to decompose (Malaysia Digest, 2015; Zen et al., 2013). In 2018, the Ministry of Energy, Science, Technology, Environment and Climate Change (MESTECC) has launched Malaysia's 'Roadmap towards Zero Single-use Plastics, 2018-2030', with an expectation that all relevant stakeholders will pay their roles effectively to eliminate single-use plastics waste from the natural environment. Albeit the many responses from the people, there are still a lot to be improved not only from the government's side but also from all, in order to become a better Malaysia.

Malaysia enacted two important laws to tackle sustainable solutions to waste management problems in this changing situation, namely, the Solid Waste and Public Cleansing Management Act 2007 (Act 672) and the Solid Waste and Public Cleansing Management Corporation Act 2007 (Act 673). The Solid Waste and Public Cleansing Management Act 2007 ensures the management of solid waste and public cleaning in order to maintain adequate sanitation and related issues, while the Solid Waste and Public Cleansing Management Corporation Act 2007 provides for the establishment of the Solid Waste and Public Cleansing Management Corporation.

In the 9th Malaysia Plans for 2006-2010, recycling and disposal was privatized and the Solid Waste Management Bill for improved service was introduced to reduce financial burdens and to include the private sector participation. In the 10th Malaysia Plans (2011- 2015), the federal government takes full responsibility for the management of solid waste from the local authorities, whereby the collection of solid waste from households has been privatized to three concessionaires and the licensing of other private operators for the management of solid waste and public cleaning services.

2.2.1 Perspective of solid waste generation in Malaysia

Wastes are uncontrollably produced day by day as buying power and spending gain popularity among humans (Mat Salleh & Ku Hamid 2013). The increasing population growth, the economic environment, rapid residential development and the living standards in the community have led to greater waste generation, particularly in developing countries (Agamuthu & Fauziah, 2011; Guerrero et al., 2013). The Ministry of Urban Wellbeing, Housing and Local Government stated that the production of waste in Malaysia was around 38,563 tonnes per day in 2015. In 2020, this amount of waste has already exceeded the expected 49,670 tons of waste (Figure 2.1).

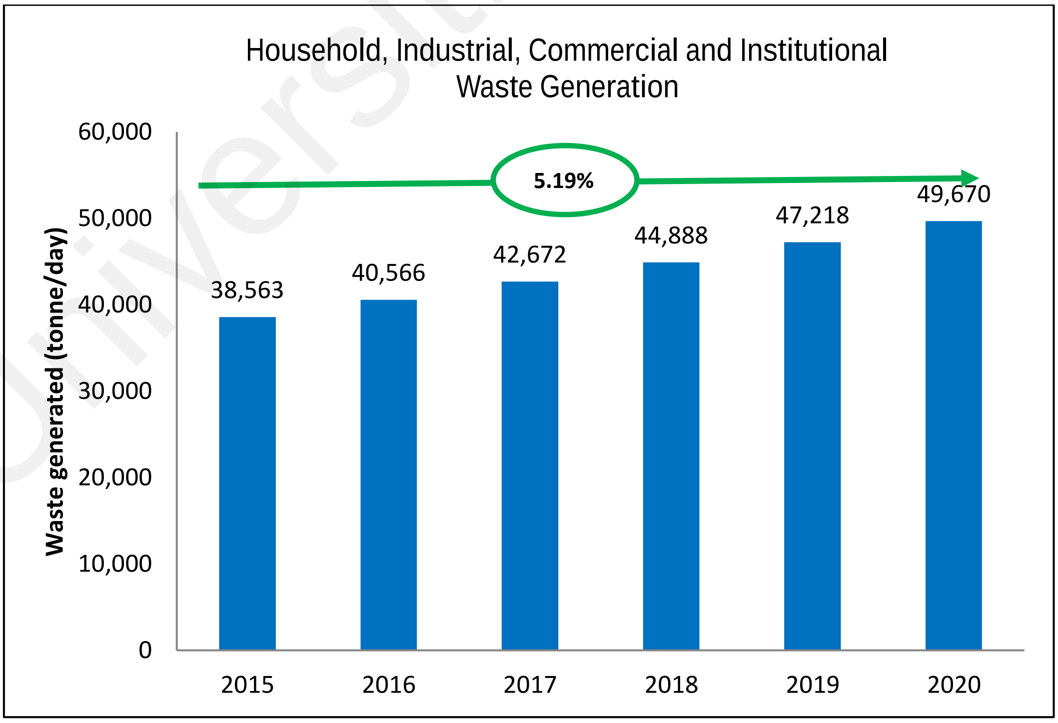


Figure 2.1: Solid waste generation growth

The generation of waste in Malaysia is growing over time, thus a more effective management system and alternatives for the disposal of solid waste are needed in the coming years (Tarmudi et al., 2009). Urbanization and economic growth are expanding, contributing many more amounts of waste, and the local authorities are always trying to find new strategies and management, including demand management, new landfill sites and supply management (Lau et al., 2004; Saeed et al., 2008).

Malaysia's sources of solid waste are usually from residential, commercial, institutional, construction and demolition, and municipal facilities. Malaysia's solid waste is also different from other countries where it contains a high moisture content-ranging from 52.6% to 66.2 %, which is due to its tropical climate with heavy rainfall (Abushammala et al., 2012; Chua et al., 2005). Zarak and Adam (2009) have also reported that, there are a few factors that can be contributing to the waste generation. Population growth, the lifestyle of certain area, the number of people who resides in a household as well as the climate and season can affect the amount of solid waste generation.

Moh and Abd Manaf (2014) have reported that the total composition of waste in Malaysia is monopolized by municipal solid waste (MSW) (64%), followed by industrial waste (25%), commercial waste (8%) and construction waste (3%). MSW mainly comprises approximately 20 various types of waste which are food waste, paper (mixed), cardboard, plastics (rigid, film and foam), textile, wood waste, metals (ferrous or non-ferrous), diapers, newsprint, high grade and fine paper, fruit waste, green waste, batteries, construction waste and glass; these groups can be classified into organic and inorganic wastes. Normally, household waste is the main source of MSW in Malaysia and 41.06% of it consists of food waste which almost all food waste is sent to landfills for disposal.(Table 2.2) (Malakahmad et al., 2017; Nadzri, 2013).

Table 2.2: Typical Composition of MSW in Malaysia (Malakahmad et al., 2017)

Component	Food	Yard	Paper	Plastic	Glass	Metal	Textile	Total
Wet weight	41.06	2.45	20.93	22.23	3.63	1.96	7.74	100
Moisture	37%	1%	15%	1%	0%	0%	0%	53%
Water (weight)	15.29	0.02	3.07	0.15	0.00	0.00	0.01	18
Dry weight	25.77	2.43	17.86	22.08	3.63	1.96	7.73	81

The waste composition can be different due to social standard where more organic waste and fewer recyclable materials are in rural areas, unlike high income areas (Abushammala et al., 2013) where they produce more inorganic wastes such as plastics and paper (Gallardo et al., 2014). In 1995, the lowest rate of waste generation is reported to be from countries with low incomes, i.e., on average 0.64 kg/capita/day, while this rate is an average of 0.73 kg/capita/day for middle income countries (Lau, 2004). This rate increased by 55% in 2009 by 1.62 kg/capita/day, with the national average at 0.8-0.9 kg/capita and with approximately 31 million people who generated nearly 13.9 million tonnes of municipal solid waste at 1.23 kg/capita/day in 2016. This is expected to be increasing linearly, reaching to 2.23 kg/capita by 2024 due to the rapid development of urban cities, rural-urban migration, the increase in per capita income, and the change in consumption patterns (Pariatamby & Bhatti, 2020; Saeed et al., 2009; Zainal, 2018). In order to choose the correct disposal option, waste is characterized by various physical characteristics such as food waste, paper, polystyrene, glass, tin and so much more (Zarak & Adam, 2009). Some study shows that there is a similar trend of waste composition around Asia (Indonesia, Dhaka, Kathmandu, Bangkok, Hanoi and Kuala Lumpur) (Table 2.3) where the major composition is organic waste with more than 50% of the average wet weight (Ramli et al., 2009). However, recyclable solid waste has different percentage rates among these 6 cities. A significant difference can be seen between Bangkok and other Asian cities. This is due to the high recycling rate in Bangkok which is at 25% compared to Kuala Lumpur (17%), Indonesia (7%), Dhaka

(15%), and Hanoi (10%). Kathmandu also has a high recycling rate of 50% of which almost 41% of scrap waste is collected through a door to door collection system. Solid waste management is a major challenge for Malaysia in proper waste management, together with serious concerns about the public, strong moral and ethical values which lay out the direction for Malaysia to become a fully developed nation in 2020 (Ahmad et al., 2013).

Table 2.3: Waste composition of main country in Asia in tonnes per year (Islam et al., 2017; Kawai & Huong, 2017; Maskey & Singh, 2017; Rajarjo et al., 2018; Shams et al., 2017; Yen et al., 2017)

Type of waste	Indonesia	Dhaka	Kathmandu	Bangkok	Hanoi	Kuala Lumpur
Food waste	31.21	68.69	66.4	52.37	49.1	41.06
Plastic	-	4.75	12.0	6.23	12.2	22.23
Paper	13.624	9.73	9.0	9.11	9.5	20.93
Leather	5.125	0.5	1.1	0.00	0.1	-
Metal	2.554	0.17	1.9	0.76	0.6	1.96
Glass	2.387	0.83	3.1	0.00	1.4	3.63
Textile	1.721	3.06	2.2	1.20	1.8	7.74
Wood	0.677	3.78	-	0.67	0.9	-
Yard	0.010	-	-	4.54	1.4	2.45
Others	2.218	8.3	4.5	24.69	1.5	-

2.3 Landfills in Malaysia

Malaysia and many parts of the world's landfill constitute the basis for municipal solid waste disposal (MSW) and are expected to remain so for several decades (Beaven et al., 2014; Li et al., 2009). Almost all of the landfills in Malaysia are poorly designed and managed, however, landfilling is expected to be the preferred mode of waste disposal because landfills have advantages such as disposal of large amounts of solid waste at comparatively lower costs. There are relatively 142 landfills in Malaysia and most of them were built with no leachate collection and treatment facilities as well as landfill gas collection system (Aziz et al., 2012; Kalantarifard et al., 2011). Nonetheless, promising alternatives such as incineration and composting are possible, but high treatment and disposal costs are a key reason why Malaysia is still depending on landfills as the main method of waste treatment, particularly in the developing countries (Laner et al., 2012; Li et al., 2009).

Malaysia has two systems for categorizing landfill sites, the first is based on landfill decomposition processes and is known as anaerobic landfill (1); (2) daily covered anaerobic sanitary landfill; (3) improved sanitary anaerobic landfill with leachate collection pipes and (4) forced aeration semi-aerobic landfill. The second classification system is used for the operational purposes for which the landfill is categorized into five types: (1) open dumping, (2) open tipping site, (3) landfill with disposal of bundles and waste covered by a layer of appropriate cover materials, (4) landfill designed with a leachate recirculation and aeration pipe system and (5) sanitary landfill. However, Malaysian landfills are categorized into the second classification: (i) dumping into water bodies; (ii) open dumps; (iii) controlled tipping and (iv) sanitary landfill (Abushammala et al., 2011; Fazeli et al., 2016; Ramli et al., 2009; Tarmudi et al., 2009).

Table 2.4: Classification of landfill sites in Malaysia (Mohd-Salleh, 2020)

	Levels	**Available facilities**
I	Controlled dumping	Minimal infrastructure (fencing and premeter drains)
II	Sanitary landfill with daily cover	Class I facilities (with gas removal system, separate unloading and working area, daily cover and enclosing bund (divider constructed as the embankment of different waste cells). Elimination of informal scavenging and supply of facilities to protect the environment
III	Sanitary landfill with leachate circulation	Class II facilities (with a leachate recirculation system for the collection, recirculation and monitoring of leachate from landfill)
IV	Sanitary landfill with leachate treatment	Class III facilities (with leachate treatment system)

The National Solid Waste Management Department has currently reported that over 315 landfills have been built all over Malaysia with a total of 142 active landfills and 173 closed landfills. Most of these landfill sites have no lining system, gas control, leachate control or treatment have been wide spread with different sizes and ages (Yusoff et al., 2013). However, only 18 sanitary landfills are still operating and play a substantial role as the ultimate depositary of solid waste in Malaysia (Fauziah & Agamuthu, 2012). These include Seelong and Tanjung Langsat Sanitary Landfill in Johor, Kuching Utara, Sibuti and Kemunyang Sanitary Landfill in Sarawak and Tanjung 12, Bukit Tagar and Jeram Sanitary Landfill in Selangor. There are 23 landfills located in Selangor that are ready to serve over 4,800 tonnes per day of solid waste depending on an estimated population of 5.9 million people where eight are still operating and 15 have been closed. Just a few are classified as Level 4 and most of them could be classified as Level 0 or 1 (Suratman et al., 2012) (Table 2.5).

Table 2.5: List of sanitary and non-sanitary landfills in Malaysia (JPSPN, 2019)

State	**Level of Operation**		**Non-operating**	**Total**
	Sanitary	**Non-Sanitary**		
Johor	1	8	28	37
Kedah	1	3	11	15
Kelantan	0	10	10	20
Melaka	1	0	7	8
Negeri Sembilan	1	2	16	19
Pahang	2	8	22	32
Perak	1	15	15	31
Perlis	1	0	2	3
Pulau Pinang	1	0	1	2
Sabah	1	21	4	26
Sarawak	3	43	20	66
Selangor	3	2	15	20
Terengganu	1	8	12	21
Federal Territory of K. Lumpur	0	0	10	7
Federal Territory of Labuan	1	0	0	1
Total	**18**	**120**	**173**	**293**

Other than the four different categories of landfills, there are also types of landfills that must be included as a necessity waste disposal element in landfilling. The types of engineered waste disposal facilities are divided into three. The first one is municipal solid waste landfills which mostly contain waste that is less toxic, where the wastes are from private homes, institutions, schools and businesses which are without hazardous wastes. The second types is the hazardous waste landfills which must be extremely well designed to minimize the potential of hazardous compounds escaping into the environment since this type of landfills are only facilitated for more toxic chemicals and dangerous by-products. The third type of engineered waste disposal facilities is the surface impoundments which deal with liquid waste disposal. This also applies to landfills for hazardous waste and surface deposits (Mohd Masirin et al., 2008).

Not like other countries in South East Asia, landfilling in Singapore is the lowest preference in solid waste management. This is due to its land limitation, where Singapore's landfill capacity is primarily reserved for waste that can no longer be treated (Bai & Sutanto 2002). While in Indonesia, even sanitary landfills are built in big cities such as Jakarta, they still practicing open dumping and burning in open spaces because operational measures are not implemented. This not only causes negative effects to the environment but is also socially unacceptable (Aye & Widjaya 2006). Likewise, in Thailand open dumping has been the option for many years, but currently it encourages and is gradually replacing the open dumpsites with sanitary landfills that will help in reducing the negative impacts from the landfill on the environment (Cheimchaisri et al., 2007). In Malaysia, landfilling has been the only method being used for the disposal of MSW, even landfill is becoming more difficult because the construction of new landfill sites is facing land shortages with the dramatic increase in land prices and high demands. In addition, the existing landfill sites fill up really fast (Latifah et al., 2009). Other than landfilling, there are also a few other methods that have been used in Malaysia including recycling, composting, incineration and inert landfill (Table 2.1).

But landfilling is the cheapest way, in terms of capital cost and exploitation (Yusoff et al., 2013).

Malaysia is currently experiencing population growth due to industrialization, urban migration, affluence, population growth, tourism, and a high influx of foreign workforce or students. This has led to massive development projects, including the construction of residential and commercial buildings, construction of spacious highways, tourist resorts, and so on. Development and urbanization come with the challenges of increasing MSW generation. The total Malaysia's population as in June, 2020 is 32.3 million, an increased of 1.2% from 31.9 million as compared to 2019. The total population comprises 32.3 million (99%) citizens and 50,0000 (0.15%) non-citizens. The annual population growth rate decreased to 1.3% in 2020 as compared to 1.34% in 2019. The decline was attributed to the decreased in the fertility rate 2.01% in 2020 compared to 2.09% in 2019.

Malaysia indicates that nearly 33 million Malaysians are foreseen to produce 1,676 million tons (or 45,900 tons per day) of waste in 2020. The apparent correlation per capita income with the level of solid waste production is significant, that is to say that higher gross domestic product (GDP) causes higher waste generation (Namlis & Kamilis, 2019). Malaysia's solid waste contains an exceptionally high amount of organic waste and has a high humidity and a bulk density of over 200 kg/m^3. A waste characterization study found that the main components of Malaysian waste were food, paper and plastic which comprise 80% of the overall weight. These characteristics reflect the nature and lifestyle of the Malaysian population (Ghinea et al., 2016; Manaf et al., 2009)

2.4 Potential of waste minimization in Malaysia

Nowadays, there is a growing interest in the simultaneous utilization of different options for source and waste management, with design strategies for management policies of integrated and sustainable resource and waste. To solve the issues that are caused by the landfill and for better management at the same time, landfilling can be used with other methods of waste management such as recycling, composting and incineration.

Recycling

Recycling is the conversion of waste materials such as paper and cardboard, plastics, glass and metals into new and useful products with an economic value. In this process, wastes materials are collected either from the source or landfills and are separated according to type, compressed to reduce their volume, packed and transported to intermediate dealers or directly to the recycling plant where they are entered into the manufacturing chain to produce secondary materials or new products (Ayodele et al., 2018). About 80% of municipal solid wastes are recyclables, which are disposed at the landfills and under the category of municipal solid wastes, the contribution of household waste is the highest among the sources consisting of recyclables, which at the most 70-80% of total solid waste composition in the landfills. Regardless of its composition or type, wastes are simply dumped in an open ground area without any attempt for recovering or recycling. Malaysia has targeted that 22% of its total solid waste could be recycled by the year 2020 but the current recycling rate is about 15%, compared to other developed countries, where the recycling rate is about 30-47%. At present, recycling has not become a universal way of life in Malaysia and only a few are really practicing it religiously. The implications of the lack of such a practice are the loss of these resources and the rapid utilization of the landfill space, thus reducing the length of the life-span of landfills in this country. These not only would create environmental problems but are also unsustainable from the economic point of view (Moh & Abd Manaf, 2014).

Composting

The composting process is defined as an anaerobic biological process that depends on a microorganism's population, which converts the organic substance of the wastes into stabilized humus and less complex compound. In composting, carbon and nitrogen compounds are easily transformed and used as energy and protein sources of microorganisms, thereby producing heat, CO_2, NH_3, H_2O, organic acids and mature compost product at the end of the process. Composting is a process highly valued in waste management owing to its robustness and the possibility of obtaining a valuable product with soil amendment potential (Bolong & Saad, 2020; Saalah et al., 2020). Composting could be an alternative waste management strategy in overcoming waste management issues in developing countries such as Malaysia where there is an over-reliance on landfilling and open dumping as well as the limited land area for waste disposal. It involves simpler technology and relatively lower processing fee compared to other MSW management technology. Amature compost that is free from heavy metals and pathogen can be used as a soil conditioner or organic fertilizer (Leow et al., 2019; Lim et al., 2019). It is estimated that materials such as papers, aluminums, plastics, glass and metals make up 55% of municipal waste, while a bulk of 45% is municipal waste that comes from food waste. It is common for household to segregate recyclables; however, that is not the case of food waste. This is mainly due to lack of food waste recovery, low awareness among the populace and the low demand for products that are derived from food waste. Converting this large portion of waste into a valuable product with soil amendment potential by composting will help achieve promising solutions for food wastes management (Aja & Al-Kayiem, 2014).

Incineration

Incineration is a disposal method that involves combustion of waste material. Incineration and other high temperature waste treatment systems are sometimes described as ‘thermal treatment’. A solid waste incinerator is a type of facility which is designed, built and operated at specified design conditions. A typical incinerator processes wastes that have been collected as input material, and achieves its goal, i.e., the treatment of waste material and as a secondary benefit recovers heat energy from the combustion process. Incineration is carried out both on a small scale by individuals and on a large scale by the industry. It is used to dispose of a wide range of types of solid waste. It is recognized as a practical method to dispose of certain hazardous waste materials (such as biological medical waste). Municipal solid waste incineration is also favorable due to its well-recognized properties in volume reduction and energy recovery. According to this point, incineration of MSW has been taken into consideration in many countries that are faced with limited landfill space. Numerous studies have been published in recent years in which this method has been applied for the environmental evaluation of incineration and landfilling scenarios of MSW in different countries.

2.5 Leachate

One of the problems arising from the use of landfills without a proper liner or top cover is the formation of leachate which can negatively affect ground water and surface water (e.g. river and coastal areas). This is common in developing countries especially in Southeast Asia where more than 90% of the landfill is built with no leachate treatment system and management due to the rapidly increasing population and urbanization and industrialization, thus becoming a major problem to the environment (Rafizu & Muhammad Alamgir, 2012; Tra¨nkler et al., 2005). The resulting leachate appears to contain high organic and inorganic content and has high moisture elements such as nitrogen ammonia, heavy metals, organic and inorganic salts. Uncontrolled leachate can enter groundwater or combine with surface water and pollute soil, groundwater and surface water. The adverse effects that come from pollution of leachate are widely studied and it is very important to treat leachate to meet the standards before being discharged into the environment (Li et al, 2009).

2.5.1 Leachate generation and characterization

As is known, landfill leachate is a highly complex liquid containing several chemicals and the liquids are also different depending on the physical (weathering), chemical (desorption) and microbiological (degradation of organic waste occurring within a landfill. Some studies have also found that the age of the landfill, the waste thickness of the landfill, as well as the climate and the local season can affect the composition of landfill leachate (Moody & Townsend, 2017). It is very important to understand the deeper processes that occur in the landfill which can be a guideline in managing landfill leachate. This can also provide information or knowledge on the composition of landfill leachate, and in turn provide input to design leachate treatment (Morling, 2017).

Leachates from landfill are generated by various factors, including infiltration of ground water, infiltration of leachate into the ground (a potential pollution of the ground water may occur), rainfall (precipitation), water from the deposited waste, mainly due to the static pressure and evaporation from the site.

Older landfill sites were often operated in an unsophisticated way; management and operation rarely include sufficient protection devices and large open storage areas where the waste was disposed. In addition, several ‘old’ sites are exposed to vast quantities of water from the various sources as mentioned above. Some of the important points that define the impact of rainwater are, besides the magnitude and frequency of precipitation, the landfill area that has been directly exposed to rainwater and allowed to sink into the landfill, and the form of the landfill that allows rainwater to 'run off' from the landfill as surface water. Figure 2.2 presents a schematic picture of the water balance in a landfill.

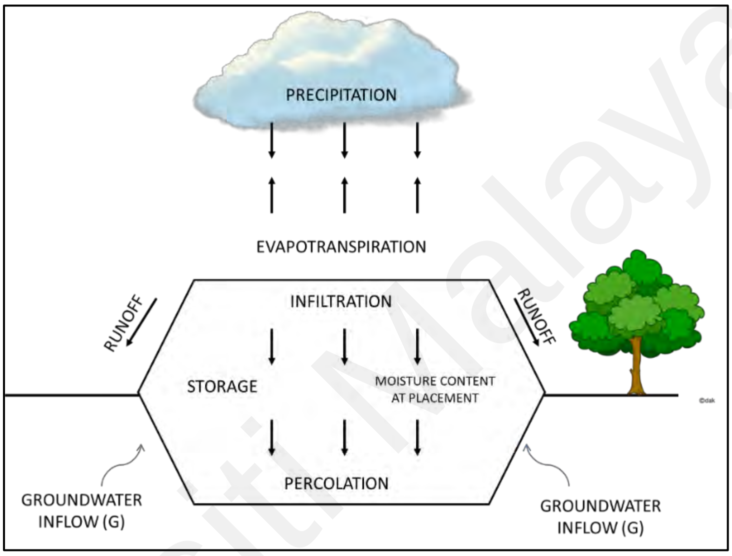


Figure 2.2 Schematic scheme of how leachate is generated (Vaverková, 2019)

The excess of rainwater that is percolating through the waste layers in a landfill will generate landfill leachate which is defined as the aqueous effluent. This percolating water is a mixture of physical, chemical and microbial processes in the waste which transfer pollutants from the waste material. This percolating water is called leachate that may contain a variety of pollutants which include inorganic macro-components, heavy metals, dissolved organic, xenobiotic organic compounds as well as micro-organisms (Kjeldsen et al., 2002; Renou et al., 2008; Zhang et al., 2012). Biological processes that occur in the landfills involve four main phases, as listed in Table 2.7. The fourth phase which is labeled as a humid phase is a phase that takes 100 years after the landfill is closed. Most of the future changes in the composition of leachate are based on analogies and logical theories based on chemistry rather than observations.

Table 2.6: Simplified characterization of the biological performance in a landfill related to disposal time (Adhikari et al., 2014)

Biological phase	Characterization
First phase: Aerobic phase	
Duration	Some weeks
Characterization of landfill leachate	pH ~ 8 High levels of heavy metals
Second phase: Acidic (anaerobic) phase	
Duration	Some years
Characterization of landfill leachate	pH ~ 5 High concentration of VFA High levels of BOD Ratio COD/BOD is low: 1.3:1 – 2.0:1 High levels of NH4-N, organic N and PO4-P High levels of heavy metals
Third phase: Methane phase (anaerobic)	
Duration	>100 years
Characterization of landfill leachate	pH ~ 7 Low concentration of VFA Low levels of BOD Ratio COD/BOD is high 20: 1 – 10:1 High levels of NH4-N; Moderate to low levels of organic N Very low levels of PO4-P Low to very low levels of heavy metals, apart from Fe and Mn

The composition of landfill leachate is complex and variable with different chemical and microbiological dependent on so many factors (Yao, 2013); factors that can contribute to the leachate formation, i.e., the chemical composition and the production rate in landfills. Those factors are the characteristics of the waste, the interaction between the percolating landfill moisture and the waste, the hydrology and climate of the site, the landfill design and the operational variables, microbial production processes that occur during the stabilisation of the waste (KahramanUnlu & Rowe, 2004). In general, leachate is a soluble organic and mineral compound that is formed when water infiltrates into the refuse layers, extracts a series of pollutants and initiate a complex interaction between the hydrological and biogeochemical reactions that plays as mass transfer mechanisms for producing of moisture content that is adequately high in order to initiate the liquid flow. This is caused by the force of gravity, precipitation, irrigation, surface runoff, rainfall, recirculation, co-disposal of liquid waste, decomposition of refuse, intrusion of groundwater and the initial moisture content in landfills (Foo & Hameed, 2009).

Table 2.7: Leachate Characteristics in developing and developed countries (Hussein et al., 2019; Nazrieza et al., 2015; Robinson & Luo, 1991;Singh & Mittal, 2009; Visvanathan et al., 2007; Vithanage et al., 2014; Zafar & Alappat, 2004)

Parameters	Shenzhen xiaping, China	Pathumthani, Thailand	Okhla, New Dehli	Sabak Bernam, Malaysia	Hongkong	USA
Age (Years)	2	9	9	7	10	16
Alkalinity (mg/L)	-	6,620	12000-32000	1200-1550	3230-4940	2250
pH	7.8	8.1	7.6-8.2	8-8.1	7.6-8.1	-
Chloride (mg/L)	-	2530	16,000	420-1820	522-853	700
SS (mg/L)	250	12.5	-	111-920	3-124	-
TS (mg/L)	-	848	24000	-	-	-
COD (mg/L)	13040	4300	6000	1250-2570	641-873	400
BOD (mg/L)	3220.5	418	3-207	726-1210	-	80
TKN (mg/L)	-	1,256	-	-	889-1180	-
NH_3-N (mg/L)	2090	-	1000-3000	3-8	784-1156	-
Ni (mg/L)	0.39	0.25	0.026-1.05	-	-	-
Cd (mg/L)	0.01	0.002	0.001-0.05	0-0.001	-	<0.05
Pb (mg/L)	0.08	-	0.009-0.646	0-0.03	-	1.0
Cr (mg/L)	0.046	0.07	0.001-0.0898	-	-	-
Hg (mg/L)	-	-	0.002-0.018	-	-	-

Bashir et al. (2010) reported that young leachates are characterized by high BOD_5 (4000 – 40,000 mg/L), high COD (6000 – 60,000 mg/L), NH_3-N (<400), BOD_5: COD ration typically ≤1.0 and pH range between 4.5 to 7.5 while stabilized landfill leachates are normally characterized by high strengths of COD (500-4500 mg/L), low BOD (20-

550 mg/L), high NH_3-N (>400), a pH range of 7.5-9.0 and BOD:COD ration of <0.1. This produces large quantities of non-biodegradable organic compounds with high molecular weights, such as humic and fulvic substances that are not easy to degrade (Foo & Hameed 2009). This is also reported by some studies on leachate characteristics which recorded high concentration of BOD5, COD and also ammoniacal nitrogen there are huge difference in leachate quality and this is are directly related to the waste management practices, climate conditions, and waste characteristics, as well as the landfill operation method (Table 2.8). In earlier stages, the concentration of heavy metals is higher due to higher metal solubility but will decline with the landing age as the solubility of many metal ions decreases with the rise in pH. The only heavy metal with an increase in pH concentration is lead. This is because lead forms very stable complexes with the humic acids. Other heavy metals that are also present in leachate are Cu, Zn, Cd, Hg, etc. Table 2.9 shows three different types of leachate according to the landfill age (Shehzad et al., 2015).

Table 2.8: Landfill leachate classification with respect to operational year (Shehzad et al., 2015).

Parameters	Young	Intermediate	Stabilized
Age (years)	<5	5-10	>10
pH	<6-5	6-5-7-5	>7.5
COD (mg/L)	>10,000	4000-10,000	<4000
BOD	>10,000	200-10,000	50-2000
BOD_5/COD	0.5-1	0.1-0.5	<0.1
Color	<1000	NA	1500-7000
TOC/COD	<0.3	0.3-0.5	>0.5
NH_3-N (mg/L)	<400	NA	>400
Heavy metal (mg/L)	Low to medium	Low	Low
Organic	80%	5-30%	
Compound	(VFA)	(VFA)	(HA) + (FA)
Biodegradability	Important	Medium	Low
Kjeldahl nitrogen (g/L)	0.1-0.2	NA	NA

Note: NA, not available; VFA, volatile fatty acid; HA, humic acid; FA, fulvic acid

2.5.2 Leachate Management/Treatment

It is important to treat the landfill leachate in such a way that complies with the standards for discharge into sewer or natural waters. Even so, the treatment of landfill leachate is becoming a concern for both the environment and the economy, with much stricter discharge standards imposing higher treatment costs (Li et al., 2009). Over the years, there are many treatment processes that have been explored including physic-chemical and biological techniques with their own advantages and disadvantages. Those treatments also vary from biological treatment to membrane technologies such as: microfiltration, ultrafiltration, nanofiltration and reverse osmosis (Benyoucef et al., 2016).

The selection of the most relevant type of treatment is always difficult. The type of treatment to be selected for the leachate relies on the chemical and biological parameters of the leachate such as pH, chemical oxygen demand (COD), biological oxygen demand (BOD), total nitrogen (TN), total phosphorus and metals, which in turn are frequently related to the age of the leachate. A lower concentration of biodegradable material that is not suitable for the use of biological methods due to bio-refractory organic matter will most likely be present in the case of stabilized leachate originating from a more mature landfill. This type of leachate requires chemical treatment to be safely discharged (Chen 2017). However, compared to biological techniques, most of the countries in Asia are using the physicochemical treatment (coagulation-flocculation, adsorption, membrane processes and oxidation) of leachate which is more cost-effective and can be completed in a shorter period of time (Kumari et al., 2018).

Table 2.9: Type of landfill leachate treatments (Kamaruddin et al., 2017; Raghab et al., 2013)

Treatments	Description
Aerobic Biological Treatment	Aerated lagoons and activated sludge
Anaerobic Biological Treatment	Anaerobic lagoons and reactors
Physicochemical treatment	Air stripping, pH adjustment, chemical precipitation, oxidation and reduction
Coagulation	Using lime, alum, ferric chloride and land treatment
Advanced technique	Carbon adsorption, ion exchange

There are many different methods presently in use for the treatment of landfill leachate. Most of these methods are adjusted from waste-water treatment processing and can be separated into two categories biological treatments and physical or chemical treatments. There are methods of leachate treatment are shown in Table 2.10.

2.5.3 Generation of leachate with different treatment

Naturally, many different strategies have been proposed in order to attempt to counter and reduce the production of waste, such as composting, recycling and incineration. Composting for example is an efficient manner of managing organic waste because they reduce the volume and weight of the initial waste by approximately 50%. However, composting at the industrial scale generates large volumes leachate. Composting leachates originate from: (1) the water content of the organic waste itself, (2) the water generated during the composting biochemical reactions, (3) the rain water (open facilities), as well as (4) the water added in order to adjust the moisture content. Leachate production is linked to the composting technology, the type of wastes composted, and the climatic conditions. Generally, composting facilities have the capacity to treat 1,000–1,500 ton per day of waste with a reported leachate productions ranging from 4 to 400 m3/d (Roy et al., 2018). Same as the leachate that results from the disposal of solid waste in landfills, composting leachates contain various hazardous substances that can have potential adverse effect on the environment, and therefore need to be sufficiently treated prior to their disposal (Elsami et al., 2018). However, according to the study by Badillo et al. (2019), the utilization of compost leachate as a fermentation substrate for plant growth-promoting bacteria, will benefit in reducing the volume of compost leachate that is to be treated, as well as contribute in a cost-effective production of biological amendments through a circular economy mode.

As well as composting, incineration has also become one of the most popular waste treatments in developing countries in Southeast Asia such as in Singapore. Incineration is able to reduce the volume of solid wastes by 80% which makes them popular in countries that have limited territory for landfills (Gao et al., 2019). However, one of the most important issues in MSW incineration plant is fresh leachate chiefly results from rain-water percolation, biochemical reactions, and has inherent moisture content. The characteristics of the concentrated leachate from MSW incineration power plants are vastly different from that of traditional anaerobic landfills which are characteristically rich in organic and inorganic contaminants, including humid acids, ammonia nitrogen, heavy metals, xenobiotic and inorganic salts. Therefore, direct discharge of leachate from MSW could severely cause destruction to its receiving medium and endanger public health. Innovative technology should be taken into consideration for the treatment of this refractory leachate ((Ren et al., 2018; Wang et al., 2018).

2.6 River water pollution in developing countries

2.6.1 Introduction

Rivers provides a variety of ecosystem services for both living and non-living animals through, for instance, climate regulation, air and water purification, and nutrient cycling. Other water bodies such as the oceans, wetlands and lakes, support river ecosystems in a variety of ways. The oceans, which account for 97% of the world's water bodies, provide important food production functions and control climate temperatures, whereas wetlands sustain natural processes as well as provide food, shade, and shelter for a diverse range of species that are beneficial for the provision of genetic resources and the regeneration of river basin habitats. As rivers have been used for social and economic development, little attention has been paid to the needs of the river ecosystem, leading to the loss and degradation of their ecosystem services (Khalid et al., 2017)

The status of rivers in Malaysia in terms of water quality has always been a matter of concern for the various local authorities, government agencies and the general public. Seven out of 80 river basins located downstream are found to be polluted and among the main pollutants are biological oxygen demand (BOD), ammoniacal nitrogen (NH_3-N) and suspended solid (SS) which are due to rapid industrialization, construction, agriculture and urbanization. Therefore, it is very important to study the pollution levels of these rivers in a scientific way to enable them to be managed more optimally (Al-Shami et al., 2010).

The political process tends to affect the structure, priorities and implementation of water resource management policies. Since 1971, the Federal Government of Malaysia has begun to play an important role in environmental issues but faces problems in coordinating policy, as states were granted some level of independence to determine their own environmental policy under the Constitution. The effectiveness of the Department of Environment (DOE) of Malaysia in enforcing policy is also limited, given its limited operational budget. According to the Department of Statistics Malaysia, a total of 140 river basins have been monitored, and it appears that the percentage of clean rivers in Malaysia has decreased remarkably, from 63.6% in 2007 to 52.8% in 2012. The percentage of slightly polluted and polluted river basins has increased over this same time period, from 31.5% to 38.6% and from 4.9% to 8.6%, respectively (Poon et al., 2016).

Table 2.10: Selangor River quality year 2010 and 2014 (Afroz & Rahman, 2017)

Year	Suspended solid			Biochemical oxygen demand			Ammoniacal Nitrogen		
	Clean	Slightly Polluted	Polluted	Clean	Slightly Polluted	Polluted	Clean	Slightly Polluted	Polluted
		%			%			%	
2010	47.6	18.8	33.6	8.4	55.2	36.4	24.5	46.1	29.4
2014	70.7	15.7	13.6		10.7	89.3	29.3	42.1	28.6

BOD, NH_3-N, and SS remain to be important in relation to river pollution. High BOD can be caused by the improper treatment of sewage or effluent from the agricultural and manufacturing industries. While the prime sources of NH_3-N are from livestock and domestic wastewater. From the formulated Water Quality Index (WQI), the total number of contaminated rivers (including the slightly contaminated Class III River) is declining by 10% based on all the streams that are monitored in 2007, and approximately 5% in 2011. Table 2.11 shows that on BOD-based river classes, contaminated rivers (class III and IV) are increasing from 34.6% (in 2010) to 89.3% (in 2014), of the total number of monitored rivers.

Sources of water pollution can be categorized as point and non-point sources. Point sources refer as sources with discharges entering the water body at a specific location, for example pipelines or emissaries. Point sources include discharges from industries, sewage treatment plants, and livestock farms. Non-point sources are sourced from diffuse sources which do not contain examples of specific release points from which agricultural activities and surface runoff originate (Juahir et al., 2011). Table 2.12 shows the pollution sources in the water body in Malaysia. It has been found that the total number of polluting sources has decreased in 2014 compared to 2013. At the individual sources of water pollution, there is a major increase in food services, rubber mill, public and private wastewater treatment plants as well as the wet market. Analysis of the manufacturing industries in 2000 reveals that the food and beverage industry has made up for 23.7% of the total water pollution, whereas electricity and electronics make up 11.4% of the total water pollution. The chemical industry makes up11.2%, and the paper industry generates 8.8% of the total contamination. The finishing industry or textile accounts for 7.4% and 5.3% of the sources of water pollution, respectively. Effluents from factories, oil palm, and rubber that are generated in water resources have amounted to 5.3% and 2%, respectively (Muyibi et al., 2008). In general, Selangor, Johor, and Perak have been severely contaminated by these sources of parameters (DOE, 2014; RafiaAfroz & Ataur Rahman, 2017).

Table 2.11: Sources of river water pollution in Malaysia (Rafia Afroz & Ataur Rahman 2017).

Type of source	Number of Source (%)		Change (%)
	2013	2014	
Manufacturing industries	0.276	0.225	-0.051
Rubber mill	0.004	0.005	0.001
Palm oil mill	0.026	0.0003	-0.026
Animal pig	0.045	-	
Public	0.349	0.416	0.068
Private	0.246	0.3	0.054
Individual septic tank	87.190	85.76	-1.430
Commercial septic tank	0.218	0.24	0.022
Food services establishment	11.593	12.95	1.357
Wet markets	0.052	0.11	0.058
	100	100	

2.6.2 Selangor River

The State of Selangor, Malaysia, has a long history of river pollution problems that are associated with land use changes. The Selangor River is one of the main rivers in the Selangor state of 110 km of 1500 m and is the longest river in Selangor. The river flows from the northern part of the state of Selangor, from Fraser's hill and Genting Highlands to the south, across Hulu Selangor and the lowlands in Kuala Selangor before ending at the Straits of Melaka in Kuala Selangor. The Selangor river basin is one of the four major river basins in Selangor (Klang, Bernam and Langat river basins). The basin is approximately 70 km long and 30 km wide and about 28% of the Selangor state which is made up of many smaller streams and rivers with a total of 19 tributaries and the catchment size is about 2000 km^2 (Boelee et al., 2017; Leong et al., 2007; Santhi & Mohd Mustaf, 2013; Fulazzaky & Seong, 2010; Tan & Mustafa, 2004). Sungai Kali, Sungai Serah, Sungai Buloh, Sungai Kerling, Sungai Sembah, Sungai Kundang and Sungai Rawang are the main tributaries of several major towns in Selangor including Kuala Kubu Bharu, Rawang, Serendah, Bestari Jaya and Kuala Selangor (Othman et al., 2014).

Table 2.12: List of waste disposal sites located in Selangor River (JPSPN, 2002; Yahaya et al., 2016)

Landfill	Nearest River	Year of operating	Type of Landfill	Operator
Kuang Inert	Dungon River	2007–Present	Non-sanitary Active	Worldwide Landfill Sdn. Bhd
Jeram	Sembilang River	2007 – Present	Sanitary Active	Worldwide Landfill Sdn. Bhd
Bukit Tagar	Bangkar River	2005 – Present	Sanitary Active	KUB-Berjaya Enviro Sdn. Bhd
Kundang	Kuang River	2002 – 2006	Non-sanitary Closed	Alam Flora Sdn Bhd
Kubang Badak	Kubang Badak River	1985-2007	Sanitary Closed	Worldwide Landfill Sdn. Bhd
Bukit Beruntung	Sabai River	NA	Non-sanitary	Majlis Daerah Hulu Selangor
Sungai Sabai	Beletak River	2000-present	Non-sanitary	NA
Ulu Yam Bharu	Liam River	1997-2007	Non-sanitary Closed	Majlis Daerah Hulu Selangor

Selangor's water supply is 60% of the Selangor river basin while 40% is from the Klang and Langat river basins. Selangor river catchment area is very important in providing water resources in Malaysia especially to more than four million people and industries around Kuala Lumpur, Petaling, Gombak and Hulu Selangor where this includes the consumption of 2,500 million liters of water a day. In addition, the

Selangor River is also a source of income for fishermen and market traders as Selangor River is an important habitat for many species of fish and shrimp. Other than that, Selangor River is also popular among local and foreign tourists as it is the place of the world's largest population of fireflies, which is in Kampung Kuantan and Bukit Belimbing (Othman et al., 2014; Sakai et al., 2017).

Besides being a tourist attraction and water resources to the locals, Selangor River has also become a place where various types of pollutants are discharged from the industrial area or residential area, and also as the solid waste disposal site. Up to date, there are eight solid waste disposal sites, five of which are still active and only two are sanitary landfills. Table 2.13 shows a list of solid waste disposal sites that are located along the Selangor River.

According to the Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations 2009, the construction of one solid waste disposal site must be within the buffer zone of 500 meters from the main water system. However, not only in Selangor but most of the landfill sites in Malaysia are close to the main rivers. In Selangor alone, there are 20 solid waste disposal sites in 5 main river basins which are the main sources of water for agriculture, productivity, industrial and water resources for the locals. This is very worrying because every year the solid waste disposal site produces over a million-liter of leachate. Additionally, most of these disposal sites are categorized as non-sanitary which do not have the perfect leachate treatment system.

2.6.3 Addressing River water pollution

The 1974 Environmental Quality Act (EQA) was revised from 1977 onwards to govern prevailing contaminants and to levy discharge charges; it was further updated in

1978 to tackle the water pollution from palm oil mills. The regulation remained the main policy tool under the EQA, complemented in 1989 by the proposed toxic waste and in 1993 by sea pollution. Nevertheless, the EQA's performance remained low due to a limited budget, limited human and technological capital and poor external bureaucratic support. Conflicts emerged because requirements were set by the federal government and the monitoring of water quality was carried out by the DOE, while compliance was mostly left to the states. In 2010, the DOE of Malaysia developed a River Water Quality Index (WQI). The quality level of the river water is determined by a water quality index (WQI), a single dimensional number mathematically extracted from large quantities of water quality data into a single number (Othman et al., 2012). Most countries use the WQI approach to evaluate the overall health of the river, where these metrics vary from country to country but share a similar concept, in which a few important parameters are chosen and multiplied to the numerical ranking for river water quality assessment (Zeinalzadeh & Rezaei, 2017). The WQI has a value from 0 to 100, with a higher index value for better water quality. The quality of river water can be assessed either with individual parameters for any particular interest or with a few relevant parameters to determine basic values of the overall water quality (i.e., one number and a statement such as ‘good’) (Othman et al., 2012; Vishnu Radhan et al., 2017).

River water is categorized according to the WQI into three categories: clean (81-100); slightly polluted (60-80); and polluted (0-59) (Department of Statistics Malaysia, 2012). The WQI normally consists of six parameters: biochemical oxygen demand (BOD), dissolved oxygen (DO), suspended solids (SS), chemical oxygen demand (COD), ammoniacal nitrogen (AN), and pH. Another parameter that is frequently taken into account is the river water temperature (TEMP) (Mohamed et al., 2015). In 1987, Malaysia focused on sustainable development and formed the administrative and legal authorities, a national environmental agency and a Ministry of the Environment and National Environmental Law. The success of Malaysia's sustainable development initiatives with regard to environmental quality has, however, been limited in pursuit of political, social and economic objectives (Poon et al., 2016).

Table 2.13: National Water Quality Standards for Malaysia

PARAMETER	**UNIT**	**CLASS**					
		I	**IIA**	**IIB**	**III**	**IV**	**V**
AN	mg/l	0.1	0.3	0.3	0.9	2.7	>2.7
BOD	mg/l	1	3	3	6	12	>12
COD	mg/l	10	25	25	50	100	>100
DO	mg/l	7	5-7	5-7	3-5	<3	<1
pH	-	6.5-8.5	6-9	6-9	5-9	5-9	-
Colour	TCU	15	150	150	-	-	-
Electrical Conductivity	µS/cm	1000	1000	-	-	6000	-
Floatables	-	N	N	N	-	-	-
Odour	-	N	N	N	-	-	-
Salinity	%	0.5	1	-	-	2	-
Taste	-	N	N	N	-	-	-
TDS	mg/l	500	1000	-	-	4000	-
TSS	mg/l	25	50	50	150	300	300
Temperature	^{0}C	-	Normal +2^{0}C	-	Normal +2^{0}C	-	-
Turbidity	NTU	5	50	50	-	-	-
FC	count/100 ml	10	100	400	5000 (20,000)[a]	5000 (20,000)[a]	-
TC	count/100 ml	100	5000	5000	50,000	50,000	>50,000

Malaysia also follows WQI compound to assess the overall water quality of the river. The existing WQI equations are proposed by the Department of Environment Malaysia (DOE) and is referred to as the Malaysian Department of Environment-Water Quality Index (DOE-WQI), which is an opinion-poll formula where a panel of experts is consulted on the choice of parameters and on the weightage to each parameter (Othman et al., 2012). A WQI assigns a quality value for an aggregate set of calculated parameters. It usually consists of subindex values that are assigned to a given parameters where its calculation is compared with an optionally weighted parameter rating curve and is combined in the final index. The WQI is calculated using six parameters WQI: DO, BOD, COD, TSS, NH_3-N and pH with the inclusion of intermediate sub-indices (Vishnu Radhan et al., 2017). The calculation for obtaining this sub-index will be explained further in Chapter 3.

Table 2.14: Water Classes and Uses

Class	Uses
Class I	Conservation of natural environment Water supply I – Practically no treatment necessary Fishery I – Very sensitive aquatic species
Class IIA	Water supply II – Conventional treatment required Fishery II – Sensitive aquatic species
Class IIB	Recreational use with body contact
Class III	Water supply III – Extensive treatment required Fishery III – Common of economic value and tolerant species; livestock drinking
Class IV	Irrigation
Class V	None of the above

Table 2.15: DOE Water Quality Index Classification

PARAMETER	UNIT	CLASS				
		I	II	III	IV	V
Ammoniacal Nitrogen	mg/l	<0.1	0.1-0.3	0.3-0.9	0.9-2.7	>2.7
Biochemical Oxygen Demand	mg/l	<1	1-3	3-6	6-12	>12
Chemical Oxygen Demand	mg/l	<10	10-25	25-50	50-100	>100
Dissolved Oxygen	mg/l	>7.0	5-7	3-5	1-3	<1
pH	-	>7.0	6.0-7.0	5.0-6.0	<5.0	>5.0
Total Suspended Solid	mg/l	<25	25-5-	50-150	150-300	>300
Water Quality Index (WQI)		>92.7	76.5-92.7	51.9-76.5	31.0-51.9	<31.0

2.7 Material Flow Analysis Modeling

2.7.1 MFA definition

MFA (material flow analysis) is defined by system boundaries in space and time, and by material flow entering, leaving, and taking place within the system including associated processes (transformations, transport and stock changes. According to Leray et al. (2016), MFA is a tool aimed at describing and quantifying the metabolism of human activities or the underlying set of biophysical flows and stocks linking society and natural environment. MFA also delivers a complete and consistent set of information about all flows and stocks of a particular material within a system (Brunner & Rechberger, 2004). While for waste management, MFA is defined as the graphical illustration of a well-conducted MFA depicts the flow of waste materials, resulting products and emissions in a visually clear and transparent manner. MFA is an excellent tool to calculate the amount and composition of wastes by balancing the process of waste generation or the process of waste treatment. It is also a well-suited tool for cost-efficient and comparatively accurate waste analysis (Brunner & Rechberger, 2004).

According to Fujie et al. (2007), there are three types of MFA research develop; 1) MFA for all materials at national level where some country used MFA as an indicator towards sustainability and published a methodological guide for MFA. In some studies, they use MFA to compare four nations for example USA, Germany, Netherlands and Japan. 2) MFA that concentrates on specific substance which have harm effect on human for example lead, copper, mercury, phosphorus as well as construction material. This type also known as Substantial Flow Analysis (SFA). 3) MFA for regional and sector level as for Japan, they use MFA as a tool for policy making and effective on local government policy because field of MFA is small and intensive for example for local city level, rural village and prefecture level. According to Steubing et al. (2010), material flow analysis is used to analyze matter flows including chemical elements, compounds, materials or commodities that are based on material balancing which represents the law of material conservation. Steubing et al., (2010) also divided MFA into three categories: 1) Substance Flow Analysis which is used to relate critical emissions of substances to processes, products and material inputs in the system; 2) Process-based Material Flow Analysis which is used to analyze specific questions of resource and waste management and 3) Industry-based MFA which is used to assess the environmental impact of economic development by analyzing the total material throughout a system.

MFA can be used to quantify the flow of materials in a system defined by spatial and temporal boundaries and it is based on the principle of mass conservation. It is also a method that is used to describe, investigate and evaluate the metabolism of anthropogenic (or geogenic) systems through space and time. There are four steps in MFA: (i) model building stage- analysis of the system and the involved processes and materials; (ii) data collection which involve the measurement of the material or mass flows; (iii) calculation of material or mass flows and (iv) interpretation of the results (Staeubing et al., 2010). By comparing all inputs, stocks and outputs of a process which is presented in a flow diagram, the results of a MFA can be controlled and can be made to be an attractive decision-support method tool in resource management (Lau et al., 2013). The flows are depicted by arrows, the widths of which are shown proportionally to the flow quantities which make it very easy, especially for a non-technical audience to see where the major flows in the value chain are (Rollat et al., 2016). MFA can be regarded as indirect pressure indicators for environmental degradation where MFA and the related indicators have hereby emerged as a rapidly expanding field of research that serves to measure and analyze the socio-industrial metabolism of national economies (Kovanda et al., 2012). For over 20 years, MFA has become an instrument to describe material flows and stocks within various systems (Cencic & Rechberger, 2008).

2.7.2 MFA of waste flow

Decisions regarding waste management should not only be technologically acceptable but should also consider environmental and social perspectives because waste management is a complex process which involves a wide range of technologies and disciplines (Font Vivanco et al., 2012). It is more challenging to serve the best present and future needs of a particular community when the numbers of options are increased, especially in order to decide the combination of collection, processing and disposal system (Barlishen & Baetz, 1996). There are many reasons why MFA can be an excellent tool regarding waste management. According to Brunner and Rechberger (2004), MFA allows not only the calculation of the amount and composition of wastes but also MFA is a well-suited tool for cost efficient and comparatively accurate waste analysis. Every stage of the material or substance flows (the sources, transfer, accumulation and fate) through and within a system, are the core objective of MFA that can be applied to any organizational level (individuals, households, firms) as well as to various spatial and temporal scales (Leray et al., 2016). The aim of the study is to examine the material flow of leachate from the landfill; thus, it is necessary to understand the leachate production process.

Mainly, the term waste has been applied to solid waste and some liquid wastes where the emission of substances to the air, water and soils have been separately accounted for. Waste could not be generated without resource inputs as well as tracing the course of the wastes. The starting point of waste generation is the extraction of resources from nature as an input to human activities. Wastes are labeled as residues which are by-products with negative economic value, and as undesirable residues from production and consumption activities (Moriguchi, 1999). Because the aim of the study is to examine the material flow of municipal solid waste management, it is necessary to understand the process from the beginning. The processes in municipal solid waste management involve: the collection of the waste from the sources including household, industrial, institutional and the delivery to the transfer station, recycle center or landfill; sorting for waste reduction or re-use, dump into the landfill; landfill processing which includes physical, chemical, biological processes, storage and leachate treatment; and treated leachate discharge to surface water or public sewers. According to Act 672:

Solid Waste and Public Cleansing Management 2007, the basic process in municipal solid waste management is divided into six stages; generation, separation, storage, transportation, treatment and process and disposal.

Besides that, Malaysia also has new law on solid waste management where the principal processes options are being classified in a system for integrated waste management. There is also a following hierarchy in Malaysian solid waste management: waste minimization, reuse, material recycling, energy recovery and landfill (Lau, 2004).

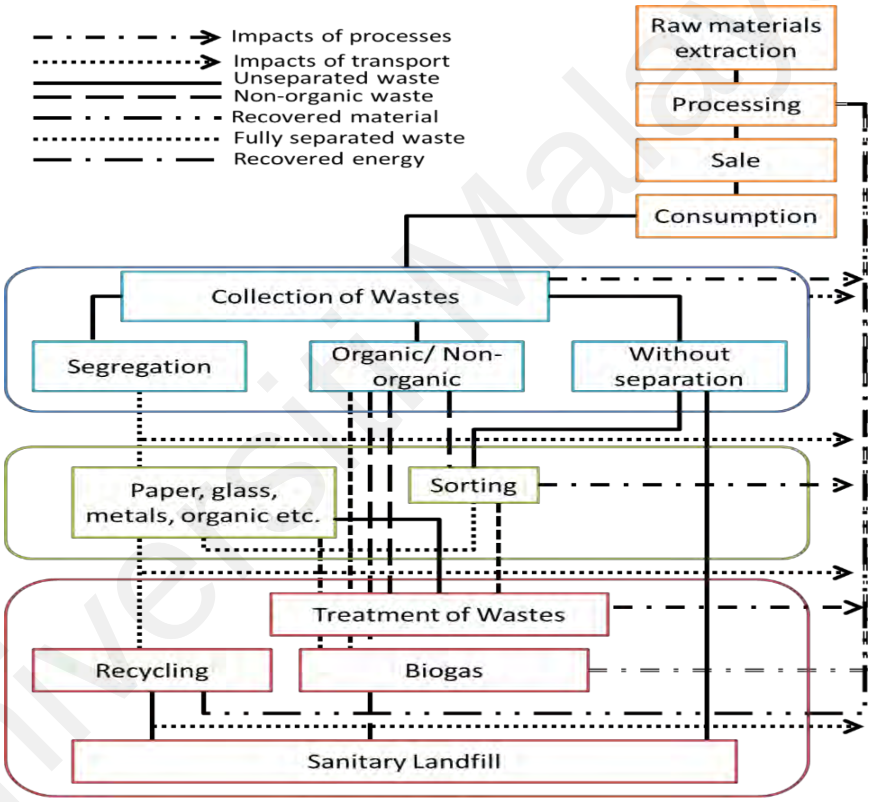


Figure 2.3 Material Flow in the municipal solid waste management system (Ramachandra 2011)

Considering the waste management hierarchy, one of the greatest challenges is figuring out how to diversify treatment options, improve the reliability of infrastructure systems, and leverage the redistribution of waste streams among incineration, compost, recycling, and other facilities to their competitive advantage region wide. It is inevitable that regional waste management techniques have a number of possible solutions due to varied population densities, incomes, multiple locations for waste management infrastructure, protected landscape areas, and high-value ecological services. A waste management plan which utilizes all technology is required in order to accomplish this which requires an increase in material recycling and energy recovery, and landfill disposal would be limited to inert materials and residues from recovery and recycling as shown in Figure 2.3.

As a result, MFA could be applied to measure for improving the regional or corporate management of materials including the optimization of resource exploitation, consumption and environmental protection. MFA can also be used to set up monitoring programs to evaluate the effects of policy makers and as a tool for the early recognition of the impact of different scenarios of socioeconomic development (Binder, 2007).

2.7.3 MFA to address river water pollution

MFA has been applied in many different studies in the various fields. In developing and emerging countries, MFA has been used for several purposes such as to establish a regional water balance, to model resource management for agricultural systems or to simulate water and nutrient flows for urban wastewater. MFA has a high potential as a flexible instrument in environmental management. In order to assess river water pollution, MFA allows the breaking down of the complexity of the system and to gain a first broad overview over the pollution problems, and their relationships. The relevant dimensions of pollution flows are shown and the essential factors influencing these are identified. Presented in a model of a size which can be handled, the different pollution sources can be put in relation to each other and the possible causes and mitigation measures be evaluated.

In investigating into origins of the pollution sources, MFA describes the anthropogenous contribution to the conditions of the river system. MFA also simulates the processes generating the pollutant, river models can be added to simulate the effects of pollution that is discharged along the length of the river. An MFA model allows an assessment of the entire path of pollution generation, i. e., from its origin through its different transformations and diversions to its final discharge into the river. Thus, the key pollution sources and main parameters influencing these sources can be identified. Mitigation measures have to target these main parameters in order to achieve an effective impact.

2.8 River water quality modeling

Planning and management activities require an evaluation of the hydraulic and water quality situation, frequently beyond the range of field data. In this situation it is important to formulate both hydraulic and water quality models that are general enough to (1) define the observed conditions; and (2) predict planning scenarios that may substantially differ from observed conditions. In stream water pollution control, the main objective is to assess if the system complies with the maximum pollutant releases, which are allowed from point and nonpoint source pollution, so that the pollutant levels in the receiving streams meet the water quality standards. The water quality models for in stream water pollution control have been calibrated and verified with the data that have been collected prior to model development, during surveys that are designed to check the basin wide water quality for regulatory compliance (Radwan et al., 2003).

Though constant monitoring of water quality and the effect of human activities (e.g., agriculture) on aquatic environments is feasible, this method would be very costly and inefficient, as it might be too late to take action to address a problem when it is found in an aqueous environment. A better solution is to simulate the effect of different practices (e.g. agriculture and other practices) on surface water quality (rivers, lakes) through mathematical models; this enables prompt action before identifying an issue that can be very hard to solve later. Modelling studies have been carried out to improve prediction accuracy in terms of the number of parameters that are to be modelled, and the effect of critical and other available inputs of the chosen parameters of the model. The model selection to predict the system's behavior is based on the number of parameters it can measure and the accuracy of the data source that is available (Ma et al., 2011). In recent years, this method has become very popular and is very effective in the management of aquatic systems (Gikas, 2014).

Over the years, various water quality models for a variety of bodies of water have been developed (for example, rivers, lakes, ponds, estuaries etc.). Some have included basic water quality indices (e.g. dissolved oxygen and the demand for biochemical oxygen), while others incorporated more advanced criteria for water quality (e.g., the levels of eutrophication and toxicity). For example, Thayer and Krutchkoff (1967) applied a 3-dimensional algorithm to advanced water quality spatial analysis, and Pelletier et al. (2006) confirmed the applicability and flexibility of the QUAL2Kw framework for simulation of river water quality.

QUAL2K is an upgraded version of the QUAL2E river and stream water quality model. QUAL2K is developed by the US Environmental Protection. Agency can simulate the migration and transformation of conventional pollutants. The model views the stream as a single-dimensional, uniform stream channel with the effect of point source and non-point source emission loads. The model also simulates adjustments with a user-chosen time step within an hour in a daily cycle. In addition to being broadly implemented to the environmental management of relatively large rivers, the framework model also includes a few new features that make it relevant to shallow, upland and other rivers.

Table 2.16: Main surface water quality models and their versions and characteristics (Wang et al. 2013)

Models	Model version	Characteristics
Streeter-Phelps models	S-P model Thomas BOD-DO model O'Connor BOD-DO model Dobbins-Camp BOD-DO model	Streeter and Phelps established the first S-P model in 1925. S-P models focus on oxygen balance and one-order decay of BOD and they are one-dimensional steady-state models.
QUAL models	QUAL I QUAL II QUAL2E QUAL2E UNCAS QUAL 2K	The USEPA developed QUAL I in 1970. QUAL models are suitable for dendritic river and non-point source pollution, including one-dimensional steady-state or dynamic models.
WASP models	WASP1-7 models	The USEPA developed the WASP model in 1983.WASP models are suitable for water quality simulation in rivers, lakes, estuaries, coastal wetlands, and reservoirs, including one-, two-, or three-dimensional models.
QUASAR model	QUASAR model	Whitehead established this model in 1997. QUASAR model is suitable for dissolved oxygen simulation in larger rivers, and it is a one-dimensional dynamic model including PC QUA SAR, HERMES, and QUESTOR modes.
MIKE models	MIKE11 MIKE 21 MIKE 31	Denmark Hydrology Institute developed these MIKE models, which are suitable for water quality simulation in rivers, estuaries, and tidal wetlands, including one-, two-, or three dimensional models.
BASINS models	BASINS 1 BASINS 2 BASINS 3 BASINS 4	The USEPA developed these models in 1996. BASINS models are multipurpose environmental analysis systems, and they integrate point and nonpoint source pollution. BASINS models are suitable for water quality analysis at watershed scale.
EFDC model	EFDC model	Virginia Institute of Marine Science developed this model. The USEPA has listed the EFDC model as a tool for water quality management in 1997. EFDC model is suitable for water quality simulation in rivers, lakes, reservoirs, estuaries, and wetlands, including one-, two-, or three-dimensional models.

The model includes the following assumptions: (a) the advective transport depends on the mean flow; (b) the water quality markers are mixed across the cross-section; and (c) the ionizing transport is associated with the concentration gradient. The model allows users to simulate the following components: (a) Dissolved Oxygen, (b) Temperature, (c) Phosphorous, (d) Nitrate, Nitrite, Ammonium and Organic Nitrogen, (e) Chlorophyll-a, (f) up to three conservative solutes, (g) one non-conservative constituent solute, and (h) coliform bacteria. Furthermore, Nitrate, Phosphate and Dissolved Oxygen are represented in more detail; while most determinants are simulated as first order decay. The QUAL2K model is suitable for modeling pollutants in freshwater that rely on sediment interactions, especially as a sink of inorganic and organic substances.

The initial step of the standard QUAL2K model is to divide the river system into reaches (up to 50) and each of these is then divided into a number of subreaches (up to 20 per reach) of equal length. The data requirements of the model in terms of flow and water quality data include the single values of each determinant being modeled. The main feature of this model is the river reach. The data that are required for each river reach includes: (a) flow data and hydraulic terms, (b) initial conditions, (c) reaction rate coefficients, (d) local climatological data for heat balance computations, and (e) rate parameters for all of the biological and chemical reactions. The output of the model includes solutions to the pollutant mass balance and the flow for each reach. The main advantage of QUAL2K is the capability of simulation of algae (Chlorophyll-a), an extensive documentation of its code and theoretical background. QUAL2K is available for free download from its website. The model requires a small amount of data to represent the sediments and only partial hydraulic terms (Tsakiris & Alexakis, 2012)

QUAL2 K allows the user to determine several of the kinetic parameters on a targeted reach basis. QUAL2K can simulate the migration and transformation of a wide variety of constituents including dissolved oxygen, temperature, biochemical oxygen demand, organic nitrogen, ammonia nitrogen, nitrate nitrogen, total nitrogen, sediment oxygen demand, organic phosphorus, inorganic phosphorus, total phosphorus, phytoplankton and algae. The model can also simulate such other variables, such as pH, alkalinity and pathogenic bacteria. The illustrations and uses of this model are described in detail in Chapter 3.

CHAPTER 3: METHODOLOGY

3.1 General

This chapter describes the materials and the methodologies that were applied to achieve the objectives of the research. The approach applied in this study follows the method of a Material Flow Analysis (MFA) water quality assessment and QUAL2K. This chapter includes the details information of the study area, data collection procedure, as well as the data analysis and model setup. Figure 3.1 shows the research workflow developed which consists of three main stages.

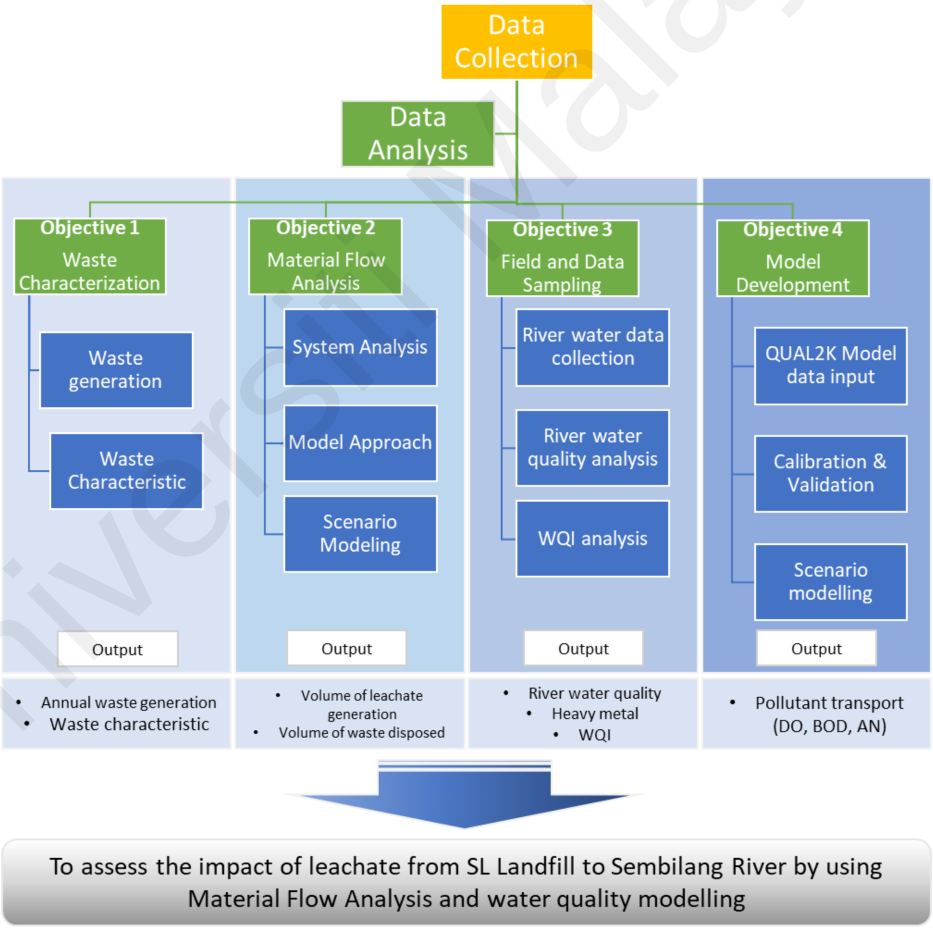


Figure 3.1: Research workflow

The first phase involved an analysis using the MFA method. The purpose of MFA is to quantify the flow of waste of the inputs, stocks and outputs in a particular region and time. For this research, a sanitary landfill which accepts waste from households, industries, institutions, etcetera is studied. In the second phase, the water quality of Sembilang River were measured and analyzed using the standard method. The water quality model was developed using QUAL2K software. Modelling includes hydraulic (discharge) and water quality.

3.2 Study Area

The study area is Sembilang River which lies in the Selangor River basin that is located within Kuala Selangor, in the state of Selangor, Malaysia (Figure 3.2). The catchment area is 633.79 m^2. The river's length is approximately 7,840 m long. A number of agricultural activities are located along the Sembilang River which includes Bukit Panjong Estate, Athlone Estate, Choh Estate, Jeram Estate and Bukit Cherakah Estate.

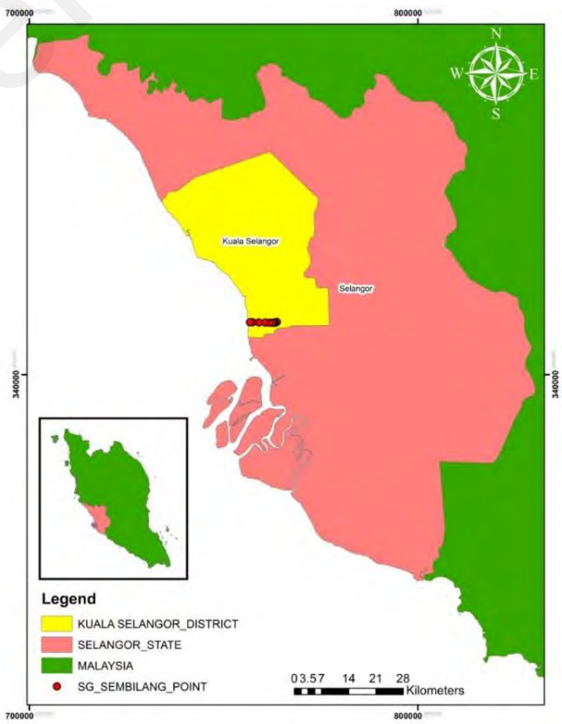


Figure 3.2: Study area located in Kuala Selangor, Selangor

Figure 3.3 shows a map of the study area that has been obtained from the satellite image Landsat 8 covering sampling points along the Sembilang River from the upper stream to the downstream. Spatial data collection has also been carried out in the field by marking GPS (latitude and longitude location) of all sampling stations on the study area. All ten sampling points (J01, J02, J03, J04, J05, J06, J07, J08, J09, J10) were used during the sample collection for water quality and water modelling. The landfill is located downstream of the river at the third sampling point. Each sampling point has been described in detail under section 3.3.3.

Figure 3.3: Map of study area obtained from Landsat8 for 2016

3.2.1 Land use

Generally, most of the land use along the Selangor River is forests and agriculture. More than 57% of the basin area is still covered with natural forest areas, including in northeastern part near to the Selangor River Dam and the swamp forest that is covering the central and lowlands. Meanwhile, 23% of the basin area is used for agricultural activities, especially rubber and oil palm plantations. Similarly, Kuala Selangor's land use can be categorized as peat swamp forest, mangrove forest, urban and associated areas (residential area, homestead, industrial, institutional areas), water bodies (rivers, canals, mining pools) oil palm plantation, mixed horticulture, upland forest, paddy fields and coconut plantation. Table 3.1 shows the percentage of land use in Kuala Selangor by category.

Table 3.1: Major land use in Kuala Selangor (Mohammad et al., 2017)

Landuse categories	**%**
Peat swamp forest	30.39
Mangrove forest	2.49
Urban and Associated areas	7.52
Water bodies	2.67
Oil palm plantation	37.97
Mixed horticulture	3.3
Dipterocarp forest	1.41
Paddy fields	5.37
Coconut plantation	8.87

The economy of Sembilang River is based predominantly on agriculture (palm oil plantation) and primary industries. At the upstream of the river, lies SL Landfill which was built in 1997. Along the river from upstream until before the downstream is covered with palm oil plantation and there are several residential areas with a population of 9,500. At the upstream of the river, there is Tuan Mee Estate workers estate which is located 800 m from the landfill. At the downstream of the river, there are also a few villages and housing area which is located 3 to 5 km from SL landfill including Simpang Tiga Village, Tambak Jawa Village, Sungai Serdang Village, Tok Muda Village and Bukit Kerayong Village, where these areas are located at downstream of the river near to Pantai Remis. Other than that, there is a small industrial area that is located downstream of the river where factories process rubber, plastic and timber. Located south of the river is the tourist attraction and for seafood enthusiast, Pantai Remis.

3.2.2 Hydrological information

The climate in Selangor is dominated by humid and tropical climate. The characteristic climate featured here is uniform temperature with minimal variation throughout the year. The rainy season, i.e., Northeast monsoon is usually from October to April and the dry season, i.e., Southwest monsoon is from May to September. Beginning of the southwest monsoon in May, however, there is no heavy rain (Chong et al., 1990). The highest monthly rainfall is in October to November and April to May. The average daytime temperature can reach 32˚C and drop to 23˚C at night. The average annual rainfall varies between 2,000 to 3,000 mm throughout the watershed. The southwest monsoon had the greatest impact on the western part of the Peninsula, particularly in characterizing the rainfall pattern of the northwest region. Open water evaporation ranges from 1,600 mm to 1,800 mm, while the relative humidity is 80% on average each year (Breemen, 2008; Shafie & Julien, 2009; Zin et al., 2013). The Selangor river experiences an average discharge of 57 m^3/s, with a seasonal rainfall variations that cause the flow to exceed 122 m^3/s or to fall below 23 m^3/s, which is about 10 percent of the time (Nelson, 2002).

The main cause of this study was in the Selangor River and specifically in the Sembilang River because in Malaysia, almost all solid waste disposal sites are built near the river. There are five major solid waste disposal sites are located in the Selangor River, namely, the Great River Landfill, Sungai Sabai Landfill, Bukit Beruntung Landfill, Bukit Tagar Sanitary Landfill, and the SL Sanitary Landfill which is in Sungai Sembilang. The Selangor River is Selangor's main raw water source, accounting for 63% of the total surface water abstraction for domestic, business, trade, industry and other uses by the people of Selangor. Therefore, it is important to know the amount of solid waste that is disposed as well as the amount of leachate that is produced from the landfills that are located near to the river.

i) **SL Landfill: Overview**

SL is under the concession agreement for a period of 25 years old with the Selangor State Government. Size of landfill is 160 acres and it is designed with the capacity for to accommodate 8 million tons of waste. About 2,500 tons of wastes were disposed of at a landfill daily, and sothus far, 7.1 million tons of waste has been added to dumping sites (Jotin et al., 2012). SL landfill has estimates estimated that the landfill site that is available this is ready for closing on in year 2017. Therefore, the state government has located of 130.55 acres of an adjacent land adjacent to the existing site in order forto continue the run the lifespan of this landfill. This has been carried out and obtained by the State Economic Planning Unit (UPEN) and obtained. The expansion of the SL shall have a daily capacity of 1,500 to 3,000 tonnes/day tonnes per day with a total target of 7 million tonnes for its lifespan and is expected to provide municipal waste disposal services for an additional 8.3 years after the year 2017.

The landfill development embraces all the elements that are required to be in place in the landfill to ensure that the waste that has been brought in is efficiently disposed and managed at the landfill cell. The main constructed components include waste reception area, internal and external road network, washing facilities for vehicles, parking for landfill equipment and vehicles, workshop or maintenance area and firefighting facilities and equipment.

The land use around this landfill site is pioneered by agricultural activities, especially the cultivation of oil palm owned by Tuan Mee Estate and Sime Darby Estate (Mussa et al. 2015). The nearest residential area to this landfill is within 800m, which is the placement for Tuan Mee estate workers. In addition, there are fish landing areas located downstream of the study area, Sembilang River and several nearby rivers. Fishing activities are usually carried out 1-10 km from the coastline until the Pantai Remis. In addition to fishing activities, there are also aquaculture activities downstream of the study area, namely shrimp pond culture, shellfish breeding and marine hatchery operations. No recreation activities were conducted around the study area, however at downstream areas recreational activities were conducted at Seri Kumining and Pantai Remis pools for fishing on the shore and at Sembilang River for fishing on the boat. These activities provide income for the locals.

3.3 Methodology

3.3.1 Waste Data Collection

The review of secondary data has been done for this study. Firstly, there is the desk study which involved the consultation of official reports, articles, legal documents, published and unpublished literatures and case studies. The information accessed, captures a wide range of information on SL Landfill. The primary data collection consists of the source of waste that is received by the landfill, waste generations and waste compositions. Study visits were made to the SL Landfill for a year from 2015 to 2016. Data of waste in tonnage on a monthly basis were also collected from SL Landfill for year 2005 until 2016. The landfill caters for seven major municipalities in the Klang Valley, namely, Kuala Selangor (KSDC), Subang Jaya, Kajang (KjCC), Petaling Jaya (PJCC), Shah Alam (SACC), Ampang Jaya (AJMC) and Selayang (SMC). The existing information and data from SL landfill had clearly stated that the generated waste in Malaysia including Selangor was collected without any prior isolations process. This means that the wastes received at the SL Landfill were mixed wastes that were of various types. The waste composition study was done to identify the types of waste that are disposed in SL Landfill. In this case, the types of waste that are received are domestic waste, bulky waste, garden waste and domestic sewage sludge. The received waste was categorized based on the Solid Waste and Public Cleansing Management Act 2007, Act 672.

3.3.2 MFA Methodology

Figure 3.4 shows the Material Flow Analysis (MFA) framework model that is used in this study, which is based on Brunner & Rechberger (2004) approach. Figure 3.4 shows the five phases that are involved, which are labeled as 1) System analysis 2) Model approach 3) Data acquisition and Scenario development. In this study, the model system selected was SL landfill with two major materials that are being observed, namely, solid waste disposed and the amount of leachate generated. Three scenario case studies were analyzed as a method towards reducing the amount of leachate that would be discharged into the Sembilang River.

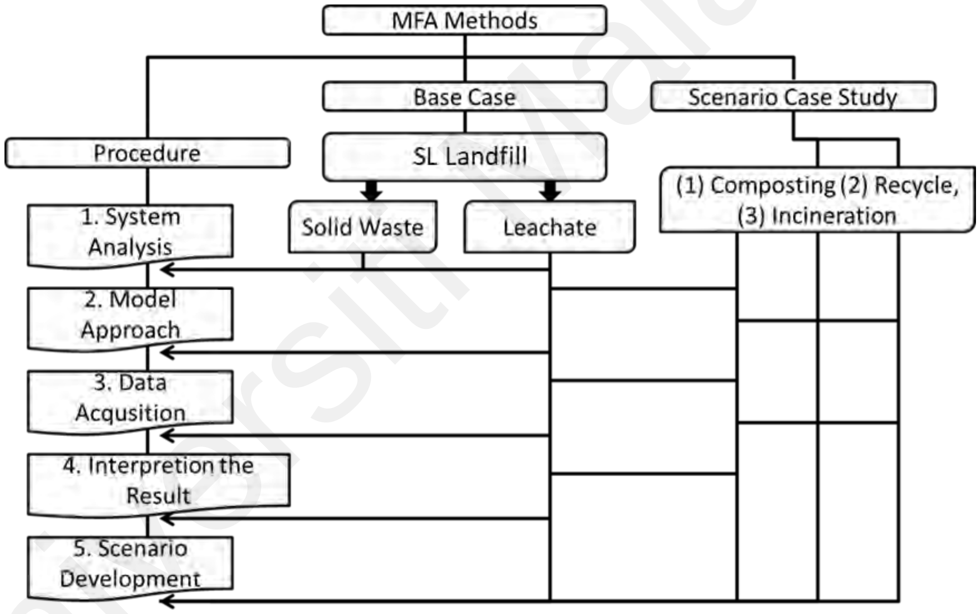


Figure 3.4: The framework of MFA study

MFA comprises the following main steps:

1. The system analysis defines temporal and spatial boundaries, the desired goods, processes, indicator substance. Based on an acquired understanding of the system, the relevant balance volumes and flows of the system are identified.
2. The relationships within the system are formulated as mathematical equations, in which the variables describe the flows and stock change rates of the system. A

set of parameters is used to quantify these variables. These parameters are either measured data (e.g. concentrations or area/populations) or estimated or calculated transfer coefficients (e.g. waste distribution).

3. The input data for these parameters is acquired from available secondary sources, complemented by the estimations and specific primary data assessment, and calibrated in consultation with experts.
4. With the compiled dataset, the current state of the material flows (waste flows within SL landfill) is simulated.
5. With the aid of a sensitivity analysis, the critical parameters of the system, i.e. the key process which influence the leachate flows, can be identified.
6. In targeting the sensitive processes, mitigation measures can be most effective. Thus, to decrease the leachate flows, possible mitigation measures (scenarios) are simulated and evaluated for their effectiveness. A model for SL landfill is implemented using STAN 2.6.

Table 3.2: Terms and description used in this study

TERMS	DESCRIPTION	In this study
Goods	Goods are any economic entities of matter with a positive or negative economic value and are made up of one or several substances	Waste, leachate
Processes	Processes are defined as the transformation, transport or storage of materials	Waste receiver, landfill, leachate pond, buy back centre, landfill gas collection well
Flows	Flows are defined as a mass flow rate with the ratio of mass per time	Incoming waste flow, waste flow, leachate flow, precipitation and evapotranspiration flow, effluent flow, surface runoff flow, landfill gas
Transfer coefficients	Transfer coefficients describe the portioning of materials in a process	The sum of the transfer coefficients to all output flows must be 1, considering that transfers into the stocks are also counted as outputs.
System	System is the actual object of investigation. It connects the flows and stocks of materials and substances by processes and is limited by system boundaries, which are defined in space and time	SL landfill

i) System analysis

SL landfill is chosen as a system boundary for the study and the year 2016 has been selected as a time scale of a period of one year since this 3-year research has commenced in 2015 and end by 2017. The complete data was on the whole of 2016 data that had been collected from the year 2016; it was the most consistent and represented the normal situation in Malaysia. Therefore, the water quality data had been collected in the same year. All the indicators in the system had been recorded in the unit of ton per year. The boxes designate processes and the arrows represent flows. The system was divided into six main subsystems: MSW, MRF, Landfill, Buy, back centre, and leachate pond. Only processes and goods that are related to leachate flow will be discussed, which includes landfill gas calculation based on calculation below.

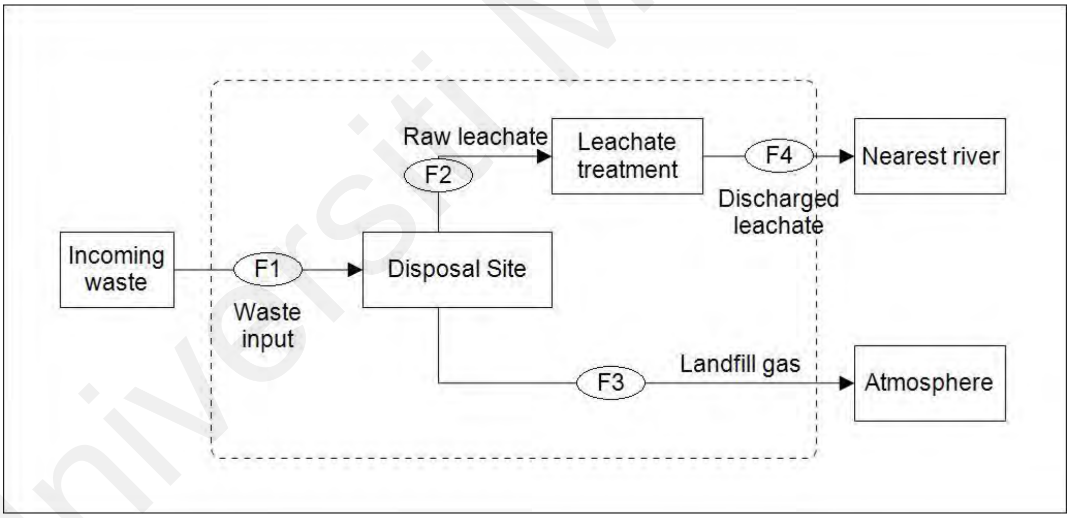


Figure 3.5: Typical landfill system in Malaysia

The processes included in the MFA model of the total leachate flows are presented in Figure 3.5. This refers to the general Malaysia's landfill system, through sorting of the waste and landfill site, until the processes of treatment and the final discharge to the nearest river. The analysis of this system is ended with a downscaled MFA model framework using the qualitative approach.

ii) Model Approach

This part of the analysis is based on data that are obtained mainly from the official national statistics and information from various institutions and landfill operator, available reports and other literature sources. The list of the main information and data sources for the MFA of the total leachate flow is presented in Appendix A.

iii) Data Acquisition and Calculation

In this phase, the construction of this static model involved different and independent mathematical equations and formulas, according to individual expertise. The detailed description for every mathematical formula involved is available in Appendix A. The quantification process of mass accounting flow was performed on related subsystems. Based on the assumption in the context of this study, the system refers to the neutral dependent variables (atmosphere), while the subsystem refers to the non-stationary independent variable (MSW, MRF, landfill, leachate pond, buy back centre, landfill gas collection well).

Data Acquisition

This section is depended on the mass conservation MFA model input of variable parameters that are used in each research method. The statistical data was obtained from various sources (Appendix B).

Data Calculation

There were two key formulas that were used in this study:

a) Material flows are calculated from the following equation (Rechberger 2001):

$$Xij = Mi \times Cij \, , \quad (3.1)$$

where
X = substance flow (tonnes/ year or kg/year)
M = mass flows of goods (tonnes/ year)
C = substance concentrations in these goods (tonnes/tonnes or kg/tonnes)
i = 1,….,k indicates the goods type
j = 1,….,n indicates the substance type

b) The following equation is used to described leachate generation (Baucom & Ruhl 2013):

The basic configuration of this method is that the landfill consists of a covered surface, a compacted waste compartment, and a lining system.

Where AET= actual evapotranspiration; b= water production by biodegradation of waste; I_g= water from underground; J=leachate recirculation; L= leachate generated; L_c= collected leachate; L_I=leachate infiltration in clay liner; P=precipitation; R_{off}= runoff; R_{on}= run-on; S=water in sludge; U_w= water content in wastes; U_s= water content is soil cover; W_g= water consumed in the formation of landfill gas;W_v= water lost as water vapor.

The water balance of the landfill was derived; making use of assumptions in instances where it is applicable that infiltration through the top of the waste pile is calculated using equation 3.2.

$$I = P + J + R_{on} + R_{off} - AET \pm U_s \quad (3.2)$$

where:
I: Infiltration (mm/year) P: Precipitation (mm/year)
J: Leachate recirculation (mm/year) R_{off}: Runoff (mm/year)
R_{on}: Run-on (mm/year)
AET: Actual evapotranspiration (mm/year)
U_s: Water content in soil cover (mm/year)

Assuming that:

1. The final soil cover is existent and the moisture content of the daily thin layers

of soil is assumed to be at field capacity, and is assumed to not contribute significantly to the total moisture content of the cells (U_s=0)

2. The landfill has been designed so that water from outside the site does not enter (R_{on} = 0).

Therefore, infiltration (I) through the top part of the waste pile becomes:

$$I = P + J - R_{off} - AET \quad (3.3)$$

Where the change in waste water volume, due to external sources (PL), is computed as:

$$P_L = I + I_g \quad (3.4)$$

where Ig: is the water from the aquifers entering the landfill (mm/year). Assuming that water entering the landfill from aquifers is negligible (I_g = 0), the change in waste water volume, due to external sources (P_L), is computed as:

$$P_L = I \quad (3.5)$$

Then, the total leachate production is computed as:

$$L = P_L \pm U_W + b \quad (3.6)$$

where b is water production by the biodegradation of waste (m^3/year) and U_w is the water content in waste (at field capacity) (m^3/year). The water produced, due to the biodegradation of waste, is assumed to be very small and negligible (b = 0). Therefore:

$$L = P_L \pm U_W \quad (3.7)$$

Water from the site surface is normally absorbed by the waste before the field capacity is reached. Even if water absorption exceeds this amount, water movement by waste takes place initially under unsaturated conditions or, if ample water is present, under saturated conditions.

Landfill gas production was calculated based on EPA's Landfill Gas Emissions Model (LANDGEM) (Emkes et al. 2015; Meraz et al. 2004)

$$Q_n = k \,.\, L_0 \,.\, \sum_{I=0}^{n} \sum_{J=0.0}^{0.9} \frac{M_1}{10} \,.\, e^{-k.ti.j} \quad (3.8)$$

where,
Q_n = CH_4 generation rate ($m^3 \cdot yr^{-1}$) in year *n*,
k = first-order waste decay rate (yr^{-1}), 0.04 yr^{-1}
L_0 = CH_4 generation potential (m^3-$CH_4 \cdot Mg^{-1}$ wet waste), 100 $m^3 \cdot Mg^{-1}$
M_1 = waste mass placement in year *i* (Mg)
j = deciyear time increment
t = time (yr)

Methane output

$$M_{x,t} = (B_A - B_I)/B_I \quad (3.9)$$

where,
methane output for site 'x' at time 't'
B_A = actual methane output (m^3/yr)
B_I = ideal value for methane output (m^3/yr)

iv) Result of MFA Model Simulation

After the calibration and quantification processes for each material (solid waste and leachate) was performed, the results for MFA model simulation for the current material flow in SL Landfill was obtained. The results for MFA model simulation were summarized as MFA physical inventory. A calculation was performed according to the respective case scenario scale.

v) Scenario Development

Scenarios are developed to determine the best management in terms of reducing leachate to be discharged into the river in terms of reducing the waste that is disposed into the landfill. Scenarios (Scenario 1, Scenario 2 and Scenario 3) were done by modification and improvement of existing condition (Status quo). Each scenario represents a different treatment options, resulting in specific flows of goods including recycling products, emissions and residues.

1) Status quo

The existing condition of the waste management system in SL Landfill are receiving, recording, structuring and compacting waste in a landfill site. Waste sorting is still done manually by scavengers. Further into landfill MRF system that has not reached the design usage of the MRF as well as composted and recycled raw materials (still very low activities).

2) Scenario 1: Recycle

To increase recycling rates at SL Landfill, the potential recyclables were isolated in the MRF system: any remaining wastes that have been subjected to isolation but are not suitable for recycling will be disposed of at the landfill. For recycle two solid output fractions are considered: recycled waste and leachate generation.

3) Scenario 2: Composting

Whereas in Scenario 2, the appropriate wastes for composting will be isolated in the MRF system. The categories of waste that are suitable for composting are organic waste, textile, leather and garden waste. Composting generates two solids of output fractions: compost, which can be use as plant fertilizers, and leachate generation. In addition, for both scenarios, off gas and surface water are also generated. Literature data about the brought in waste, leachate and effluent production were used to characterize all the processes.

4) Scenario 3: Incineration

Scenario 3 focuses on the achievement of the alternative energy target. The categories of waste that are suitable for incineration are mainly plastic, paper and organic waste. Incineration provides the best way to eliminate methane gas emissions from waste management processes. Furthermore, energy from waste projects provides a substitute for fossil fuel combustion. These are the two ways incineration helps to reduce greenhouse gas emissions. In addition to disposing of waste and reducing landfill space, WTE electricity and/or heat for use on site and export off site.

The scenarios are developed aiming to reduce the leachate generation and effluent discharged to the river. The following criteria have been used in accordance with the goals of waste management and the shortcomings of the status quo: (1) Conservation of resources (material, energy, space), (2) Minimization of landfill space by waste pre-treatment before landfilling and (3) No negative impact of emissions on water (reduction of effluent discharge to the river). These three criteria cover all relevant aspects that are necessary for developing a new waste management system for the SL Landfill, such as conservation of material, energy and space, and environmental protection. The level of separate collection of waste is different for all two scenarios and is considerably higher than the status quo.

3.3.3 Water Quality Methodology

i) Data Collection

Water quality sampling was conducted in order to know the present water quality of Sembilang River. Water samples were collected from 10 sampling stations for every two months from September 2015 to September 2016. The length of Sembilang River is approximately 7km. The samples were analyzed and the results were recorded.

ii) Sampling Methods

A Global Positioning System (GPS) was used to record the exact latitudinal and longitudinal coordinates of each location for later identification on digital maps. Other factors such as anthropogenic activity, point sources, Non-point sources were also taken into account during the selection of the sampling stations in order to provide the opportunity to relate results to the conditions and environment in which they were collected. Locations of the sampling stations are presented in Figure 3.3. Water samples were collected during the period from September 2015 to September 2016. Table 3.3 shows the description of the sampling stations.

Table 3.3: Location point of study area pindah atas bawah map

Location Point	Status	Coordinate		Remarks
		Latitude (Deg.)	Longitude (Deg.)	
J01	Upstream	3.196	101.373	Upstream of SL Landfill
J02		3.194	101.370	Upstream of SL Landfill
J03	Downstream	3.194	101.367	Where landfill effluent discharge
J04		3.194	101.360	300 m from the landfill
J05		3.194	101.353	Palm oil plantation site
J06		3.195	101.330	School
J07		3.195	101.326	Factories
J08		3.195	101.320	Industrial zone
J09		3.195	101.315	Highway culvert
J10		3.195	101.311	Nearer to the sea

International Organization for Standardization (ISO 1985) was followed for sample handling and preservation. Replicate samples were collected in 500ml plastic bottles from each location. Vessels were thoroughly rinsed with water from the surface layer of the river or equivalent water source before collection. This procedure was exercised to lower the risk of sample contamination. Water was collected upstream from where the person carrying out the collection stood. In this way, any mixing in the water column from the movement of the sampler could be avoided. The filled bottles were wrapped in aluminum foil and placed in an ice box to be kept out of direct sunlight. The purpose of this step was to minimize degradation of chlorophyll *a* and any nutrients and metals that were present in the sample. Samples were transferred to a refrigerator for storage until further analyses were conducted.

iii) Water Quality Parameters

The parameters chosen for analysis of water quality for this study are presented in Table 3.4 below.

Table 3.4: Type of water quality analysis

Analysis Type	Parameter	Apparatus/ Test name
In-situ	Temperature; dissolved oxygen (DO), DO%, conductivity, total dissolved solid (TDS), salinity and pH	Handheld Multi parameter Instrument (YSI, Inc.)
	Turbidity	Turbidity meter 2100P (HACH, Inc.)
	River width	Leica Distro Laser Distance
	Proppeller (n), velocity calculation	Current meter
	River water level	Depth Sounder
Laboratory	Biochemical oxygen demand (BOD)	APHA 5220B: Open Reflux method
	Chemical oxygen demand (COD)	APHA 5210B: 5Days BOD Test
	Ammoniacal nitrogen (NH3-N)	ASTM D3590-II: Standard Test Methods for Total Kjeldahl Nitrogen in Water
	Total suspended solid (TSS)	APHA 2540B: TSS dried 103^0 to 105^0
	Heavy Metal	ICP-AES analysis
	Nitrate and Phosphate	APHA 4500P
	Total coliform, E. coli	MPN method

These parameters were primarily chosen from an assessment of the standard characteristics for measuring the water quality presented from the literature (as shown in Chapter 2). By measuring these parameters it also provided the possibility of determining both their individual and collective effects on riverine water quality.

All those field apparatuses for in-situ analysis were calibrated prior to use based on the manufacturer's directions.

Temperature, dissolved oxygen (DO), conductivity, and pH were measured insitu as field parameters by YSI meter, while BOD_5, COD, TSS, O&G, turbidity, PO_4, SO_4, NO_3, NH_3-N, total hardness (TH), and fecal coliform (FC) were analyzed in the laboratory. BOD_5 was analyzed as described by 5-day test, and COD was assayed by means of the open reflux method. Additionally, total suspended solids (TSS) were determined by total solids dried at 103–105°C (APHA 2540D method). Moreover, ion analysis (phosphate and nitrate) and ammonia nitrogen were assayed by following the standard method APHA 4500 and nitrate ions were analyzed using a standard addition method since some sampling stations showed limit of quantitation in the on-site analysis where the LAQUAtwin was calibrated using a standard solution of 150 ppm and 2000 ppm, respectively. Furthermore, total hardness was determined by convenient Inductive Coupled PlasmaMass Spectrometry (ICP-MS ug/L). Eventually, fecal coliform was determined based on the membrane filter technique following the MPN method (IDEXX). The samples preparation for heavy metal analysis had been completed following USEPA-2007. Digested samples were analyzed for most of the metal concentrations by an ICP-optical atomic emission spectrometry. For this evaluation of water quality, the total dissolved elements and major ions concentrations which were analyzed included: Cd, Cr, Cu. Ni, Pb, Fe, Al, Zn and Mn.

3.3.4 Water Quality Index (WQI) Calculation

The pollution level of the river water quality assessment was conducted by calculating the WQI. The DOE water quality classification based on WQI value are presented in (Appendix-E). The water quality index was obtained with the following equation (DOE, 2009) is given by equation 3.10.

$$WQI = 0.22SI_{DO} + 0.19SI_{BOD} + 0.16SI_{COD} + 0.16SI_{SS} + 0.15SI_{AN} + 0.12SI_{pH} \quad (3.10)$$

Where, WQI = water quality index; SI_{DO} = sub-index of DO; SI_{BOD} = sub-index of BOD; SI_{COD} = sub-index of COD; SI_{AN} = sub-index of AN; SI_{SS} = sub-index of TSS; SI_{pH} = sub-index of pH; these sub-indexes are calculated by the flowing equations:

SIDO	$=0$	for	$DO < 8$	3.11a
	$=100$	for	$DO > 92$	3.11b
	$= -0.395 + 0.030DO^2 - 0.00020DO^3$	for	$8 < DO < 92$	3.11c
SIBOD	$= 100.4 - 4.23BOD$	for	$BOD < 5$	3.12a
	$=108e^{-0.055BOD} - 0.1BOD$	for	$BOD > 5$	3.12b
SICOD	$= -1.33COD + 99.1$	for	$COD < 20$	3.13a
	$= 103e^{-0.0157COD} - 0.04COD$	for	$COD > 20$	3.13b
SIAN	$= 100.5 - 105AN$	for	$AN < 0.3$	3.14a
	$= 94e^{-0.573AN} - 5 \lvert AN - 2 \rvert$	for	$0.3 < AN < 4$	3.14b
	$= 0$	for	$AN > 4$	3.14c
SISS	$= 97.5e^{-0.00676SS} + 0.05SS$	for	$SS < 100$	3.15a
	$= 71e^{-0.0016SS} - 0.015SS$	for	$100 < SS < 1000$	3.15b
	$= 0$	for	$SS > 1000$	3.15c
SIpH	$= 17.2 - 17.2pH + 5.02pH^2$	for	$pH < 5.5$	3.16a
	$= -242 + 95.5pH - 6.67pH^2$	for	$5.5 < pH < 7$	3.16b
	$= -181 + 82.4pH - 6.05pH^2$	for	$7 < pH < 8.75$	3.16c
	$= 536 - 77.0pH + 2.76pH^2$	for	$pH > 8.75$	3.16d

3.3.5 Water Quality Modelling

QUAL2K is a water quality model that has been developed by the United State Environment Protection Agency (US EPA) with the capability to simulate various river water quality that are well mixed laterally and vertically. This model is the modernized version of QUAL2E with several modifications that were made in the computer code to overcome its limitations. It has an advantage to be implemented with the current Microsoft Windows Environment. In this study, QUAL2K has been chosen to model the quality of Sembilang River in order to assess the environmental impact of multiple pollution discharges along the river. Moreover, QUAL2K model was chosen for the present study due to the selected optimal river water quality improvement program through simulation of various hypothetical scenarios and to determine whether the implementation of this scenario is able to achieve the desired goals. The sequence of steps that are needed to develop a water quality model using QUAL2K is illustrated in Figure 3.6.

i) QUAL2K

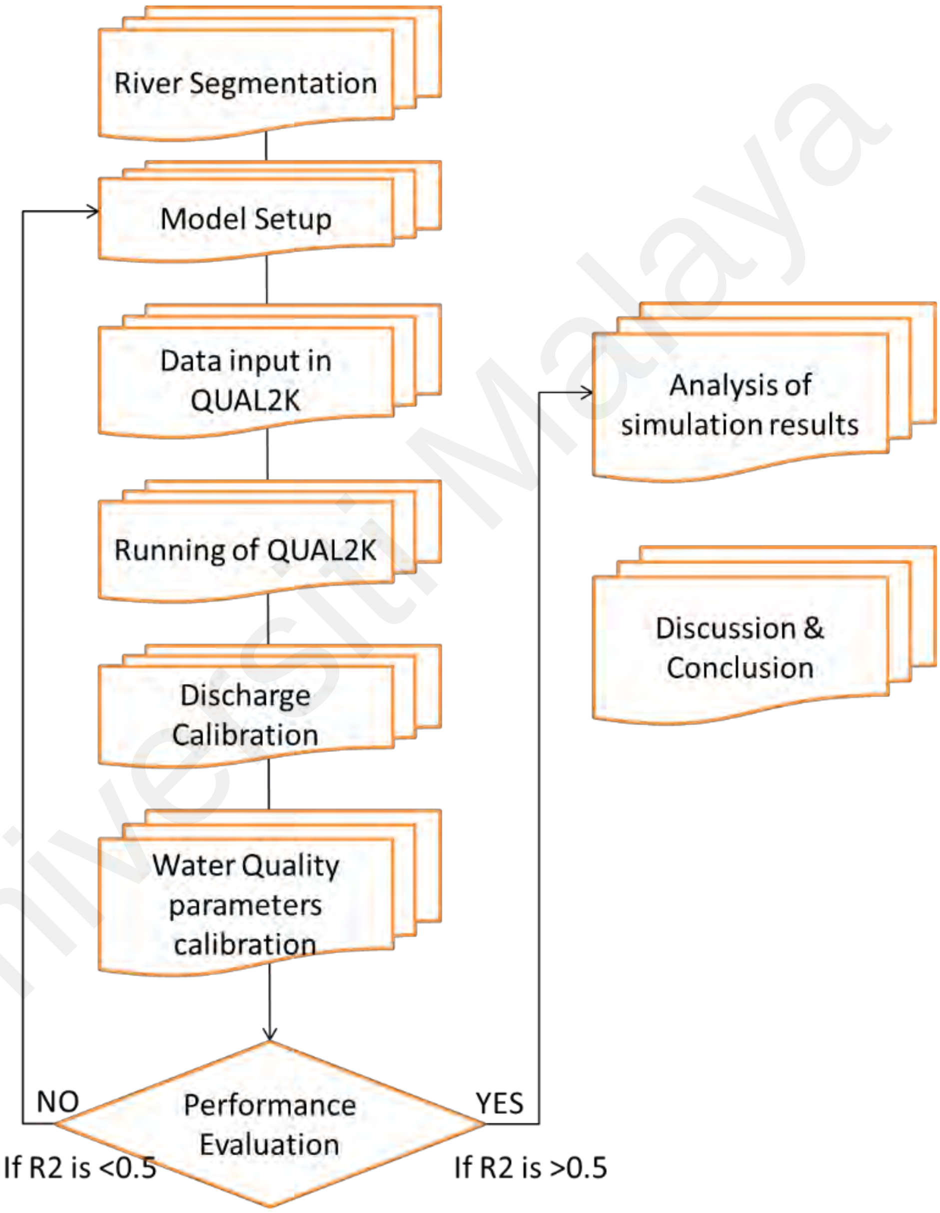


Figure 3.6: The framework of water modeling study

ii) River System of Sembilang River

In a river system consisting of only one river (no tributaries), the QUAL2K model divided the river as a series of reaches. These represent stretches of river that have constant hydraulic characteristics (slope, bottom width, etc.). As represented in Figure 3.7, starting from the headwater of the river's main stem, the reaches are numbered in ascending order. In such a way, both point and non-point sources along with point and non-point withdrawals (abstraction) can be positioned anywhere along the channel's length.

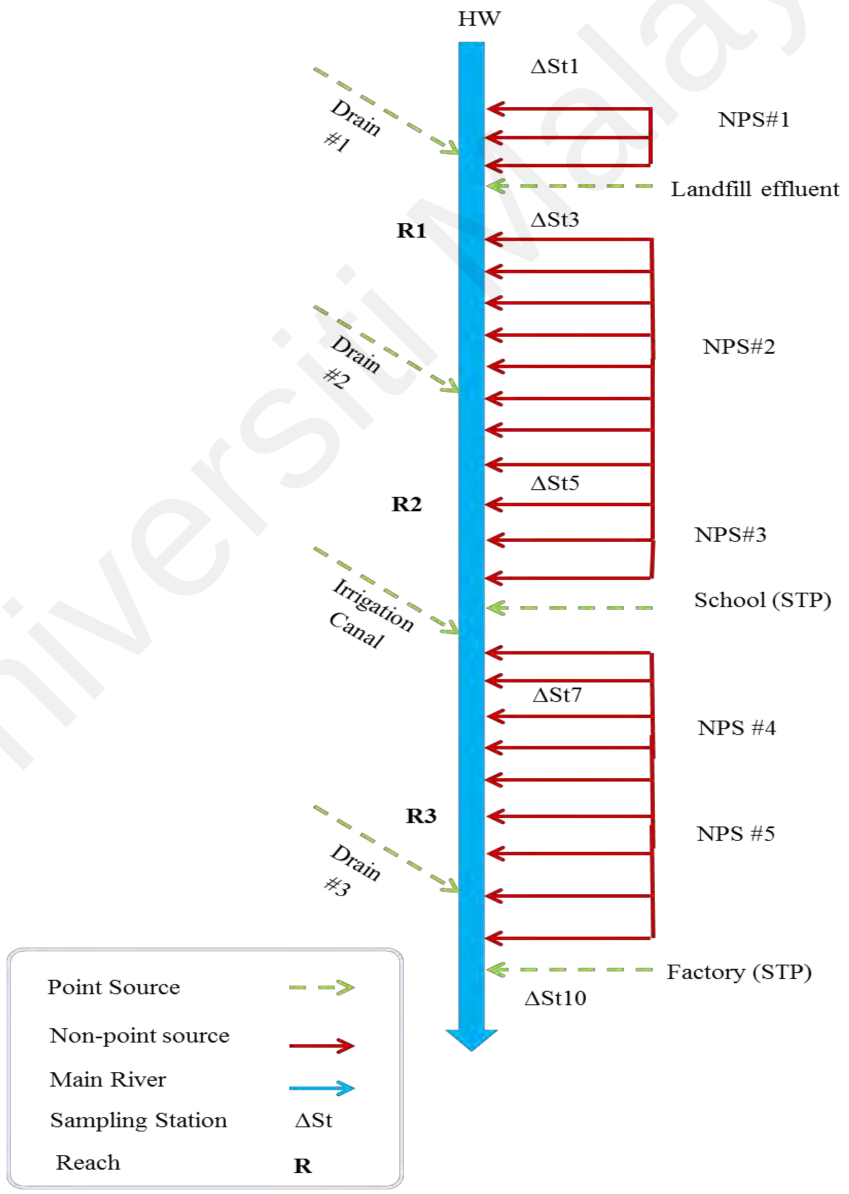


Figure 3.7: Schematic of the Sembilang River network

Sembilang River is a short river so it was divided into 3 reaches. Figure 3.7 shows the schematic diagram of the Sembilang River and illustrates the reaches, the sampling stations and the head water. The upstream border is a few meters from SL Landfill, while the downstream border is 7 km upstream from the coastal region.

iii) Flow calculation in QUAL2K

Flow calculation in the QUAL2K model is based on one of three formulas, which are: the Manning formula, Rating curves or weirs. In this study, flow calculation was performed based on Manning's formula. Each element in a particular reach can be idealized as a trapezoidal channel in Manning's formula (Figure 3.8). Manning's formula can be expressed as equation 3.17 under steady flow conditions:

$$Q = \frac{S_0^{1/2} A_c^{5/3}}{n\, P^{2/3}} \qquad 3.17$$

where Q = flow (m^3/s), S_0 = bottom slope (m/m), n = the Manning roughness coefficient, Ac = the cross-sectional area (m^2), and P = the wetted perimeter (m).

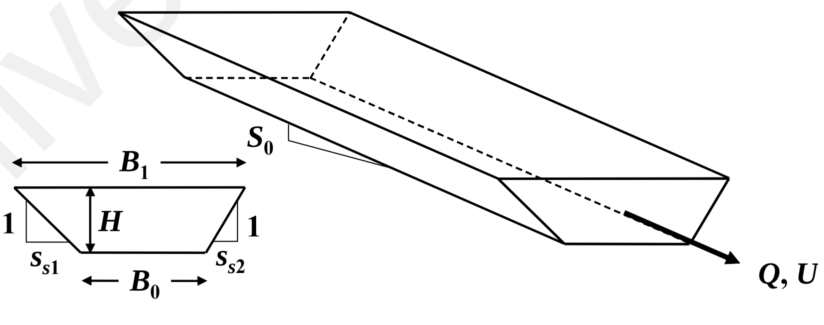


Figure 3.8: Trapezoidal channel

The cross-sectional area of a trapezoidal channel is computed as

$$A_c = [B_0 + 0.5(s_{s1} + s_{s2})H]H \qquad 3.18$$

where B_0 = bottom width (m), s_{s1} and s_{s2} = the two side slopes as shown in Figure 3.10 (m/m), and H = element depth (m).

The wetted perimeter is computed as follows:

$$P = B_0 + H\sqrt{s_{s1}^2 + 1} + H\sqrt{s_{s2}^2 + 1} \tag{3.19}$$

After substituting equation 3.18 and 3.19, equation 3.20 can be solved iteratively for depth (Chapra & Canale, 2006),

$$H_k = \frac{(Qn)^{3/5}\left(B_0 + H_{k-1}\sqrt{s_{s1}^2 + 1} + H_{k-1}\sqrt{s_{s2}^2 + 1}\right)^{2/5}}{S^{3/10}\left[B_0 + 0.5(s_{s1} + s_{s2})H_{k-1}\right]} \tag{3.20}$$

where k = 1, 2, …, n, where n = the number of iterations. An initial guess of H_0 = 0 is employed. The method is terminated when the estimated error falls below a specified value of 0.001%. The estimated error is calculated as:

$$\varepsilon_a = \left|\frac{H_{k+1} - H_k}{H_{k+1}}\right| \times 100\% \tag{3.21}$$

As presented in Figure 3.9, the steady-state flow balance is implemented for each model reach according to equation 3.22 :

$$Q_i = Q_{i-1} + Q_{in,i} - Q_{out,i} \tag{3.22}$$

where Q_i = outflow from element i into the downstream element i + 1 (m^3/d), Q_{i-1} = inflow from the upstream element i – 1 (m^3/d), $Q_{in,i}$ is the total inflow into the element from point and nonpoint sources (m^3/d), and $Q_{out,i}$ is the total outflow from the element due to point and nonpoint withdrawals (m^3/d). Thus, the downstream outflow is simply the difference between inflow and source gains minus withdrawal losses.

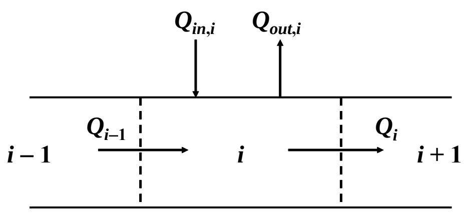


Figure 3.9: Element flow balance

The total inflow from the sources is computed with 3.23:

$$Q_{in,i} = \sum_{j=1}^{psi} Q_{ps,i,j} + \sum_{j=1}^{npsi} Q_{nps,i,j} \qquad 3.23$$

where $Q_{ps,i,j}$ is the jth point source inflow to element i [m^3/d], psi = the total number of point sources to element i, $Q_{nps,i,j}$ is the jth non-point source inflow to element i [m^3/d], and $npsi$ = the total number of non-point source inflows to element i.

The total outflow from withdrawals is computed as equation 3.24:

$$Q_{\text{out},i} = \sum_{j=1}^{pai} Q_{pa,i,j} + \sum_{j=1}^{npai} Q_{npa,i,j} \qquad 3.24$$

where $Q_{pa,i,j}$ is the jth point withdrawal outflow from element i [m^3/d], pai = the total number of point withdrawals from element i, $Q_{npa,i,j}$ is the jth non-point withdrawal outflow from element i [m^3/d], and $npai$ = the total number of non-point withdrawal flows from element i.

The non-point sources and withdrawals are modeled as line sources. As in Figure-3.10, the non-point source or withdrawal is demarcated by its starting and ending kilometer points. Its flow is then distributed to or from each element in a length-weighted fashion.

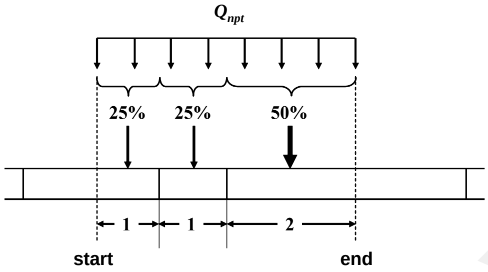


Figure 3.10: The distribution of non-point source flow to an element.

iv) Water Quality Calculations

This model can simulate fate and transport of many parameters and contaminants including temperature, pH, carbonaceous biochemical demand, sediment oxygen demand, dissolved oxygen, various kinds of nutrients, phytoplankton and bottom algae. In this study, DO, BOD and NH_3-N were chosen as the river water quality measurement parameters along the Selangor River basin. QUAL2K calculates the DO according to the following formula:

$$S_o = r_{oa}\text{PhytoPhoto} + r_{oa}\frac{\text{BotAlgPhoto}}{H} - r_{oc}\text{FastCOxid} - r_{on}\text{NH4Nitr} - r_{oa}\text{PhytoResp} - r_{oa}\frac{\text{BotAlgResp}}{H} + \text{OxReaer} \quad 3.25$$

Where $r_{oa}\text{PhytoPhoto}$= phytoplankton oxygen produced (g O_2d^{-1}), r_{oa}BotAlhPhoto= bottom phytoplankton oxygen produced (g O_2d^{-1}), r_{oc}FastOxid = O_2 required for carbon decay (gO_2gC^{-1}), r_{on}NH4Nitr = O_2 required for NH_4 nitrification (gO_2 gN^{-1}), r_{oa}PhytoResp = phytoplankton oxygen consumption (dO_2 d^{-1}),

r_{oa}BotAlgResp = bottom phytoplankton oxygen consumption($gO_2\ d^{-1}$) and roa, roc, rod and ron are parameters whose values were suggested by Chapra.

OxReaer as calculated by equation 3.26

$$\text{OxReaer} = k_a(T)\left(o_s(T, elev) - o\right) \qquad 3.26$$

where $k_a(T)$ = the temperature-dependent oxygen reaeration coefficient [/d], $o_s(T, elev)$ = the saturation concentration of oxygen [mgO_2/L] at temperature, T, and elevation above sea level, *elev*.

The DO increases due to plant photosynthesis. It is lost via fast carbonaceous biochemical oxygen demand (CBOD) oxidation, nitrification and plant respiration. Depending on whether the water is undersaturated or oversaturated, it is gained or lost through reaeration.

Regarding carbonaceous BOD, QUAL2K represents organic carbon in two forms, i.e. slow oxidizing form (slow CBOD) and a rapidly oxidizing form (fast CBOD). The slow oxidizing CBOD increases owing to detritus dissolution and is lost through hydrolysis and oxidation. In contrast, the fast oxidizing CBOD is gained through the dissolution of detritus and the hydrolysis of slowly reacting CBOD, and it is lost as a result of oxidation and de-nitrification. Therefore, the obtained BOD data is considered fast CBOD for the model input.

v) Hydraulic Characteristics in QUAL2K

After the outflow for each element is calculated, the depth and velocity are computed in one of three ways: weirs, rating curves, or Manning's equation. The selection decision will be made by the model according to the following conditions:

1. If the height and width of the weir are entered, the weir option is implemented.
2. If the height and width of the weir are zero and rating curve coefficients are entered (a and α), the rating curve is applied.
3. If neither of the above two conditions is met, Qual2K computes manning's equation.

vi) QUAL2K Model Simulation

QUAL2K is capable of modelling a wide range of chemical and biological pollutants in a river, such as nitrogen and phosphorus species, CBOD, pathogens, algae, phytoplankton suspended solids and detritus. The model simulates physical-chemical process including chemical equilibrium, water quality kinetics, dispersion, advection, settling and interactions with the atmosphere and river bed (sediment oxygen demand). The predicted water quality parameters throughout the modeled river include salinity and temperature, pH, dissolved oxygen concentration and the various pollution quantities.

vii) Data Input in QUAL2K Model

QUAL2K requires several data spread on several worksheets. There are two types of worksheet data input in QUAL2K, i.e. simulation data worksheets and calibration data worksheets. Simulation data worksheets are headwater, reach, diffuse sources, point sources, while calibration data worksheets are hydraulic data and water quality data. Table 3.5 shows the data input of the worksheets and their sources.

The necessary headwater data for input into the QUAL2K model are water quality parameters and hydraulic data. The model allows several water quality parameters to be entered in accordance with data availability as well as the study objectives. The hydraulic data needed by QUAL2K at the headwaters includes elevation, discharge, cross-section (bottom width), channel slope and the roughness coefficient ‘n’. These data are determined at the sampling stations from the field measurements as well as the GIS techniques and roughness coefficient. On the other hand, the water quality parameters were obtained from in-situ and laboratory lab analysis data. Similar data was required for each reach with an addition of the number of elements as well as the location of upstream and downstream for each segmented reach in kilometers. These data were obtained from the digital spatial map, DEM and the sampling data. Tables 3.5 and 3.6 illustrate the reach data used for running the models.

Table 3.5: QUAL2K data input in the worksheets and their sources

No.	Worksheet name	Data	Source
1	Headwater	Q, Channel Slope, roughness ‘n’, Bottom width	Sampling, DEM
		Elevation	DEM
		Water quality parameters	Sampling
2	Reach	Location (up and downstream of each reach), Downstream Long/Lat	DEM
		Elevation (Up and downstream)	DEM
		Channel Slope, roughness ‘n’, Bottom width	DEM
3	Diffuse sources	Location	DEM
		Inflow	Previous study (Yaakob 2015)
		Water quality parameters	Previous study (Yaakob 2015)
4	Point sources	Location	Digital map
		Inflow	Secondary data
		Water quality parameters	Previous study (Ishak et al. 2016)
5	Hydraulic	Location of sampling stations	GIS map
		Q	Sampling
6	Water quality data	Location of sampling stations	GIS map
		Water quality parameters	Sampling

The model represents the non-point sources (NPS) as two points based on their distance from the reach’s downstream. Therefore, the locations of the pollution sources are determined using GIS tools. NPS are distributed according to the land use distribution along the Sembilang River. With respect to the point sources, the model defines the location as a single point based on its distance from the reach's downstream. Thus, GIS tools were used to determine the location of the point sources.

Table 3.6: The used reach data for QUAL2K model

Reach No.	Reach length (km)	Location		Number of Elements
		Up-stream (km)	Downstream (km)	
Reach 1	2.28	6.93	4.65	1
Reach 2	2.57	4.65	2.08	1
Reach 3	2.08	2.08	0.00	1

viii) Calibration and Validation

Model calibration and validation are critical steps in achieving good model performance. Model calibration is defined as the process of tuning the parameter values to attain optimal agreement between the simulated and observed data. In other words, model calibration is the method of justifying the input data of the parameters until the model's output matches the observed data set (Abidin et al. 2018). Value estimation of different parameters and constants in the model structure is involved. Model calibration should be supplied with the numerical parameter values as well as the initial condition of the state variables and boundary conditions. The process of parameter justification can be done either manually (trial and error method) or automatically, by searching for an optimal value of a given criterion (Cheah 2016; Sadek 2017). However, the manual means is the most common and is recommended by the authors. Model validation, on the other hand, entails assessing the degree of reliability of the calibrated model using one or more independent data sets, but not the same data that is utilized for model calibration. In this study, two model calibration stages have been done, i.e. hydraulic and water quality parameter calibration. Water discharge was chosen for hydraulic calibration, while the DO, BOD and AN were selected for water quality calibration.

ix) Output

QUAL2K produces two output types, i.e. spatial output, which is defined by pink tabs for each parameter, and temporal output, which is defined by blue tabs for each parameter. The generated graphs for spatial output show the change in each parameter through the entire river section defined in one specified period. On the other hand, the generated graphs for temporal output indicate the concentration change in a specified river reach over a 24 hour period.

x) Performance Evaluation Criteria of Model

The farrier concocted,

$$R^2 = \frac{(n\sum_i^n M_i * S_i - \sum_i^n M_i * \sum_i^n S_i)^2}{\left[n\sum_i^n (M_i)^2 - (\sum_i^n M_i)^2\right] * \left[n\sum_i^n (S_i)^2 - (\sum_i^n S_i)^2\right]} \quad 3.27$$

where M = the measure data, S = the simulated data and n = the number of data points. According to (Henriksen et al., 2003), the R^2 value of ≥0.85 is considered as excellent, between 0.65 and 0.85 is considered as very good, between 0.5 and 0.65 is considered as good, between 0.2 and 0.5 is considered as poor, while values less than 0.2 are considered as very poor.

Standard error can be defined as the standard deviation of a sample that is used to estimate the value. In other words, it is a measure of the accuracy with which a sample represents the real value (ref). it can be calculated by the following equation:

$$SE = {}^{SD}/_{\sqrt{n}} \quad 3.28$$

Where, SE = standard error, SD = standard deviation, n = number of samples

CHAPTER 4: RESULTS & DISCUSSION

4.1 Population and waste generation

Selangor is Malaysia's golden state that accounts for the highest number of population concentration in Malaysia with 6.53 million people representing 19.9% of the total population in Malaysia. Selangor is Malaysia's most populous state, as well as the state with the largest economy in terms of gross domestic products. The total population of all these areas is 3,588,533 with a rate per person at 0.27 kg per day per person. Due to the economic impact and the rapid increase in population and lifestyle changes, MSW production has grown rapidly. Table 4.1 presents the waste generated per head per year for selected Selangor districts for the year 2015 including Kuala Selangor District Council (KSDC), Subang Jaya City Council (SJCC), Klang City Council (KCC), Petaling Jaya City Council (PJCC), Shah Alam City Council (SACC), Ampang Jaya Municipal Council (AJMC), and Selayang Municipal Council (SMC).

Table 4.1 shows waste generated per head per year for selected Selangor district in 2015. When municipal solid waste generation data are calculated on a per capita basis, each individual in Selangor is said to generate around 1.5 kg per day. However, there is considerable variation in waste generation across Selangor district. A number of variables, such as local climate, the economy, demographic characteristics of the population, the amount of tourism in the region and population density are potential variables which may account for the variation in the amount and type of waste produced when waste is measured on a per capita basis. The highest waste generated per head per year was KSDC with 0.39. Kuala Selangor is one of the rapid develop area in Selangor. These societal changes influence the characteristic of given households, including family size, residential location and community status. Correlation between household solid-waste generation and composition and relevant socioeconomic parameters.

Table 4.1: Waste generated per head per year for selected Selangor district (Department of Statistics Malaysia)

Municipal	Population, 2015	Annual MSW generated (tonnes)	Waste generated per head per year (t/person/year)
PJCC	539,999	85,136	0.16
SACC	517,377	180,636	0.35
KSDC	91,976	36,091	0.39
AJMC	570,842	27,376	0.05
KjCC	662,120	191,817	0.29
SJCC	709,708	17,435	0.02
SMC	496,511	3,809	0.01

While SJCC and SMC shows had the highest population in Selangor compared to other districts with the annual solid waste production being the second highest makes its waste generated per head per year 0.01 and 0.02 respectively. This is because the SJCC is mainly residential and institution areas. Most people living in Subang Jaya work in the vicinity districts such as Shah Alam, Petaling Jaya, Klang and even Selayang. Therefore, the production of solid waste is less and similar to that of Petaling Jaya, where most of the residents are working in the surrounding area. Major sources of MSW in the metropolitan area are residential areas such as Petaling Jaya and Subang Jaya, commercial or market areas, offices and institutions where 35% of waste generation are from commercial and market area. As the economy grows and the population becomes more urbanized, there is a substantial increase in solid waste generation. The composition of MSW often varies depending on residents' cultural behaviors and economic status, urban structure, population density, and area of commercial operation (Suthar & Singh, 2015).

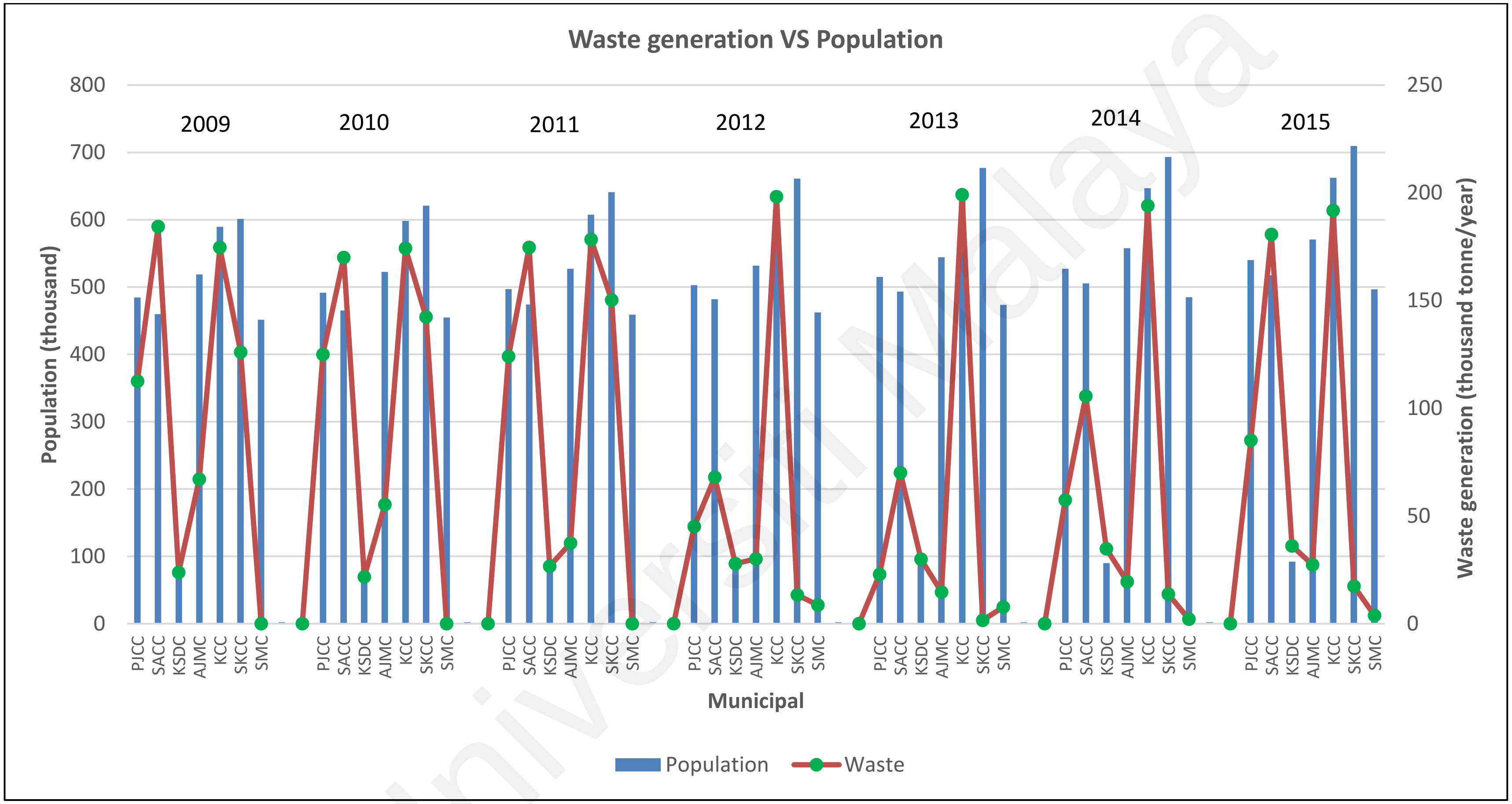


Figure 4.1: Waste generation compared to population growth in selected district in Selangor

Kuala Selangor district is one of 9 districts in the state of Selangor where SL is currently located. Kuala Selangor has a population of 209,590 people and a land area of 117,844 ha. Kuala Selangor district is more rural than urban but in the past 10 years and have undergone rapid industrialization and development and is now one of the fastest economies among the districts in Selangor. Urbanization and improved socio-economic factors have been known to affect lifestyle changes and are intended to help generate waste. Various studies have studied the relationship between waste production, composition and socioeconomic factors (Abdulredha et al., 2018; Gallardo et al., 2018; Khan et al., 2016). Kuala Selangor has also become a tourist spot where there are several popular tourist areas such as Kuala Selangor Nature Park, Kampung Kuantan Firefly Park, Sasaran Sky Mirror and Remis Beach which is located downstream of the study area. Recently, there has been research in tourism that is related to waste generation (Mmereki et al., 2016) where in the recent years it has led to an increased in the production of wastes and to alteration in the composition of these wastes as well (Shamshiry et al., 2011).

Figure 4.1 above shows the total solid waste and population growth for seven municipalities in Selangor from 2009 to 2015. All these municipalities send solid waste to SL for disposal. Based on the figure, it is clear that the number of solid waste that is generated is in line with the population size of each municipality. Overall, the amount of solid waste that is produced has decreased over the years. The most significant reduction was in 2012 at 77% (391,464 tonnes) compared to the previous year. This may be because the Malaysian government had introduced the Solid Waste Management and Public Cleansing Act 2007 (Act 672) in 2007 and the Act took effect starting September 1, 2011 to enable full privatization. Accordingly, the total solid waste was reduced by 11% in 2013 compared to 2012 with a total volume of 345,894 tonnes. During this period various initiatives have been undertaken by the government in reducing solid waste. These include the budget allocated for 3-color recycling trucks and the construction of recycling centers as well as recycling awareness programs through print and electronic media (advertisement, school buses, mascot and participation in expositions and road shows) (KPKT, 2006).

However, in 2014 and 2015 there was a slight increase in the amount of waste generation by 20% compared to previous years. The total waste brought to SL for disposal in 2014 and 2015 was 427,250 tons and 542,299 tons respectively. Many studies found that the increase in solid waste in 2014 was due to the Malaysian's lack of awareness despite the various initiatives undertaken by the authority. Thus, in September 2015, the government implemented a new rule on the Solid Waste Management and Public Cleansing Act 2007 (Act 672) where it would be compulsory for Malaysians to separate wastes according to categories. As a result, the growing recognition of the separation of solid waste at its source has led to an increasing recycling rate that is 17.5% in 2016, which rising from 10.5% in 2012 and 15% in 2014 (Alias et al., 2018). The urban population, which accounts for more than 65% of the total population, is also the largest source of waste.

According to the municipality, the highest population was in the SJCC followed by the KCC from 2009 to 2015. However, the total amount of solid waste generated was the highest of the KCC, where the total over the seven years was 1,310,440 tonnes per year. In contrast to the SJCC, the amount of waste was in the lowest group of which 2013 recorded the lowest volume of only 1,570 tons. The difference between population size and total solid waste is supported by a study conducted by Rybova (2019) in which the average municipal waste generation per person decreases with an increasing number of household members. Similarly, a study conducted by Mazzanti & Zoboli (2009) have assumed that population density and urbanization will be negatively related to landfilled waste. However, a study by Ramachandra et al. (2018) has found a significant relation between average household size and waste generation. Household waste production is strongly correlated with the average family size, financial status, as well as income and education levels. This increasing trend could be the result of changes in consumption habits as well as the increasing affordability of consumer goods (Periathamby et al., 2009).

4.2 Annual Waste disposed in SL

From the result, it was found out that, a total of 948,505 tonnes of solid waste from various local authorities have been transported by the contractor to SL annually. As described earlier in Chapter 3, this solid waste is generally municipal solid waste or non-hazardous waste that is received from several areas in Selangor including Klang, Shah Alam, Ampang and Kuala Selangor districts, respectively, under the authorities of Klang City Council, Shah Alam City Council and the Ampang Council which contribute 54.3% of Klang Valley's population. The local authorities that have been sending solid wastes to SL landfill are the Petaling Jaya City Council (PJCC), the Shah Alam City Council (SACC), the Kuala Selangor District Council (KSDC), the Ampang Jaya Municipal Council (AJMC), the Kajang Municipal Council (KjCC) Subang Jaya Municipal Council (SJCC) and Selayang Municipal Council (SMC) Table 4.2 presents the annual generation of solid waste for various local authorities in Selangor.

Table 4.2: Annual solid waste generation (in tonnes) for various local authorities and transfer station in Selangor.

	2009	2010	2011	2012	2013	2014	2015
PJCC	112,529	124,980	124,122	45,149	22,835	57,422	85,136
SACC	184,325	170,007	174,679	67,974	70,041	105,699	180,636
KSDC	23,841	21,695	26,737	27,920	29,923	34,773	36,091
AJMC	67,097	55,317	37,357	30,086	14,675	19,453	27,376
KjCC	174,695	174,316	178,281	198,241	199,056	194,034	191,817
SJCC	125,986	142,417	150,230	13,396	1,570	13,775	17,435
SMC	-	-	-	8,697	7,794	2,094	3,809
Total	688,473	688,731	691,405	391,464	345,894	427,250	542,299
tone/day	1,888	1,887	1,894	1,072	948	1,170	1,496

The presented amounts in Table 4.2 only account for the waste delivered to the, the solid waste data show an increase of waste that is sent to the SL for the year 2009 to 2015. From the result, there is an increase in the first three years, 2009, 2010 and 2011 with 688,473 tonnes in 2009, 688,731 tonnes in 2010 and 691,405 tonnes in 2011. This increment is contributed by the solid waste from SACC for a total of three years alone with a total of 529,010 tonnes. However, there has been a decline in the total solid waste that is disposed at the SL in the next four years to 542,299 tonnes in 2015 compared to 691,405 tonnes in 2011. Although in 2012, SMC has started sending waste to SL, the amount of waste that is sent to SL in the last four years is still low compared to the first three years. This shows the complexity of waste generation where waste generation is dependent on factors such as population, industrialization, age, sex, ethnicity, level of education and also income (Khajevand & Tehrani, 2019). It is generally assumed that growth and development would result in significant waste disposal independently. Many studies have been conducted to address the relationship between population growth and waste generation around the globe. For example, in an Indian case study, an exponential correlation between population growth and solid waste development has been estimated by analyzing the effects of the rising birthrate and immigration on municipal solid waste.

The results also show that the amount of waste disposed in SL from SJCC has also decreased by almost 90% from 2012 to 2015 compared to the previous three years. This decline reflects a milestone through Local Agenda 21 which is a plan that is related to environmental development that emphasizes sustainable development as its agenda. Through Local Agenda 21, local communities are involved in the implementation of activities that lead to sustainable development which in this case is through the Program of Sustainable Plastic Use, 'anti-litter' Campaign and Environmental Awareness & Recycling Program. There are 20 recycling centers and 1 composting center in the MPSJ administrative area. This to some extent can divert waste from reaching landfill through those programs where the benefits are the conservations of landfill space. The study by (Yusoff et al., 2018), hold great possibility for recyclable wastes diversion practice which should be able to recover more than 35% of the total waste generation. The study has also reported that more than 376 tonnes per day of waste generation could be diverted and has the potential for to be recycled and reduced.

From the result, in 2015, Kajang which is under the administration of KjCC has recorded the highest amount of waste disposed in SL compared to the other six municipalities of 191,817 tonnes per day in 2015. This has been due to the failure of the RDF plant in Semenyih where the impact of the composition of the solid waste that has been collected consists huge amount of food waste (75%), as compared to the plant that has been designed to receive a food waste composition that is 30% to 49% (Abdul Rashid et al., 2016). This has caused all the solid waste that is disposed in the plant to be sent to the SL for disposal. The trend has also shown that an area with a higher level of urbanization tends to generate more MSW. This may result from changes in consumption patterns due to changes in the level of income and the growth of trade and industry in the respective area.

Taking on the number of waste that has been disposed at SL since 2007, it can be seen that the waste that is disposed has increased on an average of 20% yearly, and will continue to increase in the years to come. The government of Selangor adopted various strategies in solid waste management system to encourage the public to participate in 3R (reduce, reuse and recycle) programs but the results have been disappointing. The government has aimed to increase the recycling rate over the years to 22% by the year 2020, to achieve a lower volume of waste to be sent to landfills for disposal.

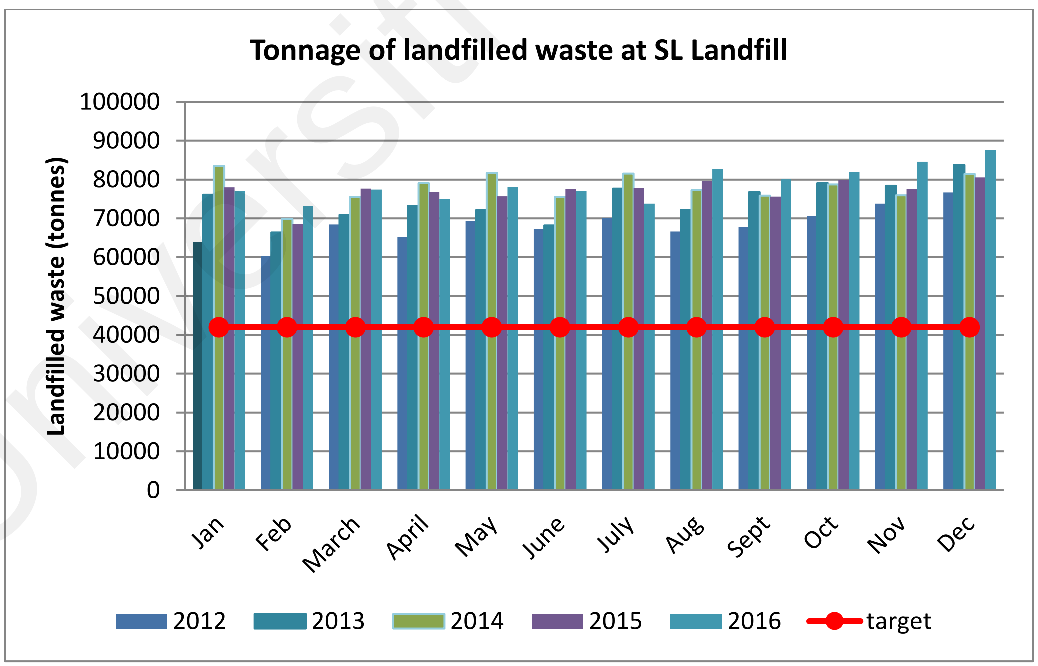


Figure 4.2: Tonnage of landfilled waste at SL from 2012 to 2016

Figure 4.3 above shows the amount of solid waste that is disposed at the SL for each month from 2012 to 2016 in tonnes per year. The red line indicates the targeted amount of waste to be disposed at the landfill based on lifespan of the landfill. The total amount of solid waste that is disposed in the landfill each year exceeded the targeted amount. For every month in five years, the total amount of waste disposal is between 60,000 and 80,000 tonnes. Accordingly, SL has been approved by the Selangor State Government for 130.55 acres of land for expansion with a total target of 7 million tonnes for its lifespan and has been provided by the municipal waste disposal services for the District of Shah Alam, Klang, Petaling and Kuala Selangor for an additional 8.3 years after 2017. It is obvious that an increase in MSW generation would lead to a substantial decrease the lifespan and the total remaining capacity of the landfill.

4.3 Waste composition

Figure 4.3 shows the composition of waste in SL. Each waste category is displayed in terms of tonne per year.

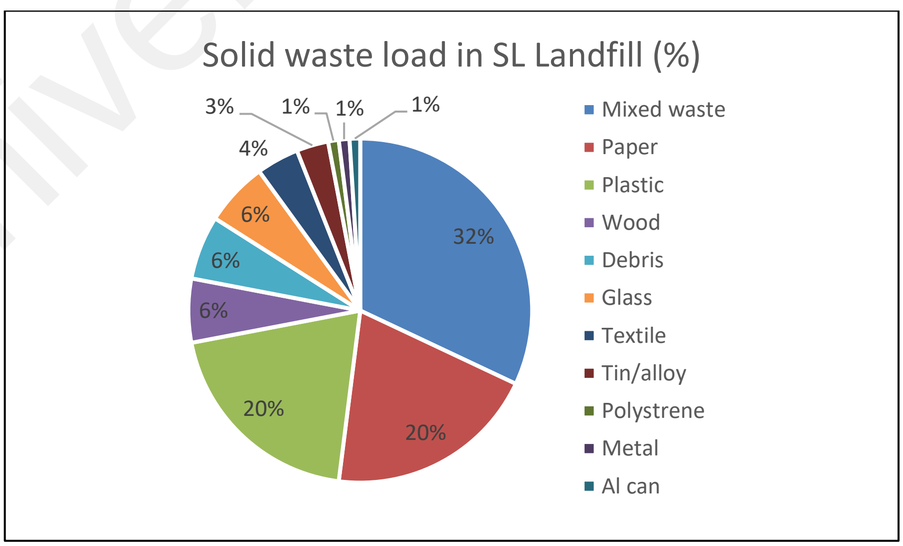


Figure 4.3: Key sources of solid waste load to SL in 2016

Waste composition is another important factor that need to be looked into in order to improve waste management in SL. Organic waste, paper, plastic, wood, debris, glass, textile, tin/alloy, polystyrene, metal and aluminum can are the type of waste that have been delivered to the SL. The results show that the largest amount of incoming waste is the mixed waste. Some materials such as plastic bag, plastic bottle, wood or board, glass, aluminum and beverage carton have been sold to the recycle parties. However, these are just a small portion compared to the total waste that goes for disposal. SL does not accept pharmaceutical, chemical, veterinary, liquid, oils, medicinal products, grease, acids, sludge, radioactive, solvents, resins, powders, electronic paint waste or anything that the DOE considers to be hazardous or toxic or has been classified as scheduled waste. Municipal solid wastes that are disposed in SL can be segregated accordingly to the types of waste as presented in Table 4.4.

It is found that there are 12 specific waste fractions that have been analyzed in this analysis. The largest group is mixed waste, representing 32% of the generated MSW. Mixed waste is made up of food and non-recyclable waste, such as paper, plastic etceteras that have been contaminated and mixed together with water from food waste, while 68% is a mixed of organic and inorganic friction. The results clearly indicate that the composition of organic wastes is dominated by food waste (mixed). This contains remnants of foodstuffs, plant waste, leaves and rotting vegetables. Previous studies found that food waste accounted for a significant portion of solid waste in developing countries (Takahashi et al., 2019). Table 4.3 shows the MSW composition in SL. It is apparent from the results that huge amount of food waste which mostly come from households and businesses, such as restaurants, hotels and markets. Main sources of the aforementioned waste in SL are presented in Table 4.4.

Table 4.3: Waste composition in SL

No.	Type of Waste	Weight (kg)	% Composition by weight
		Organic	
1.	Food waste	307,316	32.40
2.	Debris	61,653	6.50
3.	Paper	190,650	20.10
4.	Wood	53,116	5.60
5.	Textile	35,095	3.70
		Inorganic	
1.	Plastic	190,650	20.10
2.	Glass	56,910	6.00
3.	Tin/Aloy	29,404	3.10
4.	Polystyrene	11,380	1.20
5.	Aluminum can	9,485	1.00
6.	Metal	2,846	0.30
Total		**948,505**	**100**

Table 4.4: Type of waste source to the SL

Source of Waste	Facilities or activities wastes are generated	Waste generated
Municipal/Household waste	Settlements: bungalow, terraces, high-rise and apartments	Food, paper and paper packaging, plastic, metals and hazardous household waste
Commercial waste	Shop-houses, restaurants, stalls, night markets, hotels	Food, paper and paper packaging, plastic and metals
Industrial waste	Light and medium industries	Mostly paper and paper packaging plastic and metals

Mixed waste

Comparing all the twelve types of waste that are involved (Figure 4.4), it is found that the highest waste load percentage is 32% with 303,000 tonne per year and this is contributed by the mixed waste. Figure 4.4 indicates the volume of the mixed waste that is sent to SL. Mixed waste that is disposed in SL includes food waste which is due to the waste from kitchens. Data shows that this mixed waste also includes food waste from the market (fruits and vegetables) as well as expired foods coming from food industries in Kuala Selangor. This food waste may increase with the increase in economy and population where the Selangor population is predicted to increase to 7.6 million by 2030. Land-filled food waste can cause significant long-term environmental impacts, as food waste would degrade in anaerobic conditions to release methane, a potent greenhouse gas.

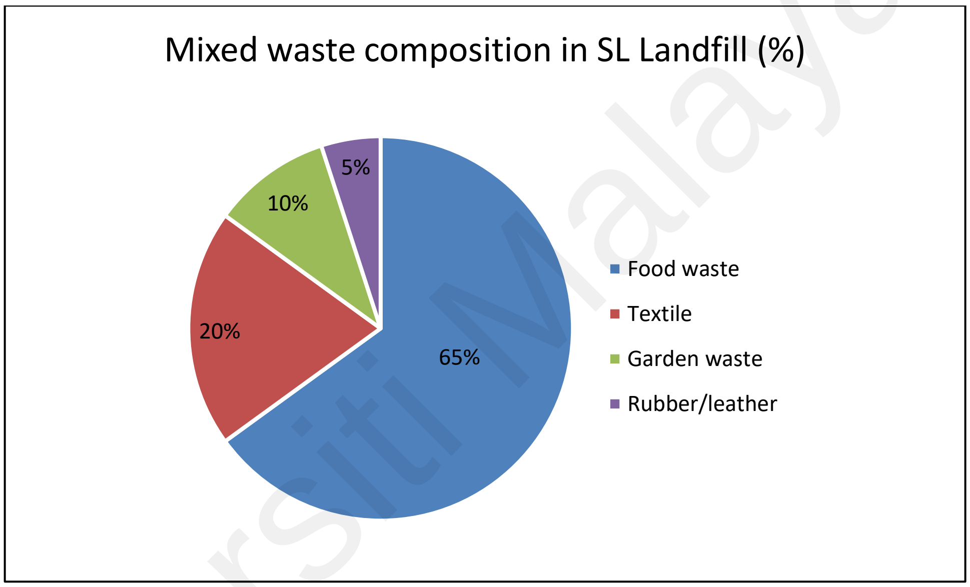


Figure 4.4: The breakdown of the mixed waste sent to SL

The huge quantity of organic waste in the amount of solid waste could cause environmental problems, but it could also be important for the recovery of resources where the organic waste could be composted, and the rest of the material could be recycled. The amount of leachate in the waste disposal differs depending on the volume of organic waste spread within the landfill. The higher the organic waste, the more leachate is generated. The quantity of landfill gas in a landfill site also relies on the organic proportion of the MSW. A high organic waste flow can, however, be converted into generated high-quality compost and therefore is beneficial.

Plastic waste

Plastic waste is the third largest type of waste that is sent to SL. In this landfill the plastic waste is classified as follows. Plastic bag which accounts for 64% by weight, other plastics- this includes HDPE plastic and plastics PET, which is 20% and 16% by weight, respectively. With the current use of plastic in a wide range of products and containers, it is expected that the volume of plastic waste will also rise in the disposal site (Zalasiewics et al., 2019). This is supported by a statement by Bovea et al. (2010) and Kalanatarifard and Yang (2012) where, most plastic items have a life cycle of less than one year and most of those plastics are then disposed at landfill sites. This is caused by plastics that are produced by non-renewable sources. Plastics are not inherently dangerous; fundamentally their resistance to the natural processes of biodegradation is the factor that they are taking up large amount of landfill space.

The volume of plastics waste that SL has received for 2016 is presented in Figure 4.5. The results show that the plastic bag volume in SL is the highest compared to the HDPE plastic and PET plastic container. The amount of plastic waste that is disposed in SL shows a high difference compared to plastic HDPE and PET plastic container with a difference of 70%. Some Asian countries such as Indonesia have shown similar results (Lokahita et al., 2019) and Thailand (Challcharoenwattana et al., 2015). From the observation at the landfill it was found that plastic bottles of soft drinks were distributed throughout the waste piles in the dumping site. Furthermore, plastic containers take more space in waste sites. In an effort to reduce the use of plastic and to further reduce the plastic that will be disposed of at landfills in Selangor, the Selangor State Government has launched a 'No Plastic Bag' campaign since the1st January 2010 to reduce plastic waste, especially plastic bags that are disposed at solid waste disposal sites.

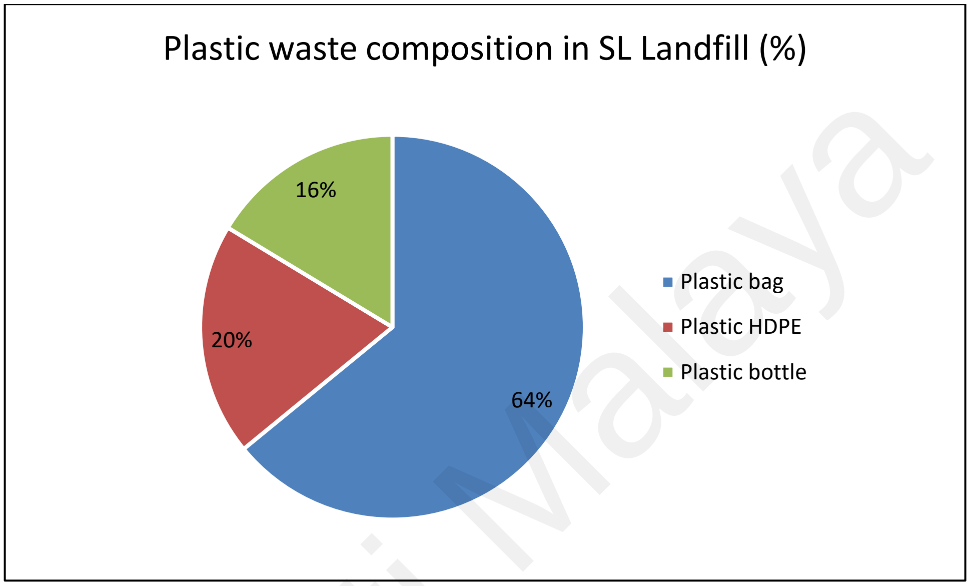


Figure 4.5: Quantity of plastics waste in SL in year 2016

According to an analysis on the management of plastic waste in Peninsular Malaysia by the National Solid Waste Management Department, the Ministry of Housing and Local Government Malaysia in June 2011, the market segment for plastics in 2010 is dominated by the packaging sub-sector where 42% covers both the flexible and rigid packaging. Additional major market shares include electric and electronics with 26%, followed by the automotive subsector (11%), the household sector (10%), the construction sector (7%), agriculture and other sectors (2%) respectively.

Paper waste

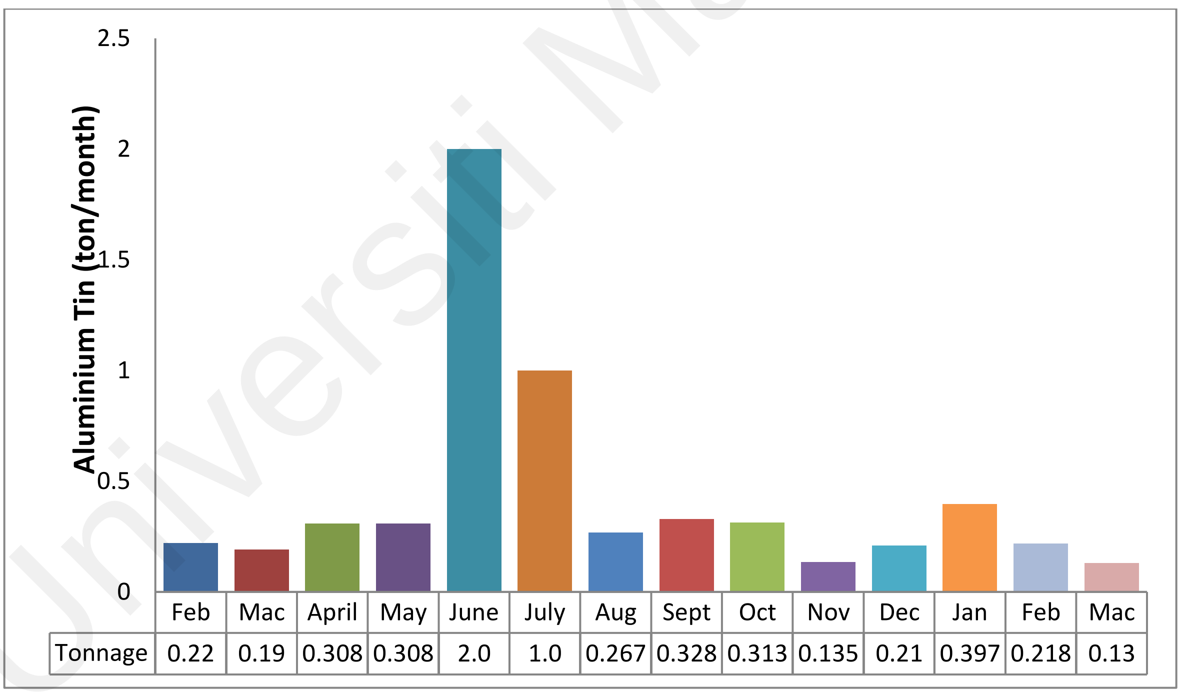
Paper, such as paper packaging that includes cardboard, combined packaging and paper such as newspaper, journals and books, is the second most characterized waste in SL. This accounts for 20.10% by weight of the total waste that is sent to SL and has been disposed in the landfill all these years. Although the recycling market of waste paper items such as old paper, magazines, books, etcetras, is well known, the recycling rate for waste paper is very small due to poor collection and segregation practices. It has also been found that a large portion of the used and soiled paper is dumped together with other kinds of solid waste and this turns the supposedly recyclable waste to non-recyclable waste and ultimately finds its way to the landfill sites.

Glass waste

6% of waste input to the landfill comes from glass wastes with 56,910 ton per year. Glass is one of the main portions in SL landfill. It is found that, primarily it is glass bottles for drinks and food, and secondly flats glass that may occur during the source-separated fraction or from sorting of co-mingles which is collected waste fraction or mixed waste. In SL, glass waste is categorized as colored glass and clear glass. However, both types of glass are not separately recycled because of the poor demand for recycled glass due to their quality. This is supported by a statement issued by Larsen et al. (2009) that there is no recycling of glass products since some blame this on the low value of used bottles because recycled glass is heavy and breakable which poses a hazard for households with kids. This has led to almost 100% of glass ending up in dumpsters and subsequently in the landfills.

Aluminum waste

In the markets there are usually two types of aluminum products, namely aluminum cans (drinks) and other aluminum products (such as aluminum doors, windows, etc.). However, aluminum waste such as doors and windows will be sent directly to the inert landfill while only a small amount of aluminum waste will be sent to SL. The aluminum waste in SL is only 3% of the amount waste in SL with 9,485 tonnes per year. Figure 4.6 shows the amount of aluminum waste that has been sent to recycling parties. The rest will usually be sold to scavengers who collect the aluminum waste daily at the landfill and only a small amount will be disposed.



	Feb	Mac	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mac
Tonnage	0.22	0.19	0.308	0.308	2.0	1.0	0.267	0.328	0.313	0.135	0.21	0.397	0.218	0.13

Figure 4.6: Tonnage of aluminium waste in SL in year 2016

Normally, the produced waste aluminum waste is also exchanged through several layers of agents or intermediaries before they are finally sold to the aluminum manufacturing industries to manufacture other aluminum goods. In Malaysia, the average official recycling figure for aluminum cans is around 51% for households and 69% for enterprises. The recycling levels of aluminum cans are estimated to be much higher at some commercial properties, such as restaurants and hotels, at more than 90%.

Debris

The debris is 6.50% by weight of the total amount of waste sent to SL. This comprises mainly small, inseparable materials including food particles, paper waste and other residues. Debris primarily arises from household and street sweepings. Debris can also contain soil and pneumatic waste. The waste fraction in SL also consists, to some degree, of wood and garden waste. Wood and garden waste have occupied 5.6% by weight. Textile waste which have occupied by weight 3.7% besides woods and garden waste. This kind of waste contains worn and torn garments and sack clothes. Since 1997, the disposal of textile waste in landfills has been a concern since most of the textile and apparel industry at that time have made the attempt to lessen the disposal of post-producer textile waste in landfills (Domina et al., 1997). However, until 2019, the problem of textile waste disposal remains a concern because of the lack of technologies and infrastructure for recycling (Rapsikevičienė et al., 2019). Nunes et al. (2018) found that textile waste can be used as a renewable resource to produce thermal energy thus reducing the disposal of textile waste into landfills.

4.4 Material flow analysis

In the following section, the material flow analysis (MFA) method that is used in the study is presented. It is used to measure the total waste flows in the measured system. From this, the amount of leachate that is discharged into the investigated river is also known. This is important in maintaining the cleanliness of the investigated river in terms of reducing discharge to the river with the reduction of solid waste that is dumped at the investigated landfill. The description of the systems that are chosen for the study, the defined systems' boundaries and the selection of goods, processes and relevant substances that have been included in the assessment are presented. Table 4.5 shows the materials that are relevant to waste management in SL.

Table 4.5: Materials that related to waste management in SL.

Flows	**Decision Support Criteria – MFA on the Level of**		**Note**
	Goods	**Substances**	
Landfilled wastes	Reduction of waste generation	Reduction of hazardous substances in generated waste	To conserve resources and reduce environmental impacts through WM
Recyclable waste	Increase in recyclable material and reduction of landfill volume	Reduction of recyclable waste with hazardous or beneficial substances	To conserve landfill volume and ensure that only that waste remains which can be stored without danger to future generations
Landfill gas	Increase in energy recovery		To converse resources (energy)
Leachate	Reduction of leachate generation	Reduction of water pollutants in generated leachate	To protect the environment, improve water quality and ensure the achievement of legal objectives
Recycling material	Increase in secondary raw material generation	Reduction of hazardous substances in the secondary raw material	To conserve raw materials and to ensure that reclaimed materials do not present a greater risk than comparable primary raw material
Off-gas	Reduction of emissions from landfill	Reduction of air pollutants and climate-relevant gases (SO_2, NO_x, CO_2, N_2O, CH_4)	To protect the environment, improve air quality and ensure the achievement of legal objectives.
Liquid emission	Reduction of long-term emissions from landfill	Reduction of leachate load	To provide aftercare treatment and ensure that only such waste remains which can be stored without endangering future generations

4.4.1 Case Study: SL Landfill Waste Management

Based on the case study of waste management systems at SL, the mass-balance of the system will be discussed in this section. The outcome of this study demonstrates the MFA's ability to design a solid waste management system with results that support both the given environmental and resource's goal.

i) Scope

The geographical area considered for the MFA model is SL. The system boundaries based on the border of this landfill. The system boundary of SL included all leachate generation related activities in the landfill. This includes waste reception area, landfill, leachate pond and landfill gas collection well. Recycle material, air emissions are also included in order to investigate their potential role in leachate generation or contribution to the whole system.

The main factor in leachate production will be the quantity of solid waste that is disposed in landfills, especially organic waste. The reduction and addition of organic waste plays an important role in leachate generation at SL. This organic waste can be minimized if the process of separation is initiated or the separation is carried out in the landfill and subsequently used for composting purposes. The quantity of waste disposed in the landfill can also be decreased by increasing the recycling rate in the landfill and by applying the incinerator. These processes are described in section 4.3.4.

All subsystems show the main flows carrying the materials to, from and between processes. Groundwater and soil compartment are excluded from the system because it is does not affect the leachate production; therefore, this study will only present the surface-level modelling for this landfill. The time scale is one year, simulated for current conditions (year 2016) using the most recent available data. The inputs into the SL system are solid waste as well as precipitation which are also the principal aspects of the leachate generation. The outputs, which are measured and calculated by means of transfer coefficients, are secondary products for material or energy recovery and emissions to the environment.

ii) System Analysis in SL Landfill

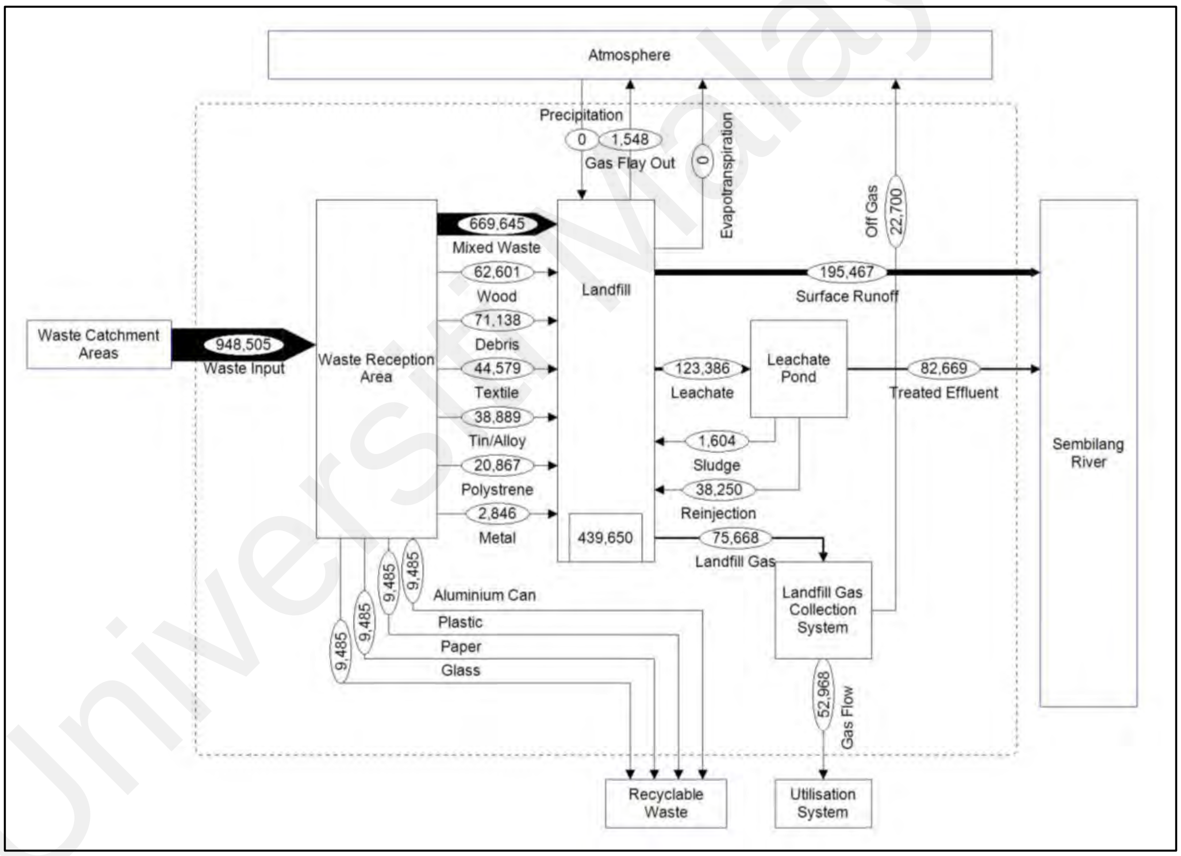


Figure 4.7: The MFA model for solid waste in SL for year 2016

Based on the case study of a nationwide waste management system, this section elaborates further on the evaluation, and was conducted to obtain information concerning waste flows in the analyzed systems. A brief explanation of the processes that analyzed the waste management is included in this section. One subsystem model is associated with leachate generation that results from the disposal of solid waste at SL, while another three more scenarios that involve recycling, composting, and incineration are presented in the next subsection.

Figure 4.7 shows the system analysis for the overall SL. The system includes surface water network (Sembilang River) as well as all activities that are relevant to leachate generation in the landfill and are indicated as boxes. The results that are obtained in the material flow analysis model for solid waste of SL for the year 2016 with every compartment that functions upon it are shown in Figure 4.8. The total input into the examined system is about 948,505 tonnes of waste. About 96% of the waste is transferred into landfill for disposal with 910,565 tons per year which include 71% (669,645 tons/year) of mixed waste, 8% (71, 653 tons/year) of debris, 7% (62,601 tons/year) of wood, 5% (44,579 tons/year) of textile, 4% (38,889 tons/year) of tin or alloy, 2% (20,867 tons/year) of polystyrene and 0.3% (2,846 tons/year) of metal. About 4% (37,940 tons/year) of recyclable waste is segregated before it is sold to the recycle center.

With the import and export of precipitation (0.0028 ton/year), evapotranspiration (1,182 mm/year) as well as surface runoff from the landfill, 13% of leachate was collected into leachate pond with 123,386 tons per year. Of the total leachate input to the leachate pond, treated effluent accounts for 67% which goes into Sembilang River and 33% of sludge is disposed back into the landfill.

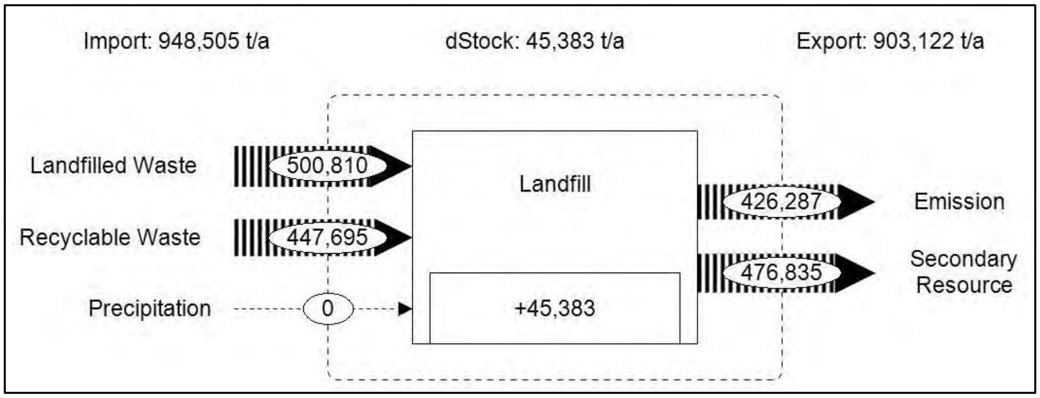


Figure 4.8: The balancing system for input and output

Figure 4.8 shows the balance of inputs and outputs that is involved in solid waste and the secondary resource yields in SL (recyclable waste and gas recovery for electricity). As mentioned above, 89% of the total solid waste from various waste collectors (municipal council and transfer station) is brought to SL for the disposal process. This solid waste is divided into two categories, namely, residual waste and recyclable waste. Furthermore, precipitation also plays a major part in this system as it relates directly to leachate production with 2802.1 mm/year. The two outputs resulting from the process of solid waste disposal that could have an adverse impact on the environment are leachate production as well as landfill gas. Both of these outputs represent 49% of the total output with 426, 695 tonnes per year. However, landfill gas will be discussed further as it is in the Scenario section. Other outputs such as leachate emissions into the soil will not be discussed as this study focuses on leachate discharge into nearby rivers.

The study also found that secondary resources were also generated from this system with 51% of the total output at 476, 835 tons per year. Secondary resources are materials that can be recycled or reused as energy or raw materials. These materials can be used for many productive purposes (Bleicher et al., 2019). These secondary resources can be divided into two categories, namely, recycled materials and gas recovery as waste to energy. The result shows that more than 70% of the total gas landfill is used as an electricity source. Several studies have been conducted on the relationship between leachate quantity and landfill gas. The study by Liu et al. (2018) found that continuous leachate production would have a significant impact on the landfill gas production rates. In another study that is conducted by Ehrig (1983), it is stated that the effects of solid compaction and leachate recirculation on top of the landfill will increase gas production and at the same time reduce the organic content of the leachate. Therefore, it is important that the amount of solid waste disposed in the landfill is reduced as it can reduce the landfill gas production as well as the organic content in the leachate, and thus improve the quality of the leachate that is released into the environment.

iii) Leachate pond subsystem

Figure 4.10 shows the leachate flow balance in the SL system for the year 2016. The total annual load of waste in SL was 910,565 tonnes per year, which was made up of 123,386 tonnes of raw leachate every year (Figure 4.9). This shows that 13% of the leachate is produced from the total amount of waste that is disposed at the landfill. The leachate treatment process at SL includes equalization pond 1 and 2, and the treatment processes include Sequencing Batch Reactor 1, 2 and 3 before being channeled to the Sembilang River as treated effluent. The amount of leachate reduced in various unit operations in leachate treatment pond were small and not included in the calculation/flow. The percentage of leachate evaporation at the leachate collection system is 0.113 tonnes/year. Of the three levels of raw leachate treatment, SL produces 79,917 tonnes effluent each year. Prior to being channeled into Sembilang River, this effluent characteristic will be analyzed first according to the standards that are set by the DOE on industrial waste disposal namely Environmental Quality (Industrial Effluents) Regulations 2009. In addition to effluent, the output of leachate subsystem also includes sludge and the reinjection of leachate back to the landfill. This sludge will go through conditioning and filter press process before being disposed at the disposal site with 1.3% (1,555 ton/year) of total leachate produced. Sludge is the by-product that contains many toxic substances, which includes bacteria, heavy metals and certain organic pollutants, that can lead to serious contamination of the environment. Sludge has been a serious challenge in many countries, so proper management, treatment and disposal of sludge is extremely important (Atalia et al., 2015; Yang et al., 2015).

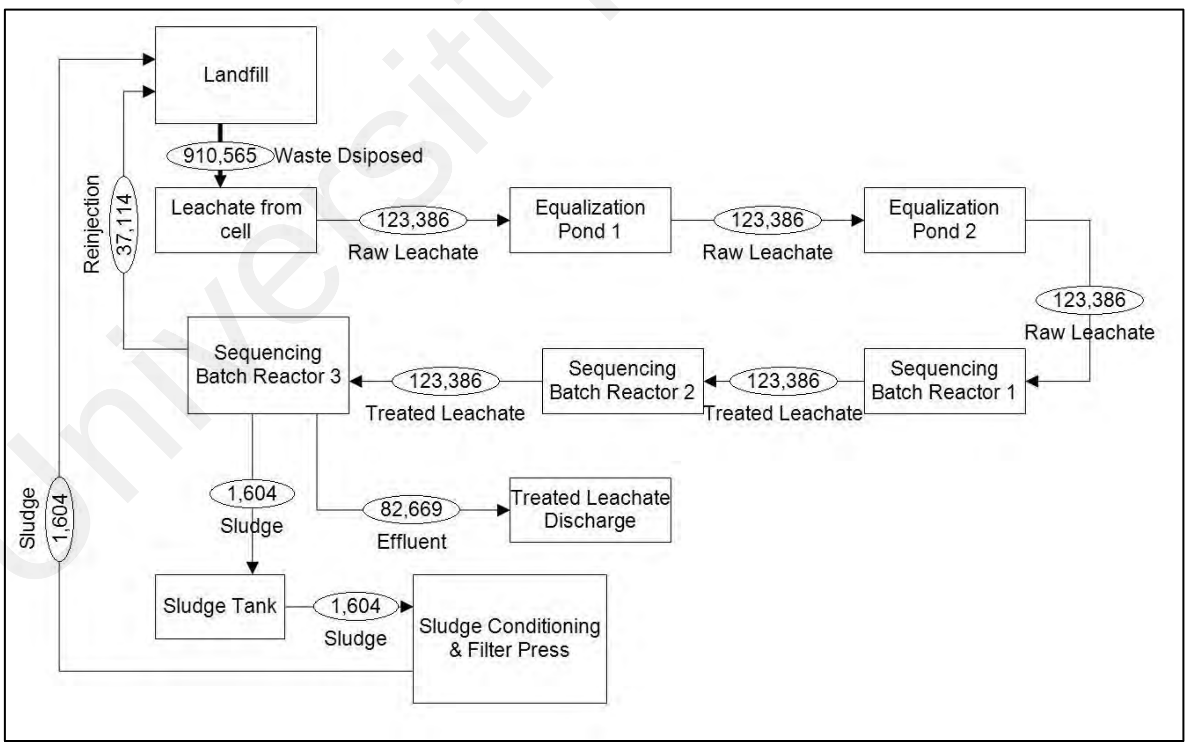


Figure 4.9: The balancing system for leachate pond in SL, 2016

Meanwhile, leachates that have been treated and are not discharged to the Sembilang River will be reinjected back into the landfill. This reinjection of leachate is called concentrated leachate with 31% (37,114 ton/year) of total leachate produced. Concentrated leachate was obtained from the use of the membrane during the reverse osmosis process in the Sequencing Batch Reactor 3. The reinjection of concentrated leachate is essentially similar to the recirculation of untreated leachate that is often carried out in bioreactor landfills (Calabrò et al., 2018; Cingolani et al., 2018; Yang et al., 2018). A few studies have demonstrated that the pollutant mass that is compared with raw and condensed leachate is identical, the only difference is due to the amount of the recirculated solution, and hence it is polluted concentrations. Normally, concentrated leachate usually accounts for 15-30% of the overall generated leachate.

With the amount of effluent resulting from this treatment process, it is important that this amount can be minimized and at the same time reduce the adverse effect on Sembilang River. This can be seen when all regulatory authorities across the globe have set strict daily discharge levels for treated leachate that must be preserved in any surface water sources, sewage systems, aquatic habitats or on land until its disposal, i.e., of treated leachate in order to ensure minimum environmental impact (Mukherjee et al., 2015). Malaysia has specific guidelines concerning the development, management and operations of a landfill and the post-closure measures that are required to prevent pollution under the Environmental Quality (Industrial Effluents) Regulations 2009.

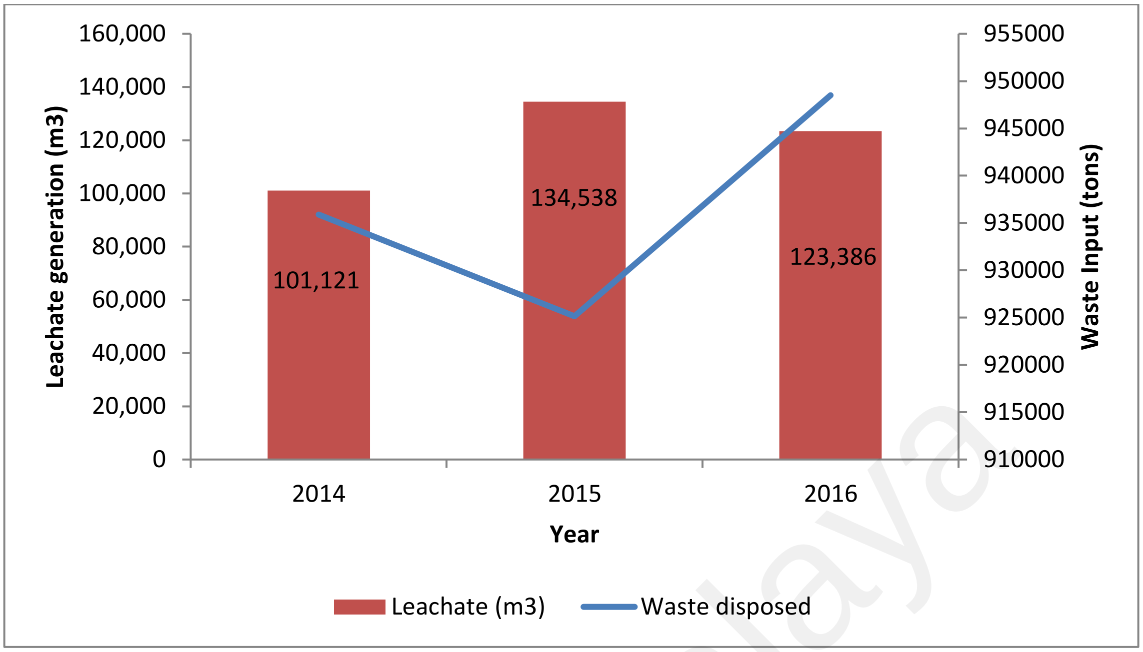


Figure 4.10: The amount of leachate produced in SL in 2014-2016

Despite a reduction in the amount of leachate production, results show that, leachate production is increasing year by year. Figure 4.10 shows that the amount of leachate that is produced in 2014 is 101,121 m^3, followed by 2015 with a 25%, increase, which is 134,538 m^3. However, there was a decrease of 8% from the previous year with a total volume of 123,386 m^3 in 2016.This percentage is not in line with the amount of waste that is brought into the landfill where in 2015 the amount of waste has been reduced compared to the previous year, but the amount of leachate that is produced has increased. Leachate generation increased as the remaining waste in the landfill contribute to the high leachate volume in 2015 even though there were reduction waste disposal. As the waste in the landfill decomposes over time, leachates are continuously generated in the landfill even after a landfill site closure, landfill will continue to produce leachate and this process would last for 30-50 years. As is known, rainfall is one of the key factor to the production of leachate and therefore the production of leachate in easy calculations is considered a fraction of the rainfall (Alibardi & Cossu, 2018). This is further supported by the annual rainfall that is provided by the Meteorological Department where the annual rainfall in 2014 has been lower with 1778.8 mm compared to 2015 that has a higher rainfall with 2250.8 mm. That reflects the biggest single contribution to leachate production to be rainfall. The most critical situation happens during periods of light rainfall over a long lapse of time; a short blast of heavy rainfall during a storm can derive in an abrupt saturation of the cover material with the result that the remainder is shed as run-off, so there is little net infiltration (Canziani & Cossu, 2012).

As outlined in the regulation, leachate resulting from any landfill needs to undergo a treatment process to ensure that the leachate that is to be discharged into the environment will not pollute the body of water as well as the groundwater as defined by the Second Schedule- Acceptable Conditions For Discharge of Leachate of the Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations 2009 (Aziz, 2015). In 2016, the total leachate discharged to the Sembilang River is 82,669 tonnes per year. At this stage several elements need to be taken into account in order to meet the characteristics of the sanitary landfill. Among them are quantity control, leachate stabilisation quality, removal of dissolved organics, ammoniacal nitrogen, heavy metals, final polishing and sludge conditioning (sludge conditioning and dewatering).

Among the water quality parameters that are used are biological oxygen demand (BOD) and chemical oxygen demand (COD), Ammoniacal Nitrogen (AN), suspended solid (SS) and heavy metals as well as other pollutants that may be leached through the landfill as discussed in section 4.1 which is on the quality of raw leachate and treated leachate, where some key parameters are found to be above the standard. Table 4.6 shows the quality of raw leachate and treated leachate as a result of the sampling that has been conducted at the SL. The results of this quality of leachate and its effects on the Sembilang River are discussed further in the next section. Among the ten sampling stations along the Sembilang River, there were several stations that could be contaminated with the effluent from the landfill.

Table 4.6: Summary of raw leachate and effluent quality

Water Quality parameters	Unit	Raw leachate			Standard discharge (DOE)
		Mean	SD	SE	
pH	-	8.33	0.2	0.1	6 to 9
TSS	mg/l	2410	1384	565	50
BOD5		6428	4801	1960	20
COD		60248	10478	4277	400
AN		3518	2223	908	5
Fe	ug/l	10536	3153	1576	5000
Al		2618	830	415	-
Mn		354	81	41	200
Cu		41	15	7	200
Cr		584	180	90	50
Zn		652	164	82	2000
Cd		11	7.95	3.97	0.01
Pb		15.55	4.49	2.25	100

4.4.2 Scenario Analysis

Landfill is the only appropriate method for the final disposal of urban solid waste, among other disposal. However, if this situation persists, the landfill will be running out of space for the disposal of solid waste in the future. Therefore, in this study, proxy models are designed to determine the best management in terms of reducing waste to be dumped into landfill and the longest in terms of extending the service life of the SL age. All the scenarios that are suggested are done through modification and methods improvement of the existing conditions. In this case, three proxy system analyses are used, as one of the suggestions can be used to improve the current scenario in SL for a better system in the aspect of reducing solid waste that will be end in the landfill as well as the amount of leachate that is generated.

i) Scenario 1: Composting

Figure 4.11 shows the material flow of the composting facility for 2016. Of the 948,505 tonnes of solid waste received, 803, 348 tonnes of organic waste was separated and transferred to the pretreatment facility. 221, 332 tonnes of compost was produced as well as 38, 161 tonnes of residue, containing plastics, large wooden materials, rocks or stones and other unwanted items. The residues were sent to the landfill prior to landfilling. Leachate was recirculated during anaerobic digestion; this was not included in the model due to simplification. 95% of the digested material was recirculated to the mixed area after anaerobic digestion and combined with fresh organic material before being entered again into the digester. The production of biogas was recorded at 503,722 tonnes per year, which was sent to a utilization system that was located on-site and used to produced 8,077 tonnes per year of electricity for on-site used. Approximately 140, 932 tonnes of tin/alloy, polystyrene and metal waste was sent directly to the landfill. Of the remaining waste, 82,519 tonnes was sorted and sent for recycling (the remainder was sent to the landfill), of which includes textile or leather waste, plastic, paper, glass and aluminum can with an overall recycling rate of 54% compared to the status quo. In this scenario, the largest amount of waste remains as stock in the landfill with 83% of the total waste input. From a total of 140, 932 tonnes of waste landfilled, 10, 006 tonnes of raw leachate and 6, 704 tonnes of treated leachate is produced.

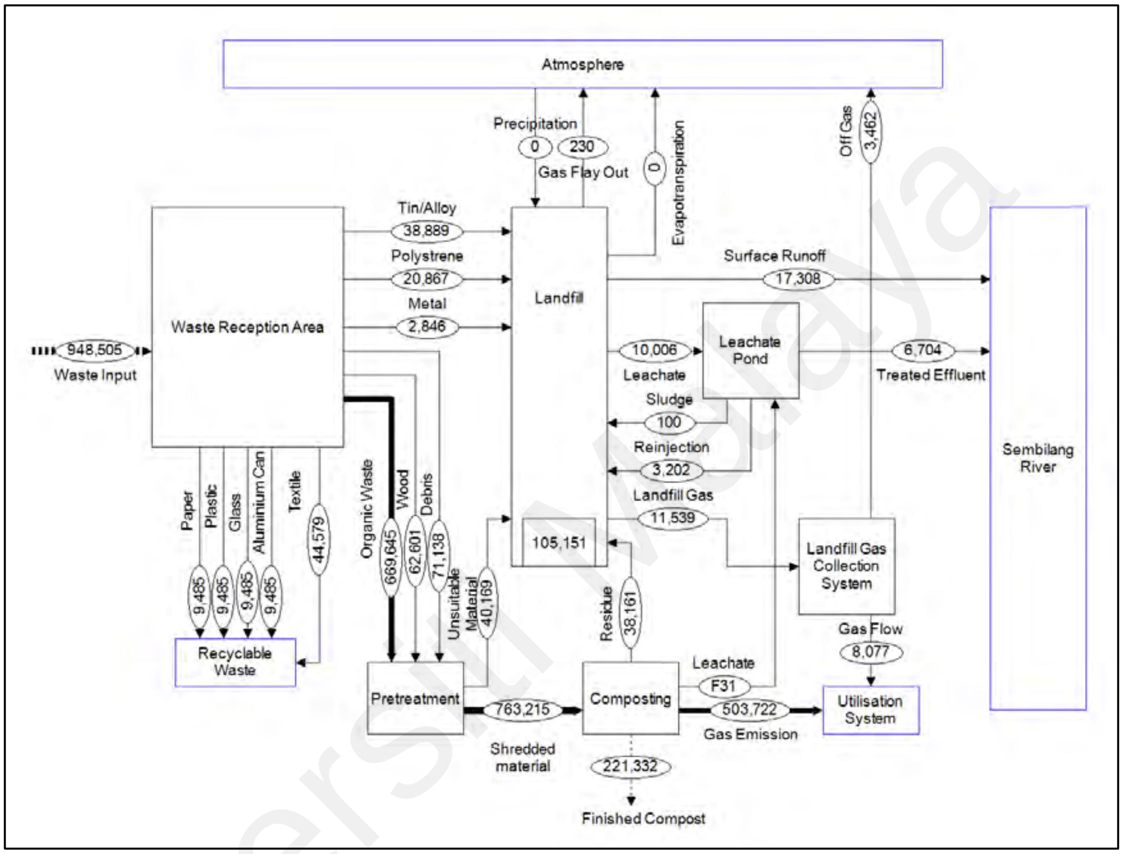


Figure 4.11: Scenario 1: Biological treatment combined with landfilling

Composting is seen as a crucial waste hierarchy mechanism and has a big role to play in reducing the amount of biodegradable municipal solid waste that goes to a landfill. Municipal solid waste composting is an option to the disposal of essential waste stream components in sanitary landfills that have drawn the attention amongst an increasing number of countries worldwide. The recent interest in MSW composting has been sparked by a need to reduce the amount of waste that reaches the landfills, either as a way to meet waste disposal goals or as a way to extend the landfill life (Renkow & Rubin, 1998). In the present study, from the total waste input, 85% was used for composting, and the remaining waste was landfilled (7%) and recycled (8%). When organic waste is composted in accordance with Sc1, the landfill's life can be extended for a few years. These results support Seng et al. (2013), who have found that composting the organic waste could significantly contribute to the reduction of waste disposal and could extend landfill life. This is also reported by Maso and Blasi (2008) in Nicaragua, where in Central America 90% of organic waste that is produced in the market has been composted and thus reducing the organic load in the landfill. It has also been suggest that by removing this amount of waste using the composting method, not only the environmental problems (landfill lifespan, leachate and landfill gas production) of land filling can be reduced but also the coasts of transportation and other costs of disposal can be reduced by 50% (Saheri et al., 2017).

Municipal solid waste is largely made up of kitchen and yard waste, similar to the type of waste that is disposed at SL Landfill. Composting of MSW is seen as a method of diverting organic waste from landfills and has proven to be an effective way to reduce solid waste in large quantities while reducing the leachate generation. Of the total landfilled waste, leachate production is decreased by 85% compared to the status quo. This is mainly because only 7% of waste has been sent for disposal and the remaining waste is composted. When organic waste is diverted for composting and any other wastes are sent to the landfill, a significant reduction in leachate production is observed. This is shown in a study conducted by Anderson et al. (2012) and Sharma and Chandel (2017) in which the combination of composting and landfill were found to be preferable options in municipal solid waste management when considering the direct and indirect burdens to the environment compared to incineration and landfill.

All in all, the waste management that is the combination of composting and landfilling of waste in SL shows that landfill gas (10%) and as a leachate (7%) has been generated with 6,602 tonne of treated leachate which is annually channeled to the Sembilang River. Compared with the current situation in SL, the resulting effluent through the use of landfill composting process will result in 92% lower. This is because the type of waste that most affects leachate production is organic waste. Through this S1, 28% of the organic waste is transformed into mature compost in comparison with half of this amount that is disposed in landfills. At the same time, the amount of waste disposed at landfills would decline.

ii) Scenario 2: Recycling

At SL, recycling has been carried out in recent years. When MRF is still in operation, solid waste coming into SL will be segregated by the employee whether it is suitable for recycling or not. However, recycling in SL is usually done by scavengers and potentially recyclable waste will be collected for recycling. This process however is only 2-5% of the amount of waste that goes into SL every day. This had led to a lot of waste that ended in landfill.

Many communities in developing countries have adopted various types of projects and strategies in recent years to facilitate waste management initiatives. A few communities have implemented recycling programs to gather recyclable waste materials while increasing the recovery of nutrients from biodegradable waste (Chifari et al., 2017). The consequence of waste recycling cannot be overstated, as it leads to a reduction in waste treatment and disposal costs, including an extension of the lifetime of landfills and environmental conservation (Isa et al., 2005). The recycling rate in Malaysia is reported to be very weak, around 5% as contrasted with countries such as Singapore (11%), Thailand (14%), Japan (40%), China (13%) and Germany (52.8%). Regardless of the opportunities for the recycling of solid waste, landfilling is heavily dependent on the waste disposal method. The awareness of waste recycling is poor, and most people cannot translate their concerns into action (Moh & Abd Manaf, 2014).

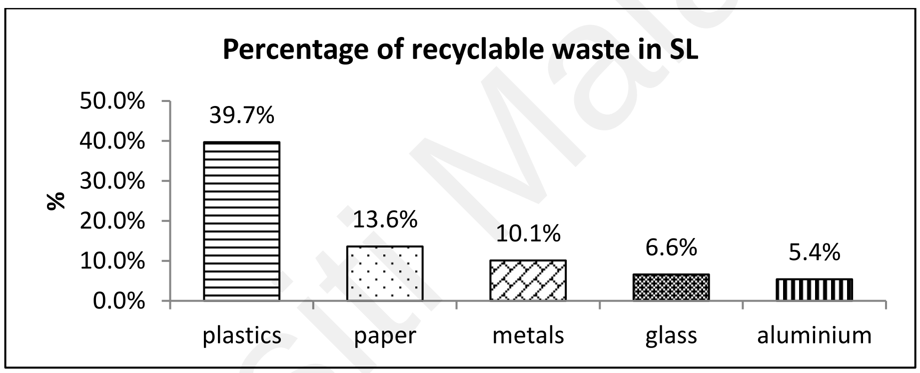


Figure 4.12: The percentage of waste at SL used for recycling

As shown in Figure 4.12, waste to be recycled in the system are dominated by plastic waste with a percentage of 39.7% of the amount of waste to be recycled by the recycled parties, this is equivalent to 552,030 tonnes per year with 13.6% waste paper, 10.1% metal waste, 6.6% waste glass, and 5.4% aluminum residue. Often, potentially recycle waste that is found in SL comprises packaging waste such as water bottles, milk boxes, polystyrene, glass bottles and so on. This waste is then segregated according to the type of waste before being recycled. As observed in Figure 4.12, in 2016, out of 948,505 tonnes of waste entering the system, 49% exited the MFA system boundary and the remaining 51% stayed in the system boundary. A total of 552,030 tonnes of waste that could be recycled are sent to the recycle facility for the appropriate sorting and reprocessing. This amount also includes waste collected from mixed waste which can also be recycled. Only the residues that are not of recyclable value due to their condition, are sent to the landfill for disposal, these represent the 25% of total recyclables waste. Although 75% (414,023 tons/year) of this recyclable waste is bought by recycle parties, approximately 25% (138,007 tons/year) of it still needs to be disposed of at the disposal site. This percentage may be further reduced if there is further home-based separation process resulting in more potential wastes to be recycled. However, this number is less compared to the real scenario in SL.

In a study conducted by Othman and Yuhaniz (2018) in Shah Alam, Selangor, most people in the area have knowledge of recycling and campaigns are conducted by the government, however, the recycling rate among the population is still low due to factors such as no facility for waste separation, no space at home and fussiness. According to Hassan and Kasmuri (2019), in addition to reducing greenhouse gases and for energy saving, recycling can also reduce waste disposal into landfills. This is supported by the proxy model that is proposed in Figure 4.13, with 58% of the total input waste, 42, 759 tonnes of leachate is channeled to the river. This is 46% lower than the amount of leachate that is produced if there is no recycling process in the landfill. This is supported by a study that is conducted by Zahari et al. (2016) and Alibardi and Cossu (2018), that states several factors that influence leachate production in landfills- landfilling practice, landfill cover practice and climatic factors, volume of waste disposed, and characteristic of the waste which also plays a major role in leachate production in a landfill.

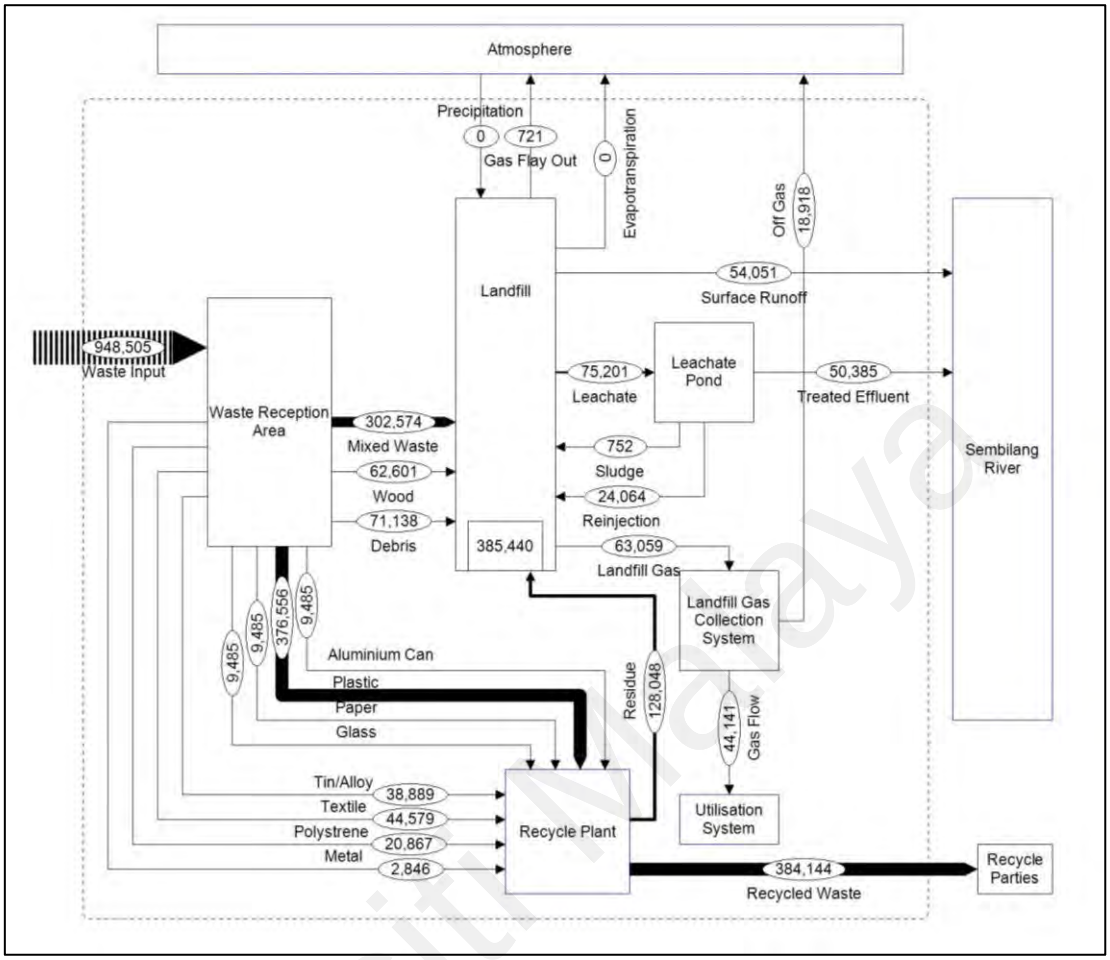


Figure 4.13: Scenario 2: Recycling combined with landfilling

In terms of the environmental impact, this approach appears to be suitable for SL's situation, comprising first and third world socio-economic characteristics. The benefits of recycling have been detailed extensively in literature reviews (Chidambarampadmavathy et al., 2017; Zink & Geyer, 2018; Ziyang et al., 2015). According to Abd'Razack et al. (2017), the main benefit of recycling is in the reducing adverse environmental impacts and having positive economic effects. Achieving total recovery of waste materials from being landfilled would also aid in conserving resources. The energy expended on the landfill site would also be greatly reduced as compared to the status quo. From the above analysis, it has been deduced that this approach would contribute significantly in minimizing the landfill space that is consumed annually. However, recycling cannot exist alone since organic waste makes up a portion of the waste.

iii) Scenario 3: Incineration

The process of reducing waste to be disposed of at the landfill thorugh the Waste to Energy (WTE) method has never been done by SL. According to the plan, the first of WTE plant at SL will be completed by 2023 which will be followed closely by another WTE plant in a few years later. The WTE plant is under the Design-Build-Operate-Transfer (DBET) scheme and will operate in solid waste management for 25 years. This WTE plant with the capacity of 50MW is built on a 25 acres area. As of the year 2023, the daily capacity of waste input to the WTE plant is 1,500 tons per day.

From the Figure 4.14, of the 948,505 tonnes per year of solid waste in 2016 that was sent to the SL, only 307,316 tonnes per year of food waste was excluded in the waste reception area. At SL, food waste that is received comes in two groups- pre and post-consumer. The food waste of pre-consumer food waste comes from markets that dispose damaged vegetables that are not suitable for sale. Meanwhile, post-consumer food waste came from the remnants that came with the rest of the councils that sent the waste to SL. With 61% of the total waste, the waste food consumed produces 28,671 tonnes of leachate a year, and on the other hand produces 40,958 tons of water emission a year. However, the leachate treatment process results in less amount of the final effluent discharged to the Sembilang River with 19,210 tonnes per year compared to the current system at SL. Food waste contains high humidity and is not suitable for incineration as it can cause many environmental issues (Paritosh et al., 2017). Therefore, in Malaysia food waste is not suitable for incineration.

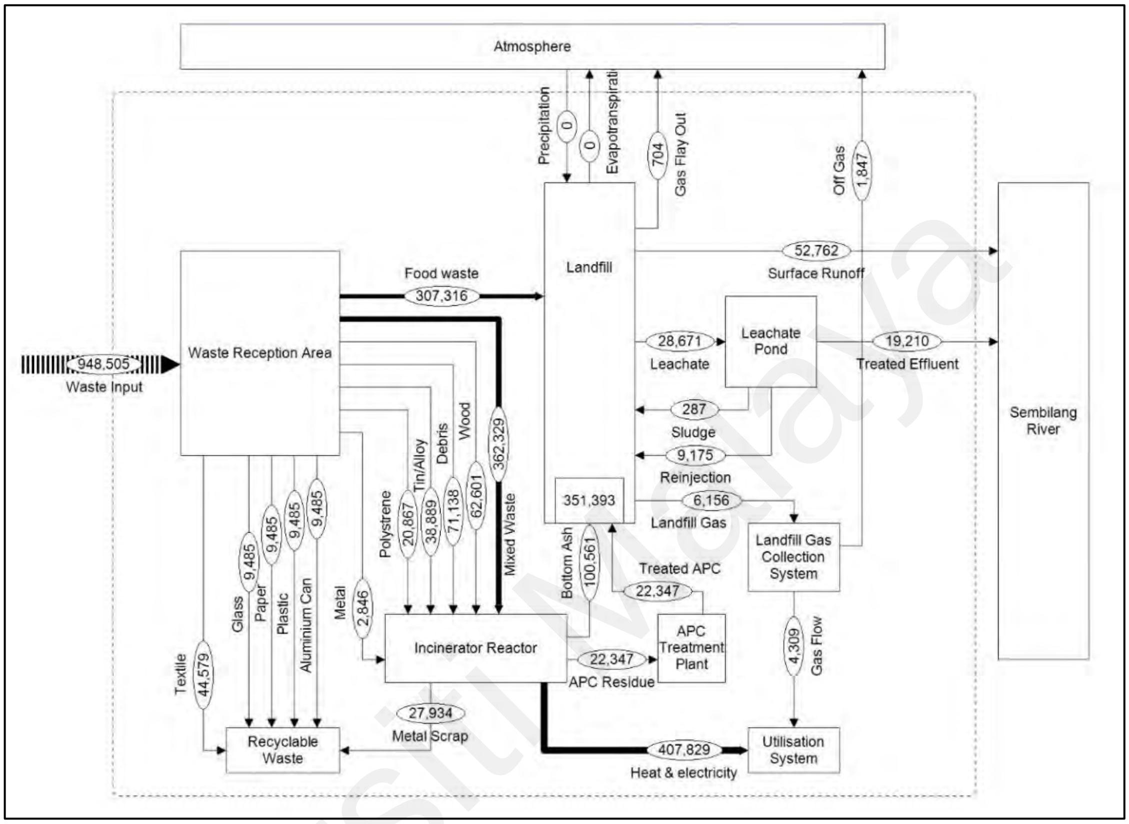


Figure 4.14: Scenario 3: Incinerating combined with landfilling

Mixed waste sent for the incinerator facility was around 568,154 tonnes per year. The rest of the mix consists of paper waste, plastic, aluminum cans and non-recyclable paper waste, garden waste, polystyrene, and metal. Textile waste and 4% of paper waste, plastic, aluminum cans and glass are recycled. The output constituents include generation of bottom ash, APC residue, metal scrap and heat and electricity. As a result of the combustion process in the incinerator reactor, 102,268 tonnes of bottom ash will be produced annually with18% of the waste inputs that go into the incinerator. This amount is quite high, and it was also reported that large volumes of bottom ash were generated by other researchers which represent about 20-25% of the waste input (Garcia-Lodeiro et al., 2016; Huber et al., 2019; Kuo & Gao, 2018). This bottom ash will be taken to the landfill for disposal. With low average weight (~ 300 kg/m^3), however, bottom ash needs additional treatment when deposited in landfills, such as cement stabilization. More uses, on the other hand, can be seen, and bottom ash can be used as a replacement for raw materials for the manufacture of other materials, such as concrete manufacturing, filling materials or roadways (Chimenos et al., 1999; Freyssinet et al., 2002; Lynn et al., 2016). There are also studies that have been conducted in Malaysia which use bottom ash in cement mortar production (Jun et al., 2017), construction bricks and also as mineral additions in concrete (Amat et al., 2017). The studies also show low risk if that ash is properly pretreated and landfilled (Mastellone et al., 2009). However, the used of bottom ash as an alternative material has not been taken into account in this study and can therefore be considered external to the system analysis of SL.

The APC traces arising from the residual combustion process at the SL, include fly ash and solid materials that are obtained from both the acid gas treatment systems and before releasing the gasses out to the atmosphere. The result of residual combustion will produce as many as 22,726 tonnes of APC residues per year. This is only 4% of the total waste incinerated. Because APC contaminants include the particulate matter capturer after the acid gas treatment plants, the waste can be either solid or sludge, and is typically distinguished by high salt, heavy metals and organic trace pollutants. This will limit concurrent applications and need pre-treatment to enhance their environmental features. Treatment followed by landfill is one of the most effective methods for handling such APC residues (Quina et al., 2008). In developed countries that use incinerators as a primary method of solid waste management, these countries have special rules for managing APCs as APC is high in alkalinity (> pH 12), volatile heavy metals, soluble chlorides and sulphate salts, and organic contaminants including dioxins and furans. In the UK for example APC residues are regulated under the hazardous waste regulation act as they have an absolute entry in the European Waste Catalog. Similarly, in Singapore, APC residues are also categorized under hazardous waste and must comply with the Environmental Public Health (Toxic Industrial Waste) Regulations (Rani et al., 2008). For this study, the disposal of APC residues was not included in the SL system because, the disposal of APC residues requires specially designed landfill cells.

The main outcome of incineration of waste at SL is heat and electricity recovery. This is 73% of the total solid waste incinerated equivalent to 414,752 tonnes per year. As per the plans at SL, a incineration of wastes at the rate of 1,500 tonnes per day can generate as much as 25 Megawatt (MW) of electricity. This can be seen at the 25-acre WTE plant which is expected to be operational in 2023. The WTE has been implemented in Malaysia in the past few years and is used for the biomass from agriculture waste and forestry residue (i.e., biomass of palm oil, paddy straw, and logging residues). Despite numerous studies suggesting the potential for economic and environmental benefits of landfill gas in Malaysia, WTE from urban solid waste is still underutilized in Malaysia (Tan et al., 2015). This is because the waste in Malaysia often has a high content of moisture which obviously affects the performance of the incinerator because the moisture would reduce the energy content of the waste resulting in a reduction in energy output. However, an incinerator can manage a wider range of waste, and those materials do not need to be separated to a large extent for disposal. This is in line with the situation of waste management in Malaysia, where waste disposal at the source is still low.

4.4.3 Comparison of three scenarios: Scenario 1, Scenario 2 and Scenario 3

From the analyzed scenarios for MSW, the highest amount of waste is disposed in landfill site in the current system of SL. It has been suggested that landfill provides among the most practical solutions for handling solid waste disposal both economically and ecologically. Improving waste disposal practices greatly reduces the amount of garbage that is disposed in a landfill (Banga, 2011). Table 4.7 shows the differences between the three scenarios.

Table 4.7: Comparison of leachate generation between the current system and the three recommended scenarios (in tonnes per year)

Scenario	Status quo Current system	Scenario 1 Composting	Scenario 2 Recycling	Scenario 3 WTE
Total waste disposed	950,419	144,234	589,177	439,686
Landfill Stock	439,650	105,151	385,440	351,393
Leachate generated	123,386	10,006	75,201	28,671
Leachate effluent	82,669	6,704	50,385	19,210
Gas recovery	52,968	511,799	44,141	412,138
Recovered recyclable waste materials	37,940	82,519	384,144	110,453

In terms of landfill life, Table 4.8 shows the amount of waste deposited to landfill has been reduced successfully. The amount of waste disposed to the landfill in Scenario Scenario1 is reduced by 89% and in Scenario Scenario2 and Scenario3 it has been reduced by 56% and 66% respectively, compared to the status quo. Scenario 1 composting showed the highest reduction followed by Scenario3 and Scenario2. Scenario1 recorded the highest reduction because the type of solid waste at SL was pioneered with organic waste which was suitable for treatment using composting methods. Whereas for Scenario3, various solid wastes can be disposed using the incinerator except for food waste. For Scenario2, however, the recycling method where waste was dumped at the landfill has decreased from 910,565 tonnes per year to 396,475 tonnes per year.

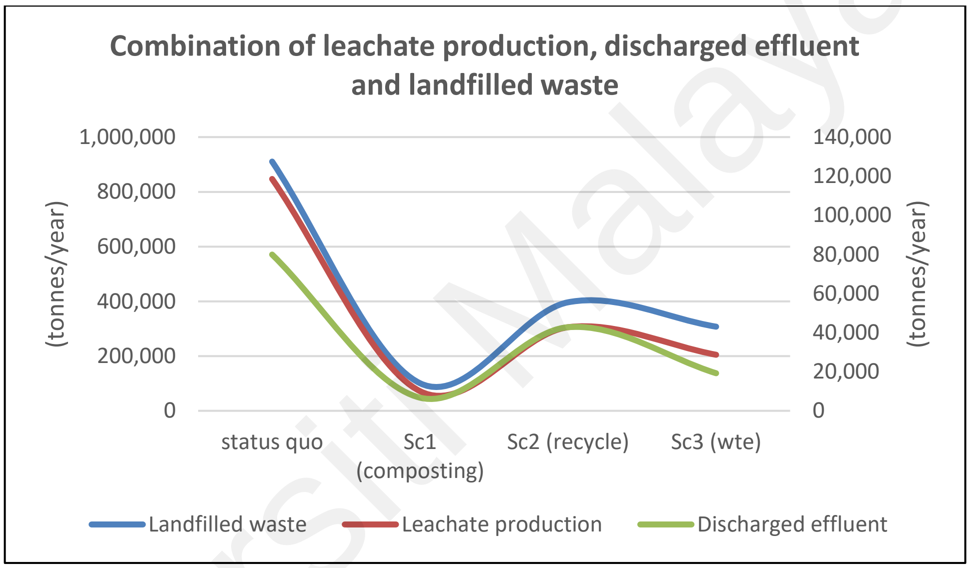


Figure 4.15: Leachate production and discharged effluent compared with the landfilled waste

From the Figure 4.15, study shows that by reducing the quantity of waste that is disposed in a landfill reduces the quantity of leachate and landfill gas that is stored in the body as landfill stock (Markic et al., 2019). The study by Zakarya et al. (2018) also supports that composting especially food waste could be the best way in reducing waste to the landfill. Whereas Waqas et al. (2018) have further stated that the economic benefits of compost include conversion of organic waste from landfills to value-added materials that are useful for numerous agriculture purposes as compared to synthetic fertilizer. And it can reduce almost 20% to 30% of the total organic waste that has been dumped onto the landfill before.

The sequences of leachate production based on the three scenarios modeled are Scenario1> Scenario3> Scenario2, each has a value of 10,006, 19,210 and 42, 759 tonnes per year. Separate collection of organic waste or running a composting process in a landfill could reduce the leachate gen and thus the amount of effluent that is to be discharged into the Sembilang River by 92%. Meanwhile, through WTE and recycling, there was a 76% and 64% reduction in leachate production, respectively. With this significant reduction, it is shown that by isolation of waste especially organic waste besides prolonging the life of a landfill, it further reduces leachate production and consequently the amount of effluent that is discharged into Sembilang River. According to Wang et al. (2018), composting proved to be excellent choices, which is devoted to reducing the environmental risk and improving composting effectiveness in organic waste management. This is also supported by Oliveira et al. (2017) where the study on the composting process is known to be one of the most appropriate options for the management and treatment of organic waste; where nutrient recycling and the resulting reuse of the organic proportion of the waste can be provided, thus minimizing environmental pollution. This shows that composting is the most suitable method in Malaysia in the efforts to reduce leachate production as well as reduce the waste that is disposed in landfills, as the highest quantity of waste in Malaysia is organic waste especially food waste. This is evidenced by the amount of waste that was brought to the SL itself is pioneered by organic waste as well as other landfills in Malaysia (Aziz & Ramli, 2018; Tang et al., 2019).

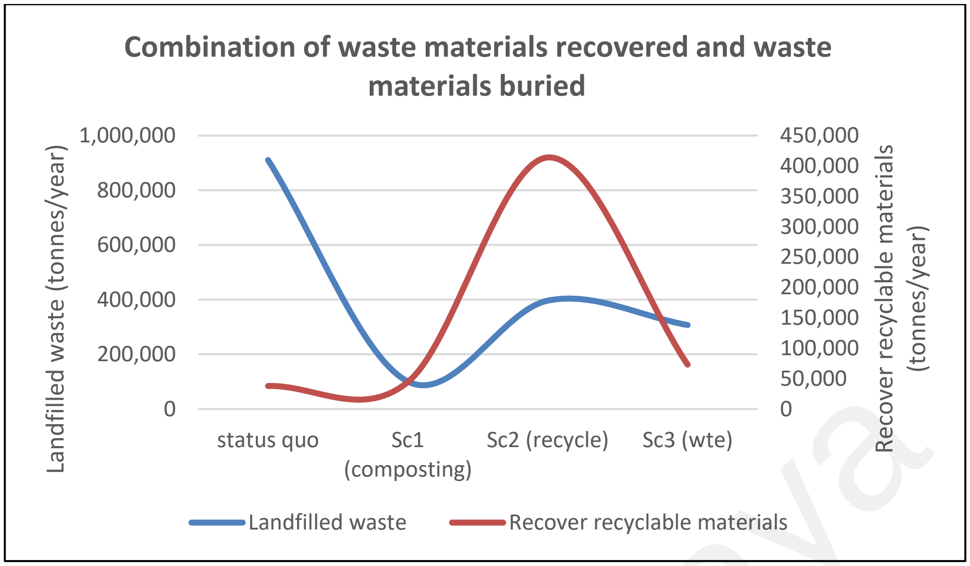


Figure 4.16: Material recovered compared with the waste material disposed

Figure 4.16 shows that, by increasing the volume of waste recycling in scenario Scenario2, the level of waste that is recycled into raw materials and goods is also increased from 37,940 tons per year to 414,023 tons per year. From the comparison of these two scenarios, scenario Scenario2 shows the highest reduction in leachate generation compared to scenario Scenario1. Although the percentage of recycled waste has increased from 4% to 58% and the percentage of waste that is sent to landfills has decreased from 98% to 42%, the resulting leachate percentage is still high. This is because most of the organic waste that is a major factor in leachate production is disposed in the landfill compared to the Scenario2 of this organic waste through the process of composting, thus reducing this type of waste to landfill.

The processing of waste into new raw materials or new products has a tremendous advantage in terms of the protection of natural resources; otherwise these new products might use natural resources for their production. Of these three modeled scenarios, besides reducing the quantity of solid waste that will be disposed in landfills, one thing that is equally important is the lowering in the production of effluent that is to be released into the environment. The amount of effluent production is also in the same order as Scenario1 <Scenario 3 <Scenario 2. Each of these three scenarios showed a reduction of 92%, 76% and 46% of the total effluent status quo. The most significant reduction was in Scenario 1. The amount of leachate production is accounted for by the amount of solid waste that is disposed along with the remnants of both processes (composting and recycling) which is no longer suitable for compost or to be recycled. This is very encouraging because the location of the river where effluent is released is very important for the locals especially for those who are involved with fishing activity and also aquaculture. With the present amount of waste disposed to landfill, the quality of the river water can be classified into class III-IV according to the water quality index. This is very worrying because it can pollute the water organisms and then enter the food chain. As mentioned before, if one of these system scenarios is executed on SL, the quantity of waste that ends in the landfill can be reduced and thereby reduces the amount of leachate and effluent production. Accordingly, the scope of assessment in this study has been restricted to discussing the proposals on waste and leachate management practice at the decision-making level.

4.5 Characterization of leachate

Landfill leachate comprises of a variety of complex variables, namely, solid waste composition, age of the waste, operation of the landfill, hydrogeological conditions of the landfill site, the water movement through the waste, landfill temperature, moisture content, pH, landfill chemical and biological activities and seasonal weather variations. Leachate generation also varies widely due to the successive aerobics. Although the freshly formed layers at the top of the landfill may have the characteristics, the leachate that is obtained emanates from the bottom layers or has lived in those layers and if it has been there for a sufficiently long period changes the bacterial behavior to anaerobic (El-Fadel 2003).

Table 4.8: Average concentrations of chemical characteristics of leachate

Water Quality parameters	Unit	Raw leachate			Standard discharge (DOE)
		Mean	SD	SE	
pH	-	8.33	0.2	0.1	6 to 9
EC	us/cm	*NA	NA	NA	-
TDS	ppm	NA	NA	NA	-
DO	mg/l	0.54	0.3	0.1	40
TUR	NTU	NA	NA	NA	-
TSS	mg/l	2410	1384	565	50
BOD5		4761	4801	1960	20
COD		60248	10478	4277	400
AN		3518	2223	908	5
NO3		2611	2291	935	-
PO4		586	80	33	-
TC	CFU/100ml	11567	993	406	-
Fe	ug/l	10536	3153	1576	5000
Al		2618	830	415	-
Mn		354	81	41	200
Cu		41	15	7	200
Cr		584	180	90	50
Zn		652	164	82	2000
Cd		11.00	7.95	3.97	0.01
Pb		15.55	4.49	2.25	100

***NA- the reading is too high**

The characteristics of landfill leachate will normally be defined by the basic parameters of chemical oxygen demand (COD), biological oxygen demand (BOD), BOD:COD, pH, total suspended solid (TSS), ammoniacal nitrogen (NH_3N) and heavy metals (Renou et al., 2008). Leachate samples were collected from the influent and effluent and various in-situ, laboratory analysis and metal analyses were performed. The following sections present the analytical results for the leachate. Table 4.8 shows the composition of landfill leachate with mean concentrations.

4.5.1 pH

pH leachate is influenced by several chemical reactions and the most important reaction is the degradation of organic matter to produce carbon dioxide as well as ammonia. Both of these substances will dissolve in the leachate and thus produce ammonia ions and carbonic acids. Carbonic acid reacts and produces hydrogen cations and bicarbonate anions which can affect the pH value of the system. In addition, the pH of the leachate can also be influenced by the CO_2 gas that is produced and reacts with the leachate.

The pH value of the raw leachate was presented in Figure 4.17. The pH value for raw leachate were 8.36, 8.5, 8.38, 8.32, 8.08 and 8.12 during the first, second, third, fourth, fifth and sixth data collection. Higher pH values were recorded from the raw leachate. The high range of pH in raw leachate suggests that a steady state has been reached between acid producing processes (e.g., cellulose and lignin degradation) and acid consuming processes (e.g. methane formation) at the landfill. Raw leachate was determined to be alkaline and acidic for the effluent. The observed variability was mainly due to the composition of waste that was disposed, the mechanism of biochemical decomposition and the impact of dilution within the disposal site. Leachate with an alkaline pH shows that the methanogenic fermentation stage has occurred throughout the landfill site. This suggests that the landfill is in the stage of methanogenic and the leachate is biologically stable.

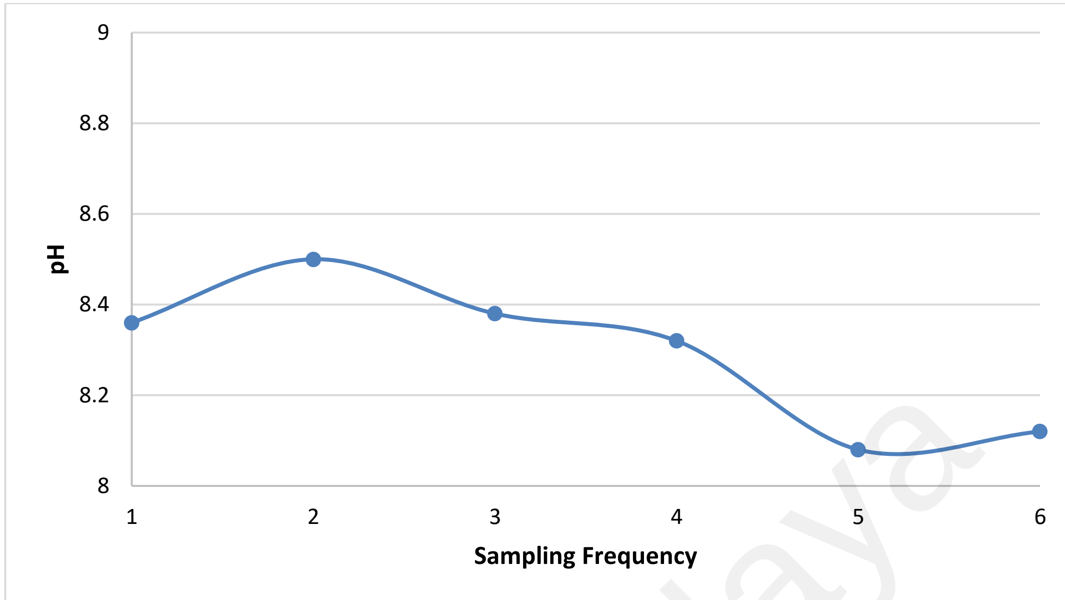


Figure 4.17: Mean pH results of leachate from SL

Depending on the increasing age of landfills, the pH will tend to be alkaline. Likewise, these shifts often interact with the essence of runoff and waste volume or consistency. The data also agrees with the pH range for mature leachate (landfill age > 10 years) that should be more than 7.5 (Zakaria & Aziz 2018). However, the pH recorded in this study is still within the range values of 6–9 that is appropriate for biological life (Noerfitriyani et al., 2018).

4.5.2 Bio-chemical Oxygen Demand

The results show that Bio-chemical oxygen Demand (BOD) concentration of raw leachate in ranged from 3,579 mg/l to 6107 mg/l as shown in Figure 4.18. BOD is widely used to determine organic matter content in leachate with some recorded BOD values of between 20 – 74 mg/l for treated leachate and 3,579 – 5816.1 mg/l for raw leachate. It is estimated that the BOD value declined over time as a result of a mixture of reduced organic contaminants leaching in the landfill (Lee & Nikraz, 2014).

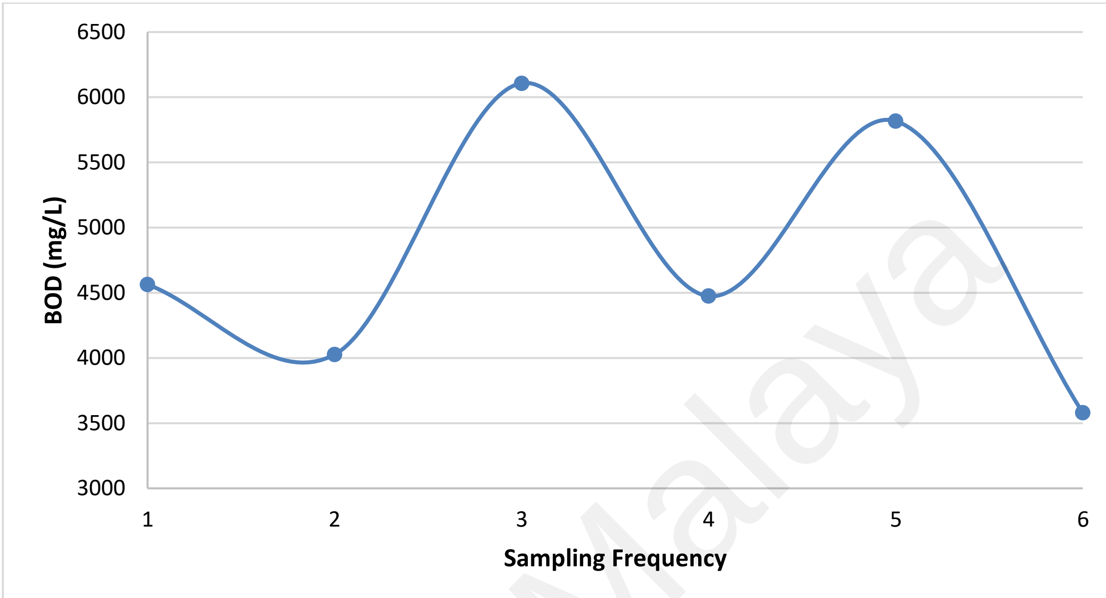


Figure 4.18: Mean BOD results of leachate from SL

The BOD level for a landfill with an age of 10 years ranged from 100-200 mg/l, while young landfill ranged from 200-30,000 mg/l (Zakaria & Aziz, 2018). The average raw leachate data was consistent with the specified range where higher organic matter content had been predicted in this leachate as a result of the production of dissolved and solubilized organic matter as reported by Lee et al. (2010). The BOD concentration was high during the third sample because of the high volume of waste have been sent to the landfill with 369,254 tonnes. The previous month also shows high volume of waste sent to the landfill for disposal with, 369,931 tonnes. This can be explained by the high concentration of BOD leachate from SL Landfill with the average of 4,761 mg/L. In a study done by Bhatt et al. (2017) shows that the highest concentrations for BOD in leachate could be due to high food waste that have been disposed off at the landfill as food is the most biodegradable composnent in the waste stream. This is in line with the food waste volume in SL Landfill with 32% of total waste sent to the landfill. The present values of BOD agree with those previously recorded (Jumaah et al., 2016; Razarinah et al., 2015).

4.5.3 BOD:COD

The time frame of solid waste that is disposed at the landfill can affect microbial activity which in turn contributes to the amount of leachate that is produced. As BOD is primarily a biochemical parameter, it generally represents biodegradability of organic matter in leachate, hence, making BOD:COD ratio a good indicator of the ratio of biochemically degradable organic matter to total organic matter. Thus BOD:COD ratio is typically a measurement that is used to characterize the organic composition in the leachate and it seems to be a good representation of waste stabilization transiting from early stage to mature stage in landfill. COD is a method to determine the amount of contaminant (organic and inorganic) in the sample. The average COD value for raw leachate was 60,248 mg/l as shown in Figure 4.20. The high COD concentration of leachate may be due to the enhanced leaching of contaminants from the wastes that was dumped at the upper layer during the initial precipitation followed by the dilution effects of rainfall as also been mentioned by Rafizul & Alamgir (2012). Greater COD values were also recorded by other studies (Ab. Ghani et al., 2017; Kaur et al., 2016; Feng et al,. 2019).

Due to the variability of the disposal of waste, it is beneficial to evaluate the relationship between the BOD: COD ratio and the leachate quality that is generated by the landfill. The average ratios of BOD:COD for raw leachate of SL were 1.27. Generally, the BOD:COD ratio describes the degree of biodegradation and gives information on the age of a landfill. This lower BOD:COD value indicates that this landfill is in the intermediate stage and is not suitable for biological treatment processes. Additional physico-chemical processes may be required to achieve the desired removal efficiency (Fan et al., 2006). Figure 4.20 shows the ration of BOD:COD that is spread over the six sampling in the landfill that has been studied.

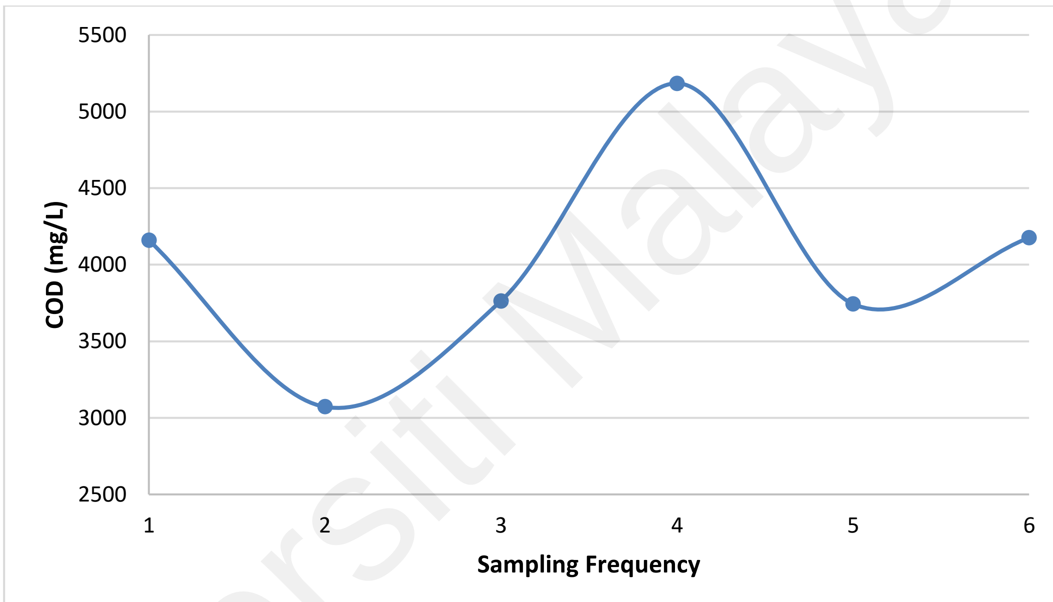


Figure 4.19: Mean COD results of raw leachate from SL

The BOD: COD proportion is normally 0.5:1 for raw domestic wastewater and may be as low as 0.1:1 for well-stabilized secondary wastewater. There is no official value for BOD:COD for the different types of wastewater (Abdalla & Hammam, 2014). The BOD:COD ratio for raw leachate decreases from 0.85 to 1.6 in first sampling to sixth sampling period, respectively. This shows that the landfill is transitioning from acetogenic phase to a more stable status of methanogenic phase. These results agree with the literature that BOD:COD ratio decreases with the landfill age. This led to decreasing biodegradability of leachate as the landfill ages, more complete oxidation for organic carbon. High concentration of COD in leachate also have been reported in a study done by Calli et al. (2005) with ranging from 5,850 to 47,800 mg/L where the BOD:COD rations usually above 0.6. is always greater than or equal to BOD. The highest COD concentrations was in Somani et al. (2019) study, with the average value more than 10,000 mg/L, which the same trend was found in Zailani et al. (2017) study as well. The average obtained BOD:COD of 1.27 from the present study agreed with literature stated by Mohd-Salleh (2020) and Shadia et al. (2020).

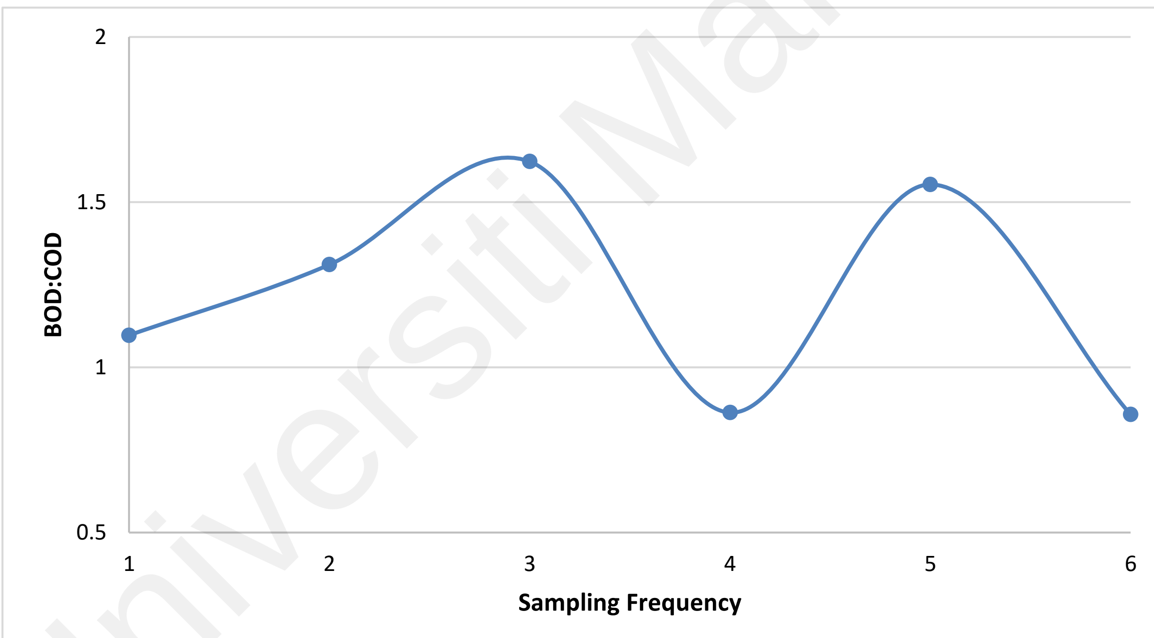


Figure 4.20: Ratio of BOD:COD over 1 year Duration

4.5.4 Ammoniacal Nitrogen (NH_3-N)

The AN mean concentration of the stabilization pond leachate was 3,518 mg/l as shown in Figure 4.21. The presence of ammonia and organic nitrogen is due to the decomposition of organic matter which is stable in anaerobic conditions, which explains the presence of a high percentage of soluble nitrogen compounds that are found in the leachate (Lee et al., 2010). Ammonia is also believed to be mainly released from the decomposition of organic matter, such as protein. Therefore, ammonia appears to be a good hint of organic nitrogen in the leachate (Lee et al., 2010).

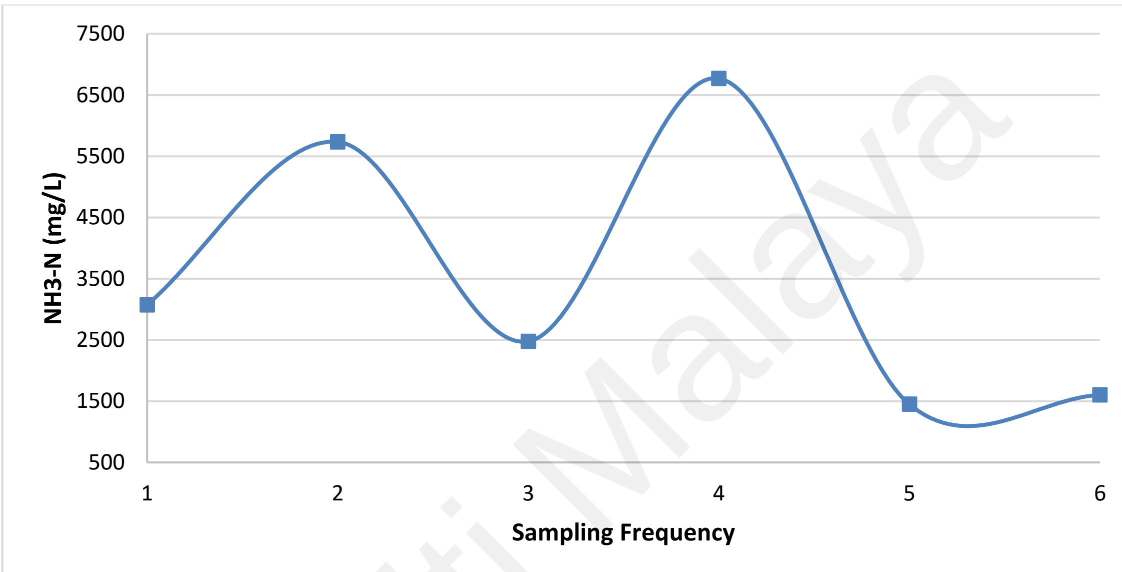


Figure 4.21: Mean NH-$_3$N results of leachate from SL

The NH-$_3$N value is still higher than the MEQA requirement. This high volume of unprocessed NH-$_3$N led to an increase in algal production, a decreased in the effectiveness of biological treatments, an intensified eutrophication and an increased in DO depletion. Therefore, NH-$_3$N is highly toxic to aquatic organisms (Aziz et al., 2015). Observed NH-$_3$N concentration ranged from 1,601 to 6,770 mg/l for raw leachate. At this concentration, the methanogen is only mildly inhibited by ammonia, but at higher pH and temperature levels, such that the NH_4 change to NH_3, which is more toxic, may induce inhibition of the methanogen archaea (El-Salam & Abu-Zuid, 2015). According to Rafizul & Alamgir (2012), high concentration of NH-$_3$N was possible in anaerobic reactors and the NH-$_3$N of landfill leachate ranged from 500 to 1,500 mg/l over a period of 3-8 years, and will stay at this level for the next 50 years.

4.5.5 Total suspended solid (TSS)

TSS average values of raw of the landfill site were 2,410 mg/l as shown in Figure 4.22. The raw leachate samples ranged between 700 to 4,360 mg/l. As shown in the figure, the TSS concentration generally decreased from the first sampling to the sixth sampling date. The highest mean TSS value was observed in the first sampling which is happen during the wet season with 4,360 mg/l for raw leachate followed by dramatic decreases in TSS value to as low as 700 mg/l for raw leachate. The values of TSS reveal that the leachate consists of a high percentage of dissolved inorganic materials that is found in the landfill and could be harmful if it makes its way into living organisms. If this situation continues, it may contribute to contamination of agricultural solids, soil, surface and groundwater throughout the affected community (Ifemeje et al. 2016).

After going through the various stages of treatment, the percentage of removal of TSS raw leachate to treated leachate is 95%. TSS is among the most widely used criteria for surface water quality problems. This is because TSS has a direct (physical, biological and ecological) and indirect (toxicological) effect on aquatic ecosystems. Hence, TSS is considered a good proxy for current water conditions and is helpful for assessing the risk of water quality hazards.

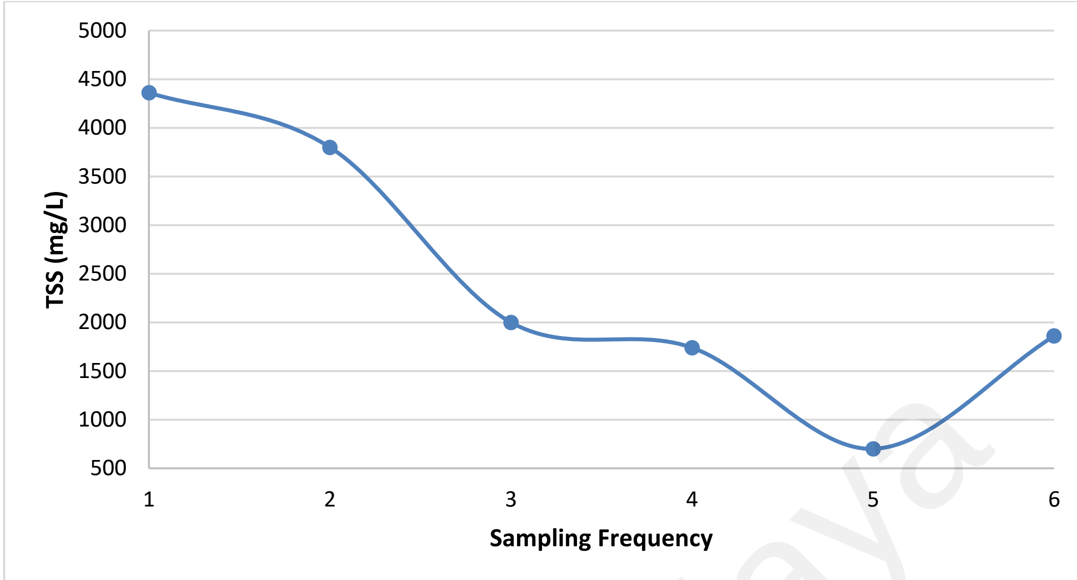


Figure 4.22: Mean TSS results of leachate from SL

4.5.6 Heavy metals

Among the various leachate contaminants, more attention should be given to metal ions, especially heavy metal ions, due to their adverse effect to the ecosystem and to the biological treatment processes. There are various types of heavy metal ions in the leachate, and the insoluble metals in the waste are transformed into soluble metal ions and are then dissolved in the leachate through physical and chemical reactions (Youcai 2018).

The availability of heavy metals in landfills was related to the nature of waste disposal, waste management practices and decomposition activities (Adelopo et al. 2018). The metal concentrations in the raw leachate in relations to the times of samplings are shown in Figure 4.24. The concentrations of heavy metals in raw leachate (Cr, Cu, Zn, Pb, Cd) were found to be relatively low, while those of Fe, Al, Mn were relatively higher with average concentrations of 16.448 mg/l, 4.336 mg/l and 2.289 mg/l respectively as shown in Table 4.9.

Table 4.9: Mean heavy metals concentration in leachate

Nt	Unit	Leachate			Standard discharge (DOE)
		Mean	**SD**	**SE**	
Fe	mg/l	16.45	10.69	5.34	5
Al		4.34	5.674	2.84	NA
Mn		2.29	1.94	0.97	0.2
Cu		0.02	0.02	0.01	0.2
Cr		0.12	0.14	0.07	0.05
Zn		0.10	0.83	0.42	2
Cd		0.001	0.001	0.00	0.01
Pb		0.002	0.002	0.00	0.1

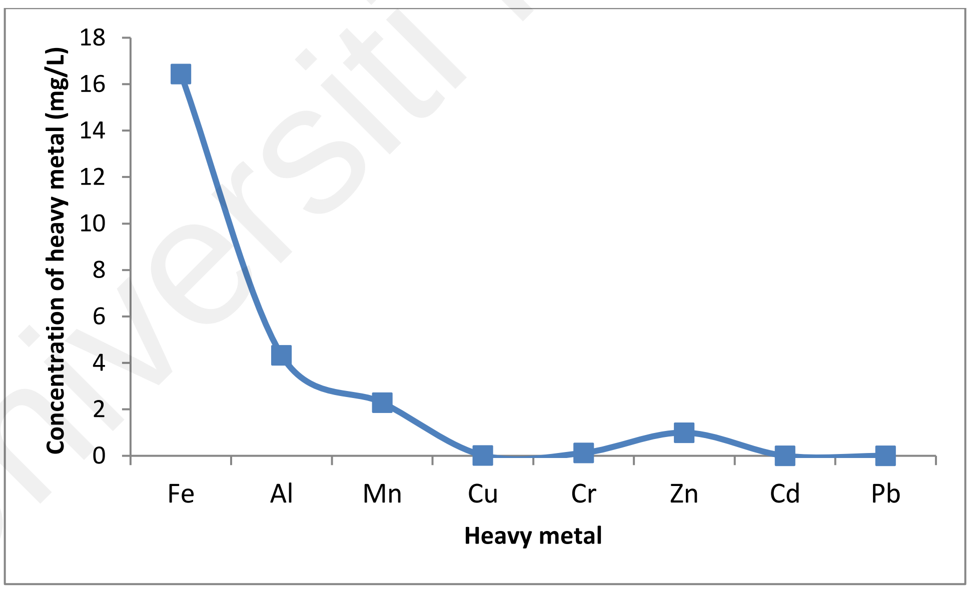


Figure 4.23: Mean heavy metals results of leachate from SL

Concentrations of Fe in the samples showed significantly higher values (>10 mg/l) in samples from leachate. The concentration of Fe varied in the range of 7.090 mg/l to 30.920 mg/l and is generally due to the disposal of Fe and steel scraps in the landfill. The dark brown color of the leachate is mainly because of oxidize ferrous (Fe^{+2}) in a ferric form (Fe^{+3}) and the formation of ferric hydroxide colloids and fulvic complex as reported by De et al. (2015). Additionally, this ion is sensitive to redox conditions and become more soluble under methanogenic conditions; therefore, the concentrations as free ions increase at neutral to alkaline pH. This could be another reason for their significant presence in the leachates.

This is supported with a study done by Naveen et al., (2017) where there are high concentrations of Fe in the leachate, while the concentrations of Zn, Cr, Cu, Cd and Pb are low. Pb and Cd enters municipal solid waste through the use and disposal of products such as nickel-cadmium batteries, Cd pigmented plastics, glasses, paints, and pigments (Bakhshoodeh et al. 2016). These heavy metals are dangerous pollutants. Since most of the wastes disposed in SL are from domestic waste, this can be demonstrated by low Zn concentrations in the leachate sample. This is in contrast to the study that is conducted by El-Salam and Abd-Zuid (2015) where Zn concentration in the leachate sample is high which is caused by the disposal of large quantities of industrial wastes within the landfill such as batteries and fluorescent lamps (De et al. 2015). The presence of Cr in the landfill leachate indicates the occurrence of tannery waste, wood preservatives and paint products. While the occurrence of Pb in the landfill leachate indicates that there is a disposal of waste consisting of Pb batteries, photograph processing chemicals, Pb based pipes and paints in the landfill site (De et al., 2015).

4.6 Water quality of Sembilang River

This section presents the results and discussion of water quality data from the Sembilang River. For the main study, surface water quality data were collected along the river at 10 sampling locations, from upstream to the downstream of Sembilang River at the Pantai Remis, Kuala Selangor. The results of physical-chemical analysis and heavy metal values are indicated in Table 4.13. Data for coliform bacteria were also collected. Each of these parameters will be discussed in the following sections.

Table 4.10: Mean, SE and SD of the Sembilang River water quality parameters throughout the study period.

Parameter	NWQS	Statistical parameters	J01	J02	J03	J04	J05	J06	J07	J08	J09	J10
pH	5-9	Mean	3.84	3.52	4.76	5.55	5.51	5.73	6.22	6.45	6.54	6.57
		SE	0.27	0.17	0.46	0.45	0.46	0.40	0.39	0.40	0.35	0.41
		SD	0.85	0.53	1.46	1.42	1.45	1.26	1.24	1.27	1.12	1.31
DO (mg/l)	5-7	Mean	4.20	4.17	3.88	3.21	3.70	4.26	4.21	3.38	3.76	4.32
		SE	0.77	0.65	0.69	0.55	0.54	0.62	0.59	0.39	0.62	0.79
		SD	2.44	2.06	2.19	1.73	1.71	1.96	1.87	1.23	1.96	2.50
Turbidity (NTU)	5-50	Mean	6.14	7.62	35.91	36.82	37.45	74.58	41.16	44.17	58.62	47.36
		SE	1.65	1.64	18.89	8.78	9.53	17.95	11.03	14.63	13.90	6.65
		SD	5.21	5.20	59.75	27.75	30.15	56.76	34.89	46.27	43.94	21.02
TSS (mg/l)	25-300	Mean	7.50	10.20	33.40	41.90	36.60	28.59	27.30	33.00	46.20	54.00
		SE	3.41	2.72	17.72	14.93	9.61	8.22	10.41	7.49	14.33	13.04
		SD	10.79	8.61	56.02	47.20	30.39	25.98	32.92	23.69	45.30	41.23
BOD (mg/l)	1-12	Mean	0.34	2.08	10.73	7.53	4.77	5.24	6.22	8.69	7.16	8.20
		SE	0.18	0.69	2.03	1.73	1.06	1.11	2.39	2.45	1.89	2.14
		SD	0.57	2.19	6.42	5.48	3.34	3.52	7.55	7.75	5.99	6.77
COD (mg/l)	10-100	Mean	19.10	44.45	134.47	90.61	84.25	86.45	79.94	91.88	74.36	59.69
		SE	4.80	7.39	33.81	14.53	22.10	19.01	15.82	18.95	13.85	9.53
		SD	15.19	23.37	106.91	45.96	69.90	60.11	50.04	59.91	43.79	30.14
NH_3-N (mg/l)	0.1-2.7	Mean	0.75	1.23	11.78	15.14	15.30	11.32	15.56	13.89	11.94	8.30
		SE	0.26	0.12	5.20	4.76	5.12	3.11	4.57	4.00	2.75	1.63
		SD	0.83	0.39	16.44	15.05	16.18	9.82	14.45	12.66	8.69	5.16
NO_3 (mg/l)	5-7	Mean	1.19	5.08	75.85	71.36	53.73	36.49	31.28	99.36	43.46	33.73
		SE	0.51	2.15	35.50	31.88	21.82	11.78	8.82	42.26	20.11	13.29
		SD	1.62	6.80	112.27	100.82	69.01	37.24	27.88	133.65	63.59	42.03

Table 4.10, continued.

Parameter	NWQS	Statistical parameters	J01	J02	J03	J04	J05	J06	J07	J08	J09	J10
PO4 (mg/l)	-	Mean	0.02	0.32	0.28	0.42	0.14	0.57	2.66	10.33	4.41	4.53
		SE	0.01	0.09	0.12	0.11	0.05	0.18	1.85	3.67	2.05	2.04
		SD	0.03	0.29	0.39	0.36	0.17	0.58	5.86	11.61	6.47	6.46
TC (CFU/100ml)	100-50000	Mean	2,100	2,350	10,875	2,750	3,825	9,450	4,562.5	1,063	4,650	5,038
		SE	787	919	3,345	864	727.7	1,361	594.4	327	612	2,165
		SD	2,489	2,907	10,577	2,733	2,301	4,305	1,880	1,035	1,935	6,847
Fe (µg/l)	1000-5000	Mean	1,667	2,736	4,623	4,533	3,991	2,822	3,016	2,493	2,289	1,927
		SE	196	344	431	828	730	720	1,069	881	800	694
		SD	620	1,089	1,363	2,619	2,309	2,278	3,379	2,785	2,531	2,194
Al (µg/l)	60-500	Mean	4,911	5,084	6,492	7,352	7,883	4,237	4,642	3,027	2,769	3,149
		SE	743	956	1079	1703	1665	906	1747	864	971	1326
		SD	2,229	2,867	3,236	5,110	4,993	2,718	5,241	2,590	2,911	3,977
Mn (µg/l)	100-200	Mean	497	568	663	792	813	804	793	584	705	559
		SE	57	102	74	118	107	104	138	157	154	118
		SD	180	323	233	372	339	330	438	497	487	373
Cu (µg/l)	20-200	Mean	31.6	22.9	27.6	26.1	40.9	24.4	30.7	22.1	21.3	19.8
		SE	14.0	9.6	11.7	10.5	10.0	10.3	12.1	10.3	9.3	8.9
		SD	44.2	30.4	37.0	33.3	31.7	32.4	38.3	32.7	29.4	28.1
Cr (µg/l)	50-100	Mean	5.41	3.53	12.01	7.70	9.32	5.78	7.50	4.69	7.08	5.55
		SE	1.34	1.07	3.73	1.65	1.63	1.37	2.01	1.12	1.84	1.14
		SD	4.23	3.40	11.78	5.23	5.15	4.34	6.34	3.56	5.83	3.59
Zn (µg/l)	400-5000	Mean	132.6	194.1	639.7	172.7	528.8	184.9	228.7	276.5	266.7	259.7
		SE	20.1	64.0	331.9	29.9	195.5	26.6	23.9	37.6	32.0	50.3
		SD	63.7	202.5	1,050	94.4	618.2	84.2	75.5	118.8	101.3	159.1

Table 4.10, continued.

Parameter	NWQS	Statistical parameters	J01	J02	J03	J04	J05	J06	J07	J08	J09	J10
Cd (µg/l)	1-10	Mean	1.43	1.47	1.58	1.47	6.49	1.46	1.43	1.67	1.47	1.44
		SE	0.71	0.74	0.70	0.68	3.08	0.67	0.65	0.65	0.59	0.57
		SD	2.24	2.33	2.22	2.14	9.74	2.12	2.06	2.05	1.86	1.81
Pb (µg/l)	10-5000	Mean	4.24	3.34	5.67	3.96	12.46	5.28	3.60	2.93	1.97	2.60
		SE	1.74	1.64	1.48	1.73	3.11	2.13	1.71	1.67	1.22	1.45
		SD	5.51	5.19	4.68	5.48	9.83	6.74	5.39	5.28	3.85	4.59
Ni (µg/l)	900	Mean	9.84	10.44	20.16	18.14	21.20	15.80	16.87	12.21	14.06	11.49
		SE	2.26	2.28	4.12	3.28	1.85	2.23	3.54	3.46	3.35	2.87
		SD	6.38	6.44	11.65	9.27	5.23	6.31	10.00	9.77	9.47	8.13

4.6.1 pH

Acidity and water alkalinity can be determined using pH parameters which are simple but important in which most chemical methods are influenced by changes in the pH value in the aquatic environment. It has huge impacts on water quality that influence metal solubility, alkalinity and water hardness. Unpolluted streams normally show a near natural or slightly alkaline pH (Jonnalagadda & Mhere, 2001). The present study showed that all the pH values were acidic, ranging from 3.53 to 6.57 with the highest value at J10 and the lowest at J02 and was outside the acceptable limits (6.5-8.5). The pH of the water samples ranged from acidic value of 3.53 to a slightly neutral value of 6.57.

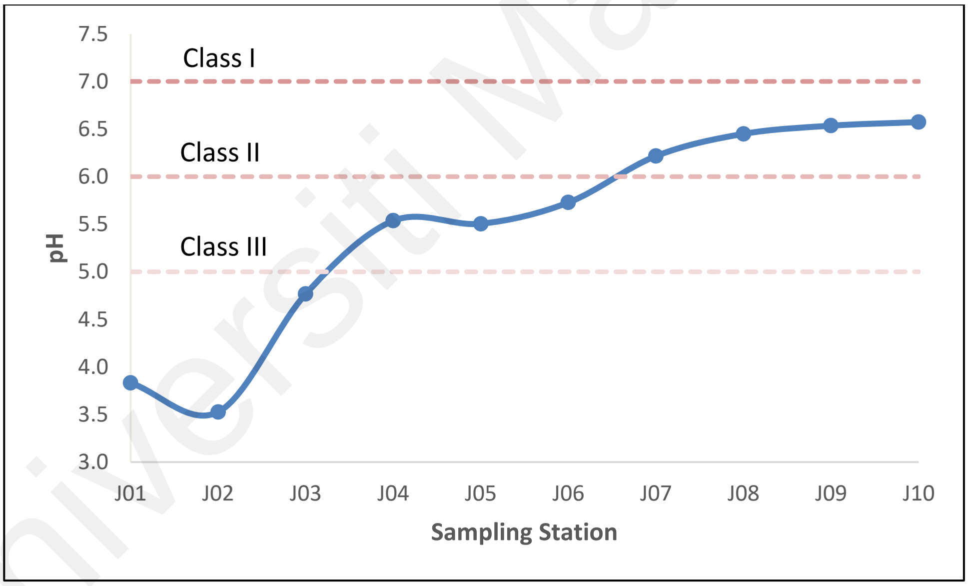


Figure 4.24: Mean pH results of at sites sampled in the Sembilang River

pH value is less than 5 at the upstream stations at station J01 (3.83) and J02 (3.53) indicating the acidic conditions is under Class III of DOE Water Quality Index Classification (Figure 4.24). The soil types in the study area are marine clay alluvium which has a low pH, below 5. This is the reason why the pH values in J01 and J02 are lower compared to other monitoring sites. Similar ranges were reported for the same river by Yusoff et al. (2018) and also in other rivers in Malaysia (Naubi et al., 2016; Kozaki et al., 2017; Hanafiah et al., 2018). The pH value increased drastically at station J03 to 4.77 after receiving effluent from SL and remained within the range of 5–6 at the downstream of the river due to the mixed river water, where there were various land usage along the river including residential areas, industrial areas and recreational areas.

However, the pH value increased to 6.57 at station J10. However, the range value was still below the acceptable limits. The higher reading of pH at the downstream of Sembilang River was caused by the palm oil plantation that was almost along the river, where NPK fertilizers were used mainly. The use of fertilizers in the form of urea or ammonia is a factor in low pH values in irrigation systems that receive runoff from agricultural activities. This is because both elements (urea and ammonia) are acidifying due to the nitrification of ammonia and leaching of nitrate, and thus contribute to the acidic pH values (Ogbozige & Alpha, 2019). The soil types in the study area are marine clay alluvium which has a low pH, below 5. This is the reason why the pH values in J01 and J02 are lower compared to other monitoring sites and the reading increase gradually after the landfill discharge point at J03. The pH value recovered along the river as mixed river water, where there were various land usage along the river including residential areas, industrial areas and recreational areas. According to NWQS of Malaysia, the ideal class for aquatic ecosystems is in the range of 6.5-9. Therefore, it is very important to maintain the aquatic ecosystem within this range because high and low pH can be destructive in nature.

4.6.2 Temperature

The temperature plays a key role in the dissolution and precipitation processes and influences both water chemistry and biological conditions because it may affect the river in so many ways such as the geographical distribution, growth rate and reproduction of aquatic life. This can be triggered by various processes: natural and anthropogenic. The impact on river temperature can include global climatic change, regional land use, power station heat effluent, river flow, water depth, cloud cover and solar radiation. Surface water is usually within the temperature range of 0°C to 30°C.

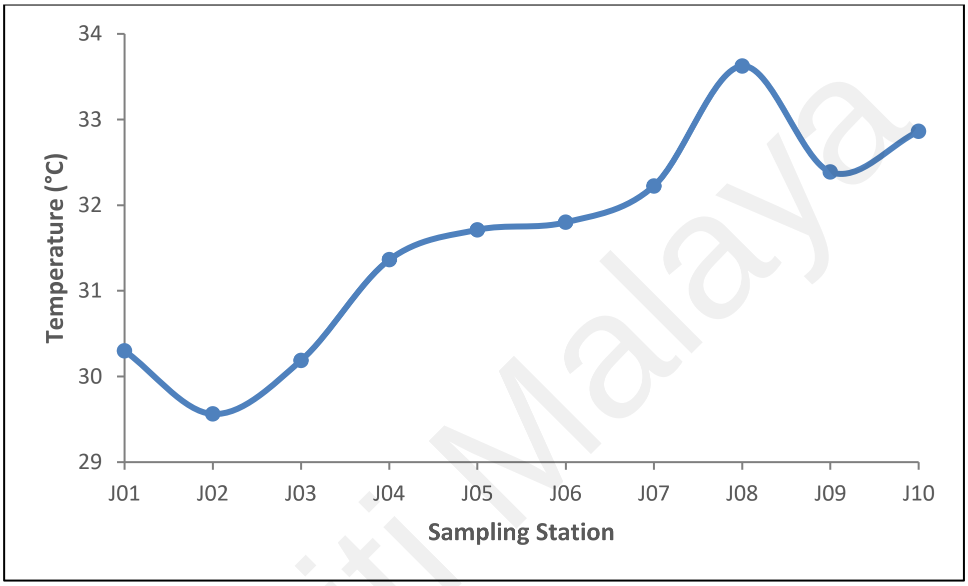


Figure 4.25: Mean temperature results of at sites sampled in the Sembilang River

For Sembilang River, the surface water temperature varied from 28.2 to 32.9℃. The mean value of temperature that was measured along the river of Sembilang River was 32.11°C (Figure 4.25). Moreover, most of the time during the ten sampling dates the weather was sunny and dry. These conditions affected the water temperature the most.

4.6.3 Turbidity

Turbidity plays a major role in regulating the penetration of light in the water column, which can form the physical environment and regulate ecological systems. Turbidity can be caused by suspended particles of organic or inorganic and dissolved matter. High turbidity can affect the transmission of underwater light and ultimately alter aquatic, animal and vegetation productivity and living conditions.

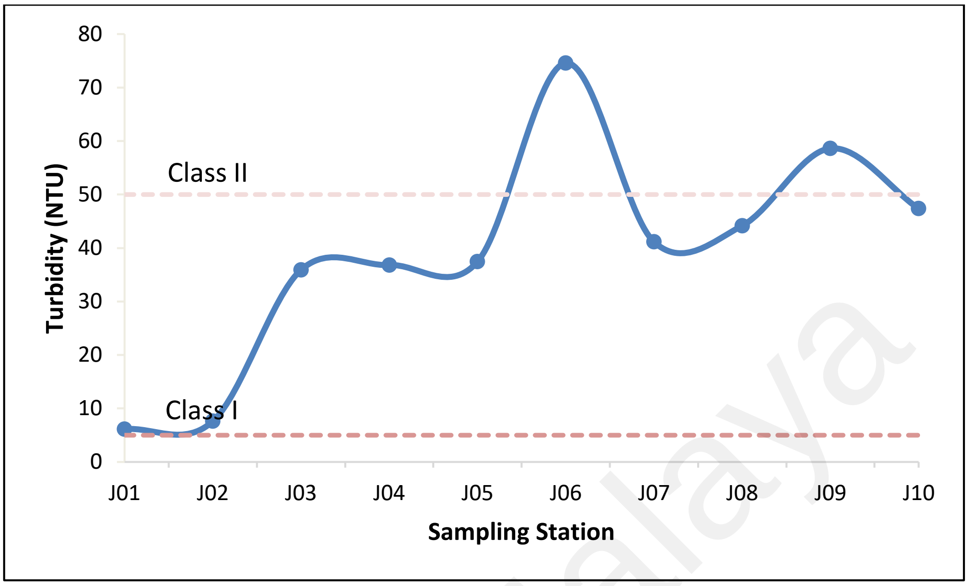


Figure 4.26: Mean turbidity results of at sites sampled in the Sembilang River

From the ten samplings at Sembilang River the results show that the mean turbidity level is between 6.14 NTU and 74.58 NTU (Figure 4.26). However, water transparency decreased significantly when the highest turbidity level was found at J06 where the river was of grass water with agricultural activities (palm oil plantation) in the watershed. The mean value for turbidity of Sembilang River is 39.10 NTU. In the present study, the turbidity value at Sembilang River is most likely due to the suspended solids originating from the runoff of anthropogenic activities and re-suspension of settled inorganic solids which is supported by the low flow rate at those stations. The murkier water in general was ascribed to the higher amounts of sediments.

4.6.4 Dissolve Oxygen (DO)

Dissolved oxygen (DO) is widely used to assess the quality of water as an influence of industrial and municipal effluents and factors of the environmental quality of watersheds. The ideal value for good water quality is 4 to 6 mg/L of DO, which ensures a healthy aquatic life in the water body.

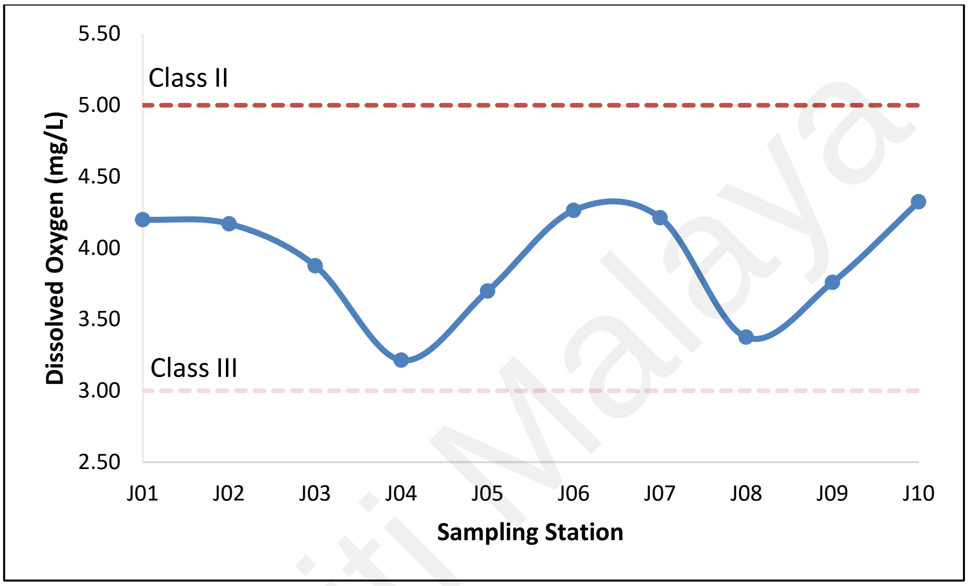


Figure 4.27: Mean dissolved oxygen concentration of at sites sampled in the Sembilang River

Sembilang River recorded the mean concentration of DO in the range of 3.21 mg/l to 4.32 mg/l (Figure 4.27) with the lowest concentration at J04 and the highest was at the downstream of the river, at J10. This concentration rate can be categorized in class III, NWQS of Malaysia. The lowest concentration of DO was affected by the effluent from the landfill and the land usage around that area which was near to the palm oil plantation. One of the reasons that caused the low levels of DO, between 3-4 mg/L, could be the lack of natural re-aeration. The sedimentary oxidation further depletes the DO levels in the water column. J04 is located at the middle segment of the river and the water quality conditions here can be considered to be moderate. The relatively low DO levels indicated that the upstream land-use activities appear to bring impact on the in-stream water quality. The DO value of a water body directly reflects the growth situation for aquatic organisms and pollution conditions. Depletions in DO can cause major shifts in the kinds of aquatic organisms that are found in water bodies and directly affect the river water quality (Amneera et al., 2013).

4.6.5 Biochemical Oxygen Demand (BOD)

The 5-day BOD (BOD_5) is the most commonly used parameter of organic contaminant that is applicable for wastewater and surface water. BOD involves measuring the dissolved oxygen (DO) that is used in the biological oxidation of organic matter by the microorganism. The level of BOD at station J01 (0.43 mg/l) and J02US (2.27 mg/l) show the lower concentration of BOD compared to other stations (Figure 4.28). Low BOD was primarily because of higher algal productivity, together with the increased of oxygen at low temperatures (Matta et al., 2017).

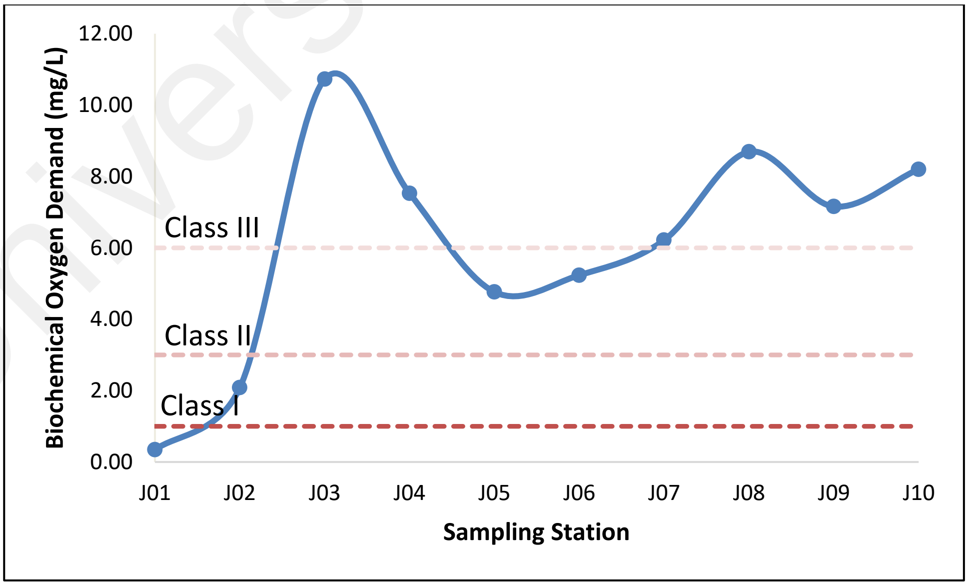


Figure 4.28: Mean biochemical oxygen demand concentration of at sites sampled in the Sembilang River

As the landfill effluent is disposed at station J03, the BOD value exhibits higher value, which is 10.73 mg/l. Excessive BOD loads damage the quality of river water. It results in low DO concentration and inadequate flora and fauna living conditions in the river (Zennaro et al., 2009). The results also show that BOD concentration increase to grade II (NWQS) from J04 to J07 and then decreases to class III at 8.69 mg/l. Direct discharge of untreated domestic waste into the river was responsible for the high organic pollution and resulted in the very high BOD values which gradually decreased at downstream of the river and this is also stated in a study conducted by Matta et al. (2017). There are small residencial area especially the palm oil plantation residensies and small food place are the cause of the high organic pollution at that area which mostly coming form the kitchen waste. High BOD concentration also may cause negative effects on the aquatic system due to high oxygen intake, which in turn causes anaerobic environment (Yilmaz & Koç, 2016).

4.6.6 Chemical Oxygen Demand (COD)

COD symbolizes the level of organic pollution in water and is defined as a number of oxygen equivalents used in the oxidation of organic compounds using strong oxidizing agents. The landfill effluent is disposed at station J03 and the COD value is higher among other sampling points with 367.20 mg/l. The COD value ranges from 0.00 mg/l to 367.20 mg/l. For station J03 to J10, most of the values are greater than 60 mg/l due to higher rate of oxygen consumption from the water which is represented as Class IV, indicating its unsuitability for any purposes. The mean value of COD for Sembilang River is 73.98 mg/l (Figure 4.29). These phenomena may be the consequences that have resulted from the organic and inorganic suspended materials runoff from the agricultural lands, in this case, that is where the palm oil plantation is, in past studies there is a direct correlation of COD and agricultural discharges. In cases where COD appears high and

BOD values are low, there are no biodegradable organic compounds or heavy metals that kill microorganisms.

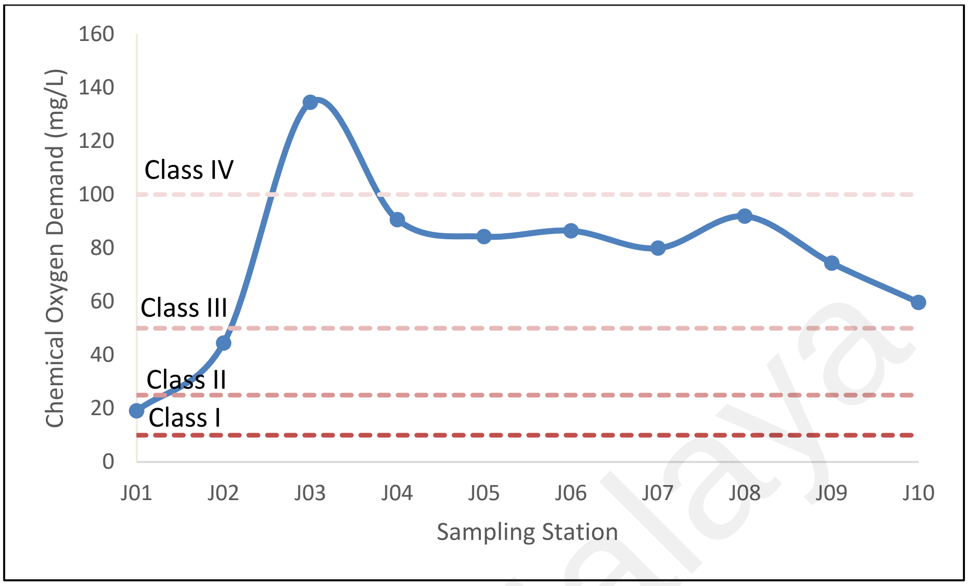


Figure 4.29: Mean chemical oxygen demand results of at sites sampled in the Sembilang River

COD have great advantages in estimating the pollution of organic matter. Nevertheless, the recorded COD values showed, a high fluctuating range of waste disposal and agricultural effluent containing a significant amount of organic matter in J03. Site J03 showed that COD values increased dramatically to more than 100 mg/L. The lower COD level indicates a low level of pollution whereas the high COD rates mean that water pollution is high in the area being studied. In addition, the widespread use of chemical and organic fertilizer and wastewater discharge affect COD levels and the high COD indications for water quality deterioration are attributed to municipal effluent discharge.

4.6.7 Ammoniacal Nitrogen (NH_3-N)

The ammonia-nitrogen (NH_3-N) concentrations of water samples varied from a minimum of 0.0 mg/L at station J01 and a maximum of 54.88 mg/L at station J05 (Figure 4.30). The permissible NH_3-N level for Malaysian rivers, according to the NWQS, is 0.9 mg/L. However, the concentration of NH_3-N has exceeded this level and is characterized in Class V. Before the landfill, the level of NH_3-N at two stations J01 and J02 show low concentration and the values range from 2.01 to 4.42 mg/L. Whereas after the landfill, all stations show a higher value (>2.7 mg/L) which is in the ranges of 6.48 to 11.01 mg/L.

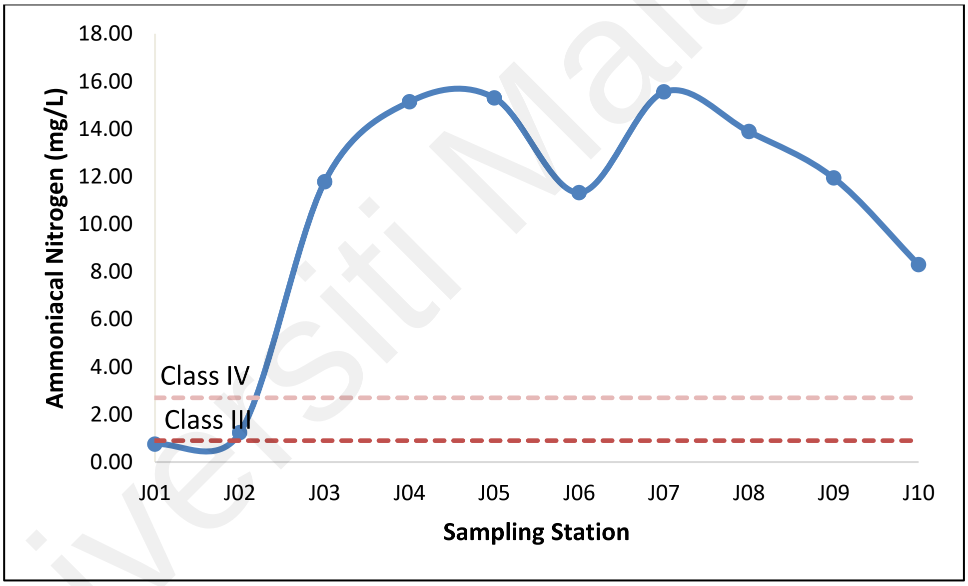


Figure 4.30: Mean ammonical nitrogen results of at sites sampled in the Sembilang River

This is indication that the river is polluted by ammonia from the fertilizers which is from the palm oil plantation at stations that are located downstream of the river. At all events, higher concentrations of NH_3-N can be toxic to fish, on the other hand, at low concentration, it could benefit as nutrients for the growth of algae. It is due to the different sources of excess nitrogen, where human waste is rich in ammonia and agriculture runoff is nitrate-rich (Allan et al., 2020). The microbial degradation of nitrogen is a major source of NH_3-N in a river. These compounds are transmitted to the environment through various sources including sewage decomposition by-products. The aqueous ammonia concentration above 0.2 mg/L may be hazardous to many aquatic organisms (Sanchez et al., 2007).

4.6.8 Total Suspended Solid (TSS)

TSS is one of the most commonly used indicators of surface water quality problems. This is because TSS has a direct (physical, biological and ecological) and indirect (toxicology) impact on aquatic ecosystems. Thus, TSS is considered a good proxy for current water conditions and is useful to assess the risk of water quality hazard. The TSS level of Sembilang River for station J01 and J02 exhibit <25mg/L, indicating the category of Class-I. After the landfill, when effluent is mixed with the river water, suspended solid increases gradually and are found to be higher at station J03, J05 and J10.

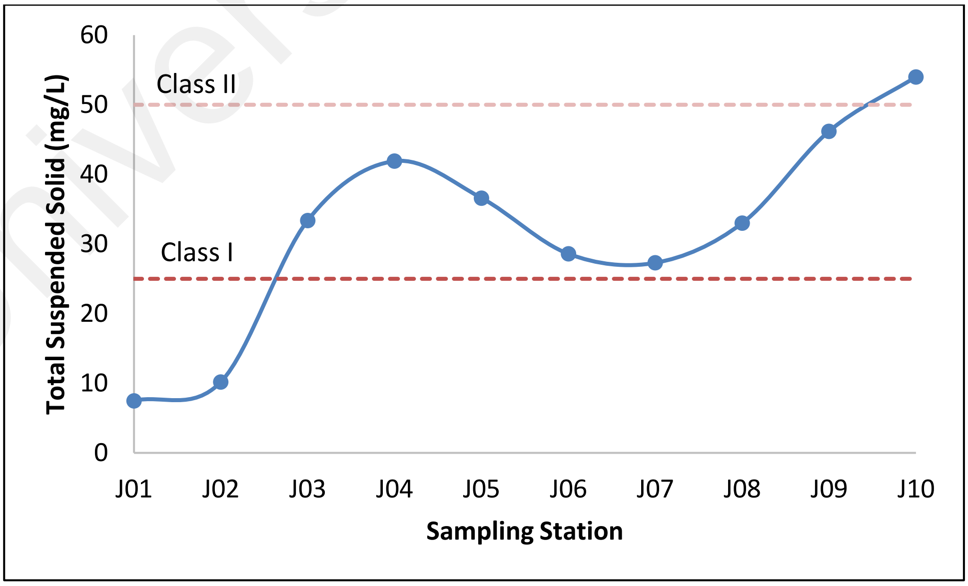


Figure 4.31: Mean total suspended solid results of at sites sampled in the Sembilang River

The value is fluctuating at downstream of Sembilang River and most of the values are of Class I-II. Past studies also show a strong correlation between TSS and turbidity. This coloration is also found in the water sample at station J09 where both results for turbidity and TSS are high. The location of sampling station can be a factor for the high result for TSS at J09 where it is located at the highway culvert, at which the river is mostly filled with garbage and there is no water stagnation. The mean value for TSS of Sembilang River is 31.9 mg/L (Figure 4.31).

Based on the NWQS, the maximum threshold limit of TSS for Malaysian rivers which support aquatic life is 150 mg/L. However, the TSS values in this study were within this limit and were categorized as Class I and II. Normally, soil erosion is considered to be the source for suspended solids that comes from the surrounding area which is caused by human activities. For example, the TSS concentrations increased starting from station J03, which recorded a relatively high siltation because of the plantation activities along the river. Increased suspended sediment and turbidity can have a direct effect on aquatic organisms, which alter the level of flow, help flood and transport the huge flow of nutrients. (Sawere & Collins, 2019; Tuttle-Raycraft & Ackerman, 2019).

4.6.9 Phosphate (PO_4)

Industrial and sewage waste with the presence of phosphates can caused growth of nuisance for micro-organisms. The maximum use of fertilizer is the major source of phosphate which comes from the industrial wastewater, agricultural or residential cultivated land into surface waters. Overall, high concentrations of PO_4 are indication of the pollution that is related with eutrophication condition and the depletion of dissolved oxygen concentrations.

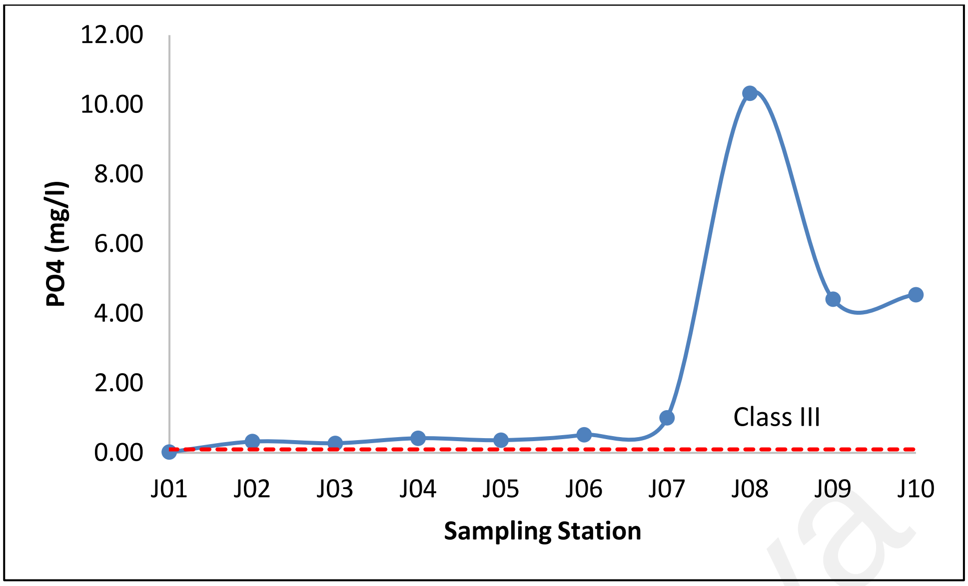


Figure 4.32: Mean phosphate results of at sites sampled in the Sembilang River

The concentration of PO_4 ranged from 0.00 to 31.7 mg/L (Figure 4.32). The highest value of PO_4 was recorded in station J08, while the least one was recorded at station J01. PO_4 values for station J08, J09 and J10 generally exceed the normal level on NWQS for Malaysian rivers which is 0.2 mg/L, hence, they fall into Class V. This can be seen where the PO_4 concentration is low starting with the upstream of the river and drastically increases at stations J08, J09 and J10. In these three stations, there are many industries, such as rubber and plastic factories that discharge large quantities of pollutants into the river. This is consistent with Zhang et al. (2018), who emphasize the important role of the waste water and domestic sewage that are discharged in their untreated forms into the river, in controlling phosphate concentration in rivers. High concentrations of phosphate cause muscle damage, breathing problems, and renal failure. The increase in the levels of phosphorus in rivers contributes to the eutrophication and degradation of DO levels (Gupta et al., 2017).

4.6.10 Nitrate (NO_3)

The nitrate (NO_3) concentrations were between 0.5 to 133 mg/L, where the highest concentration was recorded at station J08 and the lowest at station J01 (Figure 4.33). In addition, the nitrate values in this study are within the maximum allowable limit set by NWQS, Malaysia, which is 133 mg/L and is categorized as Class IV. Nitrate is a naturally occurring form of nitrogen that is very mobile in water. River water that is high in nitrate levels is extremely harmful to human and animal health; in freshwater or soil-proximity aquatic systems, nitrate levels can reach high levels that can lead to the death of aquatic life. On the other hand, non-point pollution cannot be controlled easily because it is diffused and originates from a wide range of sources and varies significantly with time due to the impact of the weather.

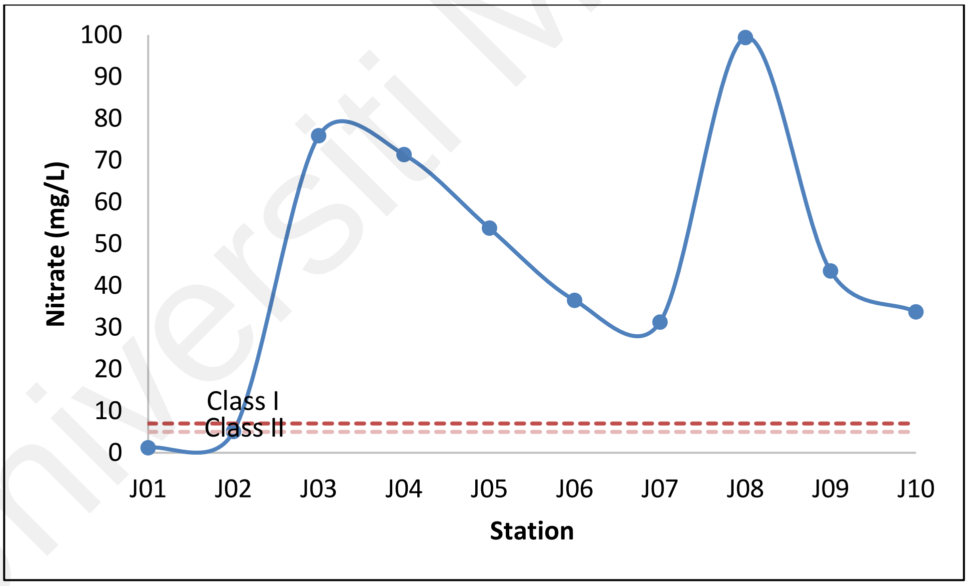


Figure 4.33: Mean nitrate results of at sites sampled in the Sembilang River

Point sources may also provide high nutrient concentrations to rivers. High levels of surface water nitrate suggest contamination from septic tanks, animal waste, fertilizer, local landfills and non-point emission sources, for example runoff from agricultural areas (Sharma et al., 2016). This can be seen through nitrate concentrations in the Sembilang River where in the first two sampling stations (J01 and J02), the concentration of nitrate in both stations is low and it is increasing starting with the sampling station at J03 which is located a few meters away from the municipal landfill. This volume decreased from 75.85 mg/L at J03 to 31.28 mg/L at J08. Nitrate concentration increased drastically at J08 with a mean concentration of 99.36 mg/L. The water quality at J08 is almost simultaneously polluted by phosphorus and nitrogen, indicating that the water pollution for these areas may be from the same sources, for example, from agricultural, residential and industrial areas.

4.6.11 Total coliform (TC)

As per the NQWS standards for public drinking water, the total coliform cannot be present in 100 ml of water samples (CFU = 0 100 m/L) (Figure 4.34). In general, higher TC counts are related to rapid urbanization in open defecation areas along the river. The discharge of municipal and industrial effluents and the drainage of agricultural land fertilization contribute to the increase in TC counts (Haque et al., 2018). In the study, the total coliform concentrations ranged respectively from 0 to 28,000 CFU, 100 m/L for all stations. In this sense, the mean concentration of total coliform was above the recommended maximum level for drinking water for all stations.

Overall, the results exceed the concentration of the total coliform bacteria that is mainly polluted by landfill effluent and domestic waste. High concentrations of total coliform in the study area specifically at station J03 and J06 are most likely related to the small villages that are located within the study area, which do not have effluent treatment systems. These communities discharge their effluents into watercourses or ground cameras. The disposal of domestic waste mostly takes place through the drains that are located at station J06, which might be a possible reason for the higher total coliform at this location.

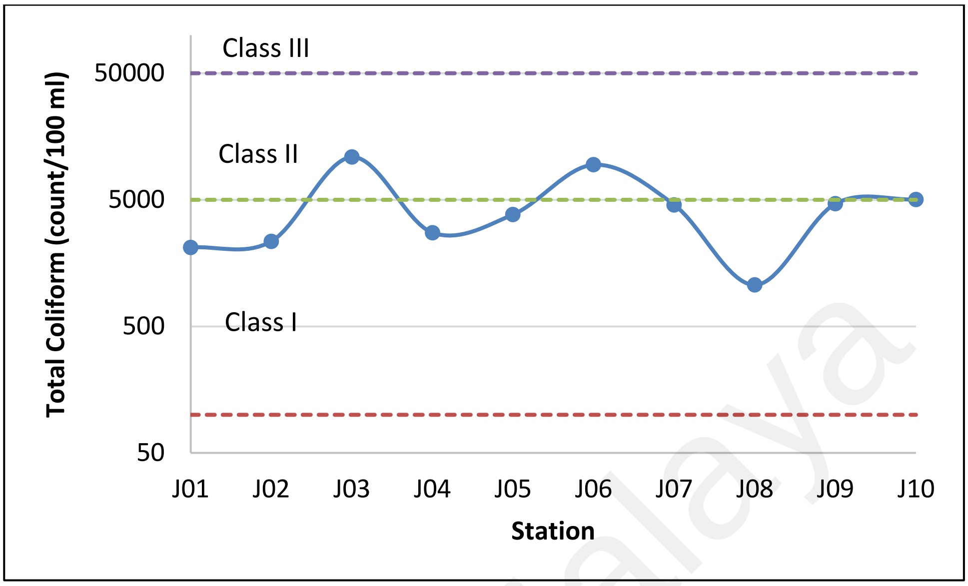


Figure 4.34: Mean total coliform results of at sites sampled in the Sembilang River

Moreover, almost all of the sampling stations studied are in contact with agricultural enterprises which are mainly in the margins of the river. Maqbool et al. (2011) and Hidayat and Mulyono (2019), reported a similar trend in the pollution of a river by total coliform coming from agricultural activities. The excessive use of organic fertilizers could pollute the rivers if the organic fertilizers are carried away by rainfall (Hidayat & Mulyono, 2019). Titilawo et al. (2019) reported that the occurrence is some major factors in which sewage and solid waste disposal systems, discharge of domestic and industrial waste, anthropogenic activities, and discharges from sewage treatment plants and runoff from informal settlements are the major threats to microbiological quality of surface water. Sembilang River has various activities aqua farming, fishing and recreational activity, with high coliform counts, it could be a source of health hazard to the communities around the river.

4.7 Water Quality Index

Water quality is measured in terms of its physical, chemical and microbiological characteristics (Tomas et al., 2017). The Water Quality Index (WQI), which summarizes the various quality parameters and the transformation of large quantities of data on water quality into a single quantity have been broadly used to assess water quality (Feng et al., 2018). WQI has always been used to categorize water quality status as 'good' or 'poor' (Table 4.11). Various chemical and biological variables are commonly converted into a single index, taking into account the relative weight and score of each variable.

Table 4.11: The WQI classes and uses (DOE, 2014)

Range	Class	Uses
< 92.7	Class I	Conservation of natural environment
76.5 – 92.7	Class II	Recreational use body contact
51.9 – 76.5	Class III	Common of economic value and tolerant species; livestock drinking
31.0 – 51.9	Class IV	Irrigation
>31.0	Class V	None of the above

The WQI for the ten stations along the river has been determined using the weighted arithmetic index method and the six parameters of the river are presented in Figure 4.35. Overall, the WQI for Sembilang River was calculated by averaging the WQI from all sampling dates in each station. On the basis of six parameters such as DO, pH, COD, BOD, NH_3-N and suspended solid the WQI value ranges from 68.03 to 43.46 mg/L. Most of the value of the data set is classified under Class III.

Range WQI value was observed in J01 (72.12), followed by J02 (64.61). With the lowest value of 45.64, the average WQI in J03 was the lowest of the ten stations. The WQI values in J04, J05, J06, J07, J08, J09 and J10 were 48.07, 52.93, 55.60, 57.25, 52.17, 53.81 and 55.28, respectively. Specifically, no sampling site had WQI values lower than 41, indicating that the water quality in this river was ‘moderate’. From the WQI standards, it reveals that most of the stations show that water quality parameters level in station J03 is more polluted as compared to the other stations (Figure 4.35). Discharged effluent from the landfill was the point source of water pollution and had a higher pollution rate. WQI showed poor water quality at that site which had effluent from sanitary landfill, while relatively better scoring of WQI at downstream of the river. Trends observed in WQI along the spatial scale also showed the impact of land use on water quality (Nazeer et al., 2014).

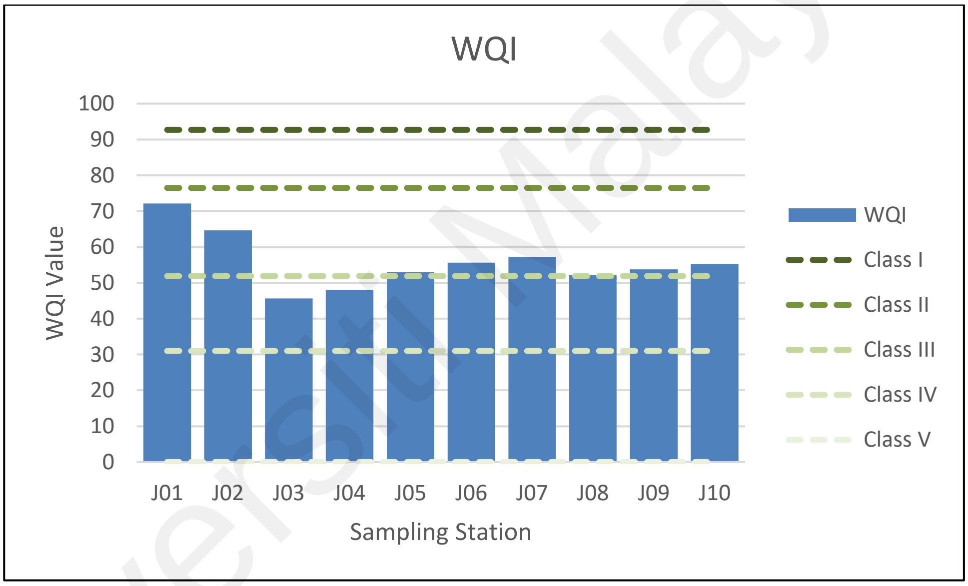


Figure 4.35: Average value of water quality of Sembilang River based on DOE Water Quality Index classification

Anthropogenic influences and land use are most likely responsible for the variations in the WQI value of this river. J01 and J02 are located in upstream of the river, where mainly no land use activity is seen in that area. With a relatively low level of disturbance from human activities, J01 and J02 exhibited better water quality than the other areas. However, water quality degradation occurs from upstream to downstream of the river, which affects the WQI value at J03 by point source pollution from landfill effluent. Anthropogenic disturbance is also high at J04 as a result from landfill effluent and non-point source pollution from agriculture. In J05, J06 and J07, the water pollution can be linked to agriculture which is the palm oil plantation. The population density is high in J08, J09 and J10 and the water quality has deteriorated in this area, especially J10 which is affected by industry and domestic sewage. Furthermore, the change in land use plays an important role in affecting water quality. Increased runoff and impaired water quality are observed when land use changes from natural to urban (Wu et al., 2018). Land use, which is dominated by built-up areas in J08, J09 and J10, has notably increased in the recent periods. This change may contribute to the relatively poor water quality in those areas. Thus, these factors are responsible for the relatively low WQI values in J08, J09 and J10.

4.8 Heavy metals

Heavy metals contamination in aquatic environment is of critical interest, due to toxicity of metals and their accumulation in aquatic habitats. Heavy metals differ in most pollutants, they are not bio-degradable and they undergo a global ecological cycle in which natural water are the main routes. They can be concentrated along the food chain, generating their toxic effect at points far removed from the source of pollution (Adelopo et al., 2018; Tiwari et al., 2019).

The heavy metal of river water samples collected from the nearby landfill area was analyzed based on their concentration. Large amounts of heavy metals degrade the aquatic environment, which poses serious challenges and risks to human health and the environment. The products of landfill waste materials are the main source of heavy metal pollutants in aquatic environment in this area. At station J03, the effluent is continuously discharged into the Sembilang River from the SL. Aluminum (Al), Magnesium (Mg), Manganese (Mn), Copper (Cu), Iron (Fe), Nickel (Ni), Chromium (Cr), Cadmium (Cd), Lead (Pb), and Zinc (Zn) were analyzed at the ten stations of Sembilang River. The results of heavy metal concentrations in surface waters of Sembilang River are shown in Table 4.8 in Section 4.6. The average concentration of studied metals in water followed a decreasing order of Al> Fe> Mn> Zn> Cu> Ni> Cr> Pb> Cd.

4.8.1 Aluminum (Al)

Al concentration in water samples from Sembilang River varied between 7,883 to 2,769µg/L (Table 4.10). The mean Al levels in the study area were above the National Water Quality Standard (NWQS) permissible limit of 500 µg/L for raw water. The presence of Al ions in river water may result from the landfill waste. As the effluent from the landfill is disposed at station J03, the value increases to the max value at station J04 with an average value of 7,352µg/L that had exceeded the permissible limit of the NWQS. After that, the average value decreases up to the station at J10 with an Al concentration of 3,149µg/L (Figure 4.36).

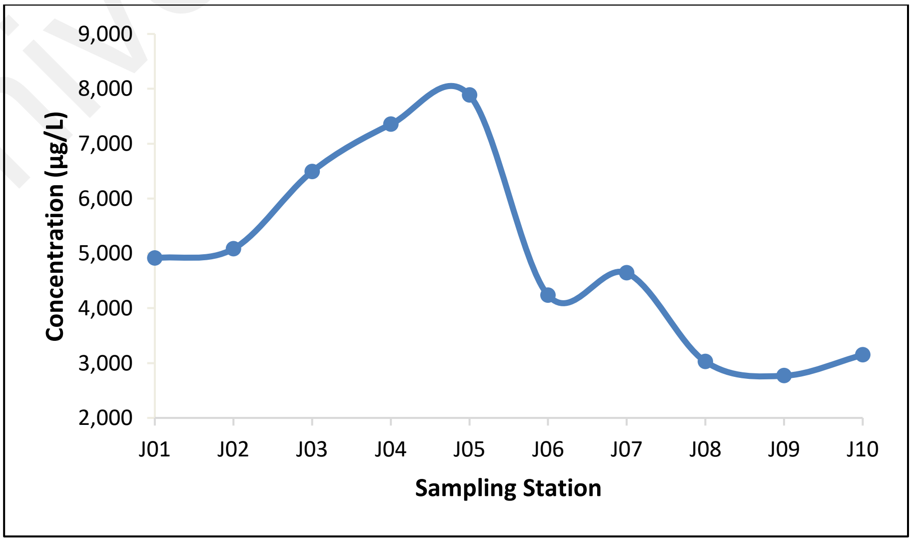


Figure 4.36: Aluminum concentration results of the sampling data set

Leaching of Al into rivers can be reduced by modern, controlled farmland drainage techniques (Sutela & Vehanen, 2017). Al concentration in surface water varies with pH of the water. High Al concentration in natural water happens only when the pH is lower than 5. This is the same as Al concentration in the Sembilang River where the pH is in the range of 6.5–3.8, Al concentration increases from J01 to J05 and it decreases at J10 where the pH of the river in this area is increasing.

Study also found that Al concentrations in coastal area typically range from 500 to 2000 μg/L, and 8 to 680 μg/L in the open ocean. This is surprising considering that several coastal areas are subjected to point source or diffuse Al inputs, such as urban runoff and general industrial inputs, as well as atmospheric deposition of Al into surface water discharges that are associated with Al and Al production activities (Angel et al., 2007). This can be illustrated by the concentration of Al at J10 with 3149μg/L where the station is located a few meters from the coastal area of Pantai Remis. Russell et al. (2019) reported that exposure to Al contributed to the mortality in School Prawn, and led to increased bioaccumulation of Al structural degradation and infection. Similarly, a study conducted by Azmat et al. (2019) on *L. rohita* showed a significantly maximum tendency to accumulate Al in its body organs. These results clearly indicate that Al concentration in Sembilang River should be controlled as the concentration of this heavy metal along the river exceeds the permissible limit. Additionally, at the downstream of the river there are aquafarming and fishing activities.

4.8.2 Manganese (Mn)

Manganese (Mn) are natural elements in the earth's crust and it can be found in a range of minerals in rocks and soils as much as 0.098 mass % (Superville et al., 2018). Mn is highly sensitive to redox conditions and is relatively mobile in the aquatic environment with concentrations in the range of 0.1–10 g/kg in fine sediments, of 100–10,000 µg/l in porewaters depending on the primary redox reactions promoted by the bacterial activity and the secondary other reactions. In the overlying waters, concentrations of up to several hundred µg/l can be assessed (Superville et al., 2018).

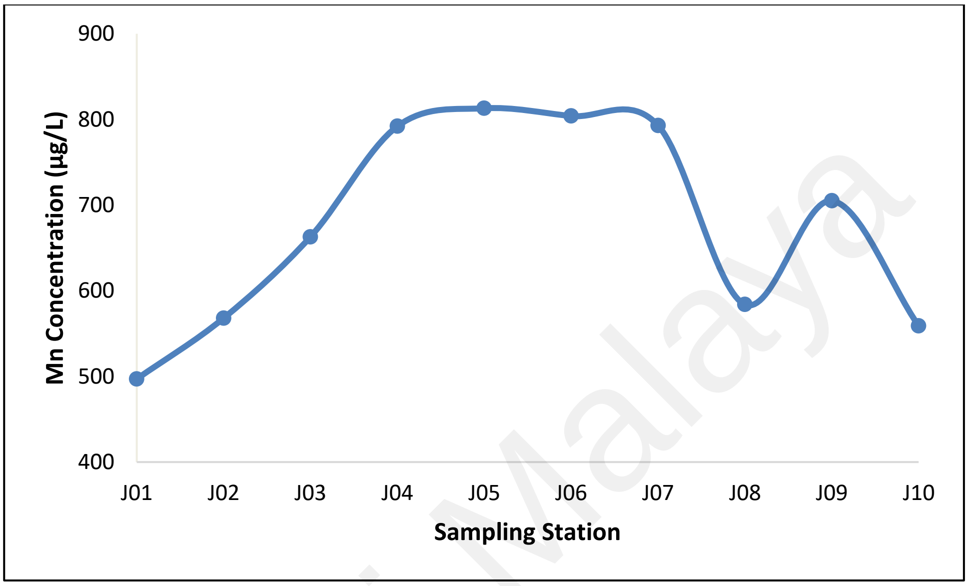


Figure 4.37: Manganese concentration results of the sampling data set

The inputs of treated effluent by SL was located 1 km upstream the monitoring stations (J01 & J02), as well as the continuous flow coming from the oil palm plantation along the monitoring stations (J04, J05, J06, J07). These two flows may dilute or enrich the Sembilang River water in Mn. The Mn concentration obtained from each station ranged from 497 to 813 µg/L (Figure 4.37). The mean concentrations of all sampling sites exceeded the maximum NWQS permissible limit of 200 µg/L for raw water. The lowest concentration was recorded from sampling site J01 before the landfill whilst the highest concentration was recorded from J05, which is located in the oil palm plantation and may be affected by the local riverine input (Table 4.10).

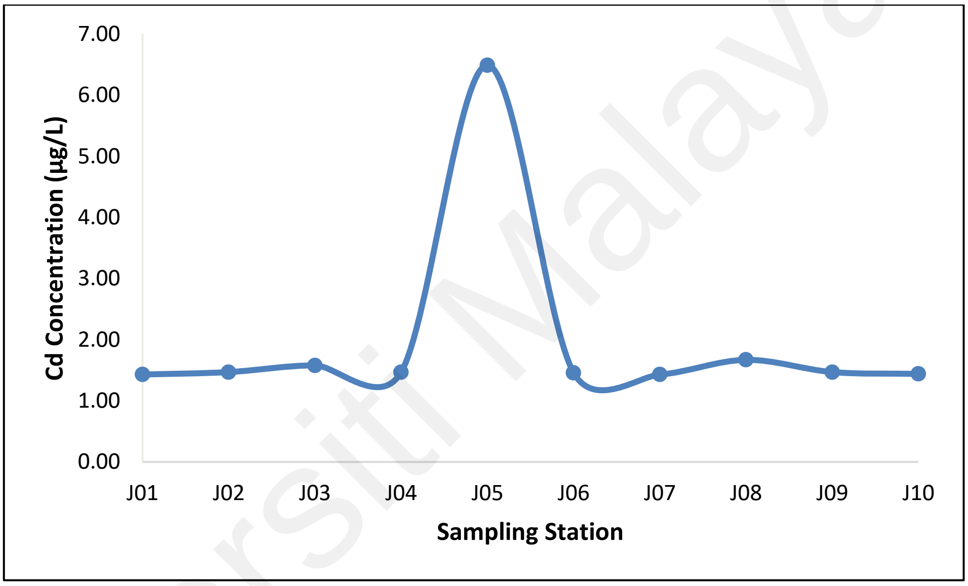
After the landfill station, the values were increasing at the downstream stations. The distribution of the concentration is not for the landfill effect, it might be from another sources such as soil and agricultural patterns for the upstream stations and industrial effect for the downstream stations of the Sembilang River. Manganese do not cause a health risk to humans, but can be harmful to the aquatic biota and chronic criteria for the protection of aquatic biota normally between 1,000 to 2000μg/L. Hernroth et al. (2019) reported that Mn has a negative impact on well-conserved cellular processes where it produces immunosuppressive effects on a broad range of biota and should be considered to be a key factor for understanding future changes in host-pathogen interactions within aquatic environments.

4.8.3 Others Heavy Metal

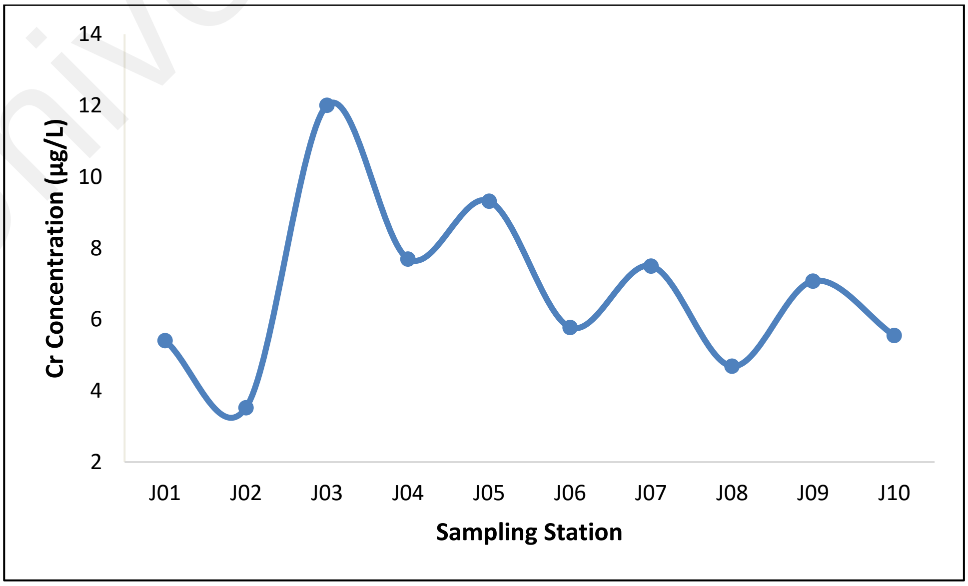
Heavy metals are of main concern due to their persistent and bio accumulative nature and may present potential environmental toxicity, abundance and persistence (Abraham & Susan, 2017; Islam et al., 2017). Heavy metals may accumulate in aquatic flora and fauna that would enter the human food chain and cause health problems (Islam et al., 2017). Heavy metals, which are both structural and catalytical in nature in proteins and enzymes, are important for biological systems within the human body, but they can be toxic when the safe levels are exceeded (Chen et al., 2018). Heavy metals, including mining, agricultural and domestic waste are released into the environment through a large number of natural and anthropogenic sources (Jeelani et al., 2017; Xia et al., 2018).

For the detailed heavy metal analysis of the Sembilang river water, (a) cadmium (Cd), (b) chromium (Cr), (c) nickel (Ni), (d) lead (Pb), (e) copper (Cu), (f) iron (Fe) and Zinc (Zn) were analyzed. From the analysis, it was revealed that these heavy metals were found in less concentration at the time of the sampling in the Sembilang River from upstream to the downstream stations. Figure 4.38 shows the percentage of the other heavy metals that affect the Sembilang River due to the different sources of pollutions. It was observed that the concentration of metals (Cd, Cr, Pb, Ni and Cu) is below the permissible limit of NWQS. The concentrations were characterized by a range of Cd (1.43 – 6.49µg/L), Cr (3.53 – 12.01µg/L), Pb (1.97 – 12.46 µg/L), Ni (9.84-21.20 µg/L), Cu (19.8—40.9 µg/L), Fe (1,667-4,623 µg/L) and Zn (132.6-639.7 µg/L).

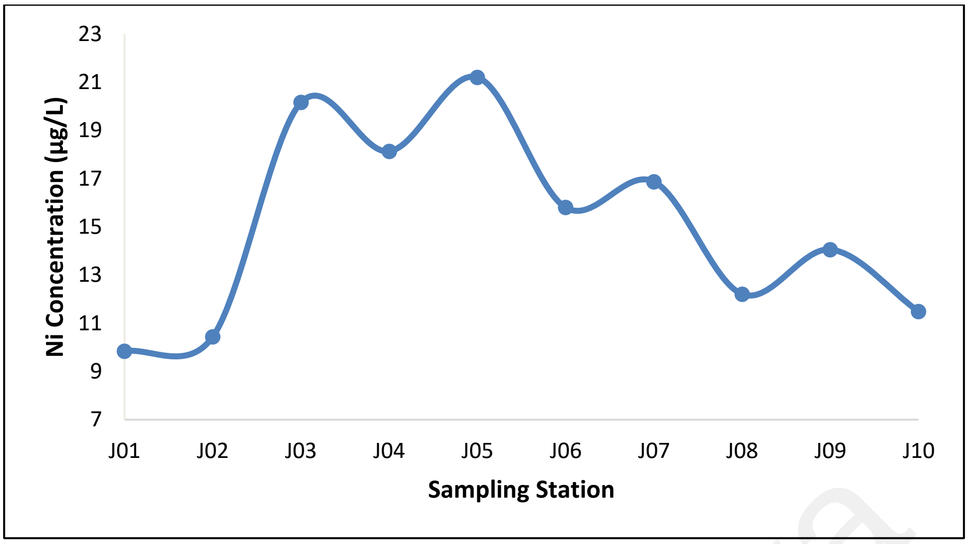
(a)



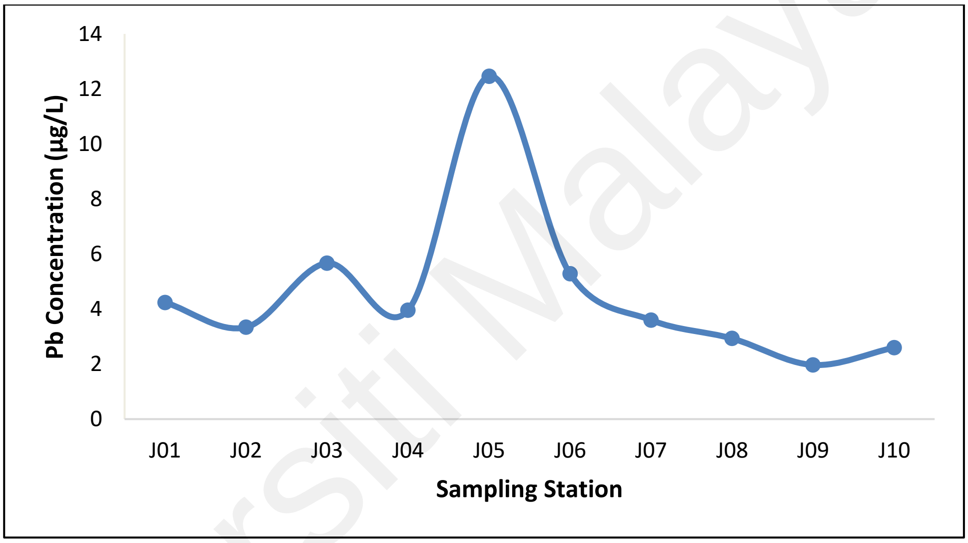
(b)



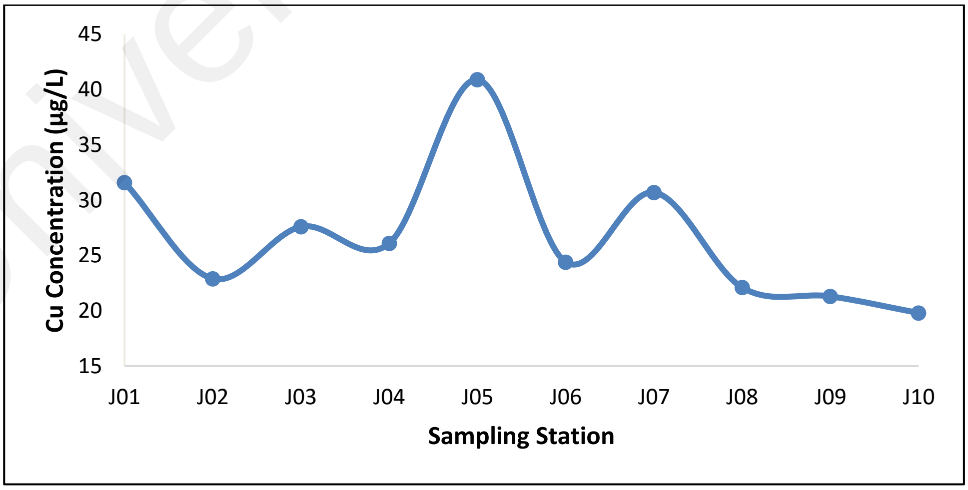
(c)


Ni Concentration (µg/L)
23
21
19
17
15
13
11
9
7
J01
J02
J03
J04
J05
J06
J07
J08
J09
J10
Sampling Station

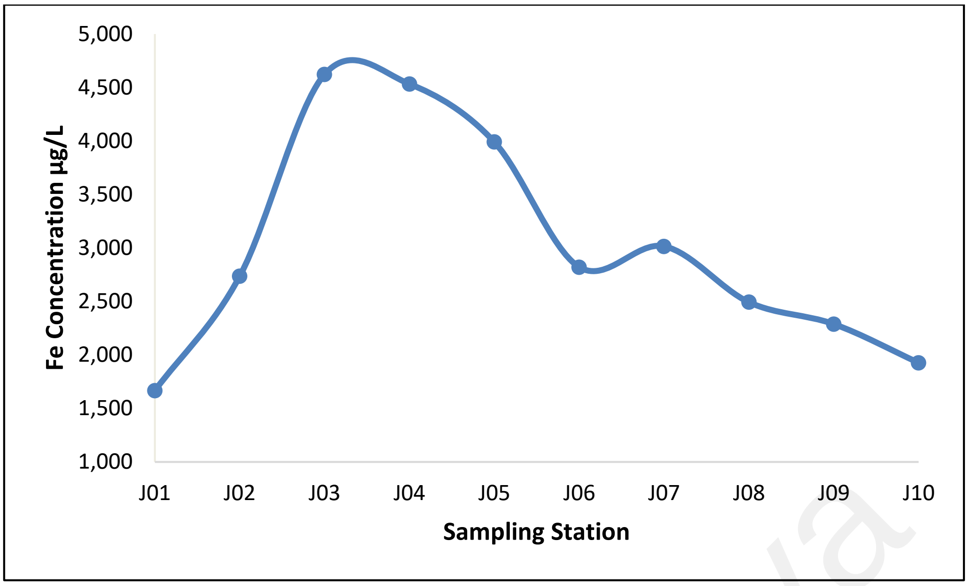
(d)


Pb Concentration (µg/L)
14
12
10
8
6
4
2
0
J01
J02
J03
J04
J05
J06
J07
J08
J09
J10
Sampling Station

(e)


Cu Concentration (µg/L)
45
40
35
30
25
20
15
J01
J02
J03
J04
J05
J06
J07
J08
J09
J10
Sampling Station

(f)



(g)

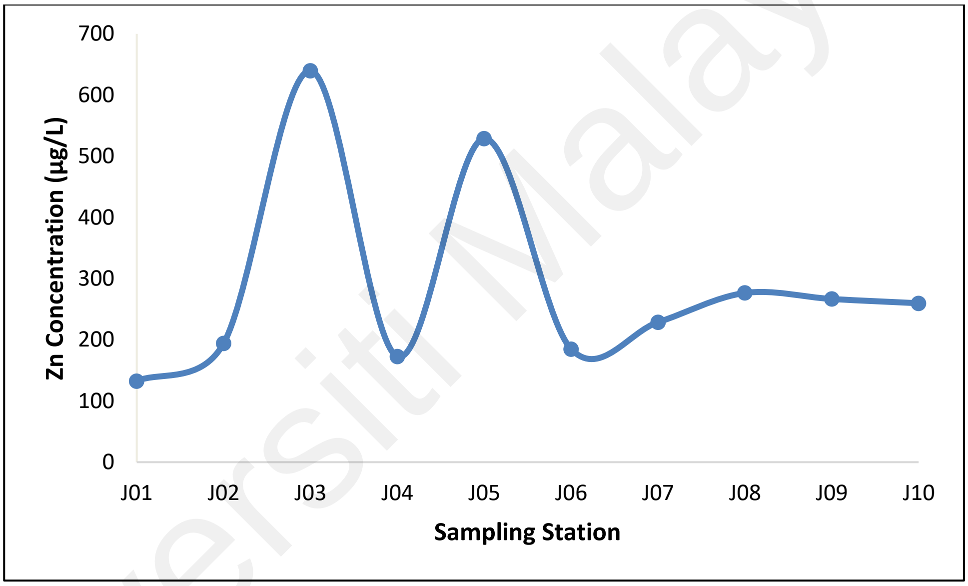


Figure 4.38: Average concentrations of (a) Cd, (b) Cr, (c) Ni (d) Pb), (e) Cu, (f) Fe and (g) Zn with below standards of NWQS

Cd concentration in water samples from Sembilang River ranged from 1.43 to 6.49µg/L in stations J01 and J03 respectively (Table 4.10). Cd are widespread in the environment from various sources, such as mining, smelting, combustion of fossil energy, municipal waste incineration, Ni-Cd batteries, etc. (Singh & Kumar, 2017). The highest concentration of Cd that was observed at J05 may be due to contact with dissolved rock and minerals as well as form agricultural sources. In addition, application of fertilizers, sewage sludge disposal and atmospheric aerosol deposition are also major sources of Cd in this area.

Existence of lead (Pb) in the environment is known to be pollution because Pb from the natural source happens to be low compared to anthropogenic activities (Singh & Kumar, 2017). In the present study, concentration of Pb varied from 1.97–12.46 µg/L. All studied samples were found to be below the permissible limit as recommended by NWQS. Pb contamination through the river may be due to enrichment from anthropogenic activities in the soil. The highest mean concentration of Pb was observed at J05. In this area the uses of pesticides from the palm oil plantation are major contributors of Pb pollution in the river.

Ni is a water-soluble trace metal derived from hydrogeochemical processes and anthropogenic activities in the water column, such as industrial wastes, crude oil power plants, colour manufacturing plants, glass and ceramic industries and discarded batteries (Sakai et al., 2017; Singh & Kumar, 2017). In the present study, Ni varied from 9.84–20.16µg/L. All of the samples were found to be below the permissible limit (900 µg/L) as suggested by National Water Quality Standard. The highest mean concentration of Ni was downstream at site J03 and J05. The downstream of Sembilang River lies within the landfill and palm oil plantation; therefore, this could be the possible reasons for the high concentration of Ni downstream. As a result, the river could have represented as an effective dispersing agent for Ni from its source area (Singh & Kumar, 2017). Cr is a highly toxic metal, but the Cr concentration did not exceed the standard limit (2500 µg/L) as recommended by the NWQS in any sample. In the present study, Cr varied from 3.53–12.01µg/L. The highest mean concentration of Cr was found at J03. This may be due to the discharge of effluent from the landfill.

Copper (Cu) is an essential element to most living creatures. But Cu is toxic at high bioavailable concentrations. With its application in industry and agriculture (e.g., Cu containing fungicides and herbicides), Cu discharge from these sources into the environment is substantial (Bui et al., 2016). The fate of Cu relies on the changing the characteristics of the physical and chemical speciation (pH, redox, ionic strength) and interaction with environmental components (mineral or organic particles) (Guinoiseau et al., 2018). The concentration of Cu in all 10 water samples was below the permissible by the NWQS (200 µg/L).

In the present study, Cu content ranged from 19.8 – 40.9 µg/L (Table 4.10). At J05 which was located at the upstream of the river, Cu content was slightly high and may be due to the soil, agriculture and geological formations. Cu content can be increase with the temperature that boosts sediments release of Cu ions and therefore increased the overall Cu content of the water column (Zhang et al., 2018). Cu was lowest at J10 with 19.8 µg/L. The result revealed that the concentration of dispersion varied due to several factors affected the upstream and downstream stations. The concentration of Cu inhibits the ordinary development of plants and animals and reduces the biodiversity especially affecting the reproduction and somatic growth rate and delay of maturation (Breida et al., 2019; Sadeq & Beckerman, 2019).

Natural water consists of various amounts of iron, based on the different criteria. Ferrous and ferric ions are the concerns in aquatic environment. The existence of Fe in natural water bodies is mostly in the form of either soluble ferrous (Fe^{2+}) ion or the insoluble (Fe^{3+}) ion (Sarkar & Shekhar, 2018). The analysis for ten river water samples showed Fe concentration in all ten stations below the maximum permissible limit of NWQS (5,000µg/L). The Fe concentration in these samples ranged from 1,667 to 4,623 mg/L (Table 4.10). Figure 4.38 for mean concentration of Fe in water samples that are collected from the study area highlights the fact that a majority of the study areas has high level of Fe in surface water (1,000-5,000 µg/L) with the site for the highest Fe concentration located downstream of Sembilang River at J03. A very high reading of J03 shows that heavy metal may have migrated from the leachate pond into the river. This was also observed for the river water samples with concentration of Fe decreasing downstream of the river. The first major fluctuation in Fe concentration in river water was reported in the sample from J03, near to the landfill, which is known for the effluent discharge into the river. On the other hand, in locations downstream of Sembilang River, low levels of Fe are reported. Here, the sampling stations were much closer to the industrial area and residential area, hence, it could be suggested that the Fe contamination in these locations was the result of localized anthropogenic sources (industrial and residential waste water).

Zinc (Zn) plays a significant role in many biological processes and is an important trace element for healthy plant growth and reproduction as well as for the health of animals and humans; it has also been recorded to cause contamination of soil, water and food chains (Guinoiseau et al., 2018). Zn is present in surface and groundwater and reaches the environment from many sources, namely mine drainage, industrial and municipal waste, urban runoff and the degradation of Zn-containing soil particles. According to the Food and Agricultural Organization (FAO) and the World Health Organization (WHO), drinking water with Zn > 3000 µg/L appears to be opalescent, produces a greasy film when cooked and has an unpleasant earthy taste (Noulas et al., 2018).

Average Zn concentrations in water samples that have been collected at the ten stations in Sembilang River over the study period are presented in Figure 4.38 and Table 4.10 Zn concentration in water samples from Sembilang River ranged from 132.6 to 639.7 µg/L in stations J01 and J03 respectively. The mean Zn levels in the study area were below the NWQS maximum permissible limit of 5,000 µg/L for raw water except for station J03 and J05. It can also be derived from the slightly high Zn values for J05 can be attributed to the presence of palm oil plantation along the river which is the fertilizers and pesticides that are used for the plantation.

Zn occurs naturally in water, but the concentrations of Zn increase unnaturally due to the addition of Zn by human activities. This is shown by Zn concentrations at J01 which is the lowest concentrations of Zn among the ten other sampling stations. Studies have shown that some soils are heavily polluted with Zn and are present in areas where Zn has to be extracted or processed or where wastewater sludge from industrial areas has been used as fertilizer (Ismail et al., 2013). Sembilang River that flows past the palm oil plantation could carry Zn along with it. The metal can enter the water during the treatment process as well as through corrosion and dissolution of the joint, which can be the potential source of Zn leaching into the water (Rahmanian et al., 2015). This can be seen in Figure 4.38 where Zn concentration increased from J01 to J03 and at J05 which recorded the highest value, and decreased at J10 which is located downstream of the river.

4.9 Water Quality Modeling

4.9.1 Introduction

Rivers are one of the main water supply sources in many areas. The water quality in rivers depends on land use in the basin and the chemical composition of runoff (Mehrasbi & Kia, 2015). Because of decreasing water quality due to the disposal of human waste into water bodies, most countries around the world are forced to develop remediation methods in order to conserve water. Industrialization and increasing populations are accompanied by the production of effluents and wastes (Mehrasbi & Kia, 2015). Most rivers and their tributaries in Selangor are reported to be polluted because of an inflow of liquid and solid wastes.

The QUAL2K model is the new version of the widely used QUAL2E to simulate water quality and hydrological conditions of the rivers as well as systems with diffusive pollution loads. In this study two model calibration stages which are water quality and hydraulic parameters have been carried out. This model can simulate fate and transport of so many parameters and contaminants such as temperature, BOD, DO, phytoplankton, various kinds of nutrients, pH and etcetera. DO, BOD and AN were selected as the water quality parameters for calibration while discharge was chosen for hydraulic calibration.

The Sembilang River QUAL2K model was calibrated and validated using the average one-year sampling data collected from September 2015 to September 2016. The sampling data for the month of September 2015 and December 2015 were used for calibration data, while the February and April 2016 data were used for validation. The sampling stations that were used for calibration and validation along the Sembilang River were J02, J05, J06, J08 and J09, while J01 was used for headwater. The data were collected for one time in a day of each months both in wet and dry season. The average data for the dry season and wet season were used as the input data. J01 was selected as headwater because it uses headwater data group to define upstream boundary conditions of the model domain. While J02, J05, J06, J08 and J09 were selected they were representing the land use activities at that area. It considers the influence of point source and non-point source pollution loads during simulation. In this study, the water quality parameters (DO, BOD and AN) were calibrated as water quality parameters. Average yearly data for September 2016 and July 2016 were used to observed the difference between the model predictions and the observed data for calibration and validation model respectively. An adjustment was done in model calibration for the water quality variables at the pollution sources to achieve a reasonable match between observed and calculation data. The rate and coefficient values of the water quality parameters were adjusted using values from literature as a first approximation, after which the values were fine-tuned through the process of QUAL2K calibration. Generally, the modeling results were quite acceptable to achieve a reasonable agreement with the measured values.

The results for the water quality parameters that have been used as input data for head water are shown in Table 4.12 while Table 4.13 shows the measurement data in the different stations along the river for comparison.

Table 4.12: Input data for head water

Parameters	Unit	Head water
Temperature	C	28.90
pH	-	3.15
Dissolved oxygen (DO)	mg/L	3.66
BOD	mg/L	3.53
Ammoniacal nitrogen	mg/L	1.85

Table 4.13: Water quality data along the river

Sampling station	Dissolved Oxygen (mg/L)	BOD (mg/L)	Ammoniacal Nitrogen (mg/L)
J02	3.79	2.27	1.04
J05	5.74	4.64	8.12
J06	5.71	7.64	7.93
J08	5.83	7.06	7.76
J09	5.95	6.77	7.51

4.9.2 Calibration Model of Sembilang River

i) Calibration of Discharge

QUAL2K model solves the governing equation using a finite-difference (implicit backward method) and is set up as a one-dimensional steady-state and completely mixed system. Calibration has been accomplished by adjustment of model parameters during successive or iterative model runs, until the better goodness of fit between the predicted and observed data is achieved. Model validation, on the other hand is the testing of the calibrated model against the extra set of data, preferably under various environmental conditions (river flow, water quality parameters concentration, etceteras), to ensure that the model can predict real situations in a dependable manner. The model parameters that were used were the same as in the calibrated model (Mustafa et al., 2017).

The QUAL2K generated results are in the form of graphs which combine the observed and the simulated discharge flow along the selected sampling stations. Figure 4.39 shows the simulation of discharge flow in the selected sampling stations. The green line shows the simulated values of discharge flow. The observed data is shown by the circles.

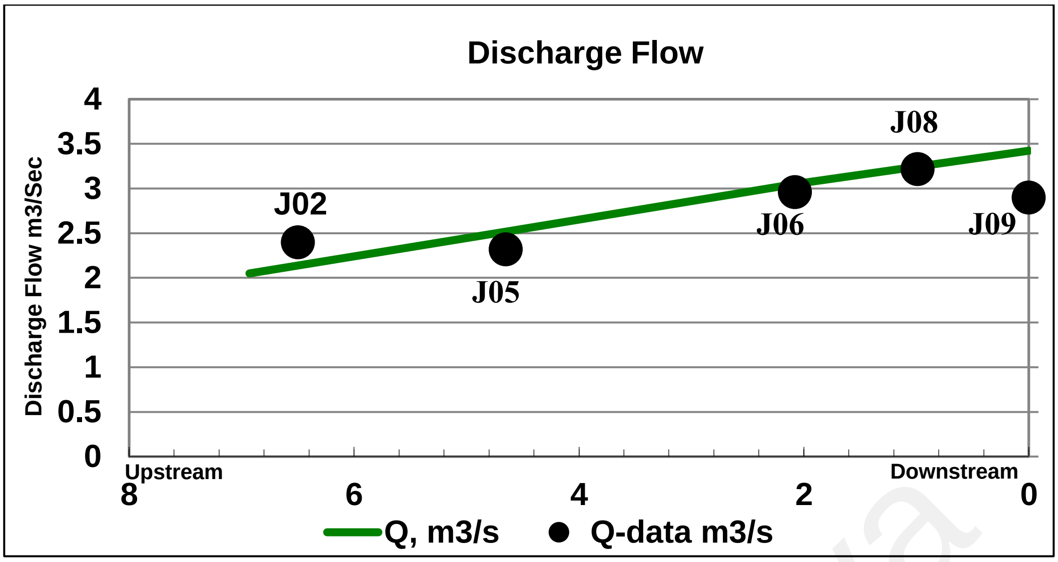


Figure 4.39: Comparison between observed and simulated discharge flow for high flow calibration model for the Sembilang River

From the plot it can be inferred that the observed data is in close proximity with the simulated data. As shown in Figure 4.42, the correlation between the observed and simulated discharge (R^2) is 0.981, which can be considered as excellent according to Henriksen et al. (2003).

ii) Calibration of Dissolved Oxygen

Figure 4.40 presents the calibration results of DO concentration levels along the Sembilang River. The observed DO pattern is comparable to that of the simulated DO upstream and downstream of the river. Figure 4.43 shows the DO calibration results along the Sembilang River. The DO starts at 3.79 mg/L and increases to 5.95 mg/L just before the Pantai Remis. A sharp decrease in the DO value (5.74 mg/L) was observed when the effluent entered the river, thereafter the value remained steady until it reached J09 where the DO value increased to 5.95 mg/L. Henceforth, it shows a steadily increasing trend as it flows downstream along the Sembilang River. The correlation between the observed and simulated DO (R^2), is 0.3402. These indicate that this correlation value is deemed as poor. Urbanization and regulation of the river DO is not fully described by the model and may partially be responsible for this result (Henriksen et al., 2003).

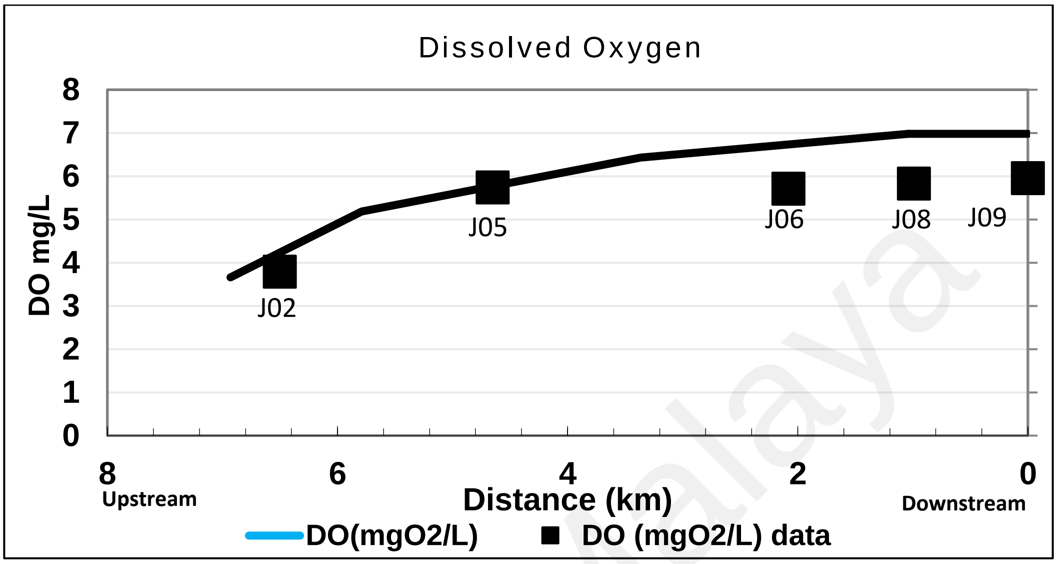


Figure 4.40: Comparison between observed and simulated DO for the Sembilang River

From the model output (Figure 4.40), it can be seen that DO concentrations for J02, J05 and J08 have met the targeted National Water Quality Standards (NWQS) for Malaysia at or above 5 mg/L, at Class IIA and IIB. The low DO concentration at J09 that was 3.79 mg/L is an indication of the entering wastewater from point sources through wastewater drains and channels from industrial areas; those wastewater add high organic and inorganic materials which resulted in low DO (Hossain et al., 2014). As shown in the figure, the DO value is the lowest at the upstream of the river but has steadily increased along the downstream river indicating that the DO content is first impacted by the low DO content from the agriculture and landfilling activity but is then diluted by river water with higher DO content along the downstream river which tends to increase significantly from the headwater. Here also the peak in the plot occurs at a distance of 2 km from the headwater which signifies the presence of the point source, the effect of which has caused a minimum value, which gradually increases along the length of the stream.

In general, the upstream of Sembilang River is not heavily polluted. The most polluted zone in the river is located downstream because of the discharge of pollutants from residential and industrial area. In the case of dissolved oxygen, the DO in surface water should not be less than 5 mg/L; most of the sampling stations along the Sembilang River are within the standard of 5 mg/L except for those downstream. The low DO concentration in headwater may due to the agricultural activities upstream of Sembilang River. DO changes are almost constant in these months.

iii) Calibration of Biochemical Oxygen Demand

The calibration results of the BOD level are presented in Figure 4.44 and the correlation between the observed and simulated BOD (R^2) at 0.9543. According to Henriksen et al. (2003), this correlation value is seen as very good. The level of BOD shows an increasing trend as the river flows downstream. In Figure 4.44, the BOD model calibration results are provided and as general observation, the level of BOD only become significant as the river passes through the populated area. It can be seen in Figure 4.38 that a sharp increase of BOD from 3 mg/L to 7 mg/L occurs at the industrial area of Sembilang River. Similar patterns can be seen between the modeled and observed values and it is classified in Class III of DOE Water Quality Index Classification. The head water was relatively better regarding BOD. This was because of the amount of land activities that had increased with the distance at the mid region of the river (after 1 km from upstream). The high level of BOD in the third reach of the river may be due to discharges of untreated wastewater from different industries.

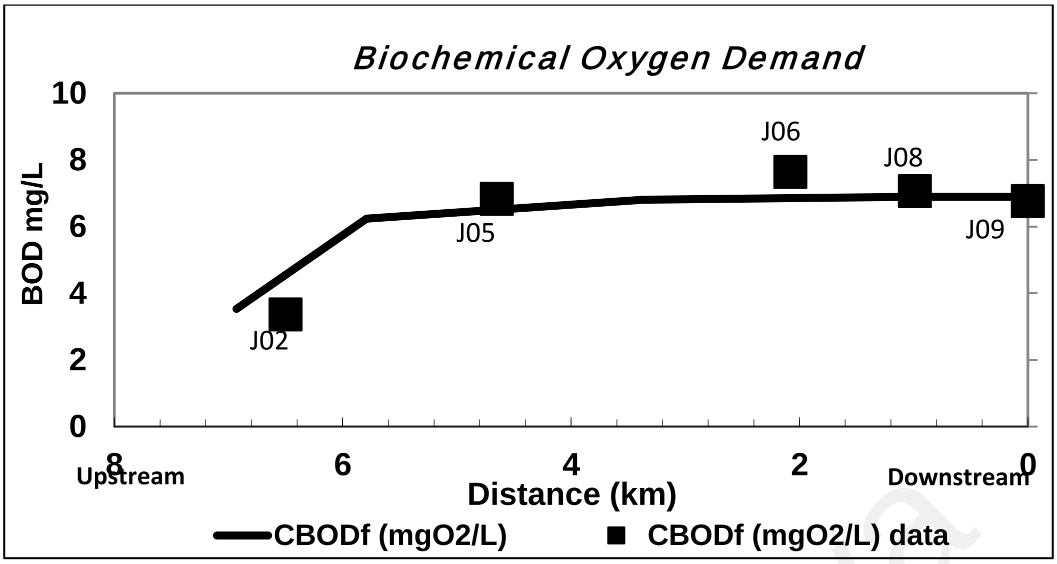


Figure 4.41: Comparison between observed and simulated BOD for the Sembilang River

Figure 4.41 shows the BOD calibration results along the Sembilang River. The BOD starts at 0.34 mg/L and increases to 5.36 mg/L just before the Remis Remis. A sharp increase in the BOD value (9.38 mg/L) was observed when the effluent enters the river; thereafter, the value fluctuated from J04 to J09 where the BOD value was in the range of 3.72 to 5.36 mg/l. From the model output (Figure 4.41), it can be seen that the BOD concentrations for all stations have meet the targeted National Water Quality Standards (NWQS) for Malaysia at or above 6 mg/L at Class III. In the case of dissolved oxygen, the BOD in surface water should not be more than 12 mg/L; most of the sampling stations along the Sembilang River were within the standard of 12 mg/L where the highest concentrations were at J03 and J04 with 1090 and 11.32 mg/L, respectively. The high BOD concentration in both stations may be due to the effluent from the landfill and agricultural activities upstream of Sembilang River.

iv) Calibration of Ammonical Nitrogen

The calibration and validation results of the AN level are presented in Figure 4.42. The agreement between the modeled and observed AN is generally very good as the correlation between the observed and simulated AN (R^2) is 0.9614. The observed AN pattern looks similar to the pattern of the simulated AN along the river. Consistent with the literature, this correlation value is seen as very good (Henriksen et al., 2003).

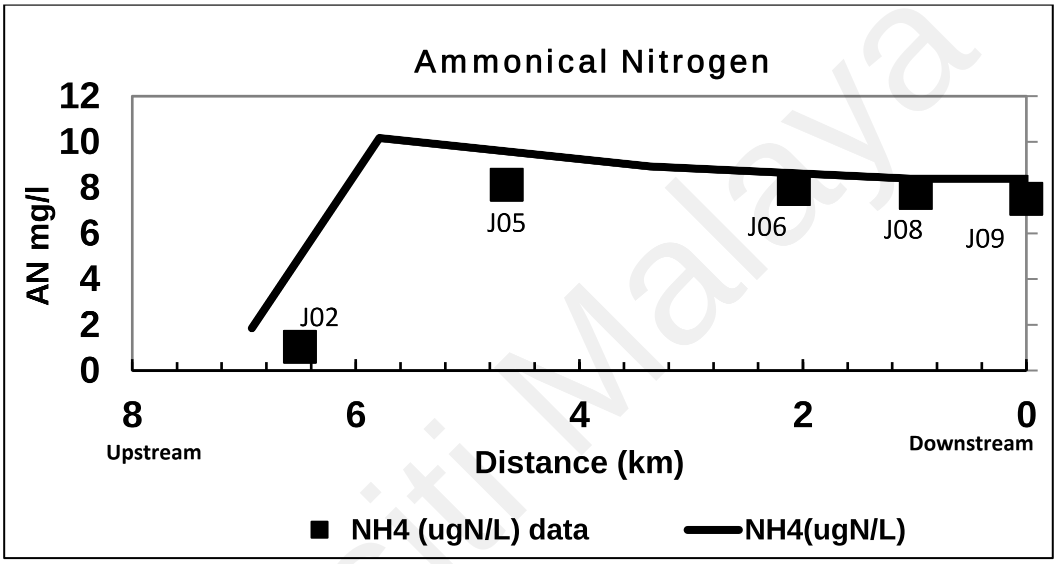


Figure 4.42: Comparison between observed and simulated NH_3-N for the Sembilang River

The NH_3-N shows an increasing trend from upstream to downstream (Figure 4.42). It starts increasing after J02 which is influenced by the landfill effluent being discharged to the river and also agriculture waste from the palm oil plantation along the river. The highest concentration of NH_3-N that is predicted by the calibration model is 10.17 mg/L at the mixture of landfill effluent and the river water. At the agriculture area, the model predicted about 8.39 mg/L – 8.92 mg/L whereas the observed value is about 7.76 mg/L – 7.93 mg/L. The correlation between simulated and observed values of NH_3-N in Sembilang River showed a high correlation coefficient (Table 4.14).

The concentration of NH_3-N rise sharply at the proximity of 5.79 km due to discharge of effluent from the nearby landfill. This is partly caused by loss of NH_3-N fertilizer and emissions of nitric oxide (NO) through nitrification, following the application of fertilizer in the fields (Mosier et al., 1998). This element is a common surface water contaminant that can cause health problems, as well as the eutrophication of water bodies that are present in many possible recharge sources include landfill, industrial spillages and septic tanks (Wakida & Lerner, 2005). According to the NWQS, the concentration of AN in this study was high and fell into Class V. The value is found to be higher than the permissible limit where the NH_3-N levels for aquatic life in the river of Malaysia is 0.90 mg/L (Gandaseca et al., 2011).

For all parameters there were a high correlation coefficient (R2) and a lower standard error as shown in Table 4.14 for the correlation between simulated and observed. Such strong coefficients of correlation between the observed and simulated values indicate that this approach in modeling rivers is perfectly accurate. Given variations in the data sets observed and simulated at some stages, the effects of calibration and validation are appropriate.

Table 4.14: Correlation between observed and simulated values

Parameter	**Calibration**	
	R^2	**SE**
Discharge	0.9810	0.3045
DO	0.9522	0.5186
BOD	0.9543	0.9660
AN	0.9614	0.6173

4.9.3 Validation Model

i) Validation of Discharge

In this study, discharge validation was made on the observed discharged at the sampling stations. The low flow model was validated using the average data of April 2016. Figure 4.43 shows the contrast of Sembilang River observed and simulated discharged. It shows that the pattern of observed discharge is similar to the simulated discharge. The correlation between the observed and simulated discharge (R2) is 0.9714, which can be considered as excellent according to Henriksen et al. (2003).

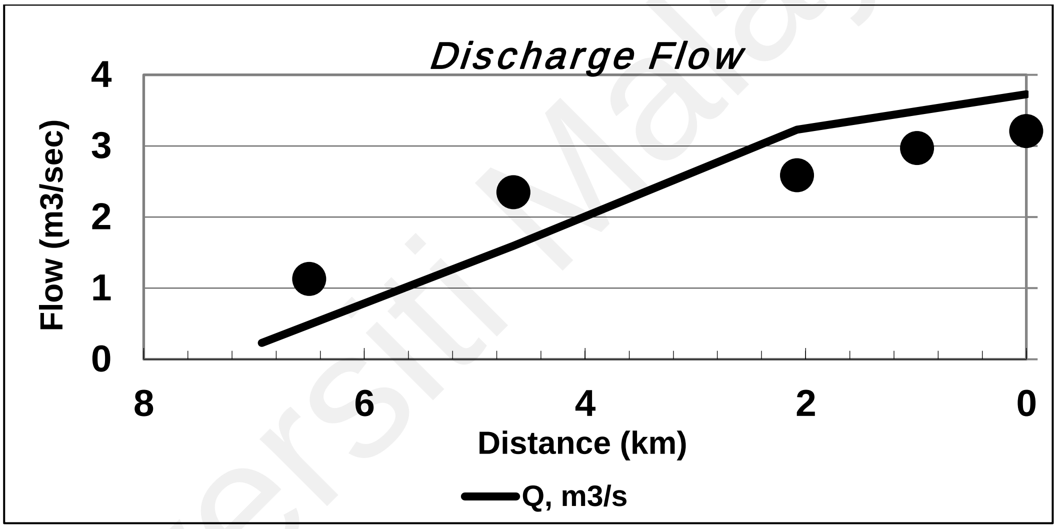


Figure 4.43: Comparison between observed and simulated discharge flow for high flow calibration model for the Sembilang River

ii) Validation of Dissolved Oxygen

Figure 4.44 illustrates the comparison between the observed and simulated DO for the Sembilang River throughout the validation process. The correlation between the observed and simulated DO (R^2), as seen in Table 4.15 is equal to 0.9363. The DO concentrations showed higher levels at the upstream. This could be attributed to less nutrient and organic pollution. Located in the upstream area with low pollution, the upper stream stations are less affected by industrial and anthropogenic pollutions (Kannel et al., 2007). From the figure, the observed DO pattern looks similar to the pattern of the simulated DO along the river, except for downstream where the measured DO at the monitoring station, which is about 1.04 km from the downstream location, is not in sync with simulated data. A similar trend was reported by Osibanjo et al. (2011) where there was a reduction in the DO concentrations in the industrial area when compared with the upstream concentrations, which is representative of huge amounts of organic loads which require high oxygen levels for chemical oxidation and decomposition. Evaluation of DO is essential to the survival of aquatic organisms and consequently in establishing the degree of freshness of a river (Osibanjo et al., 2011). However, according to the NWQS, the concentration of DO fall into Class IIB and as in Figure 4.44, DO concentration is increased either during low and high water periods (Daniel et al, 2002).

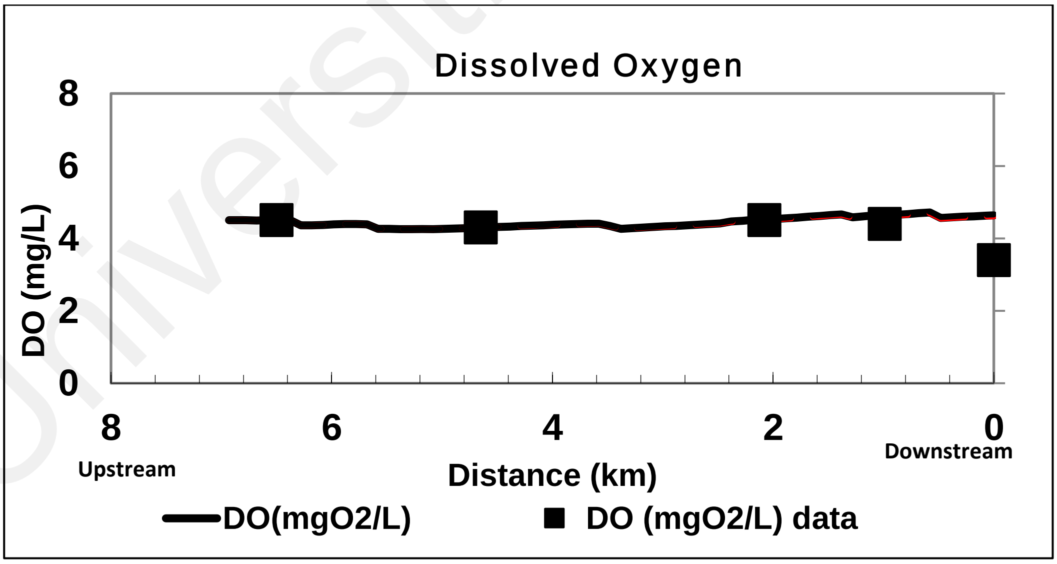


Figure 4.44: Comparison between observed and simulated DO for the Sembilang River

The DO concentration for model validation was kept similar to that of model calibration as given in Figure 4.44. In general, the simulated DO concentrations were within the maximum range of observed DO concentrations. However, the simulated concentration of DO at 1.04 km was higher than the observed concentrations. This is due to the input from industrial effluent and residential wastes and diffuse sources that are discharged into the river and this demonstrates how negative externalities from upstream affected the downstream water quality (Yoon et al., 2015).

iii) Validation of Biochemical Oxygen Demand

The validation result of the BOD level is presented in Figure 4.45 while Table 4.15 represents the correlation between the observed and simulated BOD (R^2) at 0.9383. These high correlation coefficients between the observed and simulated values show that this model is perfectly reliable in modelling the river. Figure 4.48 denotes that the validation results of BOD were according to the observed values were little bit different. The studied river water qualities do not reach the minimum BOD requirement in all reaches of the river. The high BOD concentration that was higher than 3.0 mg/l in downstream of the river is an indication of entering wastewater from the different point sources through landfill effluent and wastewater drains as well as channels from the industrial areas. Also, when comparing the observed BOD concentration of Sembilang River with the desirable water quality standard given by NWQS for Class III, it is found that most of the sampling locations are not suitable for the use in many sectors. The value for BOD varies from 2.40 to 10.74 mg/L, clearly indicating that some stations at downstream are moderately polluted and extensive treatment is required.

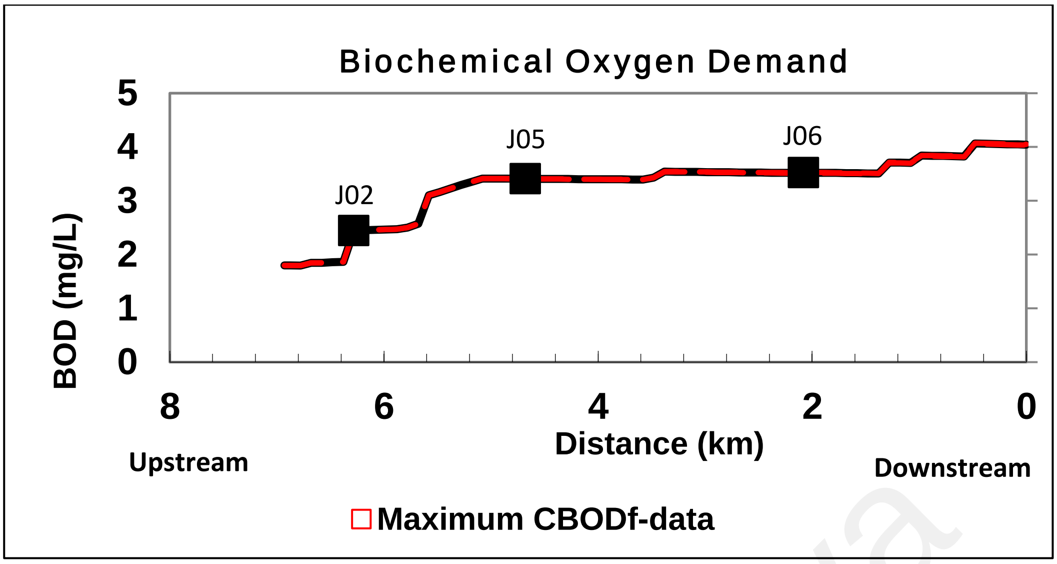


Figure 4.45: Comparison between observed and simulated BOD for the Sembilang River

The BOD concentration for model validation was kept similar to that of the model calibration as given in Figure 4.45. The BOD_5 concentration was in Class II in the upstream of the river, however, it increases rapidly as it flows downstream at km 0.99 where high BOD_5 load contributed by reach number 3. Based on field observation, the BOD_5 load comes from various sources such as agriculture and industrial waste as well as untreated sewage waste at the downstream of the river. BOD_5 concentrations reach Class III of NWQS at J09 as it receives discharge input from industrial waste nearby. This pattern has also been reposted by Kumar et al. (2018) where BOD concentration degrades from upstream to downstream because of cumulative addition of anthropogenic output. Phung et al. (2015) and Idris et al. (2016) have also reported that strong BOD loading reflects contaminants from point sources, including discharges from domestic wastewater, agricultural activities and industrial effluents that impact rivers with varying magnitudes of change in comparison to the constituent water quality and this also will affect the river water quality downstream of the river. This is supported by a study that is done by (Ling et al., 2016), where the impact of effluent can sometimes extend up to a distance of hundred kilometers from the discharge point, although the intensity of the impacts tend to decline with an increasing distance from the discharge point.

iv) Validation of Ammoniacal Nitrogen

The validation results of the NH_3-N level are showed in Figure 4.46. The agreement between the modeled and observed NH_3-N is generally very good as the correlation between the observed and simulated NH_3-N (R^2) is 0.8389. The observed NH_3-N pattern looks similar to the pattern of the simulated NH_3-N along the river. Consistent with the literature, this correlation value is seen as very good for validation model (Henriksen et al., 2003). The results indicated that NH_3-N concentration rose significantly after receiving landfill effluent from the sanitary landfill at km 5.79 (Class V). The spike ofNH_3-N concentration is expected from landfill effluent as well as agriculture activities along the river. The NH_3-N concentration remained in Class V. Based on field observation at the surrounding land use from km 5.79 to the end of simulation distance is dominated by agricultural activity, palm oil plantation. Abidin et al. (2018) reported the same observation where high concentration of NH_3-N in the river was significantly contributed by palm oil plantation. The amount of NH_3-N discharged at the upstream of the river is the major factors of relatively high concentration of predicted NH_3-N at the downstream of the river compared to the observed data. This is supported by the study that is done by (Dunca, 2018) at Timis and Bega River, Serbia where the water quality in the upstream has been in a better condition than the downstream river which indicates that the local pollutants may be contributing incrementally to the degradation of the river's quality.

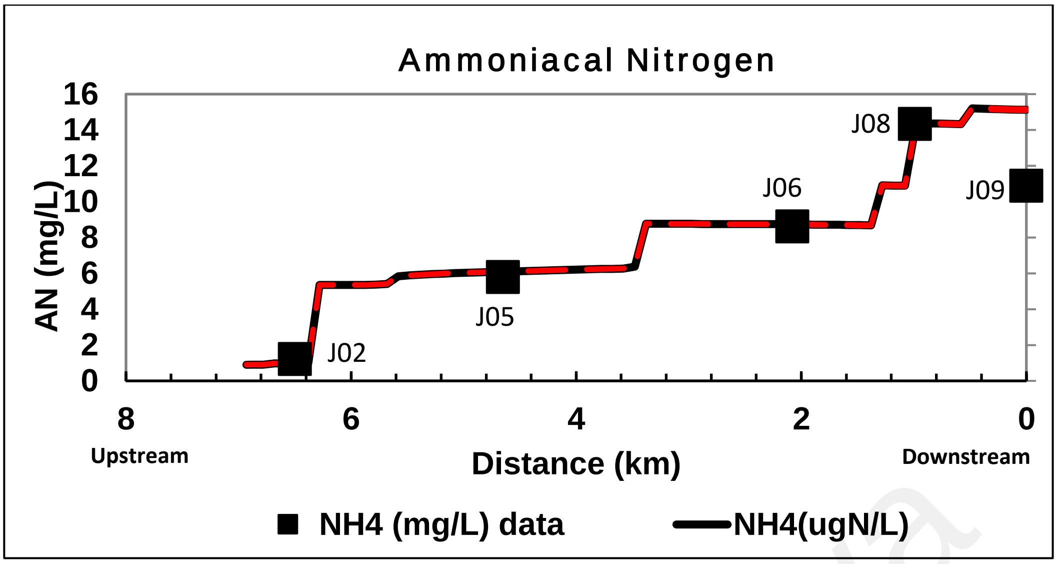


Figure 4.46: Comparison between observed and simulated NH_3-N for the Sembilang River

Table 4.15: Correlation between observed and simulated values

Parameter	Validation	
	R^2	SE
DO	0.9363	0.0915
BOD	0.9383	0.3867
AN	0.8288	0.0546

From the results, the observed and predicted values are in close agreement with each other, both during calibration and validation. Uncontrolled usage of fertilizers is the main source of nutrients and the discharge of solid waste into the river by the villagers, from aquaculture activities and urban lawn, constitute considerable sources of pollution to the river (Mehrasbi & Kia, 2015; Chen et al., 2017). This is also supported with the results from a previous study that changes in NH_3-N concentration in the river water which has primarily been affected by untreated wastewater and agriculture activities due to the impact of urban land, a result of rapid population growth and severe point-source and non-point source pollution (Ding et al., 2015).

4.9.4 Predictive Scenario Modelling

The calibrated model was implemented as an improvement measure to forecast the impact on water quality; in specific the changes in DO, BOD and NH_3-N concentration following the implementation of the action action plan. It can be said that. at some point of the Sembilang River water is not suitable for fisheries survival in which the minimum DO concentration is 7-5 mg/L, BOD concentration in rivers should not exceed 6 mg/L and NH_3-N concentration should not more than 0.3-0.9 mg/L. Therefore, a variety of scenarios were proposed and selected for the predictive scenario modeling. These scenarios are described in Table 4.16 below.

Table 4.16: Description of scenarios

Scenario	Description
SC-1	Reduction of point sources pollution load within Sembilang River
SC-2	Standard A compliance of all point sources within Sembilang River

The water quality downstream of Sembilang River is Class III, thus the simulation of predictive scenarios has been used with the aim of improving the water quality standard to Class II. The load reduction rate of different scenarios was obtained by simulating different scenarios, so that the water quality at the end of the Sembilang River met the required standard. In the scenario SC-1, point sources load within the Sembilang River were reduced until the water quality simulation results met the Class II of the water quality category. While for scenario SC-2, simulation input pollution concentrations of water quality parameters were adjusted for all point sources in the Sembilang River according to standard B under the Malaysian Environmental Quality Act 1974 (Annex B). This is due to the concentration of NH3-N at some point at Sembilang River which is exceeding Standard B.

i) Impact of Different Scenarios on DO

Variation in DO values due to the scenarios mentioned previously is presented in Figure 4.47 and the percentage changes are summarized in Table 4.17. It can be observed, upstream and downstream of Sembilang River, the DO values fall within Class III. The DO results for the two scenarios did not differ very much, but the impact of Sc-2 caused the highest increase of DO out of both the scenarios that are put forth. Due to SC-2, DO increases to 29% downstream, at Reach 3. This value meets the class-II standard. The findings show that in order to achieve the Class II standard downstream of the Sembilang River, the pollution load of point sources is required to be decreased by 80% for DO concentrations.

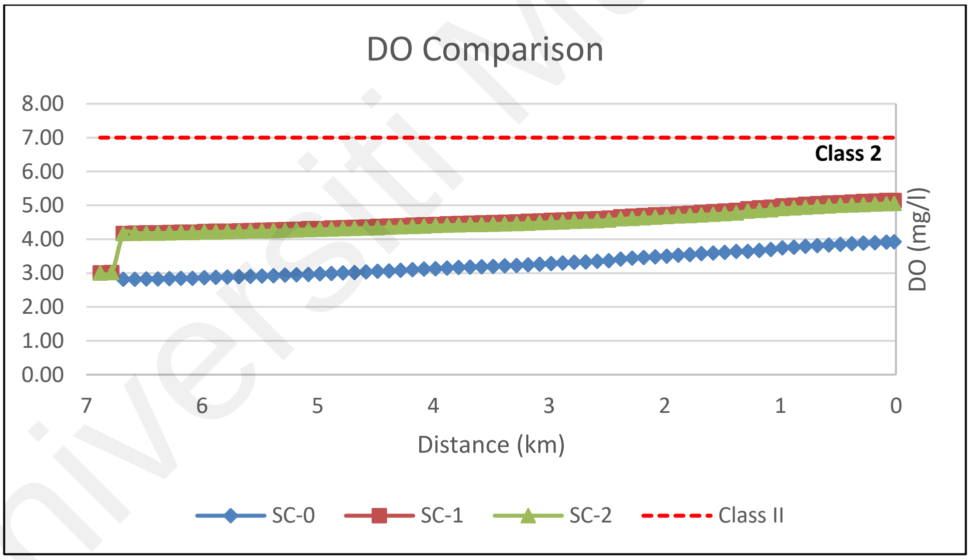


Figure 4.47: Variation of DO at Sembilang River

ii) Impact of Different scenarios on BOD

Variation of BOD as a result of the scenarios is presented in Figure 4.48 and the percentages changes are summarized in Table 4.17. The BOD concentration is upstream of the Sembilang River but the confluence of the Sembilang River has suddenly increased further downstream.

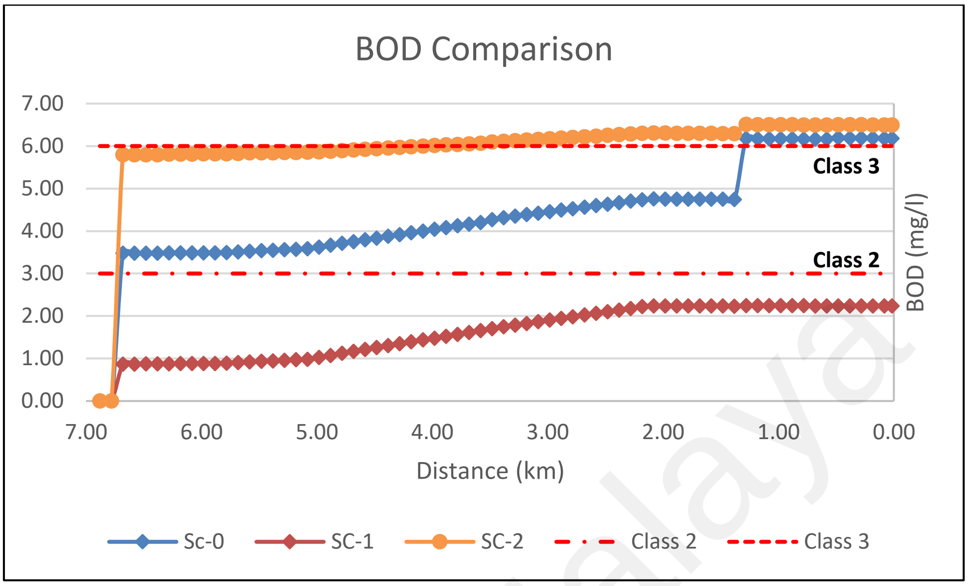


Figure 4.48: Variation of BOD at Sembilang River

The impact of scenarios SC-1 caused the reduction of BOD, allowing the BOD to come under Class-II standard downstream of the Sembilang River. However, the SC-2 scenario shows an increase in BOD values and is in the class-III standard. The BOD value decreased of 75% and 69% at the downstream Reach-1 and upstream Reach-2 respectively, of Sembilang River that was achieved due to scenario SC-1. Whereas with the SC-2 application, there was no difference where the BOD values in all three Reaches which were similar to SC-0, and were in class III from downstream Reach 1 to downstream Reach 3. Despite this, BOD only achieved a Class-II for SC-1.

iii) Impact of Different scenarios on NH_3-N

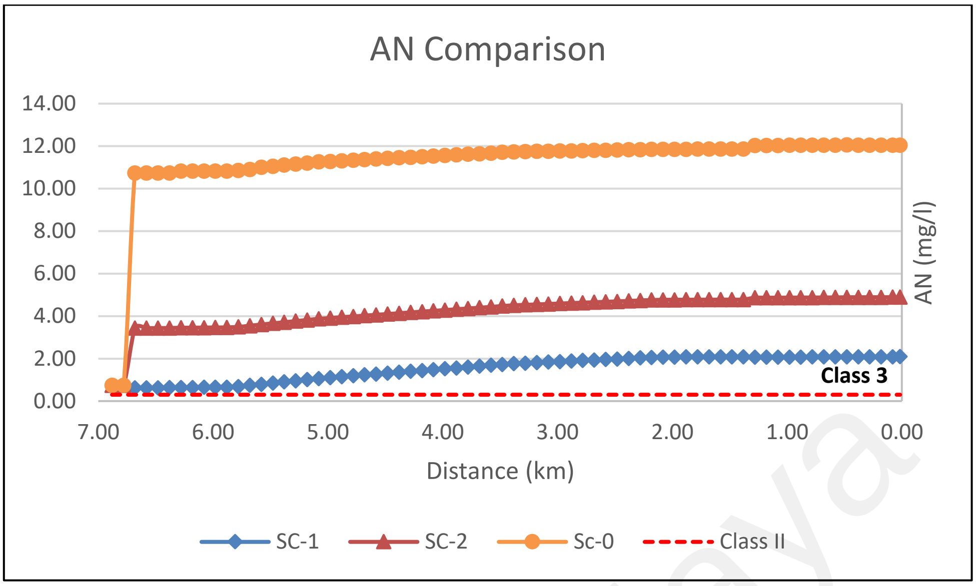


Figure 4.49: Variation of NH_3-N at Sembilang River

Variation of NH_3-N at the Sembilang River is shown in Figure 4.49 and the change in percentages is summarized in Table 4.17. Figures show that a substantial reduction in NH3-N on the Sembilang River can be possible if SC-1 is employed to achieve Class-III and Class IV standard compare to SC-0. The level of NH_3-N drops from 12.05 mg/L to 2.70 mg/L downstream of the Sembilang River. It can be seen from Table 4.23 that NH_3-N decreases to 94%, 89% and 83% at Reach 1, 2 and 3 of the Sembilang River due to SC-1. The decrease of NH_3-N in upstream of Sembilang River leads to the reduction of this parameter at the downstream of the river. The maximum reduction in SC-2 was 68% in upstream Reach 1 which was in Class-III standard.

Table 4.17 and 4.18 summarize the improvement measures of DO, BOD and NH_3-N of the Sembilang River. From the effect of discharge landfill effluent on the DO, BOD and NH_3-N levels can be seen, especially after the discharge point. The results showed the regression in the water quality in terms of DO, BOD and NH_3-N. Due to the discharge of the landfill effluent to the Sembilang River, there was a decrease of 3.43% and 9.58% of DO at Station 2 and 5, respectively. However, at the downstream of the river, there were increased of 12.61%, 18.87% and 16.47% of DO at Station 6, 8 and 9.

Table 4.17: Improvement of water quality parameters along the Sembilang River due to simulation of scenarios

Sembilang River (Change in percentage)							
Reach	**Location**	**DO**		**BOD**		NH_3-N	
		SC-1	**SC-2**	**SC-1**	**SC-2**	**SC-1**	**SC-2**
R-1	U/S	0	0	0	0	0	0
	D/S	47%	47%	-75%	67%	-94%	-68%
R-2	U/S	44%	43%	-69%	61%	-89%	-65%
	D/S	41%	39%	-61%	54%	-83%	-60%
R-3	U/S	35%	34%	-53%	46%	-83%	-60%
	D/S	31%	29%	-64%	15%	-83%	-59%

Table 4.18: Summary of DO, BOD and NH_3-N class along the Sembilang River due to simulation of scenarios

Sembilang River (NWQS Class)										
Reach	**Location**	**DO Class**			**BOD Class**			NH_3-N **Class**		
		SC-0	**SC-1**	**SC-2**	**SC-0**	**SC-1**	**SC-2**	**SC-0**	**SC-1**	**SC-2**
R-1	U/S	III	III	III	I	I	I	III	III	III
	D/S	III	III	III	II	I	III	V	III	V
R-2	U/S	III	III	III	III	I	III	V	IV	V
	D/S	III	III	III	III	II	III	V	IV	V
R-3	U/S	III	III	III	III	II	III	V	IV	V
	D/S	III	II	II	III	II	III	V	IV	V

These places DO under Class III at the upper stream and Class II at the downstream. While for BOD, there was a decreased of 76.65%, 35.58%, 30.51%, 11.65% and 7.87% of all the stations (Station 2, 5, 6, 8 and 9) along the river. BOD remained at Class I at the upstream of the river and Class II and III at downstream. However, the percentage of regression of NH_3-N due to the discharge of landfill effluent recorded for all stations along the river with 77.88%, 25.24%, 12.47%, 3.63% and 7.08%. The NH_3-N levels did not meet the standards which may be due to the landfill effluent as well as pollutants from non-point sources, including domestic sewages and non-point agricultural pollutant. This caused NH_3-N to remain under Class V at downstream of Sembilang River. Thus, the simulation also showed that there are increased levels of DO, BOD and NH_3-N in a few stations along the Sembilang River, and some have remained under same classes. Overall, it can be concluded that the model for DO, BOD and NH_3-N were in the satisfactory range of agreement with each other for both measured values and predicted values. The physical and chemical processes of a river are more easily understood by water quality modelling. At the same time, water quality modelling can show surface water more realistically rather than in dealing with water quality due to the landfill effluent to the river. This shows the use of QUAL2K to be one of the most effective models of water quality policy options in the future.

The impact of the various scenarios on level DO, BOD and NH_3-N can be seen from the simulation. SC-1 has evaluated if the point sources within the Sembilang River have an important role in the river's water quality, where all point sources have been adjusted to Class II NWQS. The results showed that water quality has improved an improvement in terms of DO, BOD and NH_3-N. Due to simulation of SC-1, DO was increased by 31% and came under Class III while BOD and NH3-N were decreased to 64% and 83% respectively, which BOD came under Class-I I at the upstream and Class-III at the downstream of the river, while NH_3-N came under Class-III at the upstream and Class-IV at the downstream of the river.

The impact of SC-2- there are not many changes to be seen in the water quality in terms of DO, BOD and NH_3-N. Due to simulation of SC-2, there was an increase of DO only at the downstream of reach-3. While from Reach 1 to Reach 2 after being applied to SC-2, the water quality is the same as SC-0. Likewise, the water quality of the river from upstream to downstream is similar to SC-0as with the other two parameters; BOD and NH_3-N. NH_3-N did not reach the requirements with a reduction in pollution load from the source of 100%. This could be due to non-point source pollutants such as household wastewater and non-point agricultural source pollution. The desired water quality could not therefore be reached by reducing only the point source emission load.

CHAPTER 5: CONCLUSION

5.1 Introduction

Based on the results of this research, many conclusions, recommendations and suggestions for future studies that are related to the research topic were obtained. This study has explored various issues that are related to the use of MFA and water quality modelling techniques in waste management, more specifically in Sanitary landfill (SL) leachate management practices. This chapter summarizes the findings and the main contributions with regard to the research objectives (see Chapter 1 in Section 1.6) and suggests the future course of using the integrated decision support technique in waste management. Although the fieldwork for this study was conducted only in one landfill, the findings that had been obtained in this study can be applied in other areas, both nationally and globally. This study has shown the potential of using the MFA, water quality and water modeling integrated technique in the planning and practice of waste management in SL. Section 5.2, summarizes the important findings on MFA, the water quality of Sembilang River and water modeling. The final section of this chapter, which is Section 7.6, discusses the recommendations and suggestions for future studies.

5.2 Conclusions

Based on study findings, the following conclusions were achieved:

1. The results showed that the waste had been disposed of in SL Landfill came from seven local authorities and the highest was from Kajang Municipal Council. The amount of waste disposed at SL landfill increased by 20% annually from 2009 to 2016. The highest composition of waste that is present at the landfill can be categorized as food waste with 32% of the total waste input.

2. The MFA approach was used to estimate the availability of solid waste and leachate production in SL. By estimating the annual production of waste disposed in SL, the MFA model has successfully revealed the input and output flows that are related to leachate production. This MFA result is considered valuable because it has managed to estimate the production of leachate and if it is applied to three recommended model proxies ie by increasing the percentage of composting, recycling and incineration in landfills, the leachate production at SL can be reduced to 60 to 70%. This in turn will reduce the effluent that is released in Sembilang River. Such compilation of information is new and it would be very useful for the environmental system planning in SL.

3. Investigating the water quality status of the Sembilang River has been implemented to enhance the understanding of the current water pollution status of the river, and to determine the impact of land use activities to the Sembilang River. The study has found that activities along the river contributed to the pollution of Sembilang River. As the result shows, the WQI for Sembilang River has been categorized under Class III of the Malaysian Water Quality Standards, showing that the water is not appropriate to be used as water supply and is in requires an extensive treatment. Thus, in general, the overall observation that has been made in this study is that the quality of Sembilang River is affected by landfill activity as well as other activities along the river.

4. The water quality results have been included in the QUAL2K modelling to assess the transport of pollutant (DO, BOD and NH_3-N) and the simulations that are included in this study have been designed to provide information on the present and

future status of the Sembilang River. The simulated results for the current condition indicate that DO, BOD and NH_3-N upstream of the Sembilang River vary between Classes I and II. The class of DO increases towards downstream where it is recorded a Class II. The BOD has been recorded as Class III and remains towards downstream. While NH_3-N has been recorded as Class III at the upstream of the river and has decreased to Class V starting from mid-stream to downstream.

5. These findings show that MFA, water quality assessment and modeling method are the appropriate methods to predict and analyzed the quality of river water, pollutant transport and effects. However, a few adjustments are still needed in future analysis and application for the different river water systems. This includes the collection of solid waste data, leachate volume and also river water quality at the same sampling date. This can give a more accurate picture of river water quality affected by effluent discharge from a landfill. The longer collection time of these three samples within 1 to 2 years is also important in providing more accurate results. This is particularly important where important steps need to be taken in maintaining the river water quality; as this river is still a source of water supply and is also a source of income for the locals. Continuous monitoring should be carried out to ensure that development activities along the river do not affect the quality of the river water. Furthermore, awareness on the importance of maintaining the quality of the river water in the locals should also be applied. although the readings obtained from this study are high, it should be understood that the readings may vary according to waste composition, environmental conditions and also biological activity occurring in the landfill which is a major factor to the characteristics of leachate not only in SL landfills and even in other landfills as well. The study belief that the landfill

management is doing well in managing the landfill at the same time protecting the environment.

5.3 Recommendations for further research

Referring to the outcome of this thesis, several suggestions can be highlighted so that further studies on optimizing the integration method as well as the scope of the study will be improved in the future. To begin, the collection of research data should involve the participation of more "actors", a longer time frame, and a wider scope of boundary. Moreover, the involvement of stakeholders in the interviews should be expanded in order to obtain a more expansive knowledge on this topic. Testing the MFA ability to be integrated with other environmental assessment techniques is also an opportunity for further research. Lastly, the errors, uncertainties, and sensitivity presented in every chapter of this thesis require further detailed investigation in order to construct more concrete and valid database and analyses. There are several point sources along the river especially in the downstream part. These include manufacturing, housing and recreational activities which can pollute the river with untreated wastewater. Therefore, it is strongly recommended that it is monitored, investigating the possible source(s) of pollution. In addition, it is proposed that the new model is utilized for simulating the effects of effelunt that is channeled into the river by setting certain flow distances in the stream. Additional methods are required to assess other aspects such as the health impact The MFA technique should be integrated into a broader multi-actor planning approach.

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