SURFACE WATER QUALITY ASSESSMENT FOR SUSTAINABLE WATER MANAGEMENT IN VARSITY LAKE, UNIVERSITY MALAYA

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ABSTRACT

Surface water quality monitoring is an important tool in the context of sustainable water management system. This study focuses on the comprehensive water quality assessment of Varsity Lake for recreational purposes and to evaluate the suitability of two river tributaries that pass through the University of Malaya (UM) campus in maintaining the lake water level. This work also aims to evaluate the effectiveness of lake rehabilitation and current water management towards sustainable water management inside the campus. Varsity Lake suffers from eutrophication and water quality degradation due to the increase pollution rates, water source scarcity and poor water management. UM management authorities have taken an initiative to improve lake water quality in the lake rehabilitation project. In this study, field and laboratory analysis were conducted to understand the transport of water quality parameters from nine sampling stations located within the campus. Water Quality Index (WQI) was generated using the six parameters, namely Dissolved Oxygen (DO), pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammonical Nitrogen (NH_3-N), Total Suspended Solids (TSS), and it is used to define the status of water quality. The research also extends towards the nutrient study by including the analysis on the Nitrate (NO_3^-) and Phosphate (PO_4^{3-}) concentrations for all sampling stations. Eleven heavy metals parameters, which include Arsenic (As), Aluminum (Al), Cadmium (Cd), Chromium (Cr) , Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Nickel (Ni), Silver (Ag), and Zinc (Zn) were analyzed using the inductively coupled plasma optical emission spectroscopy (ICP-OES). The data variations were illustrated by Whisker's boxplot and further analyzed using the multivariate statistical method to show the nature of the data patterns and the significant difference between the lake and river water quality. Statistical analysis spatially proved that lake and river have different physico-chemical characteristics and lay in separate clusters. The river water that flows in UM campus recorded a higher concentration of metals as compared to the lake. Overall, WQI result shows that lake water is in Class II (82 - 86), while the river is in Class III (65-70). Pantai River has the highest average amount of Pb, Cd and Cu, while Anak Air Batu River has the highest amount of Fe. The current water quality is also compared with the concentration in pre-rehabilitation stage by using six parameters (DO, BOD, TSS, NH_3-N, NO_3-, and PO_4^{3-}). From the study, it shows that all parameters were reduced up to 97% and this proved that the rehabilitation works and the current water management is effective in helping to improve the lake water quality. Therefore, the lake rehabilitation method can be used to improve water quality in similar water body.

ABSTRAK

Pemantauan kualiti air permukaan adalah salah satu kaedah yang penting untuk meningkatkan pengurusan sistem air yang mampan. Kajian ini memberi tumpuan kepada penilaian kualiti air secara komprehensif bagi menentukan kesesuaian air untuk aktiviti rekreasi dan mengkaji kesesuaian dua anak sungai yang melalui kampus Universiti Malaya (UM) sebagai sumber air tasik. Kajian ini juga bertujuan untuk menilai keberkesanan kerja pemulihan air tasik serta pengurusan air sedia ada ke arah pengurusan air yang mampan di dalam kampus. Tasik Varsiti mengalami eutrofikasi dan penurunan kualiti air akibat peningkatan kadar pencemaran, kekurangan sumber air dan pengurusan air yang tidak sistematik. Pihak berkuasa UM telah mengambil inisiatif bagi meningkatkan kualiti air tasik di dalam projek pemulihan tasik. Analisis di lapangan dan makmal telah dijalankan bagi mengkaji kualiti air dari sembilan stesen persampelan yang terletak di dalam kampus. Indeks Kualiti Air (IKA) telah dijana menggunakan enam parameter, iaitu DO, pH, BOD, COD, AN, TSS dan ia digunakan bagi menentukan status kualiti air. Sebelas logam berat iaitu Arsenik, Aluminium, Kadmium, Kromium, Tembaga, Besi, Plumbum, Mangan, Nikel, Perak dan Zink telah dianalisis dengan menggunakan penduaan induktif plasma secara pelepasan optik spektroskopi (ICP-OES). Variasi data dipaparkan dengan kaedah *Whisker boxplot* dan seterusnya dianalisis dengan menggunakan kaedah statistik multivariat untuk mengkaji pola dan perbezaan di antara data kualiti air tasik dan sungai. Analisis statistik spatial membuktikan bahawa tasik dan sungai mempunyai ciri-ciri fizik-kimia yang berbeza, dan berada di kelompok yang berasingan. Daripada analisis logam berat, air sungai yang melalui kampus UM mengandungi kepekatan logam yang lebih tinggi berbanding air tasik. Secara keseluruhannya, keputusan WQI menunjukkan bahawa air tasik berada di Kelas II (berkualiti tinggi), manakala sungai dalam Kelas III. Sungai Pantai

mengandungi kepekatan Plumbum, Kadmium, dan Tembaga yang tinggi manakala Sungai Anak Air Batu mengandungi kandungan Besi yang tinggi. Berdasarkan Klasifikasi indeks kualiti air Jabatan Alam Sekitar (JAS), air tasik sesuai digunakan untuk kegunaan rekreasi manakala air sungai perlu dirawat sebelum digunakan sebagai sumber air tasik. Akhirnya, kualiti air semasa dibandingkan dengan kualiti ketika pra-rehabilitasi dengan menggunakan enam parameter (DO, BOD, TSS, NH_3-N, NO_3-, and PO_4^{3-}). Dari kajian ini, ia menunjukkan bahawa semua parameter telah berjaya dikurangkan sehingga 97 % dan ini membuktikan bahawa kerja-kerja rehabilitasi yang dijalankan adalah berkesan serta membantu dalam meningkatkan kualiti air tasik. Oleh itu, kaedah pemulihan tasik boleh digunapakai bagi meningkatkan kualiti air bagi kawasan takungan air yang serupa.

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LIST OF ABBREVIATIONS

BOD	: Biochemical Oxygen Demand
COD	: Chemical Oxygen Demand
NH_3-N	: Ammoniacal Nitrogen
DO	: Dissolved Oxygen
TSS	: Total Suspended Solid
NO_3^-	: Nitrate
PO_4^{3-}	: Phosphate
DOE	: Department of Environment
WQI	: Water Quality Index
NWQS	: National Water Quality Standard
EPA	: Environmental Protection Agency
UM	: University Malaya
SD	: Standard Deviation
APHA	: American Public Health Association
AWWA	: American Water Works Association
WEF	: Water Environment Federation
HCA	: Hierarchal Cluster Analysis
Cu	: Copper
Fe	: Iron
Pb	: Lead
Ni	: Nickel
Cd	: Cadmium

As	: Arsenic
Mn	: Manganese
Cr	: Chromium
Ag	: Silver
Zn	: Zinc
Al	: Aluminum
WL	: Wetland
ML	: Middle Lake
EL	: End of Lake
SP	: Pantai River
SA	: Anak Air Batu River
CON	: Confluence
ASM	: Academy of Science Malaysia
NAHRIM	: National Hydraulic Research Institute of Malaysia
JPPHB	: Department of Development and Estate Maintenance

CHAPTER 1 INTRODUCTION

1.1 Background

Two-thirds of the Earth's surface is covered by water, amounting to approximately 1.4 billion cubic kilometers. About 97.5% of the Earth's water is in the oceans. Of the remaining 2.5%, 70% is locked in polar ice caps or glaciers. Most of the rest lies deep underground that is beyond human reach, and another sizable fraction is saline. This means that all human and other life depends on less than 1% of the total quantity of water on this planet. Lake water lies in that 1% portion. This study focuses on the lake water quality located in the study area and will be discussed in the entire research report.

Lakes are vulnerable and their overall condition is deteriorating. Lake water, which is allocated and made available for maintaining the ecological processes and particular ecological characteristics in a desirable state is referred to as the environmental flows (King, Tharme, De Villiers, & Malan, 2000; O'Keeffe, King, Tharme, & de Villiers, 2000). Environmental flow is one of the important components in water resources planning, management and allocation, where a sustainable environmental flow benefits the health and maintenance of the aquatic ecosystem.

From the Managing Lakes and Their Basins for Sustainable Use in Malaysia, Lake Briefs Report Series No.1 (2010), Malaysia is rich in lake (natural and man-made) resources. Natural lakes include large wetlands such as Bera Lake and Chini Lake in Pahang, Kenyir Lake in Terengganu and Dayang Bunting Lake in Langkawi (AS Malaysia, 2010). In this country, lakes are important water resources that contribute to the socio-economic transformation of the country (AS Malaysia, 2010). It is also discussed that most of these inland water bodies provide essential resource-provisioning services, including supplying freshwater, aquaculture and fisheries, hydroelectricity and regulating services, as well as providing natural flood mitigation and unique freshwater habitats. Lakes are also crucial for ecotourism and recreational sites. Pollution from pollutants that drain into the lake is becoming a serious threat to Malaysian lakes, causing deterioration of water quality to varying degrees.

1.1.1 Surface Water System in UM

The University of Malaya is the first university established in Malaysia. It is situated on a 750-acres (309-hectare) main campus in the south-west of Kuala Lumpur, the capital city of Malaysia. The total number of students and staff recorded until 2015 is 24, 517 ("UM Fact Sheet," 2015). Its history can be traced back to the year 1905 when the King Edward VII College of Medicine was established and the establishment of Raffles College in 1929. On 8th October 1949, University of Malaya was officially formed when the two colleges were combined. At that time, the university was established as a national institution to serve the higher education needs of the Federation of Malaya and Singapore ("Our History," 2015). During the first ten years of establishment, University of Malaya had experienced rapid growth resulting in the establishment of two autonomous divisions in the year 1959; with one division located in Singapore, whilst the other was in Kuala Lumpur. A year later in 1960, a national university in each division was established following the wishes of the divisions. The national university established in the Kuala Lumpur division was made official with the passing of legislation in 1961, founding the University of Malaya on 1st January 1962 ("Our History," 2015).

The surface water system in UM campus is divided into two types; stagnant water from the lake and freely flowing water from two river tributaries. The river water is interconnected with the outside area and passes through UM campus before merging with the Klang River, one of the major rivers in Selangor. The rivers carry all sorts of unknown pollutants from the outside area and were not classified as UM property. Meanwhile, the Varsity Lake is a closed system located on the campus and has been one of the properties of UM. This study focuses on the Varsity Lake management and extends towards the river system due to its potential to act as a lake water source.

1.1.2 Varsity Lake

Since 1962, the Varsity Lake has become the center point for all UM community in any program. The area of the Varsity Lake during the said year was triple of the current area as shown in Figure 1.1. The size became smaller in 1976 and further in 1984 where the size was reduced due to the rapid UM development. Since then, there was no significant change in the lake size and it remains to be utilized as a recreational area.

Currently, the Varsity Lake is the biggest lagoon in UM land with a surface area of 13, 760 m^2. The lake provides homes for animals and plants, in addition to be the place of recreation and enjoyment for the visitors. The recreational equipment includes kayak station and small cottages for the visitor's use. Thus, during the evening, the Varsity Lake has become one of the center of attraction for the visitors to have recreational activities, such as jogging, exercising, cycling, and kayaking. Some may just sit to enjoy the peaceful and the beautiful scenery after finishing their busy daily schedule.

However, on 15th October 2009, most of the fish in the lake suddenly died where it has become the major indicator of the bad water quality inside the lake. A study was conducted in 2009 to determine the water quality status in the lake and to know its suitability for recreational purposes. From the previous study, it proved that the water is contaminated and could not be used for recreational activities due to the high concentration of Biochemical Oxygen Demand (BOD), Total Suspended Solid (TSS), Total Dissolved Solids (TDS) as well as nutrient loads and metal concentration, especially mercury (Ashraf, Maah, & Yusoff, 2010).

Further in 2013, a severe drought occurred and worsens the water quality in the lake. The UM management decided to stop any activity in the lake to prevent any dangerous consequences to the users. The water sample was collected monthly to closely monitor the water quality and to analyze the pollutant content in the lake system. Based on the water quality recorded, it shows that the lake is continuously in poor condition. Thus, the top management has agreed to start a rehabilitation work towards the lake to improve its water quality. The work was officially started on 4th August 2014. The details on the rehabilitation work will be discussed in Chapter 3.

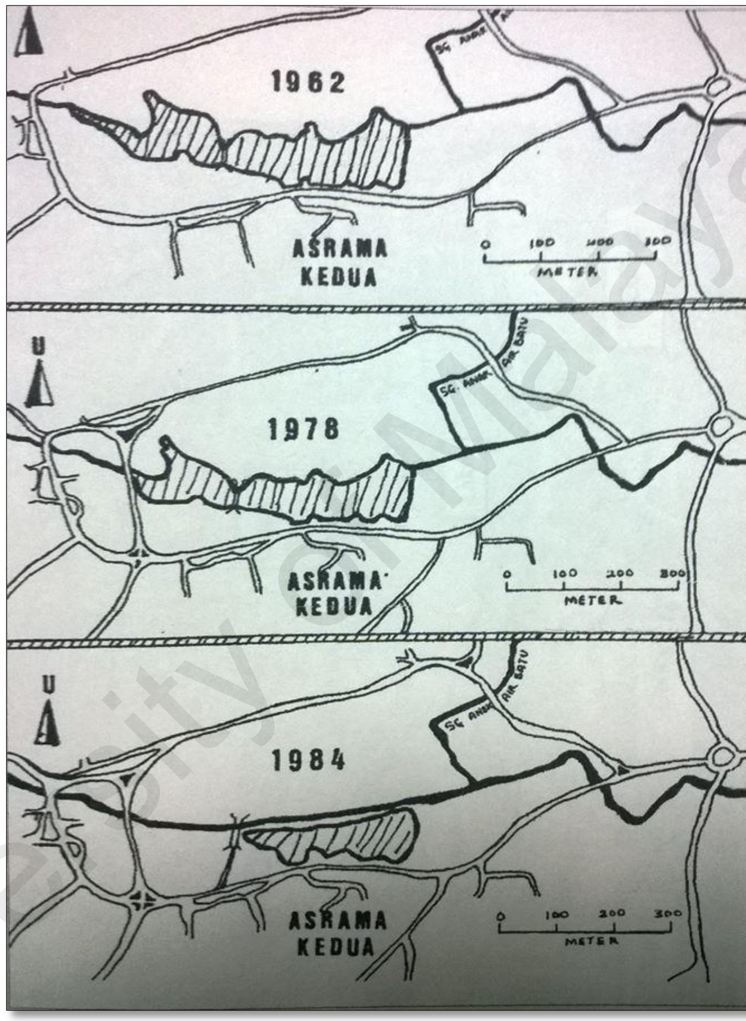

Figure 1.1: The size of Varsity Lake from 1962 until 1984 (Source: Water Warriors)

1.2 Problem Statement

The rapid development of the UM campus has driven the modification of resource utilization. This section discussed the problems faced by the Varsity Lake for the period of 15 years starting from year 2000 until 2015.

The major problem of the lake is due to its function, which is to collect the wastewater from the 2nd Residential College, the Built Environment Faculty and the Engineering Faculty as shown in Appendix C, Figure C1. It is reported that the wastewater flows directly into the lake without proper filtration or treatment (Goh Shan M., 2001).

The Varsity Lake also does not have a specific clean water source to maintain its water level apart from receiving the natural precipitation and surface runoff. On top of that, it was reported that during the year 2000, instead of transporting the wastewater, the lake water go to the stream through the leakage of the culvert. That was adding to the problems in maintaining the water level in the lake. As the conjunction to that, the management decided to block the inlet and the outlet of the culvert, while the wastewater from the 2nd Residential College and the Engineering Faculty remain flowing directly into the lake (Goh Shan M., 2001).

The overloading pollutant from the uncontrolled discharge has exceeded the carrying capacity of the lake water. The continuous discharge into the lake had caused water quality deterioration. It is found that there is a high concentration of oil and grease particles in the water due to the water flow from the cafeteria of the 2nd Residential College, the Engineering and Build Environment Faculties, which caused the BOD and TSS value to be higher than normal in the lake. It was one of the main factors that cause the death of the fishes in the lake in 2009 as shown in Appendix C, Figure C2 (Ashraf et al., 2010).

Other than that, a high Total Dissolved Solids (TDS) was reported in 2009, particularly due to the wastewater from the Engineering Faculty and the 2nd Residential College, as well as the disturbed sedimentation from the canoeing activity point. This has consequently reduced the water clarity and increases the suspended matters in the lake. Mercury concentration is also high in the lake. A body contact is usually involved in the sporting and recreational activities. The parameters of the water were compared with the Malaysian Interim Water Quality Standards (INWQS) and it was concluded that the lake water quality does not fulfill the recreational spot criteria where it is hazardous to human and aquatic life in the lake.

In addition, high level of nitrate and phosphate was reported in the lake from the outlet at the Biomedical and Chemical Engineering Department. The excess nutrient has caused the eutrophication problem and enhanced the algal bloom production. The lake surface water was covered with algal bloom where consequently will reduce the ability of the sunlight to penetrate the water system. Eutrophication problem also produces unfavorable odor and give bad scenery to the visitors as shown in Appendix C, Figure C3. Other problems faced by the Varsity Lake is sedimentation due to the non-concreted bank as shown in Appendix C, Figure C4.

Despite the problems that were experienced by the Varsity Lake, many organizations took part to improve the water quality and make the Varsity Lake alive again. The major decision made is to conduct a rehabilitation work on the lake. However, after the rehabilitation work completed, the lake water did not directly show a positive effect, but it showed a sign of eutrophic condition due to the algae bloom formation on the surface water. The utilization of Pantai River after the rehabilitation works to maintain the lake water level is suspected to cause the eutrophication problem. The wastewater from the Faculty of Science, Faculty of Social Science, and Perdanasiswa complex flow into Pantai River. Therefore the possibilities of the lake water being polluted are very high and a close study is required before utilizing it as a lake water source.

1.3 Objectives

This research is initiated due to Varsity Lake water quality degradation and major lake rehabilitation process done in 2014 as been address by previous study. Thus, the main aim of this research is to study the effectiveness of lake rehabilitation process. The study is also conducted to assess the selected water quality parameters and classify the overall lake water quality for the recreational purposes. Furthermore, this study aims to observe the river water quality due to its potential as lake water source. Thus the objectives of this study are divided into three parts as listed below:

1) To assess the water quality of the Varsity Lake for recreational purposes and to determine the suitability of river tributaries in the University of Malaya for a lake water source.

2) To classify the water quality in the Varsity Lake and river by using the Water Quality Index (WQI) and the Hierarchical Cluster Analysis (HCA).
3) To study the effectiveness of the Varsity Lake management by comparing the water quality of pre-rehabilitation and post-rehabilitation.

1.4 Scope of Study

This study focused on the surface water quality of the Varsity Lake and extends towards the river tributaries in the University of Malaya campus. The rivers involved are Pantai River and Anak Air Batu River due to their potential to act as the lake water sources. The water quality status was determined using the field test and laboratory test. It involved Water Quality Index (WQI) parameters; DO, pH, TSS, BOD, COD, and NH_3-N. Further analyses were made to know the level of nutrient content, Nitrate (NO_3^-) and Phosphate (PO_4^{3-}) concentrations as well as heavy metals for 13 elements.

Next, the water in the Varsity Lake and river were classified according to the pollution level by using the WQI and the Hierarchical Cluster Analysis (HCA). WQI covers six parameters only, meanwhile, HCA was applied by including other important water quality parameters like NO_3^-, PO_4^{3-}, water temperature, turbidity, and conductivity.

The water quality data in this study were used as the indicator for the effectiveness of lake water management by comparing the water quality trend from pre-rehabilitation (November 2013 until July 2014) and post-rehabilitation (November 2014 until October 2015). Last but not least, the difference between the pollutants concentration in the pre-rehabilitation and post-rehabilitation were reported using the percentage change.

1.5 Thesis Outline

This part will discuss on the outline for the entire thesis. From Chapter 1, the background of the research is explained to give a general idea on the water and lake usage in Malaysia and worldwide. The chapter then focuses on the function of the Varsity Lake from 1962 until 2015. The problem related to the Varsity Lake, objectives of the research and scopes of the research are also included in Chapter 1.

Next, Chapter 2 provides a review of the generic terms related to this study, such as water pollution, water quality monitoring, water quality parameters, eutrophication and WQI. Since this study includes the analysis of heavy metals and water quality management, the current status of heavy metals pollution in Malaysia and crucial keywords and technology in water management are included in the literature review.

The following chapter (Chapter 3) describes the methods and materials to achieve the objectives of the research, which include the flowchart, study area, data collection, sampling methods, and analytical procedures. The details of the Varsity Lake characteristics and lake rehabilitation process will also be discussed in Chapter 3.

Chapter 4 concentrates on the in-situ and laboratory analysis results and discussion of the research. The result of comparison between the pre-rehabilitation and post-rehabilitation is included within this chapter. Chapter 5 provides an overall conclusion and recommendations for further research.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

In this chapter, the generic and keyword terms related to this thesis were discussed in details based on the existing studies. The references used were mostly referred to the recent papers and journals within the 5 years period. However, some of the references were taken from the year earlier than that due to their major contribution to the field and their global recognition. The terms discussed in this chapter includes the general terms related to this field of study, such as water pollution and water quality monitoring. The pollution scenario in Malaysia was also discussed briefly based on the related literature. Since this study focuses on the water quality, the important parameters contributing to water quality deterioration were included. Nevertheless, the keywords related to the lake management were defined in this study, such as eutrophication and proper lake management systems.

2.2 Water Pollution

Two-thirds of the Earth's surface is covered by water, amounting to approximately 1.4 billion cubic kilometers. If we consider human water need, however, the amount is deceiving. This is because more than 97.5% of the water stated is in the ocean, while the remaining 2.5% is divided into 70% of the polar icecaps or glaciers. Therefore, this means that all human and other living things depend on less than 1% of the total quantity of water on the Earth. However, the rapid developments and anthropogenic activities have caused pollution to the water.

Water pollution occurs when pollutants (particles, chemicals or substances that make water contaminated) are discharged directly or indirectly into the water bodies without enough treatment to get rid of the harmful compounds. Pollutants get into the water mainly by human causes or factors. During recent years, there have been a lot of awareness and concerns regarding water pollution all over the world. New approaches towards achieving a sustainable use of water resources have been developed internationally. In making this approach a success, a number of policies have been identified according to the Water Pollution Control Guideline that was published by the United Nations Environment Programme (UNEP), Water Supply & Sanitation Collaborative Council and World Health Organization (WHO). The principles are as follows:

- A water pollution control policy, ideally, should be seen as part of a coherent policy framework ranging from overall statements, as such can be found in government statutes or constitutions to specific policy statements that were defined for the environment and water resources management as well as for particular sector developments.

- The policy making process should, therefore, incorporate consultations and seek consensus with all line ministries relevant for water resources management, including organizations responsible for overall economic development policies. In addition, when formulating new development policies for other sectors, water resources policy statements should be taken into account where appropriate.

- Policy statements must be realistic. Good intentions reflected in statements, such as "No pollution of surface waters shall occur..." cannot be applied in practice and therefore become meaningless in the context of an operational policy.

- The statements in a policy document need to be relatively long-lived because they must pass a laborious political adaptation process. Thus, detailed guidelines, which may need regular adaptation to the country's actual development level, should be avoided and placed into the more dynamic parts of the legislation system, such as the regulation framework, that can be amended at short notice.

In determining the water pollution, there is a need to determine the type of pollution, which are the point source (PS) and nonpoint source (NPS) pollution. PS pollution mainly includes municipal sewage discharges (from urban or highly residential areas) and industrial wastewater loads (from a variety of manufacturers). NPS pollution occurs when rainfall, snowmelt water or irrigation water runs over land, carrying and depositing pollutants into rivers, lakes, and coastal waters. NPS pollution from agriculture is regarded as the major cause of the surface water quality degradation and has attracted growing public concern (Darradi et al., 2012). Estimating the NPS pollutant loads is challenging due to the complicated hydro-meteorological and biochemical processes and the spatial variability involved in the process of pollutant transport and transformation (Ficklin, Luo, Luedeling, Gatzke, & Zhang, 2010; Nikolaidis, Heng, Semagin, & Clausen, 1998).

Therefore, it is crucial to investigate the status of water pollution by measuring and estimating the pollutants' loadings for environmental planning, management, and restoration. Another important thing to highlight is that the source of the pollution and the effects towards the environment must be known. Table 2.1 shows the pollutant categories and its sources.

Table 2. 1: Major water pollutant categories and the principal sources of the pollutants (Satiah, 2015)

CATEGORIES	DESCRIPTION	SOURCES AND EFFECTS
Oxygen – demanding materials	Any material that can be oxidized in the receiving water using dissolved molecular oxygen	**Sources:** Food residue, human waste, food processing, paper industry, and farm input, e.g: fertilizer, pesticide, and herbicides **Effects:** Threat the aquatic and human life
Nutrients	-	**Sources:** Nitrogen and phosphorus fertilizers, food – processing waste, and detergents **Effects:** Excessive nutrients lead to upset in the food web (chain), e.g: excessive growth of algae, water hyacinth
Pathogenic Organism	Bacteria, viruses and protozoa excreted by diseased persons or animals	**Effects:** Makes water unsafe for drinking, fishing, swimming. Certain shell fish become toxic
Suspended solids/ sedimentation	Organic and inorganic particles in waste water discharge into a receiving water	**Effects:** Organic suspended solids exert oxygen – demand

Table 2.1, continued

Salts	Make up the total dissolved solids (TDS) in water	**Sources:** Discharge from industries, excessive use of fertilizer (inorganic) in farming **Effects:** Damage to aquatic and plant life. Make water unsuitable for water supplies.
Toxic metals and toxic organic compound	-	**Sources:** Urban runoff, agricultural runoff –use of farm inputs, e.g: pesticides, herbicides, industrial waste water discharge (electroplating and electronics) **Effects:** Toxicity in food chain, toxic to human eye even in small quantities
Heat	-	**Sources:** Industrial processes, power plants **Effects:** Increase rate of oxygen depletion, reduce aquatic life of fish

2.3 Water Pollution Status in Malaysia

Malaysia's urban environment has been regarded as one of the least polluted areas in Asia. However, the goal of achieving industrial country status by the year 2020 and the related rapid economic development have begun to increase the industrial pollution and the degradation of urban surroundings (Borhan & Ahmed, 2012). The reduction of air and water pollution, as well as the contamination by industrial wastes, have turned to be more severe in Malaysia in recent years (Afroz, Hassan, & Ibrahim, 2003). The rapid growth prior to the economic crisis in 1997 and during the period of economic recovery in the country had increased the environmental pollution. Uncontrolled growth with regards to the ecological rules remains to be the problem until this day.

Thus, during the Seventh Plan period, to ensure the development was balanced and sustained, the environmental and natural resource issues have been addressed continually. The relevant institutional, legislative and regulatory mechanisms were strengthened and the efforts to integrate the environmental considerations into the development planning were intensified (Unit, 1996). During the Eighth Plan period, emphases were placed on addressing the environmental and resource management issues in an integrated and holistic manner. In order to ensure that the development is sustainable, resilient steps were taken to identify the prudent, cost-effective, and appropriate management approaches that yield multiple benefits. Efforts were continued to address air pollution, mitigate degradation of rivers, and improve marine and groundwater quality. Efforts were also made to promote the environmental performance measurements and market-based instruments as engaging communities in addressing the environmental and natural resource issues (Unit, 2001).

According to the report by the United Nations Development Programme (1997), Malaysia's rapid economic growth has caused environmental degradation. Water quality has also deteriorated. The rapid development has produced gaps in the precision of pollution (Abidin, 2004). Extremely dense population in urban centers has converted rivers into open sewers. Cities are substantially responsible for being polluters towards the aquatic environment through the sewage and municipal wastewater, industrial effluent and polluted urban. Water pollution affects water supply services, harms the human health and demolishes aquatic lives and habitat.

2.4 Water Quality Monitoring

Water quality assessment can be defined as the evaluation of the physical, chemical, and biological nature of water in relation to the natural quality, human effects and its intended uses (Fernández, Ramírez, & Solano, 2004). In the future, freshwater will be a scarcer resource. Therefore, a river water quality monitoring program is necessary for the protection of freshwater resources (Pesce & Wunderlin, 2000). Water quality monitoring is defined as the sampling and analysis of water constituents and conditions (Federation & Association, 2005). The constituents are divided into two types. The first includes introduced pollutants, such pesticides, metals and oil. The second type is constituents found naturally in water that can be affected by human sources, such as dissolved oxygen that water is able to contain, and pH that affects the toxicity of ammonia. According to the EPA, there are several purposes of doing water quality monitoring. One of the purposes is to identify whether the water meets the designated uses. All states have established the limit of pollutant contents that are allowable in their waters. If the chemical pollutants exceed the maximum or minimum allowable concentrations, the water might no longer be suitable for a designated area. Long-term monitoring is a proper way to do it, however, a long-term watershed water quality monitoring is costly and time-consuming (Santhi et al., 2001) and is not applicable for predicting the potential effects of future climate and land cover change scenarios (Wu & Chen, 2013).

2.5 Water Quality Parameters

Aquatic lives need an optimal condition to continue living. When the conditions are poor, organisms may die due to the environmental stress. Thus, various water quality parameters need to be measured in order to determine the health of the water so that it is safe to be used by consumers for any purposes. There are four types of water quality parameters that need to be considered, which are physical, chemical, biological, and radioactive. However, this study excludes the radioactive part and the parameters involved are described below.

2.5.1 Physical parameter

The physical parameters are temperature, turbidity, and total suspended solids. Each parameter gives a different significance impact on the water quality.

Temperature

Temperature is the measure of the amount of heat in the water where this influences the survivability and growth of the aquatic life. Different types of fish have different needs for an optimum temperature and tolerances of extreme temperatures (Davis & McCuen, 2005). Temperature is able to directly affect the other types of parameters like biological, chemical and many of the physical characteristics. Some of the aquatic plants might tolerate to cooler waters, but most of the species prefer warmer temperature and the tropical plants, in particular, will show restricted growth and dormancy in water temperature below 21ºC (Kemker *et al*, 2014).

Turbidity

Turbidity measures the scattering effect of suspended solids on the light where the higher the intensity of scattered light, the higher the turbidity (Federation & Association, 2005). Turbidity indicates the number of fine particles suspended in water. The higher concentrations of particles can damage the habitats of fish and other aquatic organisms (Said, Stevens, & Sehlke, 2004). Turbidity also closely related to the aesthetic point of view. Many pathogenic organisms may be encased in the particles and be protected from the disinfectant (Avvannavar & Shrihari, 2008).

Primary contributors to turbidity include clay, silt, finely divided organic and inorganic matter, soluble colored compounds, plankton, and microscopic organisms. Turbidity is measured in nephelometric turbidity units (NTU) or formazin turbidity units (FTU), depending on the method and equipment used. The HF Scientific DRT-15CE measures turbidity in NTU using a nephelometric method that depends on passing a specific light at a specific wavelength through the sample (Federation & Association, 2005).

Total suspended solids

Turbidity is closely related to the total suspended solids. Total suspended solids (TSS) are normally referred to the particles in water, which is usually having a size larger than 0.45 µm. These particles allow many pollutants, such as toxic heavy metals to attach to their surface area. This is not a good condition for the aquatic habitat where the consequences most likely to be similar to the high turbidity conditions. Most suspended solid are made up of inorganic materials, although bacteria and algae can also contribute to the total solids concentration. The examples of the common suspended solids include clay, silt, and sand from the soils, the phytoplankton and bits of decaying vegetation, as well as the industrial wastes and sewage.

The high TSS will cause the water color to darken, thereby decreasing the amount of light available for aquatic plants, algae, and mosses to grow by photosynthesis. It will eventually lead to the reduction of plants and will cause less food and habitat for the organism, such as snails, insects, and juvenile fish. As the photosynthesis slowed down, less oxygen is released into the water during the daytime and the plants may die. As they decay and decompose, the bacteria will use up even more oxygen from the water. The worst case scenario is that suspended solid tends to provide absorption surface and a route of transmission for many organic contaminants, nutrients, as well as heavy metals. "Many of the toxic industrial compound, such as dioxins and furans, PCB's (polychlorinated biphenyls), PAH's (polycyclic aromatic hydrocarbon), many pesticides and heavy metals, such as mercury, cadmium, lead, zinc, and chromium are 'sticky' molecules that adhere to both fine organic and clay particles" (Allan *et al*, 1995).

2.5.2 Chemical parameter

The examples of chemical parameters are pH, dissolved oxygen (DO), ammoniacal nitrogen (NH_3-N), biochemical oxygen demand (BOD), chemical oxygen demand (COD), phosphate, and nitrates.

pH

Toxicity testing is an essential tool for assessing the effect and fate of toxicants in the aquatic ecosystems. It has been widely used as a tool to identify suitable organisms as a bioindicator and to derive the water quality standards for chemicals (Adams & Rowland, 2003). The pH value gives a measure of the acid strength in the water under the study area. It gives an estimation of hydrogen ion concentration, H^+. Its value ranges from 1.0 until 14.0. The neutral pH is when the value is 7.0. The lower pH means the higher H^+ ions activity and represent a more acidic water (Davis & McCuen, 2005).

Dissolved Oxygen

DO is a measure of oxygen amount that is freely available in the water. It is expressed in unit of milligrams per liter, or as a percent saturation. DO also depends on temperature. The colder the water, the more oxygen it can hold (Said et al., 2004). In contrast to stream and rivers where DO levels are most likely to vary horizontally along the course of the waterway, the DO in lake changes more vertically in the water column. However, smaller lake with shallow water depth will have a small variation of DO. DO varies with temperature, so it is good to have an hourly data of DO but it is not feasible for the researcher to handle an hourly monitoring. According to the EPA 1992, it is important to note the time of DO sampling to help judge the data collected.

Ammoniacal nitrogen

Ammoniacal nitrogen (NH_3-N) is an inorganic chemical, which is a type of dissolved nitrogen that can be found in water and is the most favorable form for algae and plant growth. Ammonia is the most reduced form of nitrogen and is found in water when the DO is lacking in the water. Ammonia can be reduced when the DO is readily available where the bacteria oxidizes the ammonia to nitrate through the nitrification process. Ammonia is acidic and the level of acidity depends on the temperature and the pH. A high pH and temperature will give a high toxicity to the water, thus, will harm the aquatic life.

Although the concentration is very low, the existence of ammonia in the water body brings harm and toxic to the aquatic life, such as fish and the microorganism. Starting from the concentration level of 0.06 mg/L of ammonia, the fish can suffer damage on the gills since the nitrogenous waste excretion in the aquatic species occurs largely at the gills. (Dirk Weihrauch *et al*, 2009). The excessive amount of NH_3-N indicates that the water body is polluted due to eutrophication phenomenon. The source of NH_3-N to the lakes and streams are from the fertilizers of agricultural activity, human and animal waste, and byproducts from industrial processes. All of these sources are non-point sources where the most suitable way to control is by pollution prevention method, such as through filtration of the runoff from the agricultural activity, proper septic system maintenance, and control the dosage of fertilizing process.

Biochemical Oxygen Demand

The Biochemical Oxygen Demand (BOD) is the amount of oxygen required to oxidize a substance to carbon dioxide and water by the microorganisms. In the simplest term, BOD is the amount of oxygen required for the microorganisms (bacteria) to eat the organic pollutant. BOD is always expressed in milligrams per liter (mg/L), which indicates the mass of oxygen consumed per liter of solution. Other than that, BOD is also often expressed in part per million (ppm).

At room temperature, the amount of oxygen dissolve in water is 8 mg/L, whereas at freezing point, it increases to 14.6 mg/L and also increases at a high barometric pressure (low altitudes). While at the boiling point, the solubility of the oxygen is zero (Hach *et al*, 1997). For the degradation of oxidizable organic matter to take place, a minimum of 2 mg/L to 7 mg/L of dissolve oxygen level is required and needed to be maintained at the laboratory or should be available in the natural waters (Avvanavar & Shrihari, 2007)

Chemical Oxygen Demand

The Chemical Oxygen Demand (COD) is the amount of oxygen required to degenerate all pollutants in the chemical ways by a strong chemical oxidizing agent, such as Potassium dichromate in an acid medium. In general, the amount of the COD level is higher than the level of BOD (BOD5) because more compounds can be oxidized chemically than biologically. It is also often expressed as in milligrams per liter (mg/L), which indicates the mass of oxygen consumed per liter of solution. The concentration of COD exists in natural water via housing area and factories or industrial area (Talib & Amat, 2012).

Phosphate

Phosphorus is a common constituent of agricultural fertilizers, manure, and organic wastes in the sewage and industrial effluent. The sources of pollution may include the nutrient losses from waste product or even the manure, which will then spread over large agricultural fields; sediments form eroded soil, the nutrient leaching or runoff from the residential or agricultural areas. Phosphorus gets into the water in both agricultural and urban settings where it tends to attach to the soil particles, thus, moving into the surface-water bodies from the runoff.

According to the Wisconsin Lake Organization, the phosphorus will provide fuel that is needed by the algae, which will then transforms the lakes into a thick, smelly green soup where it takes 20 part per million (ppm) of soil phosphorus to grow a healthy turf and within the 25 part per billion (ppb), it can promote excessive algae growth in lakes. Generally, one pound of phosphorus can support 500 pounds of algae.

In worst case scenario, the nutrients which are the product of fertilizer and agricultural activity may cause the eutrophication; the process of enrichment of lakes and stream with nutrient, and the associated biological and physical changes. This phenomenon is a natural process, but with the dramatically increase of human activity, the lake become vulnerable due to the nutrients carried into them.

The excess of this nutrient will also lead to algae bloom, which can turn the lake into thick, smelly soup that is undesirable for swimming and recreation. As there is too much algae cloud water, it blocks the sunlight from reaching the aquatic plants where it will also lower the oxygen levels in the water, which can cause fish kills.

Nitrate

Nitrate and nitrite are naturally occurring chemicals that are part of the nitrogen cycle. Nitrate is less toxic than the other forms of nitrogen in the aquatic environment, such as nitrite and ammonia. Nitrate can be harmful in the development of early life stage in the aquatic organisms by reducing the oxygen-carrying capacity of the blood, or by disrupting the ability to maintain the proper balance of salts. The increased levels of nitrogen in the water can cause excessive plant and algae growth that depletes oxygen levels, possibly to lethal levels (M. Aqeel Ashraf *et al*, 2010).

Unlike the temperature and the dissolved oxygen, the presence of normal levels of nitrates usually does not have a direct impact on the aquatic fish and insect. However, the excess levels of nitrates in water can create a condition that makes it difficult for the aquatic animal to survive. Although this pollutant occurs naturally in soil and water, an excess level of nitrates can be considered to be a contaminant of ground and surface waters. Most sources of excess nitrates come from human activity. The source of excess nitrates can usually be traced to agricultural activities, human wastes, or industrial pollution.

Generally, the excess of nitrate becomes the sources of fertilizer for the aquatic plants and algae. But in many cases, the high amount of nitrate contributes to the rapid growth of aquatic plants and algae. It may eventually lead to the unstable amount of dissolved oxygen in the body of water. During daylight, there will be usually a high level of oxygen, but at night the level of oxygen will reduce dramatically.

The excess growth of algae also will create the condition where the organic matter accumulates. The high density of algae prevents the sunlight from penetrating far into the water. Since the algae and the aquatic plants need sunlight to grow, they might die if they did not receive enough sunlight. As these dead plants settle to the bed of the lake, the bacteria that feed on decaying organic material will abundantly increase in number, thus, dropping the level of oxygen as they consume it. As the result of this situation, the fish stress and will eventually die.

2.6 Eutrophication

In dealing with the lake water management, eutrophication is the major type of water pollution involved. Eutrophication occurs when the amounts of nutrients, such as nitrogen and phosphorus increase in lakes, estuaries, and other ecosystems and those ecosystems responded with the increased growth of plants and algae. Eutrophic conditions can occur naturally (Figure 2.1) or culturally (Figure 2.2). Human activities have resulted in enrichment of surface waters with nutrients, mainly nitrogen (N) and phosphorus (P). This has bring to cultural eutrophication problem and has become a worldwide water quality issue (Smith & Schindler, 2009), and it is recognized by scientists as the most important water quality problem (Downing, 2014).

One of the symptoms of eutrophication is excessive phytoplankton growth, mainly cyanobacteria, which may cause nuisance blooms (Carpenter, 2005). Cultural eutrophication is harmful, but it can be reversed if the nutrients come from easily identified point sources, such as sewage treatment plants or septic systems. It is far more difficult to control nutrients if they come from diffuse sources, such as large land areas with fertilized crops, lawns, or animal pastures. Eutrophic conditions can also occur naturally. This is due to nutrients occur at high levels in their regional soils and bedrock.

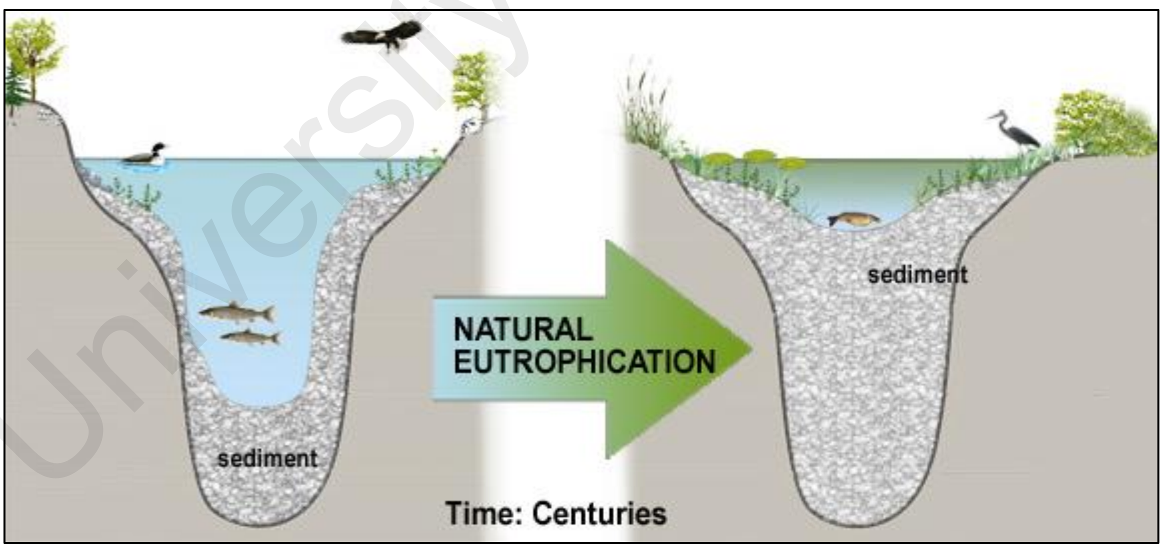

Figure 2. 1: The formation of natural eutrophication

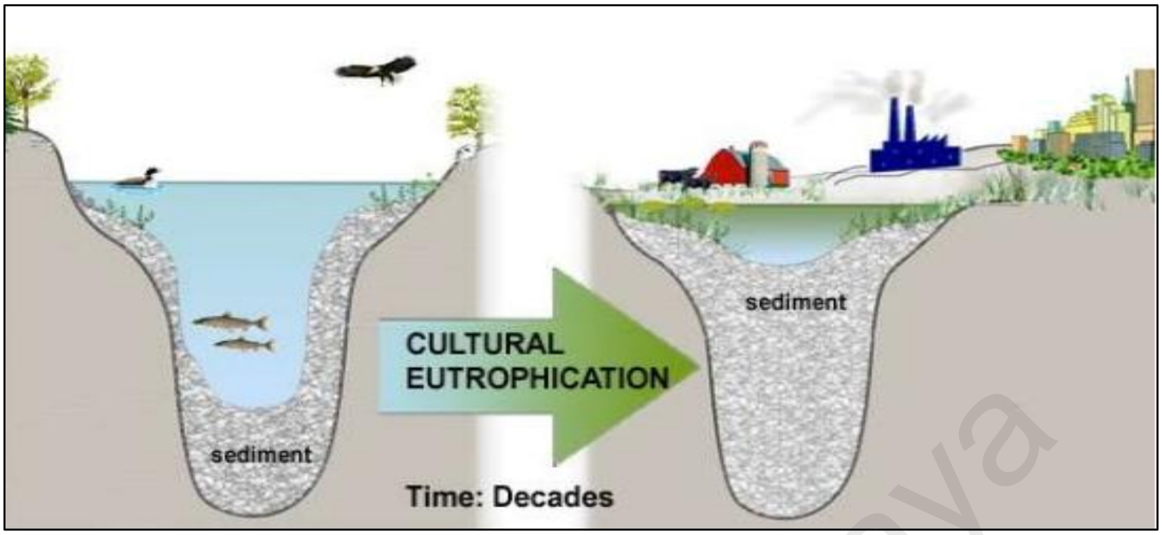

Figure 2. 2: The formation of cultural eutrophication

In a recent paper on eutrophication and climate change, a group of international experts (Moss et al., 2011) has raised the following major points.

- Blue-green algae, which causes noxious blooms in lakes and estuaries (Figure 2.3) are favored both by increased nutrients and higher water temperature.
- Lakes with warmer water will have higher densities of fish species that eat zooplankton, the microscopic animals that normally feed on and control algae.
- A particular kind of zooplankton (*Daphnia*) that is very effective in controlling algae is most susceptible to being eaten by fish, and it is also highly sensitive to warm water (Figure 2.4)
- Eutrophication reduces the ability of zooplankton to control algae because it leads to the dominance by blue-green algae, which is harder to feed on and digest.
- As a result, climate change *and* eutrophication together will limit the ability of zooplankton to control the algae by reinforcing the potential for harmful blooms.

Figure 2. 3: Algae blooms in lake near University of Missouri, Columbia

Figure 2. 4: Microscopic photograph of a Daphnia, a zooplankton

2.7 Water Quality Index (WQI)

The Water Quality Index (WQI) has been the first attempts during the mid-twentieth by Horton on 1965 and Landwehr on 1974 (Bharti & Katyal, 2011; Fernández et al., 2004). In the 20th Century, the application of the water quality indices was given an important acceptance, which is made evident at the present time by an appreciable number of formulated indices in different countries around the world, from the general to the specific purposes. It was developed to give criteria for the surface water classification based on the use of standard parameters for water characterization. Normally, WQI aims to give a single value to the water quality from the parameters to a simpler expression and thus, enabling an easy interpretation during data monitoring (Gholikandi, Haddadi, Dehghanifard, & Tashayouie, 2012). There are numerous types of WQI used to express the level of water quality of a certain area of study. The type of WQI depends on the source of pollution so that it shows the correct estimation about the water quality. Bharti and Katyal (year) has made some comparison on the different types of indices that were used worldwide based on the formula, calculation, aggregation, and flaws. However, each WQI has different approaches like the statistical analyses of the individual parameter, and the multi-stressors water quality indices (Gholikandi et al., 2012).

2.7.1 Malaysian WQI

In relation to the water quality of the Malaysian guidelines that was produced, including the National Water Quality Standard (NWQS), Environmental Quality Act (EQA), and the Malaysian Water Association's (MWA) criteria for the raw water intakes. The water quality index contains unit-less, single dimensional numbers between 0 and 100, with a higher index value that represent a good water quality. The parameters used are DO, pH, BOD, COD, TSS, and NH_3-N. The combination of these parameters allow the preliminary classification of the surface water for the purpose of various uses and provide a benchmark for evaluating the management strategies (Bordalo, Teixeira, & Wiebe, 2006).

The DOE of Malaysia developed a WQI system to analyze the trends in the river water quality based on the six parameters, which are DO, pH, BOD, COD, SS, and AN.

Fundamentally, the WQI and the NWQS of Malaysia served as the basis for the environmental assessment of a watercourse in relation to the pollution load categorization and the designation of classes for beneficial uses. The NWQS, which was developed by the DOE classifies rivers into 5 classes (I-V) according to their beneficial usage. The classes are related to the values of WQI.

2.8 Heavy Metal Contamination

Metal contamination has been shown to have serious effects on both the environment and humans. Malaysia as a developing country, is no exception in facing metal pollution that was especially caused by anthropogenic activities, such as manufacturing, agriculture, sewage, and motor vehicle emissions (Shazili, Yunus, Ahmad, Abdullah, & Rashid, 2006). Studies on metals in water and sediments indicate that some rivers in Malaysia were contaminated with As, Ag, Cd, Cu, Pb, and Zn, and some coastal sediment were contaminated by Pb, Zn, and Cd (Shazili et al., 2006; Yap & Pang, 2011; Zulkifli, Mohamat-Yusuff, Arai, Ismail, & Miyazaki, 2010) However, Malaysia has a lack of water quality criteria (WQC) based on the local aquatic biota.

The existing water quality standards (WQSs) for metals in Malaysia (National Water Quality Standards) are based mainly on the foreign criteria or standards, which have different environmental conditions compared to Malaysia. Many factors (physical, chemical, and biological) are known to affect the toxicity of metals to aquatic organisms. These factors, especially the differences in the taxonomic composition of Malaysian waters compared to those for which WQSs were developed, could result in foreign water quality criteria or standards that are over-protective or under-protective for the aquatic ecosystems in Malaysia. In order to protect the aquatic ecosystems in Malaysia, it is necessary to develop the WQC for metals based on the responses of domestic aquatic biota with local environmental factors. This information could also be used to determine the sensitive and potential organisms as bioindicators for metal pollution, especially in Malaysia (M Shuhaimi-Othman, Nadzifah, Nur-Amalina, & Umirah, 2013).

2.9 Lake Management in Malaysia

This part discusses the approaches taken by this country in managing their lakes. Lakes are essential components of the freshwater supply. However, it is far more than just acting as repositories for a valuable resource, lakes support livelihood, food production, and are often be the precious repositories of biodiversity, buffers against hydrologic and climate fluctuations, and receptor the functions for inflowing material collected across their basins.

This part will explain on the lake management systems and the content is extracted from the “Managing Lakes and Their Basins for Sustainable Use in Malaysia, Lake Briefs Report Series No.1” and “Lakes and Reservoir Management in Malaysia: Status and Issues”.

From the Managing Lakes and Their Basins for Sustainable Use in Malaysia, Lake Briefs Report Series No.1 (2010), Malaysia has no exception in developing a better lake management system. There has no comprehensive inventory of the lake resources in Malaysia. The preliminary data suggests that there are more than 90 lakes in Malaysia covering an area of at least 100,000 hectares and they hold about 31 million cubic meters of water. However, the stated amount did not include the mining ponds that were left behind, especially in Klang and Kinta valleys in the states of Selangor and Perak. The total amount of the lake is supposedly sufficient to meet the annual consumption of water for agriculture, industrial, and domestic purposes in Peninsular Malaysia for more than two and a half years.

According to the Managing Lakes and Their Basins for Sustainable Use in Malaysia, Lake Briefs Report Series No.1 (2010), the lake water is utilized to function for the following activities:

a) Hydroelectricity: Hydroelectric impoundments supply about 3600 MW of electricity every year to the national grid.

b) Water supply for the domestic, industrial, and agriculture: Malaysia's lake, either directly or indirectly supplies 98% of the total national water use. Only 2% is contributed by the groundwater that covers the Kelantan region.

c) Irrigation: Malaysia has over 2,450 sq km of irrigated land that consumes over 68% of the total water used in the country, thus, providing gainful employment to over 138,000 farming families.

d) Flood mitigation: Floods in Malaysia are a consequence of natural and human-induced factors. Batu Dam, Semberong Dam, Bekok Dam, and Macap Dam have gone a long way to prevent flooding events.

e) Fishing and aquaculture: Many lakes support fishing population including the large-scale aquaculture in floating cages. At Batang Ai, there are 2000 cages producing an excess of 300 tons of fish annually.

f) Biodiversity: Malaysia has a rich diversified freshwater fish assemblage in its lake, which supports endangered fauna (estuarine crocodile, false gharial) and indigenous flora.

g) Recreation and tourism: Most of the town parks in this country features lakes as a recreational facility. Major resort developments, such as Genting Highlands has involved lakes for aesthetic and recreational value. Many lakes also support recreational fishing.

h) Heritage and patrimony: Many of the older lakes in Malaysia support community and cultural values that are an essential part of our heritage. The folklore and legends that surround Dayang Bunting Lake in Langkawi is a part of the country's myriad mythos and cultural tapestry.

From the Managing Lakes and Their Basins for Sustainable Use in Malaysia, Lake Briefs Report Series No.1 (2010), it is also stated that the sedimentation and lakes pollution seriously impinge on the functions of the lake, consequently impact on our economy, culture, and livelihood. An ASM-NAHRIM study in 2014 on 90 lakes in Malaysia showed that 56 of them were in poor condition (eutrophic), while the balance was in a mediocre to a reasonably good state (mesotrophic).

2.10 Lake Management Solutions

Several lake management solutions that have been practiced worldwide will be discussed in this part.

2.10.1 Integrated Lake Basin Management (ILBM)

In Malaysia, cognizant of the crucial strategic and financial value of the country's lake resources, the ASM-NAHRIM have pursued a multi-stakeholder consultative process culminating in a country-specific version for a sustainable management of lakes and reservoirs in the country. The document published in 2009 entitled 'Strategies for the Sustainable Development and Management of Lakes and Reservoirs in Malaysia', suggests a vision, mission, and a set of strategies for the sustainable management of lake in Malaysia under the system called the Integrated Lake Basin Management (ILBM).

In particular, the ILBM is a way of thinking that assists the Lake Basin managers and stakeholders in achieving a sustainable management of the lakes and their basins. The ILBM was first expressed by the International Lake Environment Committee (ILEC). It takes into account that lakes have a great variety of resource values, which require sustainable development and special management. Good governance of lake can be achieved by integrating five key factors; institution, policy, participation, science, technology, and funding.

The employment of appropriate technologies, the involvement of stakeholder groups, and the implementation of structures monitoring regimes are vital tools in the

ILBM. This proposal is implemented in numerous lakes in the world as reported in the ‘Water Management Planning in Ireland’ and ‘Water Quality Management Plan: Lake Burley Griffin’. The outline of the ILBM for Malaysia is as shown below. The structure for the sustainable management of Malaysian Lakes is as shown in Table 2.2.

Table 2. 2: The structure and contents of sustainable management of Malaysian Lakes (Lake Briefs Report Series I, 2010)

Structure	Contents
Vision	Engender the sustainable use of lakes for their ecosystem services and economic values.
Policy Statement	Lakes and reservoirs will be sustained, restored and protected through the adoption of an ILBM approach.
Mission	To engender sound management of lakes through the adoption and application of ILBM principles and practices
Strategies	Strategy I: Identify and empower a lead ministry
	Strategy II: Establish a National Lake Resource Centre under Minister of Natural Resources and Environment.
	Strategy III: Establish a standing committee on lakes within the purview of National Water Resources Council.
	Strategy IV: Establish lake management committee at state level
	Strategy V: Development of a detailed action plan
	Strategy VI: Support the role of local communities in lake management
	Strategy VII: Pass appropriate legislation to strengthen existing legal framework
	Strategy VIII: Enhance networking and strengthen international strategic alliances.

2.10.2 Constructed wetland

Wetlands are transitional areas between land and water. It provides a number of functions and values. The boundaries between wetlands and uplands or deep water are therefore not always distinct. The term "wetlands" encompasses a broad range of wet environments, including marshes, bogs, swamps, wet meadows, tidal wetlands, floodplains, and ribbon (riparian) wetlands along stream channels. All wetlands, either natural or constructed have one characteristic in common, which is the presence of surface or near-surface water (Davis, 1995).

According to study by (Davis, 1995) the slow flows and shallow water depths allow sediments to settle as the water passes through the wetland. The slow flows also provide prolonged contact times between the water and the surfaces within the wetland. Most wetlands support a dense growth of vascular plants that are adapted to saturated conditions. This vegetation slows the water, creates microenvironments within the water column, and provides attachment sites for the microbial community. Some of the wetland functions and values are:

- water quality improvement
- flood storage and the desynchronization of storm rainfall and surface runoff
- cycling of nutrients and other materials
- habitat for fish and wildlife passive recreation, such as bird watching and photography active recreation, such as hunting
- education and research
- aesthetics and landscape enhancement

Numerous lake's managers have applied the constructed wetland in treating the lake water quality (Cui, Yuan, & Wang, 2011). This is because of the constructed wetlands offer a cheaper and low-cost alternative technology (Mitsch, 1995) in improving water quality. From the literature, the use of constructed wetland has demonstrated that the treatment wetland can be used for the purpose of lake water quality control. Average removal of 84.2% for COD, 53.8% for NH_3-N, 47.9% for total nitrogen, 73.3% for total phosphorus and 86.6% for suspended solids can be achieved (Cui, Yuan, & Wang, 2011).

Components of Constructed Wetlands

- **Water:**

Hydrology is the most important design factor in constructed wetlands because it links all of the functions in a wetland and because it is often the primary factor in the success or failure of a constructed wetland (Davis, 1995). Water of constructed wetlands gives significant impact on several important respects: (1) small changes in hydrology can have fairly significant effects on a wetland and its treatment effectiveness, (2) because of the large surface area of the water and its shallow depth, a wetland system interacts strongly with the atmosphere through rainfall and evapotranspiration (the combined loss of water by evaporation from the water surface and loss through transpiration by plants) and (3) the density of vegetation of a wetland strongly affects its hydrology; first, by obstructing flow paths as the water finds its sinuous way through the network of stems, leaves, roots, and rhizomes and; second, by blocking the exposure to wind and sun.

- **Substrates, sediments and litter:**

The substrates that are used to construct wetlands include soil, sand, gravel, rock, and organic materials, such as compost (Davis, 1995). The sediments and litter then accumulate in the wetland because of the low water velocities and high productivity typical of wetlands. The substrates, sediments, and litter are important for several reasons; (1) they support many of the living organisms in wetlands, (2) substrate permeability affects the movement of water through the wetland, (3) many chemical and biological (especially microbial) transformations take place within the substrates, (4) substrates provide storage for many contaminants, and (5) the accumulation of litter increases the amount of organic matter in the wetland.

- **Vegetation:**

Both vascular plants (the higher plants) and non-vascular plants (algae) are important in constructed wetlands (Davis, 1995). Photosynthesis by algae increases the dissolved oxygen content of the water, which in turn affects nutrient and metal reactions. The vascular plants contribute to the treatment of wastewater and runoff in a number of ways: (1) they stabilize substrates and limit channelized flow where they slow water velocities, and (2) allowing suspended materials to settle the take-up carbon, nutrients, and trace elements. Constructed wetlands are usually planted with emergent vegetation (non-woody plants that grow with their roots in the substrate and their stems and leaves emerging from the water surface). Common emergent used in constructed wetlands include bulrushes, cattails, reeds, and a number of broad-leaved species.

- **Aesthetic and landscape:**

Apart from being a treatment system, wetland provides intangible benefits by increasing the aesthetics of the site and enhancing the landscape (Davis, 1995). Constructed wetland can add diversity to the landscape and imitate the natural wetlands. The complexity of shape, color, size, interspersion of plants, the variety in the sweep, and the curve of the edges of landforms all add to the aesthetic quality of the wetlands. Constructed wetlands can be built with curving shapes that follow the natural contours of the site, and some wetlands for water treatment are indistinguishable to act as a natural wetland.

- **Microorganisms:**

A fundamental characteristic of wetlands is that their functions are largely regulated by microorganisms and their metabolism (Wetzel 1993). The microorganisms include bacteria, yeasts, fungi, protozoa, and rind algae. The microbial biomass is a major sink for organic carbon and many nutrients. Microbial activity: (l) transforms a great number of organic and inorganic substances into innocuous or insoluble substances, (2) alter the reduction or oxidation (redox) conditions of the substrate and thus, affects the processing capacity of the wetland, and (3) is involved in the recycling of nutrients.

Some microbial transformations are aerobic (they require free oxygen) while others are anaerobic (they take place in the absence of free oxygen). Many bacterial species are facultative anaerobes where they are capable of functioning under both aerobic and anaerobic conditions in response to changing the environmental conditions. The microbial community of a constructed wetland can be affected by toxic substances, such as pesticides and heavy metals, and care must be taken to prevent such chemicals from being introduced at damaging concentrations.

- **Animals:**

Constructed wetlands provide habitat for a rich diversity of invertebrates and vertebrates (Davis, 1995). Invertebrate animals, such as insects and worms, contribute to the treatment process by fragmenting detritus and consuming organic matter. The larvae of many insects are aquatic and consume significant amounts of material during their larval stages, which may last for several years. Invertebrates also fill a number of ecological roles, for instance, dragonfly nymphs are important predators of mosquito larvae. Although invertebrates are the most important animals as far as water quality improvement is concerned, constructed wetlands also attract a variety of amphibians, turtles, birds, and mammals.

Limitations of Constructed Wetlands

According to (Davis, 1995) there are limitations associated with the use of constructed wetlands. (l) They generally require larger land areas than the conventional wastewater treatment systems. Wetland treatment may be economical relative to other options only where land is available and affordable. (2) Performance may be less consistent than in conventional treatment. Wetland treatment efficiencies may vary seasonally in response to changing environmental conditions, including rainfall and drought. While the average performance over the year may be acceptable, wetland treatment could not be relied upon if effluent quality must meet stringent discharge standards at all times. (3) The biological components are sensitive to toxic chemicals, such as ammonia and pesticides, and (4) flushes of pollutant or surges in water flow may temporarily reduce the treatment effectiveness.

Types of Wetland

There are several types of constructed wetlands: surface flow wetlands, subsurface flow wetlands, and hybrid systems that incorporate the surface and the subsurface flow wetlands (Davis, 1995). The constructed wetland systems can also be combined with the conventional treatment technologies. The first type of wetland is surface flow (SF) wetland. SF wetland consists of a shallow basin, soil or other medium to support the roots of vegetation, and a water control structure that maintains a shallow depth of water (Figure 2.5). The water surface is above the substrate. SF wetlands look much like the natural marshes and can provide wildlife habitat and aesthetic benefits as well as the water treatment. In SF wetlands, the near-surface layer is aerobic while the deeper waters and substrate are usually anaerobic. The UM has implemented SF wetlands in the Varsity Lake. The advantages of SF wetlands are that their capital and operating costs are low and that their construction, operation, and maintenance are straightforward. The main disadvantage of SF systems is that they generally require a larger land area than other systems.

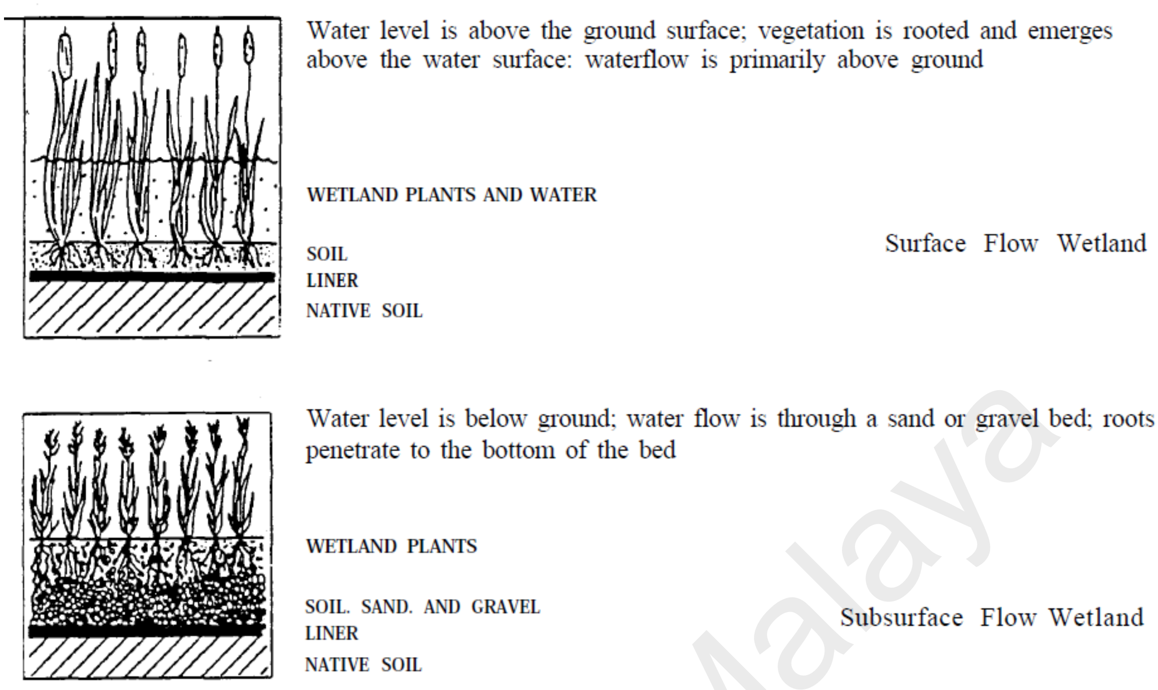

Figure 2. 5: Surface flow and subsurface flow constructed wetlands (Source: Water Pollution Control Federation, 1990)

The second type of constructed wetland is the subsurface flow (SSF) wetland. SSF wetland consists of a sealed basin with a porous substrate of rock or gravel. The water level is designed to remain below the top of the substrate. In most of the systems in the United States, the flow path is horizontal, although some European systems use vertical flow paths. SSF systems are called by several names including the vegetated submerged bed, root zone method, microbial rock reed filter, and plant-rock filter systems. Because of the hydraulic constraints that are imposed by the substrate, SSF wetlands are best suited to wastewaters with relatively low solids concentrations and under relatively uniform flow conditions. SSF wetlands have most frequently been used to reduce a 5-day biochemical oxygen demand (BOD) from the domestic wastewaters.

The advantages cited for the SSF wetlands are greater cold tolerance, minimization of pest and odor problems, and, possibly, greater assimilation potential per unit of land area than in the SF systems. It has been claimed that the porous medium provides greater surface area for the treatment contact than in the SF wetlands. Therefore, the treatment responses should be faster for the SSF wetlands, which can be smaller than the SF system that is designed for the same volume of wastewater. Since the water surface is not exposed, public access problems are minimal. Several SSF systems are operating in parks with public access encouraged. The disadvantages of SSF wetlands are that they are more expensive to construct on a unit basis than the SF wetlands. Due to the cost, SSF wetlands are often used for small flows. The SSF wetlands may be more difficult to regulate than the SF wetlands, and the maintenance and repair costs are generally higher than for the SF wetlands. A number of systems have had problems with clogging and unintended surface flows.

The final type of constructed wetland is the hybrid system. The single stage systems require that all of the removal processes occur in the same space. In hybrid or multistage systems, different cells are designed for different types of reactions. An effective wetland treatment of mine drainage may require a sequence of different wetland cells to promote aerobic and anaerobic reactions. In the combined pond-wetland system, the main functions of the multi-pond system are for storage and pretreatment of the initial urban surface runoff, improvement of landscape aesthetics, and SS removal to prevent the subsequent constructed wetlands from clogging. Moreover, a hybrid system that is composed of VFCW and the subsequent HFCW presented a higher TN removal rate because of the nitrification and the subsequent denitrification process, which induced by the different oxygen transfer capacity in the VFCW and HFCW, whereas the P removal was mainly influenced by the wetland substrates.

In Moshui Lake, two types of combined pond-wetland systems were constructed to store and treat the initial urban surface runoff together with the combined sewer overflow during the rainy season and the diluted municipal wastewater or the water during the dry season. After one year, the deposition pond-landscape pond-vertical flow constructed wetland (VFCW)-horizontal flow subsurface constructed wetland (HFCW) system was more effective than the deposition pond-HFCW system in removing chemical oxygen demand (COD), total phosphorus (TP), total nitrogen (TN), and suspended solids (SS).

There have been a number of notably successful lake rehabilitation experiences (Stephen M. Born., 1979; Sharifuddin et. al., 2013). Reducing or eliminating the sources of lakes problems may be the only measure needed to achieve desired level of improvement for certain lakes, especially those relatively fast flushing rates. In many lakes however, especially those with long detention times it is also need to rehabilitate the lake environment (U.S. Environmental Protection Agency, 1976). However, in many situations, the nutrients, sediments, or other undesirable materials are already in the lake and little can be done to directly rehabilitate the lake. The alternative in these cases is by manipulating the biota and environment within a lake (Dunst et. al., 1974). This method is often discounted as cosmetic and requiring continuous treatment but somehow produce satisfactory results (Stephen M. Born., 1979).

Several methods have been used for lake rehabilitation process such as microorganism digestion, bio flocculants, ultrasonic, big head carp, runoff control, water hyacinth, fine bubbles aeration and biofilter (Sharifuddin et. al., 2013). Lake rehabilitation also can be classified according to the type of approaches (Peterson et. al., 1974). The integration of these methods has successfully increased the water quality in lake by application of bio-friendly treatment method that consist of water hyacinth, climbing perch, big head carp bio-flocculants as well as effective microorganism. Turbidity curtain has also been used to control the surface runoff from directly entering lake whereas bubble aerator help to increase the rate of dissolved oxygen in the water body. Other techniques that have also been used for lake rehabilitation are dredging and nutrient inactivation (Stephen M. Born., 1979).

In a case of the lake receiving wastewater as the water source, wastewater treatment is probably the most widely used technique for reducing pollution loads to the lake. Advanced treatment processes designed for improved removal of critical nutrients (nitrogen and phosphorus) are operational and increasing pressure is being applied to utilize these systems (Dunst et. al., 1974). Based on Dunst et. al. (1974), diversion or rerouting of waters outside of a lake's drainage basin and accompany with other techniques, such wastewater treatment is another method for lake rehabilitation. Diversion is increasingly being practiced and has produced one of the best documented lake improvement success stories-Lake Washington, Washington. The acceptability of diversion as a lake rehabilitation strategy depends on the existence of an ecologically less vulnerable discharge location i.e., greater assimilative capacity, riverine or oceanic vs. lake environment.

2.11 Summary

From the literatures discussed in this chapter, water pollution is a global threat to the water on Earth. In studying the water pollution, it is important to know the source of pollution and understand the close relation between categories of pollutants and its source and effects. Hence, the best method to understand the source of pollution is by conducting water quality monitoring for the selected water quality parameters. Each parameter has different physical and chemical properties which reflect to the surrounding activities of the water system.

For all types of pollution, Water Quality Index (WQI) has widely used to give a single value to the water quality from several parameters to a simpler expression for easy interpretation. Based on literature, in dealing with lake water, eutrophication is the major type of lake water pollution which occurs naturally or culturally. One of the significant ways for treating polluted lake is by lake rehabilitation process which closely related to the main aim of this research.

CHAPTER 3 METHODOLOGY

3.1 Introduction

This chapter discusses the method and material applied in this study. Figure 3.1 shows the overall flow that was carried out in this research. The first approach is to determine the study area and to identify the problem involved. The Varsity Lake is selected as the study area due to the major water quality problem inside the lake. Prior to any raw data collection, the physical dimension and characteristic of the lake are measured to locate the most suitable sampling points in Varsity Lake.

The water quality data is divided into primary and secondary. The primary data is collected by conducting regular field sampling after the lake rehabilitation work was done. In this part, the parameter tested is divided into in-situ test and laboratory analysis. Meanwhile, the secondary data was collected from the existing data before the rehabilitation work started. To support the analysis, several statistical analysis approaches is done and these methods are implemented to enhance the discussion and recommendations part from this study.

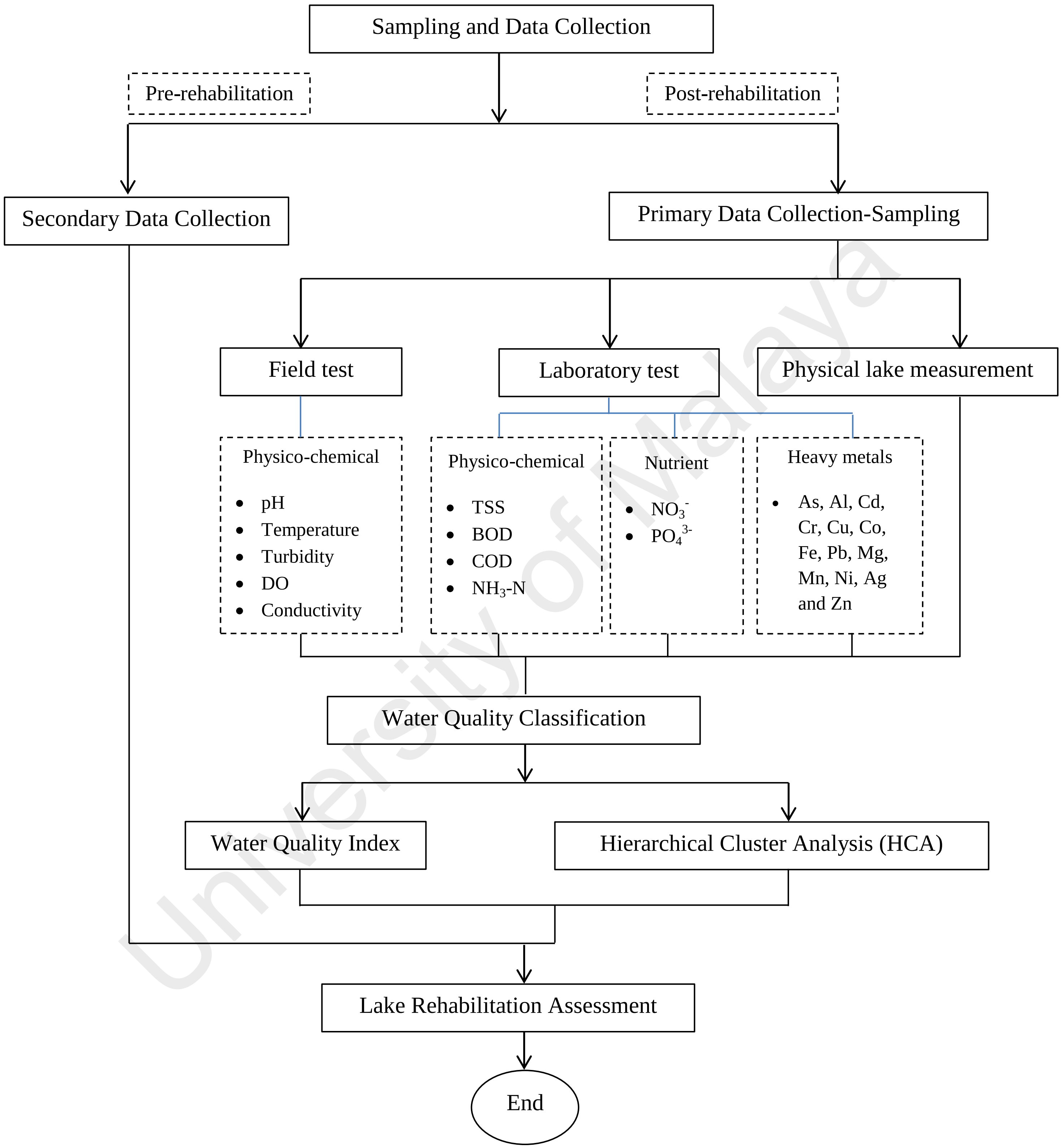

Figure 3.1: Methodology flowchart

3.2 Study Area

The University of Malaya is located in the city of Kuala Lumpur near Petaling Jaya area as shown in Figure 3.2. Two natural rivers, namely Pantai River and Anak Air Batu River and a man-made lake are located inside the campus. The Varsity Lake is the biggest lagoon in the University of Malaya land with a surface area of 14 882 m^2. The total length of the lake is 287 meters with a depth ranges from 0.3 to 2.0 meters. Currently, the lake water level is being stabilized by the underground water that is pumped at a rate of 12.5 m^3/hr for 5 hours in a day.

The two rivers (Pantai River and Anak Air Batu) are the tributaries of Klang River, thus, its water quality level will affect the Klang River water quality. Pantai River is located at the upstream of the Varsity Lake, which received the flow from outside of the residential area and it flows in a concrete channel of about 1.75 km long inside the campus and passes by the Varsity Lake. Along the way, Pantai River receives a direct discharge from the Faculty of Science, Faculty of Engineering, Faculty of Social Science, and the Perdanasiswa complex. Anak Air Batu River is another tributary, which originates from Damansara and has a total length of 1.93 km concrete channel inside the campus before merging with Pantai River as shown in Figure 3.3. Both rivers have an average water velocity of 0.5 m/s. The detail on sampling points is discussed in Section 3.4.

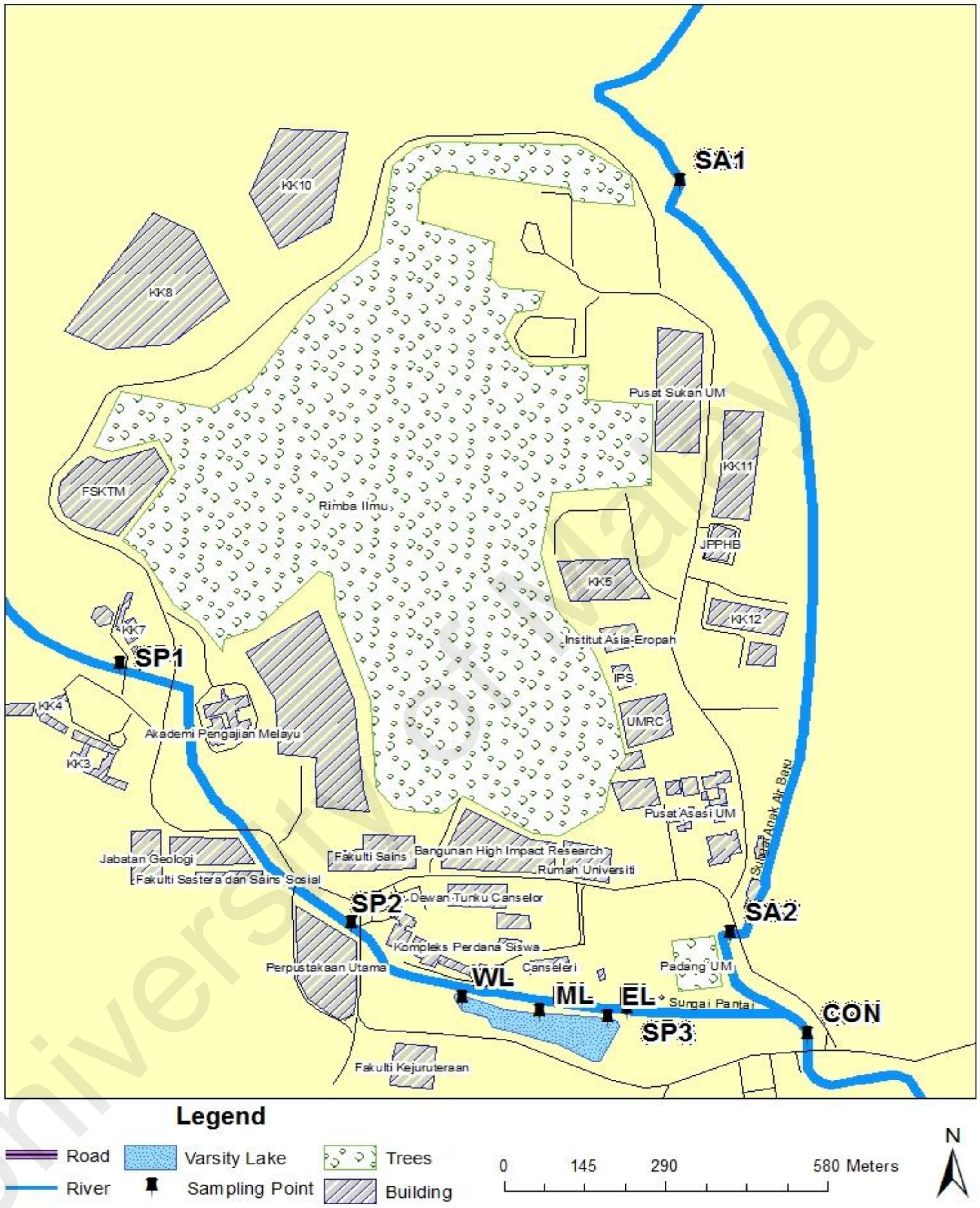

Figure 3.3: The location of the sampling points

3.3 Lake Characteristics

Since the lake contains stagnant water, therefore, the water depth plays a major role in controlling lake water quality. Based on the study by Gao et al. (2011), lake tends to shrink due to the sedimentation and decomposition of organic matter. Based on the discussion in Chapter 2, the eutrophication problems will chronologically shrink the lake, especially in the case of cultural eutrophication. Since the Varsity Lake is faced with the cultural eutrophication, thus, the physical dimension of the lake is crucial.

In this study, the lake is divided into several segments prior to taking any measurements. The measurements taken include the water depth, lake width, and also the length of the segments. The lake water depth measurements were made during the study using Hondex depth sounder. The maximum water depth during the study is 2.0 meters, near the kayak house as shown in Figure 3.4.

Based on Figure 3.4, the constructed wetland in the Varsity Lake has recorded the shallowest water depth and this is according to the actual plan in ensuring the wetland to work properly. The bottom of the wetland is elevated approximately 0.5 meters using several layers of sand and soil, which is separated by a 20 meters width rip-rap retaining wall as shown in Figure 3.5. The retaining wall is designated to filter pollutants before mixing with the entire lake system.

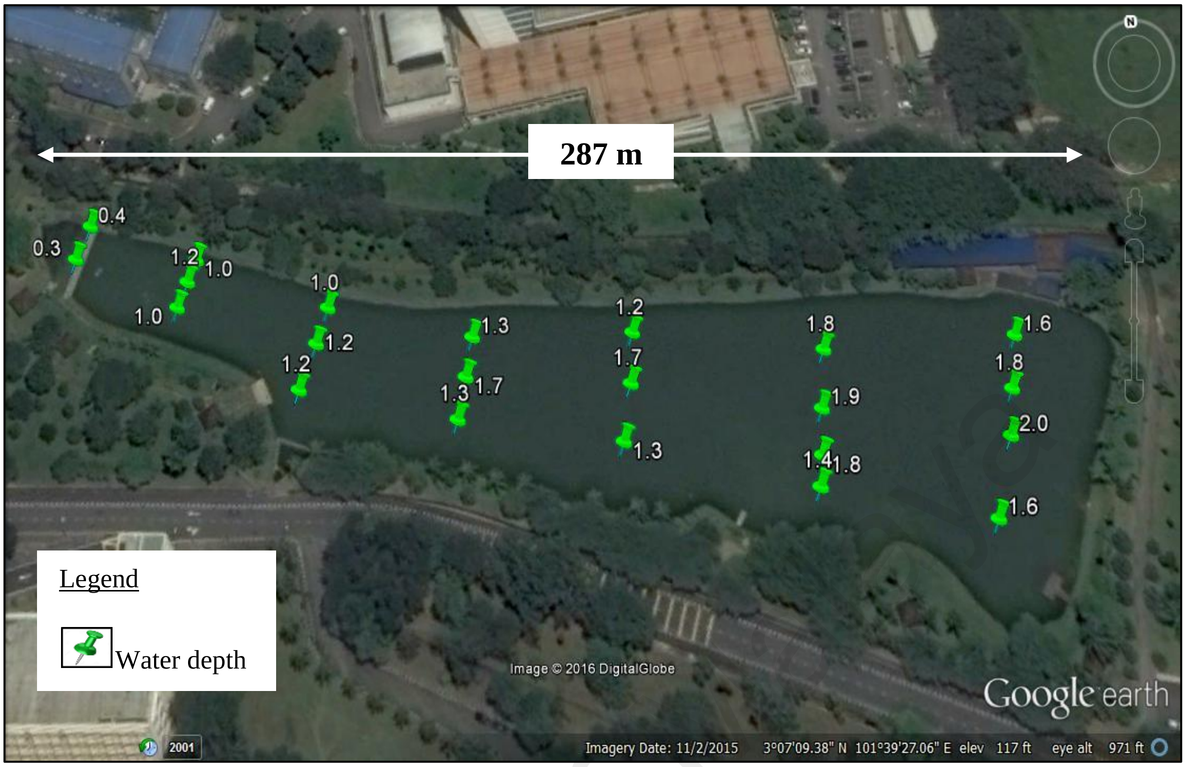

Figure 3. 4: The lake water depth measured during the study

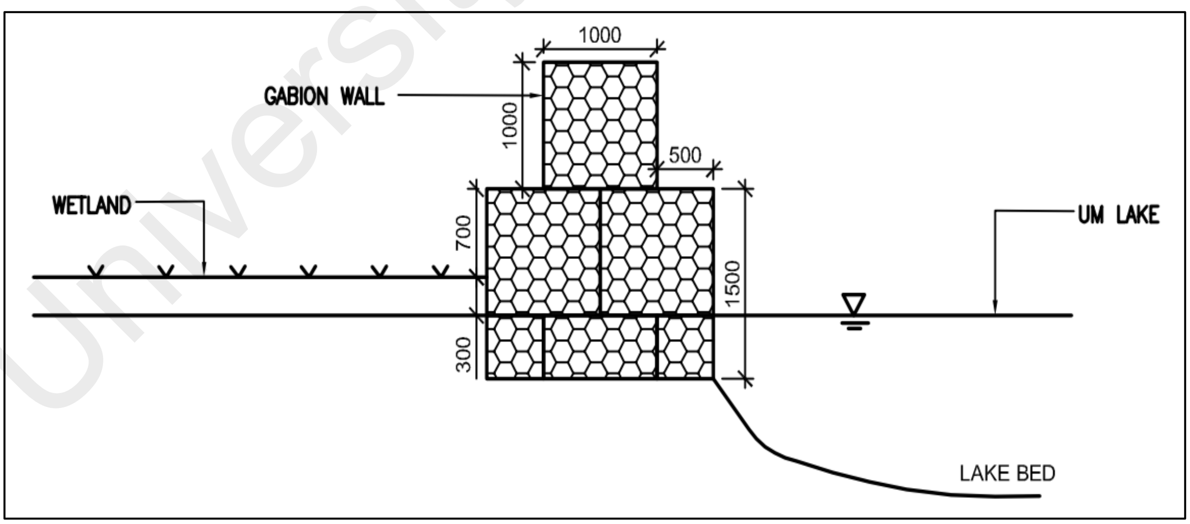

Figure 3.5: The rip-rap retaining wall design

3.4 Sampling points

Nine sampling stations were set up inside the campus where 3 points represent the Pantai River, 2 points represent the Anak Air Batu River, 3 points located inside the Varsity Lake and one point situated after the confluence of Pantai River and Anak Air Batu River. The stations were chosen according to the accessibility and the ability to give enough information of the place. Table 3.1 shows the geographical description of the sampling area and Figure 3.3 shows the location of the sampling stations inside the campus.

Table 3.1: Sampling points details

Station	Longitude	Latitude	Remarks
SP1	101.650732	3.125475	Pantai River (Near 4th residential college)
SP2	101.654423	3.121031	Pantai River (Near main library)
WL	101.656271	3.119686	Wetland area
ML	101.657613	3.119445	Middle of lake
EL	101.658580	3.119399	End of lake (Kayak house)
SP3	101.658907	3.119502	Pantai River (Near Perdanasiswa)
SA1	101.659760	3.133696	Anak Air Batu River (Damansara gate)
SA2	101.660595	3.120784	Anak Air Batu River (Downstream)
CON	101.661812	3.119112	Pantai River (After confluence)

3.5 Data Collection and Analysis

The sampling is conducted monthly from November 2014 until October 2015. Overall, there are 12 sets of data that have been collected. Three samples were collected from the Varsity Lake, two samples from Anak Air Batu River, three samples from Pantai River and one after the confluence of both rivers.

During the sampling, before filling, the sample's bottle was rinsed with water sample of that location first. After that, the sample was taken at the surface layer near to the bank by using a pail and was kept in a 1000 mL bottle. All of the samples were stored in the isothermal box during transportation. The water sample must be handled in such a way that it does not deteriorate or become contaminated before it reaches the laboratory. Other than that, during filling up of the sample, the water should be filled fully up to the beam of the bottle, avoiding air bubbles forming inside it. Any solid particles, such as the dried leaves and algae must be filtered from the bottle. Upon arrival in the laboratory, samples were kept in a cool room at 4 ºC to stop all activities and metabolism of the organism in the water.

The data analysis can be divided into several parts; field test, laboratory test, heavy metal test, statistical analysis, and mathematical formulation using the Water Quality Index (WQI).

3.5.1 Field and Laboratory analysis

For the in-situ test, the water quality parameters that were measured are pH, conductivity, turbidity, temperature, and Dissolved Oxygen (DO). Each parameter was measured using specific meters (Table 3.2), which were calibrated prior to the test. The water samples were taken to the laboratory for the test of other parameters; Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Ammoniacal Nitrogen (NH_3-N), Total Suspended Solids (TSS), nitrate (NO_3^-), and phosphate (PO_4^{3-}) by following the Standard Methods for the Examination of Water and Wastewater (Federation & Association, 2005). Details methodology and calculation on the laboratory test is explained in Appendix D.

Practically, a reasonable numerical data analysis of any complicated terrestrial processes in a watershed would be a useful tool to investigate the water quality status, to predict potential impacts of climate and land cover changes, and to find optimal solutions to pollution problems (Borah & Bera, 2002; Ficklin et al., 2010; Liu et al., 2008; Panagopoulos et al., 2011; Panagopoulos et al., 2012; Wilson & Weng, 2011; Wu and Liu, 2012a; Wu et al., 2012a,c; Zhang et al., 2011; Zhang & Zhang, 2011). In this study, the surface water quality trend for each parameter was analyzed using the Whisker box-plot, by plotting the concentration against the sampling locations to illustrate the one year trend of the UM surface water quality.

Table 3. 2: The list of equipment and method used for data collection

Test	Parameter	Equipment/Method
In-situ	pH	Hanna pH meter
	Temperature	Accumet Dissolve Oxygen meter
	DO	Accumet Dissolve Oxygen meter
	Turbidimeter	Hach turbidimeter
	Conductivity	Hanna Conductivity meter
Laboratory	BOD	Winkler's method
	COD	Open reflux method
	NH_3-N	Kjedahl method
	TSS	Gravimetric process
	NO_3^-	Merck Spectroquant Pharo 100
	PO_4^{3-}	Merck Spectroquant Pharo 100

3.5.2 Heavy Metals Analysis

The samples preparation had been completed following the USEPA-2007. 100 mL of sample was poured into a 150 mL beaker for the acid digestion procedure. 2 mL of Nitric acid (HNO_3^-) followed by 5 mL Hydrochloric acid (HCl) were added to the sample. The solution is then placed on a hotplate and digested in the fume hood. The samples were let to digest until the volume reach 15 to 20 mL. The temperature of the solution is monitored throughout the digestion process to avoid the boiling point, 100 ^oC. The beaker was then taken out from the water bath in order to cool down the solution until it reached room temperature. Water samples were then filtered through a 0.45 µm cellulose acetate membrane filter using a syringe filtration unit. This was done to obtain the dissolved metal while avoiding the clogging of spectrometry instrument during the analysis. A quality control (QC) sample was also prepared to check the recovery following the USEPA-2010 guideline.

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: As, Cd, Co, Cr, Cu. Ni, Pb, Fe, Al, Mg, Zn, and Mn. ICP multi-element standard solution was used as the standard solution. Five standards (0 mg/L, 0.5 mg/L, 1.0 mg/L and 5.0 mg/L) were analyzed in order to plot the calibration curves for quality control purposes. The wavelengths of the each element and their corresponding limit of detection (LOD) are listed in Table 3.3.

Table 3. 3: The wavelength of each element for ICP test

Metals	Wavelength (nm)	Limit of Detection (mg/L)
Ag	328.068	0
As	188.979	0
Cd	228.802	0
Co	228.616	0
Cr	262.716	0
Cu	327.393	0.07
Pb	220.353	0
Ni	231.604	0
Fe	238.204	0.13
Mn	257.610	0
Al	396.153	0.05
Mg	285.213	0.05
Zn	206.200	0.02

3.5.3 Statistical Analysis

3.5.3.1 Box and whisker plots

In order to graphically present the water quality and heavy metals data, the box and whisker or box plots were used. The box and whisker plots represent the shape of the distribution, spread, and its central value. It also illustrates the minimum and maximum values, the lower and upper quartiles, and the median as shown in Figure 3.6. On the boxplot in Figure 3.6, the outliers are identified, note the different markers for "out" values (small **circle**) and "far out" or "Extreme values" (marked with a **star**). SPSS uses a step of 1.5×IQR (Interquartile range).

The box plot implies the following

(1) If the lower hinge is longer than the upper hinge, hence, the data is left-skewed (negatively skewed)

(2) If the upper hinge is longer than the lower hinge, hence, the data is right-skewed (positively skewed)

(3) If the median is located at the centre of the box the length of the upper and lower whiskers are about the same, than the data distribution is symmetrical or normally distributed.

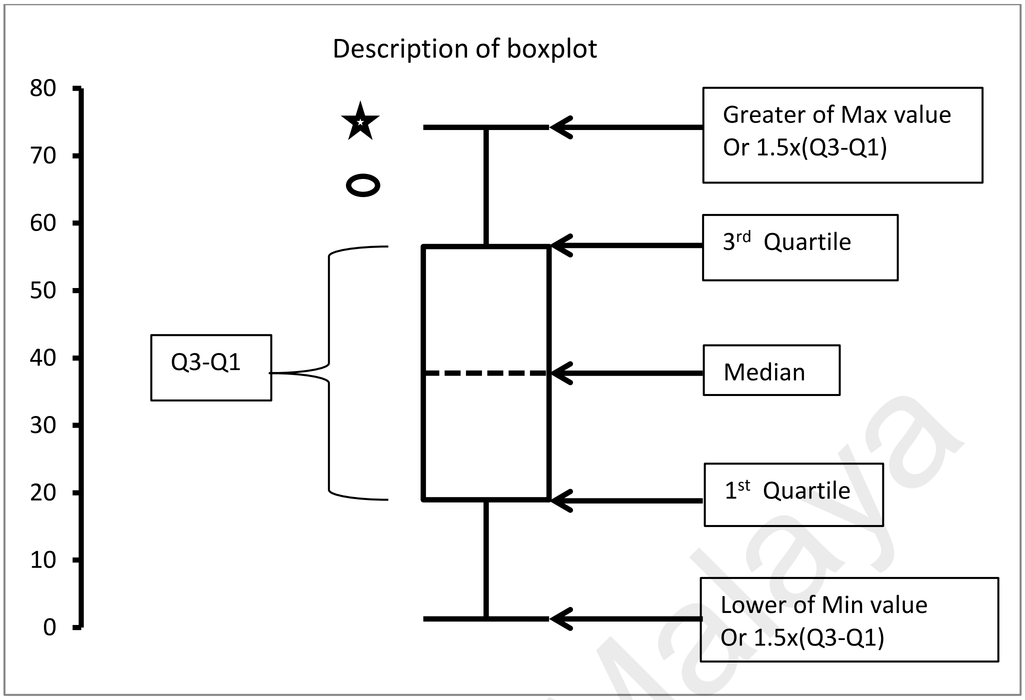

Figure 3. 6: The Whisker's boxplot

3.5.3.2 Hierarchical Cluster Analysis (HCA)

The HCA technique is an unsupervised classification procedure that involves measuring either the distance or the similarity between the objects to be clustered. The resulting clusters of objects should then exhibit a high internal (within the cluster) homogeneity and high external (between the clusters) heterogeneity. The hierarchical agglomerative cluster is the most common approach that provides the intuitive similarity relationships between any one sample and the entire data and it is typically illustrated by a dendrogram (tree diagram) (McKenna, 2003). The dendrogram provides a visual summary of the clustering processes, presenting a picture of the groups and their proximity with a dramatic reduction in the dimensionality of the original data.

This analysis is important to determine the spatial variability of the study area. The spatial variability of the surface water quality in the UM campus was performed using the hierarchical agglomerative cluster using Ward's method with squared Euclidean distances as a measure of similarity. The Euclidean distance usually gives the similarity between two sample or more, and a distance can be represented by the difference between the analytical values from the objects (Otto, 1998). For instance, the distance of object x (x_1, x_2, etc.) and object y (y_1, y_2, etc.) is expressed using the Equation 3.1.

$$\text{Distance } (x, y) = \sum_{i=1}^{n} (x_i - y_i)^2 \qquad \text{……….Equation 3.1}$$

3.5.4 Water Quality Index

WQI calculation is based on six parameters, as shown in Equation 3.2. The largest portion is carried by the DO index with 0.22 and pH is the smallest portion contributing 0.12 in the equation. The WQI equation eventually comprises of the sub-indices calculated according to the best-fit relationships given in Table 3.4. Each of the parameters has different standard limits given by NWQS as shown in Table 3.5.

$$WQI = 0.22SI_{DO} + 0.19SI_{BOD} + 0.16SI_{COD} + 0.16SI_{SS} + 0.15SI_{AN} + 0.12SI_{pH}$$

……….Equation 3.2

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.

Based on the WQI value, the water quality can be categorized into 5 classes (Table 3.6). The class of water can also be classified based on its level of pollution into three categories: clean, slightly polluted, and polluted as shown in Table 3.7. Class I water quality is considered as safe for direct drinking, Class II requires treatment for drinking purposes and is safe for swimming, Class III calls for intensive treatment for drinking, Class IV is only suitable for plant and domestic animal uses, and Class V cannot be used for the purposes listed in Classes I-IV (Table 3.8). The water quality categories are highly affected by varying characteristics in the surrounding areas.

Table 3. 4: Sub-index calculations (DOE, 2015)

Sub-index parameter	Value	Conditions
SIDO	0	DO < 8
	100	DO > 92
	$-0.395 + 0.030DO^2 - 0.00020DO^3$	8 < DO < 92
SIBOD	$100.4 - 4.23BOD$	BOD < 5
	$108e^{-0.055BOD} - 0.1BOD$	BOD > 5
SICOD	$-1.33COD + 99.1$	COD < 20
	$103e^{-0.0157COD} - 0.04COD$	COD > 20
SIAN	$100.5 - 105AN$	AN < 0.3
	$94e^{-0.573AN} - 5 \|AN - 2\|$	0.3 < AN < 4
	0	AN > 4
SISS	$97.5e^{-0.00676SS} + 0.05SS$	SS < 100
	$71e^{-0.0016SS} - 0.015SS$	100 < SS < 1000
	0	SS > 1000
SIpH	$17.2 - 17.2pH + 5.02pH^2$	pH < 5.5
	$-242 + 95.5pH - 6.67pH^2$	5.5 < pH < 7
	$-181 + 82.4pH - 6.05pH^2$	7 < pH < 8.75
	$536 - 77.0pH + 2.76pH^2$	pH > 8.75

Table 3.5: National Water Quality Standards for Malaysia (DOE, 2015)

PARAMETER	UNIT	CLASS					
		I	IIA	IIB	III	IV	V
Ammonical Nitrogen	mg/l	0.1	0.3	0.3	0.9	2.7	> 2.7
Biochemical Oxygen Demand	mg/l	1	3	3	6	12	> 12
Chemical Oxygen Demand	mg/l	10	25	25	50	100	> 100
Dissolved Oxygen	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	-	-	-
Total Dissolved Solid	mg/l	500	1000	-	-	4000	-
Total Suspended Solid	mg/l	25	50	50	150	300	300
Temperature	°C	-	Normal + 2 °C	-	Normal + 2 °C	-	-
Turbidity	NTU	5	50	50	-	-	-
Faecal Coliform**	count/100 ml	10	100	400	5000 (20000)a	5000 (20000)a	-
Total Coliform	count/100 ml	100	5000	5000	50000	50000	> 50000

Table 3. 6: DOE Water Quality Index Classification (DOE, 2015)

Parameters	Unit	Classes				
		I	II	III	IV	V
AN	mgL^{-1}	< 0.1	0.1 - 0.3	0.3 - 0.9	0.9 - 2.7	> 2.7
BOD_5	mgL^{-1}	< 1	1 - 3	3 - 6	6 - 12	> 12
COD	mgL^{-1}	< 10	10 - 25	25 - 50	50 - 100	> 100
DO	mgL^{-1}	> 7	5 - 7	3 -5	1 - 3	< 1
pH	unit	> 7	6 - 7	5 - 6	< 5	> 5
TSS	mgL^{-1}	< 25	25 - 50	50 - 150	150 - 300	> 300
WQI	unit	> 92.7	76.5 - 92.7	51.9 - 76.5	31.0 - 51.9	< 31.0

Table 3. 7: DOE Water Quality Classification Based On Water Quality Index (DOE, 2015)

SUB INDEX & WATER QUALITY INDEX	INDEX RANGE		
	CLEAN	SLIGHTLY POLLUTED	POLLUTED
Biochemical Oxygen Demand(BOD)	91 - 100	80 - 90	0 - 79
Ammonical Nitrogen(NH3-N)	92 - 100	71 - 91	0 - 70
Suspended Solids(SS)	76 - 100	70 - 75	0 - 69
Water Quality Index(WQI)	81 - 100	60 - 80	0 - 59

Table 3. 8: Water Classes and Uses (DOE, 2015)

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	Water unsuitable for any of the above uses.

3.7 Lake Rehabilitation Program

This section will discuss the practices of the University of Malaya (UM) management towards the Varsity Lake for the past 5 years. This time frame is chosen due to the drastic changes in the lake water management towards improving the lake water quality. The discussion is divided into three stages; pre-rehabilitation, rehabilitation and post-rehabilitation. The rehabilitation stage in this study is referred to the activities and works done towards the lake in improving its water quality (August 2014 until October 2014). Meanwhile, pre-rehabilitation is referred to the stage of 'do nothing' on the lake (before August 2014) and post-rehabilitation is referred to the stage after the cleaning and improvement work is done (after November 2014), Figure 3.7.

Figure 3.7: The three stages of lake water management

3.7.1 Pre-rehabilitation Stage of Varsity Lake

Prior to August 2014, there were no proper discharges of wastewater from the septic line and domestic waste of the Engineering Faculty, 2nd Residential College, and the Built Environment Faculty into the lake (Goh Shan M., 2001; Ashraf et al., 2010). In addition, it is observed that there is no specific person or organizations to manage the lake water quality. The 'do nothing' approach towards the lake has caused water quality deterioration and other problems as discussed in the 'Problem Statement' (Section 1.2, Chapter 1). Several studies were conducted to assess the lake water, Table 3.9.

Table 3.9: The method for laboratory test for pre-rehabilitation stage

Parameter	Study	Methodology
Biochemical Oxygen Demand, BOD	UM Water Warriors	Winkler's method
Total Suspended Solids, TSS	UM Water Warriors	Gravimetric process
Ammoniacal Nitrogen, NH_3-N	UM Water Warriors	Kjedahl method
Phosphate, PO_4^{3-}	Ashraf et. al, 2009	ASTM WK4052 - New Test Method
Nitrate, NO_3^-	Ashraf et. al, 2009	ASTM D3867-09 Standard Test Methods

3.7.2 Rehabilitation Stage of Varsity Lake

In 2014, the lake has brought the University of Malaya community together from various background and disciplines through Project ReviVaL (Revive Varsity Lake) or as written in this thesis as rehabilitation work. The project was led by the office of the Deputy

Vice-Chancellor of Development with the help from the Department of Development and Estate Management (JPPHB), Sports Centre, Faculties of Science and Engineering, and Water Warriors for an environmental project in the campus for the protection and conservation of water bodies in the University of Malaya, along with various individuals and student volunteers (Satiah, 2015).

The project has three stages plan: research, fixing and re-introducing life; ensuring a holistic approach to the lake rehabilitation and after a carefully detailed plan work, the rehabilitation work begins on 4th August 2014 (Satiah, 2015).

The rehabilitation work begins by stopping the wastewater that flows into the lake and rechanneling the drainage. At this stage, the wastewater from the faculties and residential college were diverted to the Pantai River beside the Varsity Lake and the pipe flow path is located under the ground as shown in Appendix C, Figure C5. All of the trees and facilities that are readily located near the construction plan were relocated to other suitable areas. Next, the existing water in the lake was pumped out to remove the wastewater that has been collected over the years as in Appendix C, Figure C6. The work aims to completely remove the polluted water inside the lake.

In addition, soil dredging has been done to remove the accumulated pollutant from the lake sediment and to deepen the lake as in Appendix C, Figure C7. The installation of rip rap retainer at the lake bank aims to minimize the sediment and suspended solids from the surface runoff as shown in Appendix C, Figure C8. Other than that, the construction of a mini wetland is done to act as a natural filter as in Appendix C, Figure C9.

3.7.3 Post-rehabilitation

After three months of construction work, the rehabilitation phase is completed in October 2014. At the early stage of the post-rehabilitation, the UM management has decided to use Pantai River as the lake water source by pumping in the river water directly into the lake as shown in Appendix C, Figure C10. After several months, it was observed that there is abundance of algae growth at the surface of the Varsity Lake. This gives an indication that the water from the river gave some bad effect towards the lake. Thus, the UM management has stopped the utilization of the river water and start introducing Najas spp. into the lake to reduce the eutrophication problem. The Najas spp. is a green plant, which acts as a nutrient absorber. The lake is now alive again, with ducks and geese and numerous local fish species introduced into the lake (Satiah, 2015). The type of fish introduced into the lake is as attached in Appendix C, Table C1. From time to time, fishing competitions were organized at the Varsity Lake to reduce the invasive fish species in the lake.

On top of that, continuous volunteer activity has been conducted for cleaning and increasing the awareness towards the lake. The UM Water Warriors included the UM staff, students, and the public to get involved in the Varsity Lake activities. Next, wide collaborations between the institutions (national and international level) also have been conducted during the post-rehabilitation stage to spread the awareness and gathering of ideas for the lake water quality improvements. Traditional knowledge and practices, as well as some cultural relations between the UM communities and the Varsity Lake, were identified to increase their awareness towards the importance of the lake. All of the information gathered is shared with the public via social networking media, such as Facebook and Instagram.

Paddle aerator and sprinkler aerator are used to circulate the water in the lake apart from the aim to maintain a good dissolved oxygen levels. The sprinkler aerator has been used from 3rd June 2015 to replace the use of Pantai River as lake water source as in Appendix C, Figure C11. The sprinkler aerator forms a water fountain that is eye catching to the visitors as well as transporting a clean ground water from the pump house beside the lake as shown in Appendix C, Figure C12.

General workers are scheduled to continually monitor the lake condition for the safety and cleaning purposes. The works include routine cleaning of the lake and taking care of the surrounding area. This is to ensure that the lake is maintained in a manner that aesthetically meets the requirements for recreational waters. Apart from that, series of monitoring have been done.

CHAPTER 4 RESULTS AND DISCUSSIONS

4.0 Introduction

In this chapter, the results and discussion are divided into four sections. In achieving the first objective of this study, the results and discussion are included in section one. The first section discusses on the physicochemical water characteristic that includes the field test (Temperature, Conductivity, DO, pH, and Turbidity), and laboratory test (BOD, COD, AN, TSS, Phosphate, and Nitrate). This section also includes the assessment of heavy metals involving 13 elements: As, Al, Cd, Cr, Cu, Co, Fe, Pb, Mg, Mn, Ni, Ag, and Zn. The second section includes results and discussion on the overall water quality classification based on the DOE-WQI and statistical analysis using the HCA to answer the second objective.

Since several developments have been done to the lake towards the lake water management, thus, the third section includes the discussion on the effectiveness of current water management by comparing the pre-rehabilitation water quality with the post-rehabilitation water quality. The comparisons were made by calculating the percentage reduction of the pollutants in the lake to answer the third objective.

4.1 Current Surface Water Quality Status

Table 4.1: Range, mean and standard deviation of water quality parameters at sampling points

Parameters		SP1	SP2	WL	ML	EL	SP3	SA1	SA2	CON
TEMP	R	28.3-33.7	27.7-31.1	29.5-35.0	29.6-36.1	29.2-35.7	28.2-32.9	28.4-35.3	28.4-33.7	28.3-33.9
(°C)	M±Sd.	30.3±1.6	29.4±1.2	32.2±1.6	32.4±1.7	32.4±1.9	30.4±1.6	31.2±2.1	30.3±1.5	30.8±1.6
p H	R	5.1-9.7	4.9-7.1	6.9-9.2	7.1-9.1	7.5-9.4	4.5-7.2	5.1-7.4	5.0-7.3	5.5-7.3
	M±Sd.	7.0±1.0	6.8±0.6	7.9±0.8	8.1±0.6	8.1±0.5	6.8±0.7	6.8±0.6	6.9±0.6	7.0±0.5
EC	R	0.19-0.29	0.18-0.27	0.07-0.39	0.07-0.15	0.07-0.15	0.19-0.25	0.22-0.30	0.22-0.29	0.20-0.27
(µS/cm)	M±Sd.	0.2±0.03	0.2±0.03	0.1±0.09	0.1±0.02	0.1±0.02	0.2±0.02	0.3±0.03	0.2±0.02	0.2±0.02
DO	R	1.1-6.7	0.8-5.9	4.6-9.8	6.5-9.2	6.7-12.8	1.6-6.4	0.9-6.74	1.6-5.0	2.8-6.2
(mg/L)	M±Sd.	4.2±1.8	3.7±1.7	7.1±1.6	7.7±0.8	8.0±1.6	4.1±1.4	3.3±1.9	3.7±1.0	4.3±1.2
NH_3-N	R	0.6-7.6	1.1-7.3	0.0-0.8	0.0-0.9	0.0-0.8	1.1-6.4	1.4-3.1	1.1-4.5	1.1-4.2
(mg/L)	M±Sd.	3.6±2.4	3.9±2.2	0.4±0.3	0.4±0.3	0.3±0.3	3.3±1.9	2.3±0.6	2.6±1.1	2.6±1.0
TSS	R	3.0-50.0	2.0-28.0	1.0-44.0	2.0-29.0	1.0-32.0	2.0-28.0	3.0-24.0	1.0-13.0	2.0-19.5
(mg/L)	M±Sd.	15.3±13.1	11.4±8.2	18.8±12.6	14.5±7.5	13.5±9.3	8.1±7.3	14.7±7.3	8.0±4.2	9.5±5.7
BOD	R	0.2-9.4	0.7-7.8	0.2-3.6	0.0-2.7	0.2-2.0	0.9-7.8	0.9-6.0	0.3-6.7	0.2-7.4
(mg/L)	M±Sd.	4.2±3.0	3.8±2.4	2.0±1.1	1.5±1.0	1.2±0.6	3.0-1.8	3.2±1.4	3.2±1.9	3.1±2.0
COD	R	10.8-135.7	2.7-67.8	2.7-136.0	5.4-65.3	2.7-74.8	2.7-40.8	10.8-384.0	10.8-65.3	0.0-64.0
(mg/L)	M±Sd.	38.4±33.3	30.8±22.3	52.0±44.2	35.2±18.2	39.4±21.7	21.5±12.9	53.5±104.5	33.2±18.6	21.2±16.5
NO_3^-	R	0.5-3.9	0.5-3.6	0.0-6.3	0.5-2.9	0.4-3.4	0.4-3.6	0.5-3.9	0.4-4.7	0.6-3.3
(mg/L)	M±Sd.	2.1±0.9	2.1±0.9	2.1±1.7	2.0±0.7	1.8±0.9	2.1±0.8	1.9±1.0	2.1±1.2	2.1±0.9
PO_4^{3-}	R	0.1-5.2	0.2-1.2	0.1-0.7	0.1-0.6	0.0-0.4	0.1-2.6	0.1-0.4	0.1-5.0	0.1-5.2
(mg/L)	M±Sd.	1.3±1.6	0.5±0.4	0.2±1.2	0.2±0.2	0.1±0.1	0.7±0.8	0.2±0.1	0.7±1.4	0.6±1.4

4.1.1 Field Analysis

Temperature

The water temperature at the study area ranges from 27.7 to 36.1^{o}C as shown in Figure 4.1. The results mean is within the range of the standard acceptable levels of the National Water Quality Standards, Malaysia (DOE, 2015). The temperature in the lake was found to be higher than the temperature in the rivers as shown in Figure 4.1. Water has a high heat storage capacity. Therefore, low velocity or stagnant water tends to accumulate higher heat (O.E. Ataer, 2009A.M. Abdallah, 1987; UCSB, 2017).

In addition, the temperature variation is affected by the location and sampling time (Mohammad Shuhaimi-Othman, Lim, & Mushrifah, 2007). During the study, a water sample from the lake was taken during noon while the sample from the river was taken during morning time. During that time, lake water receives direct sunlight in a stagnant form while the river is overshadowed by trees at the river bank and the water continuously flows. Thus, this may explain the high temperature in the lake as compared to the river.

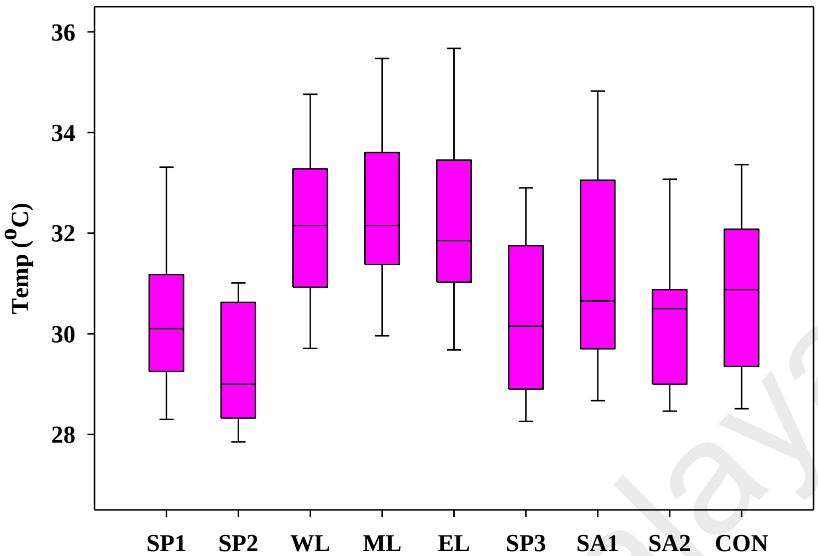

Figure 4.1: Temperature variation at each sampling point

Conductivity

In general, waters with low conductivity contain a few dissolved salts, which are usually clear and nutrient poor (vice versa). The conductivity in the UM surface water varies from 0.07 to 0.39 mS/cm. Figure 4.2 shows that the lake has low conductivity as compared to the river water. However, the mean result for all sampling stations is within the range of the standard acceptable levels (less than 1.0 mS/cm) of the National Water Quality Standards, Malaysia (DOE, 2015). Thus, this gives an indication that surface water in the UM campus has a low ion content and has an acceptable mineral ion content.

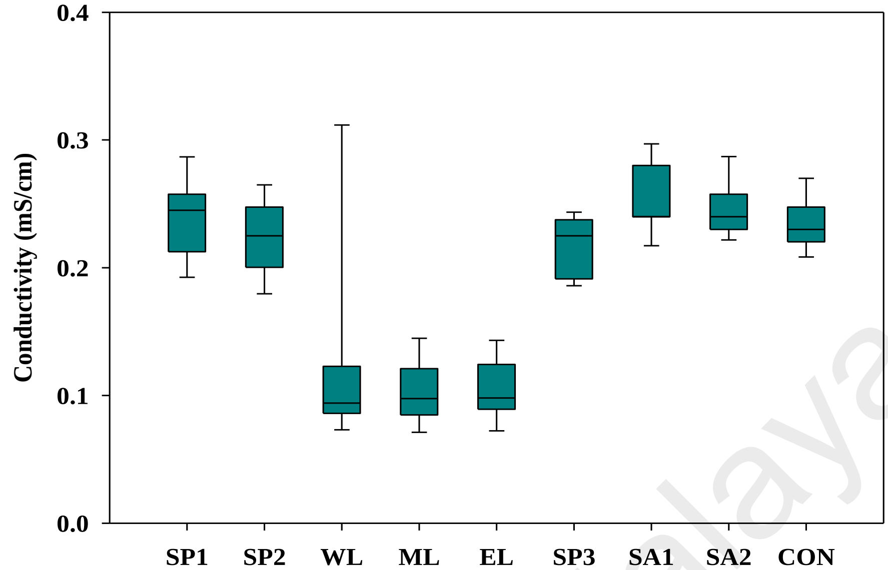

Figure 4.2: Conductivity variation at each sampling point

pH

The pH values for the study area ranging from 4.5 to 9.7 as shown in Figure 4.3. The comparing with the National Water Quality Standards (NWQS) for Malaysia (DOE, 2015), the mean pH value is within the range of the given standard. Lake water has relatively alkali characteristics, pH>7 and lies in Class I of the NWQS. The pH normally increases as a result of the photosynthetic algae activities that consume carbon dioxide that is dissolved in the water (Gandaseca, Rosli, Ngayop, & Arianto, 2011). The changes in pH value can alter the aspects of water chemistry. For example, as pH increases, only smaller amounts of ammonia are needed to reach a level that is toxic to the aquatic life, which can endanger them inside the river (EPA, 1999).

In reverse, as pH decreases, the concentration of metal may increase because higher acidity will increase their ability to be dissolved from sediments into the water, which will lead to poisoning (Kjell Johansson, Ewa Bringmark Lena Lindevall Anders Wilander, 1995; H Li, A Shi, M Li, X Zhang, 2013). For pH in the river system, caution prevention method needs to be applied in balancing the pH because the value has reached acidic condition from 4 to 5.5. However, from Figure 4.3, it shows that the pH in the river has a low interquartile range and the value is around pH 7, Class I, which indicated that the value is almost stable during the time the study was conducted.

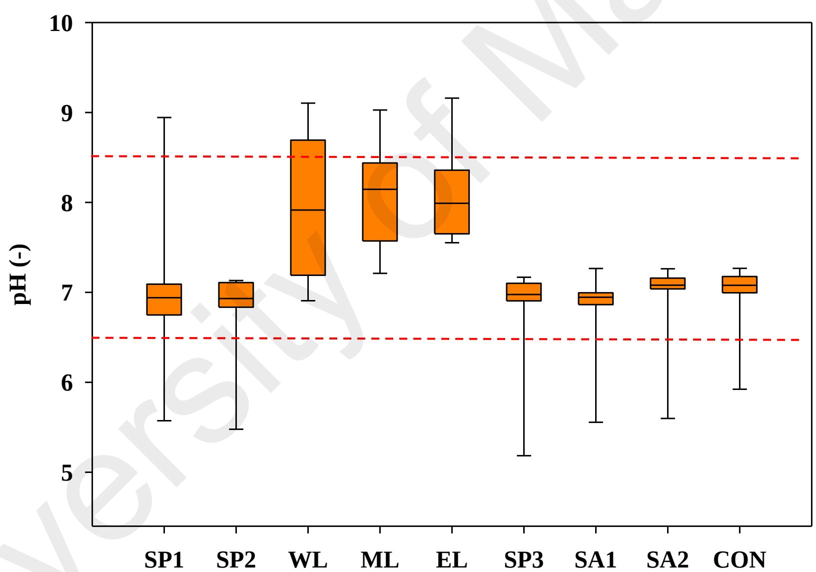

Figure 4.3: pH variation at each sampling point

Turbidity

The average turbidity values were all below the NWQS limit of 30 NTU as shown in Figure 4.4. The highest turbidity was recorded at SP1 during December 2014 because of the heavy rainfall event and high stream flow. This has caused the streams to receive a high surface runoff. Generally, the clarity of water decreased as a result of the presence of suspended particles that were deposited in the water. These outcomes support the fact that turbid water was due to high sediments resulted from the stream flow, surface runoff, and overland flow in natural waters (Yisa & Jimoh, 2010). Extreme high turbidity will reduce the number of species and organisms where fishes tend to move away from turbid water that is above 30 NTU (ALABASTER, 1982). In this study, since all stations have a mean turbidity of less than 30 NTU, so according to the NWQS, all stations have the permissible limit of turbidity (DOE, 2015) and lies in Class II of the NWQS.

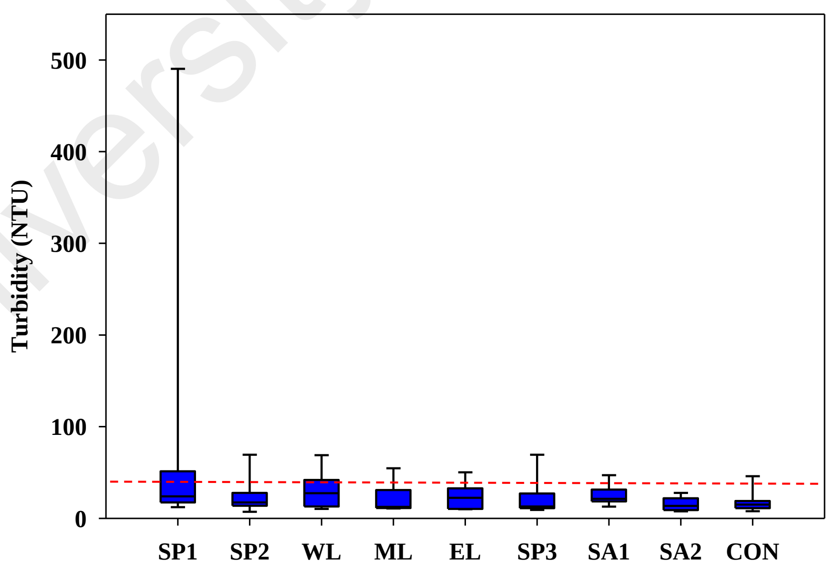

Figure 4.4: Turbidity variation at each sampling points

DO

In the aquatic system, all living organisms are dependent upon oxygen in one form or another to maintain the metabolic process that produces energy for growth and reproduction (Sawyer et al., 2003). DO readings are highly dependent on the temperature, biological activity (microbial, primary production), and the rate of transfer from the atmosphere (ANZEC and ARMCANZ, 2000). The solubility of atmospheric oxygen in freshwater ranged from 14.6 mg/L at $0^{o}C$ to about 7 mg/L at $35^{o}C$ under 1 atm pressure (Sawyer et al., 2003). Thus, this means that DO decreases with the increase of temperature. Oxygen is more easily dissolved in water with low levels of dissolved or suspended solids.

In this study, DO variations can be seen clearly throughout the sampling stations. Lake water has a higher DO as compared to the river water. The type of organisms present, such as plant, bacteria, and fungi affect the DO concentration in a water body. If many plants are present, the water can be supersaturated with DO during the day as photosynthesis occurs. During photosynthesis, plants release oxygen into the water.

In the case of the Varsity Lake during the study, the UM management has put Najas spp. to increase water clarity and reduce the nutrient load that caused eutrophication. This plant will be removed from the lake before it died to avoid decomposition of the dead plants to the bottom of the lake. Najas is a green leaf aquatic plant that undergoes photosynthesis process. The high number of Najas in the lake explained the high oxygen content in the lake.

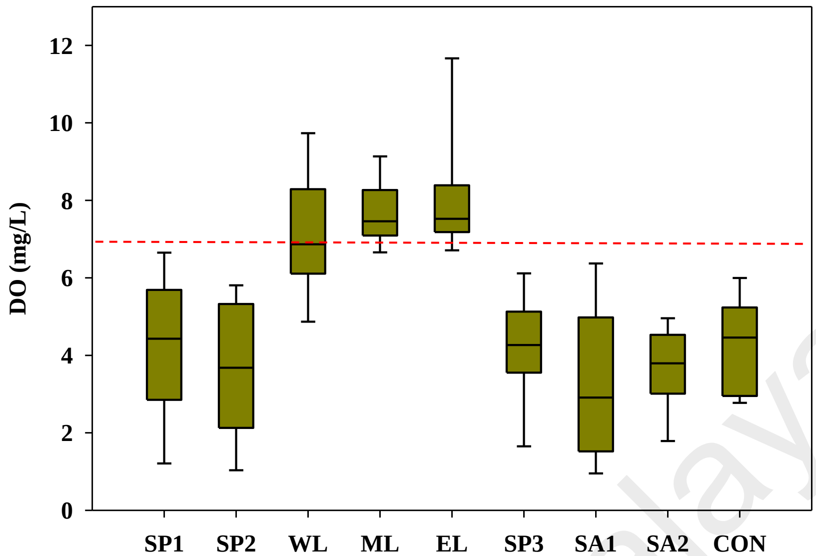

Figure 4.5: DO variation at each sampling points

4.1.2 Laboratory Analysis

BOD

BOD is a procedure for determining how fast the biological organisms use the oxygen in a water body. In this study, the mean of BOD ranges from 1.2-4.2 mg/L. Based on the NWQS, the limit for BOD in surface water is 6 mg/L (DOE, 2015), thus, all points have BOD in the permissible limit. The highest BOD was recorded in Pantai River while the lowest was in the lake as shown in Figure 4.6. This gives an indication that the river has higher biological organisms as compared to the lake and it is not suitable to be used as a water source for the lake.

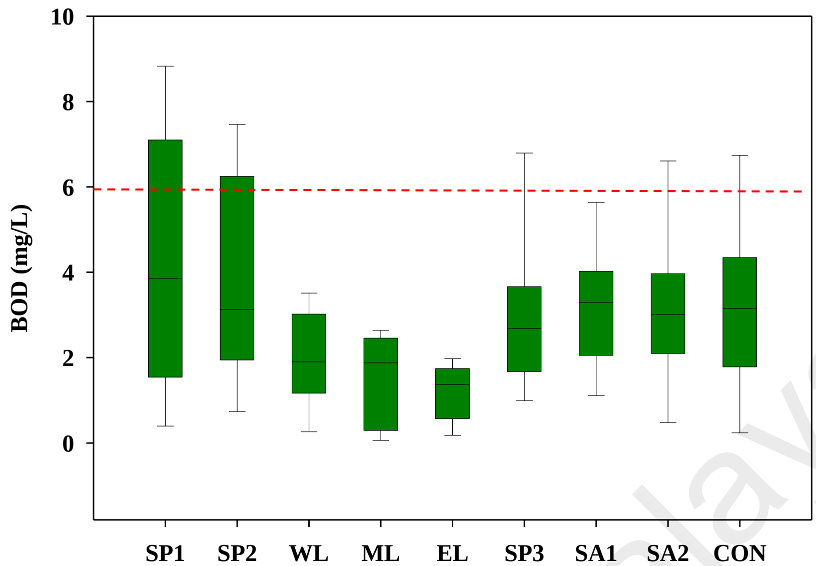

Figure 4.6: BOD variation at each sampling point

COD

In this study, COD values did not show a significant trend and it was fluctuated from time to time as shown in Figure 4.7. The mean value of COD for most of the stations was below 50 mg /L, Class III of the NWQS. Generally, the lower COD level indicates a low level of pollution (Waziri & Ogugbuaja, 2010). The mean COD concentrations in this study were all below the limit, except for the wetland (WL). Wetland acts as hot spots for some contaminants, inferring that it has the potential to filter any pollutants that pass through the system (Mutiti, Sadowski, Melvin, & Mutiti, 2015; Vidon et al., 2010). Carbon compound is prevalent in the wetland environment because of the large amounts of biomass that occupy the ecosystem. Humic substances are the products that are returned to the water after the growth-death-decomposition cycle. Since much of the humic material is not a suitable food source for the bacteria, the COD of wetlands is normally high (Kadlec, Wallace, & Knight, 1995).

In this study, a wetland that has been constructed in the lake consists of several numbers of plants other than Najas, where the plant is purposely planted in the wetland to filter any pollutants that pass through the system before continued mixing with the whole lake water. The plants undergo a growth-death-decomposition cycle and this explains the high COD in the wetland area.

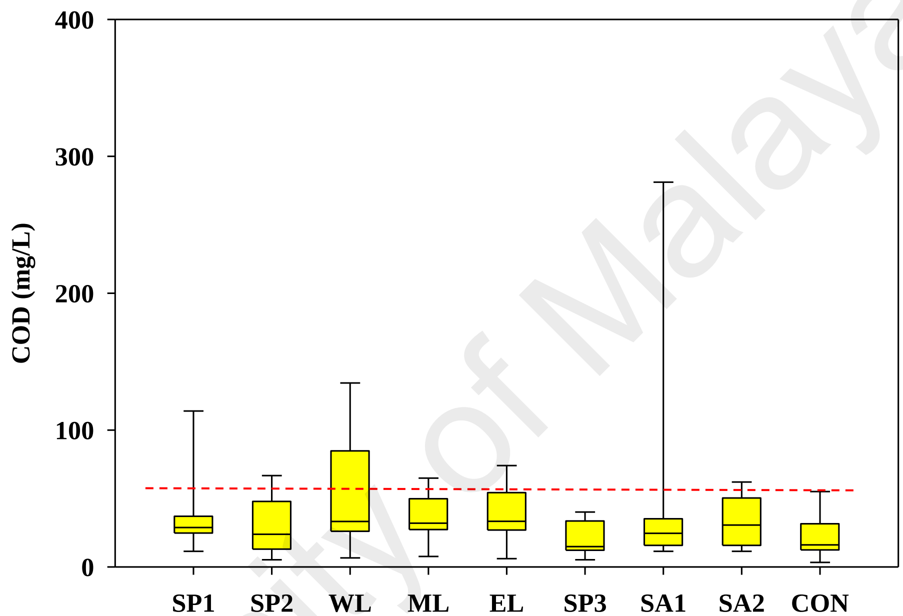

Figure 4.7: COD variation at each sampling point

NH_3-N

NH_3-N is a measure of the amount of ammonia, a toxic pollutant. From Figure 4.8, the mean NH_3-N in the UM surface water varies from 0.3 to 3.9 mg/L. The highest NH_3-N concentration was in Pantai River while the lake water has a minimal NH_3-N concentration. According to the NWQS, the limit for NH_3-N concentration, which supports the aquatic life is 0.9 mg/L (DOE, 2015). This shows that Pantai River is extremely polluted by NH_3-N, Class V while the lake is in Class III. According to (Corwin, Loague, & Ellsworth, 1999), higher NH_3-N values can be toxic to fish, but in small concentrations, it could serve as nutrients for excessive growth of algae.

For this study, the high NH_3-N content in Pantai River does not contribute to the eutrophication problem. NH_3-N is also an indication for the existence of sewage effluents into a water body. Pantai River collecting all sorts of pollutants along the river before passing through the UM campus. The pollutants are beyond this study and based on the high NH_3-N content, it can be concluded that this river is receiving a discharge from waste products, such as sewage, landfill leachate, liquid manure, and other liquid organic waste products (Aziz, Adlan, Zahari, & Alias, 2004; Manios, Stentiford, & Millner, 2002) . This means that Pantai River is not suitable to be the source of water for the Varsity Lake.

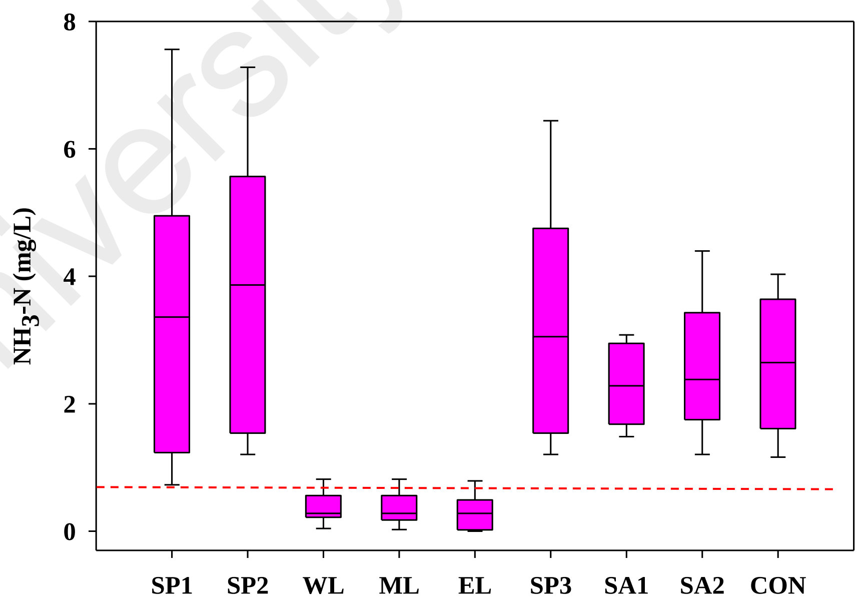

Figure 4.8: NH_3-N variation at each sampling point

TSS

The mean TSS ranges from 8.1 to 18.8 mg/L. The highest TSS, which is 50 mg/L was recorded in Pantai River and this is due to the heavy rainfall event during the sampling in December 2014 as shown Figure 4.9. Rainfall will increase the rate of surface runoff or soil erosion. Normally, soil erosion considers the best source for suspended solids that comes from the surrounding area and it will increase when the cover of vegetation was disturbed (Ooshaksaraie, Basri, Bakar, & Maulud, 2009). The mean TSS value for all station was below 20 mg/L and is complying the Class I of the NWQS, which is 25 mg/L.

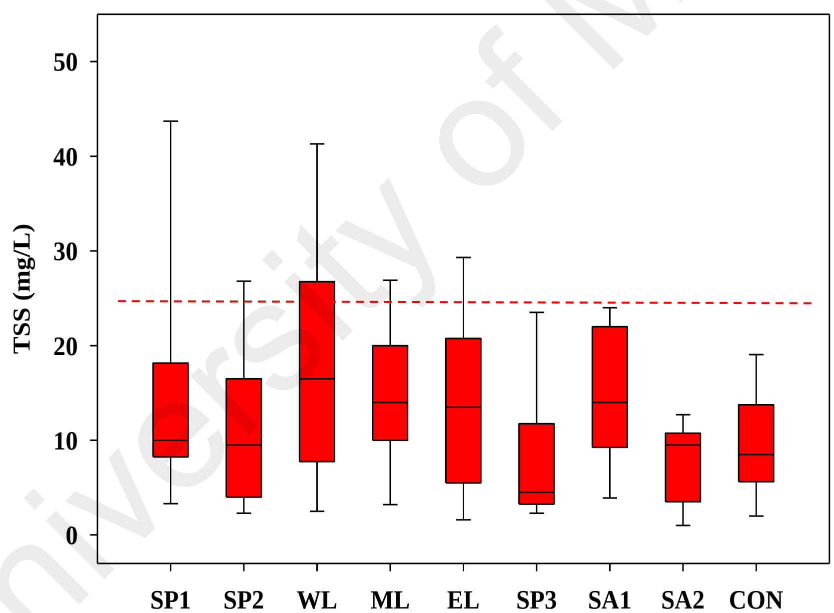

Figure 4.9: TSS variation at each sampling point

Nutrient (NO_3^- AND PO_4^{3-})

A nutrient study involving PO_4^{3-} and NO_3^- were also conducted in this study. NO_3^- values did not show a significant trend between the sampling points. The mean value ranges from 1.8 to 2.1 mg/L as shown in Figure 4.10. Based on the NWQS, the surface water in the UM has an allowable NO_3^- concentration, which is less than 7 mg/L.

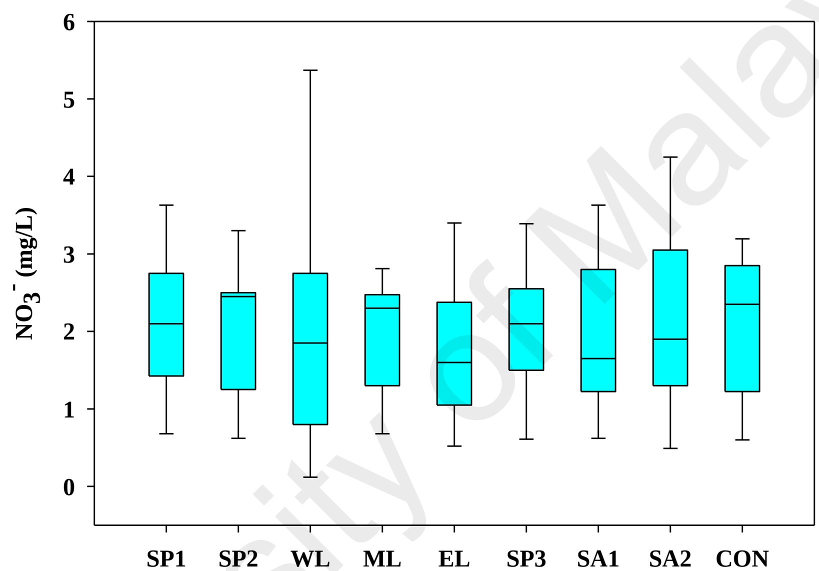

Figure 4.10: NO_3^- variation at each sampling point

As for the PO_4^{3-}, the mean concentration value shows some significant trend between the sampling points, which ranges from 0.1 to 1.3 mg/L. The maximum permissible limit set by the NWQS for PO_4^{3-} is 0.2 mg/L. The highest PO_4^{3-} was recorded in Pantai River, while the lowest was in the lake as shown in Figure 4.11. The domestic effluents particularly, which contain detergents, fertilizer runoff, and industrial wastewater are the main reasons of high PO_4^{3-} level in the surface water, such as the river and lake (Ceballas & Schnabel, 1998). From the data recorded, it proves that Pantai River receives effluents from one of the types of discharges listed above. The discharge is the combination of outside and inside the campus, such as the sewerage line of the Fourth residential college and café nearby.

Detergent polyphosphates produce orthophosphates by hydrolysis in natural water (Allen & Kramer, 1972) and these are the only directly utilizable form of soluble inorganic phosphorus (Wetzel, 1983). The use of detergents for cleaning purposes in the surrounding area reflects the high phosphate concentration in Pantai River. From Figure 4.11, it shows that the Varsity Lake has small interquartile range indicating that the PO_4^{3-} level in this lake is consistent. However, the river has reached 5 mg/L of PO_4^{3-}. The inconsistency proves that the river has different characteristics from time to time and not suitable to be the water source for the lake.

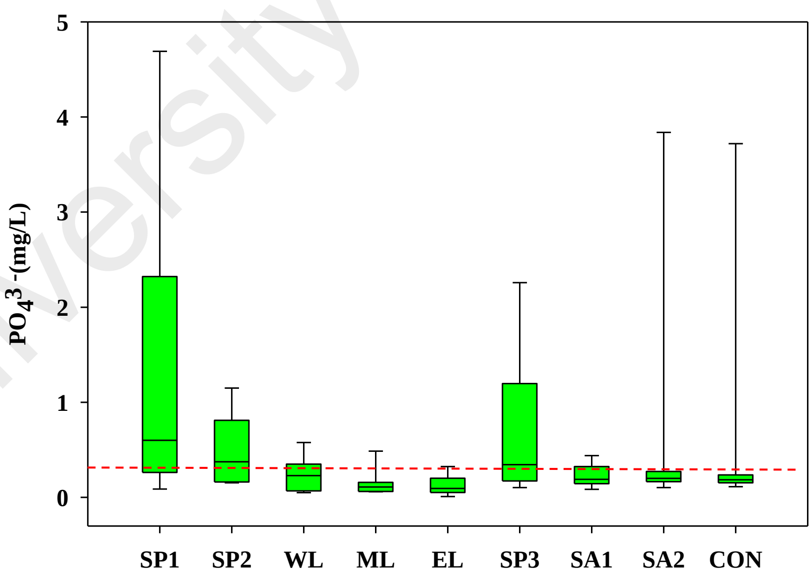

Figure 4.11: PO_4^{3-} variation at each sampling point

In general, the NWQS has put a standard water quality classes for each parameter. In this study, the water class for each parameter is summarized in Table 4.1. From Table 4.1, the conductivity, pH, turbidity, COD, and TSS shows the same class between the river and the Varsity Lake. Meanwhile, the Varsity Lake and river falls in different classes for the concentration of DO, BOD, and NH_3-N. It is observed that the Varsity Lake lies in a better class as compared to the river, indicating that the low quality of the river water shall not be utilized as the lake water source. In addition, based on the individual parameters, the Varsity Lake is suitable to act as a recreational center.

Table 4. 2: The comparison of water classes between river and Varsity Lake

Parameter	Class	
	River	Varsity Lake
Conductivity	Class I	Class I
pH	Class I	Class I
Turbidity	Class II	Class II
Dissolved Oxygen, DO	Class III	Class I
Biochemical Oxygen Demand, BOD	Class III	Class II
Chemical Oxygen Demand, COD	Class III	Class III
Ammoniacal Nitrogen, NH_3-N	Class V	Class III
Total Suspended Solids, TSS	Class I	Class I

4.1.3 Heavy Metals Analysis

The Inductive Coupled Plasma (ICP) test was done to trace the heavy metals concentration. Eleven elements were included; Cu, Fe, Ni, Cd, As, Mn, Cr, Ag, Pb, Al, and Zn. The average heavy metals distributions for the eleven elements are as shown in Table 4.2. The values are presented in mg/L unit and compared to the standard limit given by the National Water Quality Standard (NWQS). Based on Table 4.2 four elements; As, Ag, Zn, and Mn are found to be below the safe limit given by the NWQS, while Cr, Ni, and Al has exceeded the limit at SP3, Pantai River; and SA1, Anak Air Batu River. However, it was found that the concentration has exceeded the limit only once. Thus, this indicates that the source of these metals concentration is depending on the runoff and the type of discharges that went into the river.

Table 4. 3: Heavy metal concentration in University Malaya surface water

Element	Average heavy metals concentration at each sampling point									NWQS Limit (DOE, 2015)
	SP1	SP2	WL	ML	EL	SP3	SA1	SA2	CON	
As **(mg/L)**	ND	ND	0.03	0.01	ND	ND	ND	ND	ND	0.10
Ag **(mg/L)**	ND	ND	0.02	ND	ND	0.05	ND	ND	ND	0.05
Zn **(mg/L)**	0.08	0.07	0.08	0.07	0.05	0.07	0.05	0.05	0.05	5.00
Mn **(mg/L)**	0.06	0.05	0.05	0.08	0.05	0.10	0.12	0.10	0.07	0.20
Cr **(mg/L)**	0.02	0.02	0.02	0.02	0.01	**0.07**	0.01	0.01	0.01	0.05
Ni **(mg/L)**	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.01
Al **(mg/L)**	0.10	0.11	0.16	0.25	0.15	0.24	**0.59**	0.34	0.17	0.50
Fe **(mg/L)**	0.58	0.55	**1.20**	**1.02**	0.93	0.48	**1.65**	**1.25**	0.58	1.00
Cu **(mg/L)**	**0.60**	**0.48**	**0.50**	**0.35**	**0.30**	**0.39**	**0.29**	**0.34**	**0.24**	0.02
Cd **(mg/L)**	**0.07**	**0.06**	**0.07**	**0.06**	**0.06**	**0.06**	**0.05**	**0.05**	**0.05**	0.01
Pb **(mg/L)**	**0.14**	**0.11**	**0.11**	**0.10**	**0.10**	**0.10**	**0.09**	**0.08**	**0.09**	0.05

ND: Not Detected

Four elements exceeded the limit given by the NWQS (Table 4.2), which are Cd, Cu, Pb, and Fe.

Fe exists naturally in rivers and lakes and it forms naturally in soil, sediments, and ground water. This element presents in the water in two forms; soluble ferrous iron or insoluble ferric iron. Water containing ferrous iron is clear but when exposed to air, the water turns cloudy causing a reddish brown precipitate. In this study, three sampling points have exceeded the limit given by the NWQS as shown in Figure 4.12. The highest Fe recorded is in Anak Air Batu River (SA1), 1.65 mg/L. The high Fe content in the river might be due to release of Fe in the water from natural deposits and nearby construction site and industrial activity. Other studies has also reported high Fe concentration due to industrial activities (Ismail et al., 2013; Othman, Kutty, & Lim, 2009; M Shuhaimi-Othman, Ahmad, Nadzifah, & Azmah, 2012).

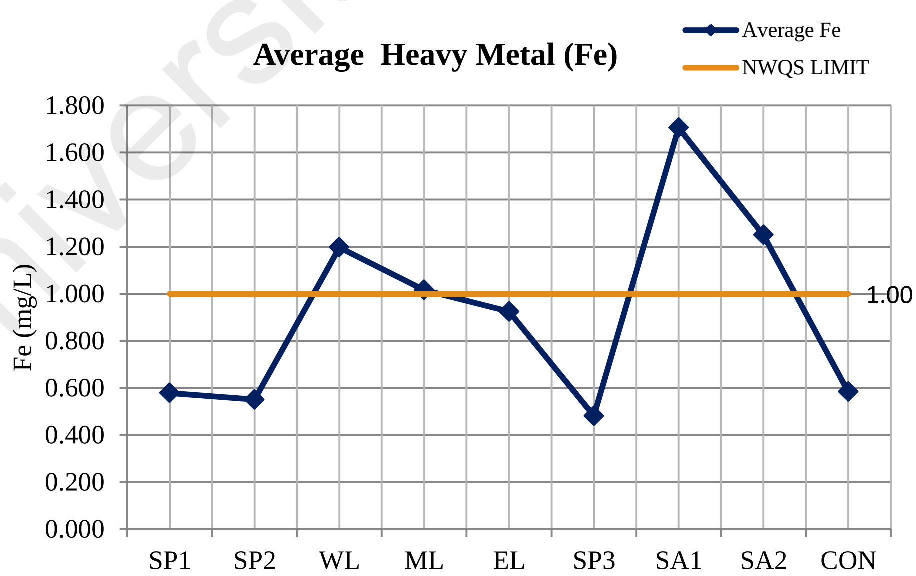

Figure 4. 12: The average Fe concentration in UM surface water

Copper (Cu) is found as a pure metal in nature. Cu is essential to all living organisms as a trace dietary mineral because it is a key constituent of the respiratory enzyme (Rainbow, 2002). In human, copper is found mainly in the liver, muscle, and bone (Albert, Porter, Kaplan, & Homeier, 2009). This small amount is essential to the overall human well-being. When copper is present in the drinking water, it can be a sign of low pH and corrosion.

In this study, the Cu in all sampling stations exceeds the NWQS limit as shown in Figure 4.13. The highest Cu recorded is in Pantai River, 0.6 mg/L. The concentration of Cu decline from upstream to downstream of study area. The trend shows that Cu concentration origins from outside of campus and reduces along UM surface water. The unknown pollutant concentration outside the campus contributes to the high Cu concentration.

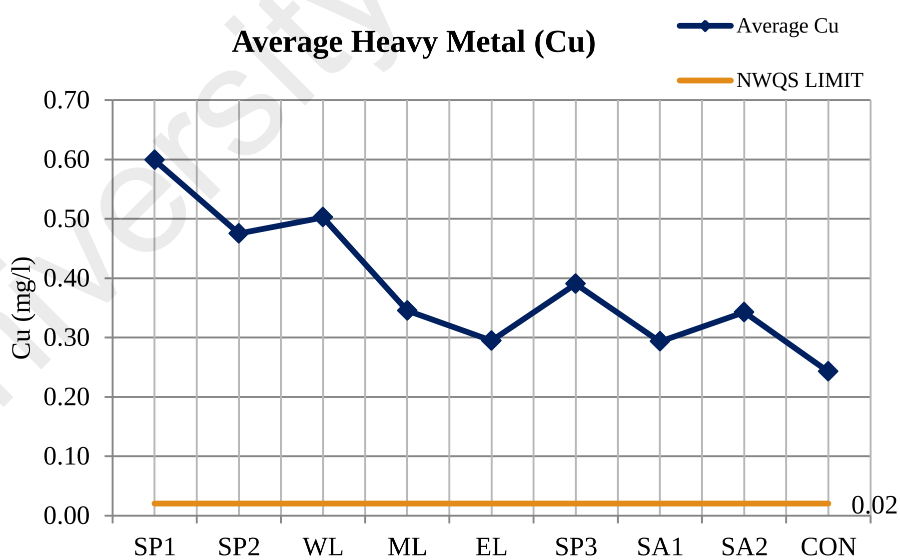

Figure 4.13: The average Cu concentration in UM surface water

In natural waters, Cd is found mainly in the bottom sediments and suspended particles (Shinoda & Friberg, 1986). In this study, the Cd content in every sampling station has exceeded the limit given by the NWQS as shown in Figure 4.14. The highest concentration recorded is in Pantai River, 0.075 mg/L. Pantai River has recorded the highest phosphate concentration and this has become one of the major sources of the high Cd in Pantai River. This is because of fertilizers produced from phosphate ores constitute a major source of diffused cadmium pollution (Bandara et al, 2011).

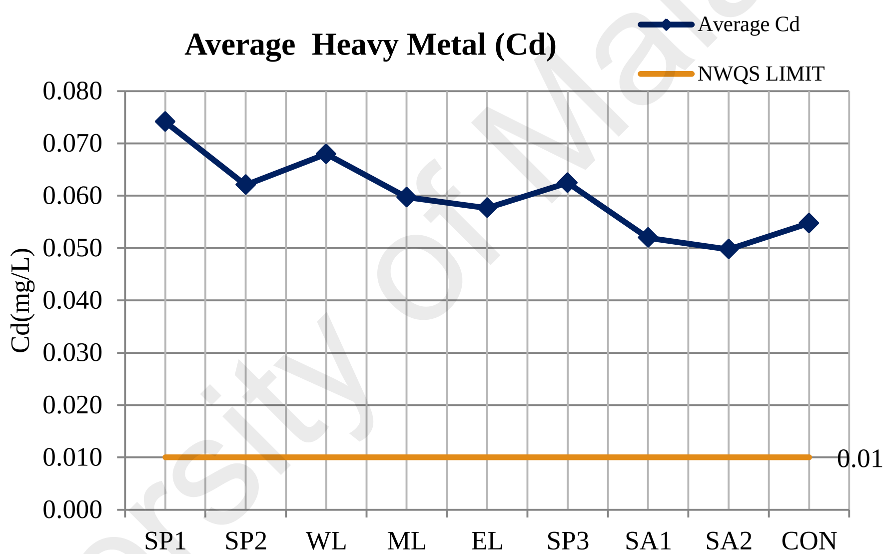

Figure 4.14: The average Cd concentration in UM surface water

Pb is present in water from the industrial activities and corrosion from the piping system. The average Plumbum (Pb) concentration for each sampling points is as shown in Figure 4.15. The highest concentration recorded is in SP1 (Pantai River) and the trend decline from upstream to downstream of study area. The high Pb in Pantai River as compared to other points gives an indication that the river is receiving and has a direct exposure towards the discharge from the industries outside the UM campus. Other studies has also reported high Pb concentration due to industrial activities (Ismail et al., 2013; Othman, Kutty, & Lim, 2009; M Shuhaimi-Othman, Ahmad, Nadzifah, & Azmah, 2012).

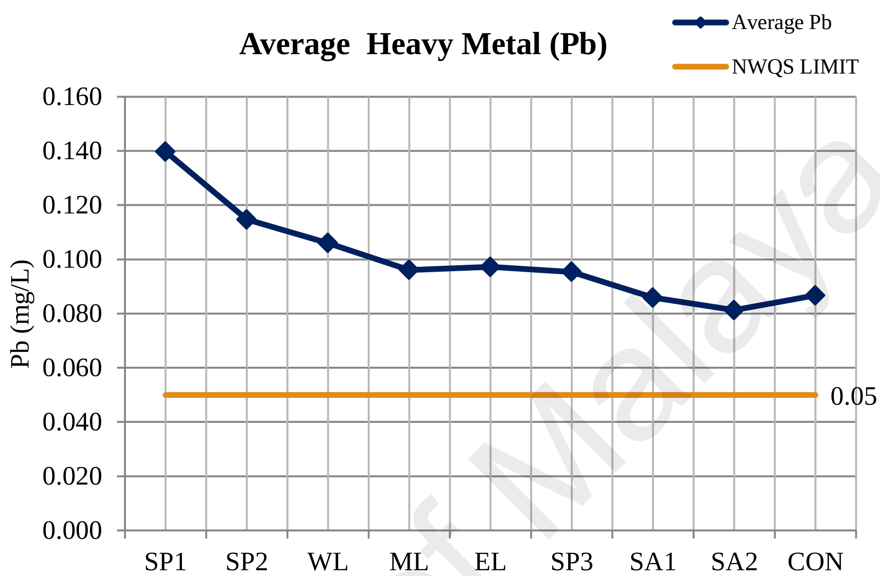

Figure 4. 15: The average Pb concentration in UM surface water

From the heavy metal analysis, it can be seen that Pantai River and Anak Air Batu has recorded higher concentration as compared to the lake. Pantai River has the highest average amount of Pb, Cd, and Cu, while Anak Air Batu River has the highest Fe amount. This gives an indication that both rivers should not be used as the lake water sources due to receiving unknown discharges from nearby industrial area and activities outside the campus.

4.2 Water Quality Classification

In this study, the water quality in the study area was classified by using two different approaches. The first method is by implementing the standard water quality classification given by the Department of Environment (DOE), namely the Water Quality Index (WQI). Furthermore, the water quality classification is determined by using a multivariate analysis, which is the hierarchical agglomerative cluster analysis (HCA).

4.2.1 Water Quality Index (WQI)

WQI is calculated using six parameters; DO, pH, BOD, COD, NH_3-N, and TSS (Equation 3.1). Figure 4.16 shows the summarization of WQI trend. The Varsity Lake has a higher WQI with a mean value ranges from 82 to 86. Meanwhile, the river water has a lower WQI with a mean value ranges from 65 to 70. As a whole, the surface water in the UM campus can be divided into two classes based on the water quality characteristics. The Varsity Lake water lies in Class II and is classified as Clean, while the river lies in Class III and is classified as Slightly Polluted.

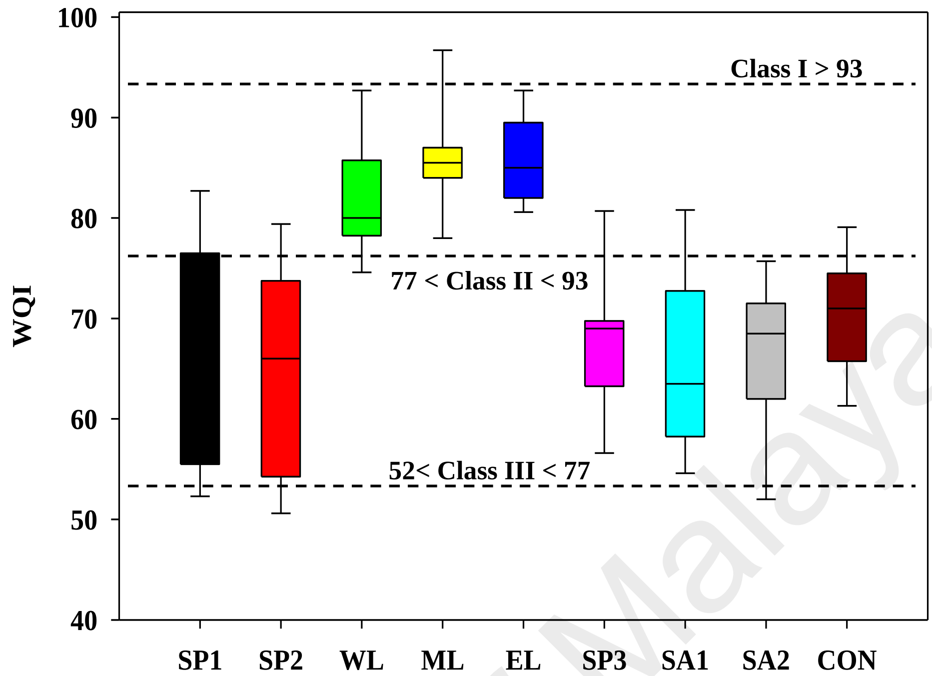

Figure 4.16: The variation of WQI at each sampling point

4.2.2 Cluster Analysis (CA)

Apart from the WQI classification, a cluster analysis was applied to the water quality data to detect the spatial similarity and dissimilarity between the sampling stations. Since the major problem of the Varsity Lake is eutrophication problem, the nutrient concentration should be considered for the water quality classification. Thus, in this study, the cluster analysis has been used to analyze the physical and chemical characteristic of the water in the UM Campus by including the concentration of PO_4^{3-} and NO_3^-. From the dendrogram, the sampling point is classified based on the percentage of similarity without considering the level of pollution. This analysis considers more parameters as compared to the WQI, which uses only six parameters.

The similarity represents the properties at each station with respect to the physical and chemical parameters. Ten parameters have been considered for these tests. The dendrogram of sampling stations obtained by Ward's linkage method is shown in Figure 4.17. The Ward's method uses an analysis of variance approach to evaluate the distances between clusters, which is Euclidean distance, in an attempt to minimize the sum of squares (SS) of any two clusters that can be formed at each step. The dendrogram provides a visual summary of the clustering processes, presenting a picture of the groups and their proximity with a dramatic reduction in the dimensionality of the original data.

The nine sampling stations located inside the campus were divided into four groups. This indicates that water quality in the UM campus has four natural background features. The first cluster, Cluster 1 corresponded to the stations SP1 and SP2, which represent the upper part of Pantai River inside the campus. From its geological condition, Pantai River receives pollutants from outside residential area and sewerage line from the residential college in UM which contain high amount of nutrient (PO_4^{3-}), NH_{3}-N and other parameters as compare to the other stations.

Cluster 2 contained stations WL, ML, and EL, which are located in the Varsity Lake region, a close water body system. Varsity Lake consistently has low concentration of nutrient (PO_4^{3-}), NH_{3}-N and most of other parameters. Thus, this has contribute to the similar cluster from WL, ML and EL. Cluster 3 included stations SP3, CON, and SA2, which are the combination of downstream of Pantai River and Anak Air Batu River in UM campus. The concentration of nutrient (PO_4^{3-}) and NH_3-N in these stations is fluctuating due to various drainage systems inside the campus. This indicates that behavior of water quality from Pantai River and Anak Air Batu River has changed as the water flows in UM campus due to the influence from various drainage systems and proves that UM daily activities have different characteristics from outside residential area. Cluster 4 only contained station SA1, which is located in the upper part of Anak Air Batu River. This cluster illustrated that SA1 does not have a significant similarity with any other stations in terms of physical and chemical characteristic due to its geographical location which receives flow from Damansara area. The function of SA1 as retention pond also contributes to the different characteristics of water in this sampling point. The consistent concentration of nutrient (PO_4^{3-}) and NH_3-N in the retention pond has contributed to the different characteristics of sampling point.

From this analysis, it can be seen that by combining and considering the nutrient concentration (PO_4^{3-} and NO_3^-) with other parameters, the lake and river lies in the different clusters due to its geological condition and concentrations of nutrients. Furthermore, this analysis shows that the behavior of river water quality in UM campus has different characteristics as compared to the water from outside of campus. Even though CA analysis has considered more parameters as compared to WQI classification, this analysis is directly proportional with the WQI classification approach. Both analyses have proved that river and lake water has different characteristics.

From WQI classification, the lake has better water quality as compares to the river. According to Table 3.6, the lake water is suitable to be used for recreational use body contact. However, river water in the UM requires an extensive treatment prior to being used as a water supply. This gives an indication that the river water should not be used as the water source for the lake in any case.

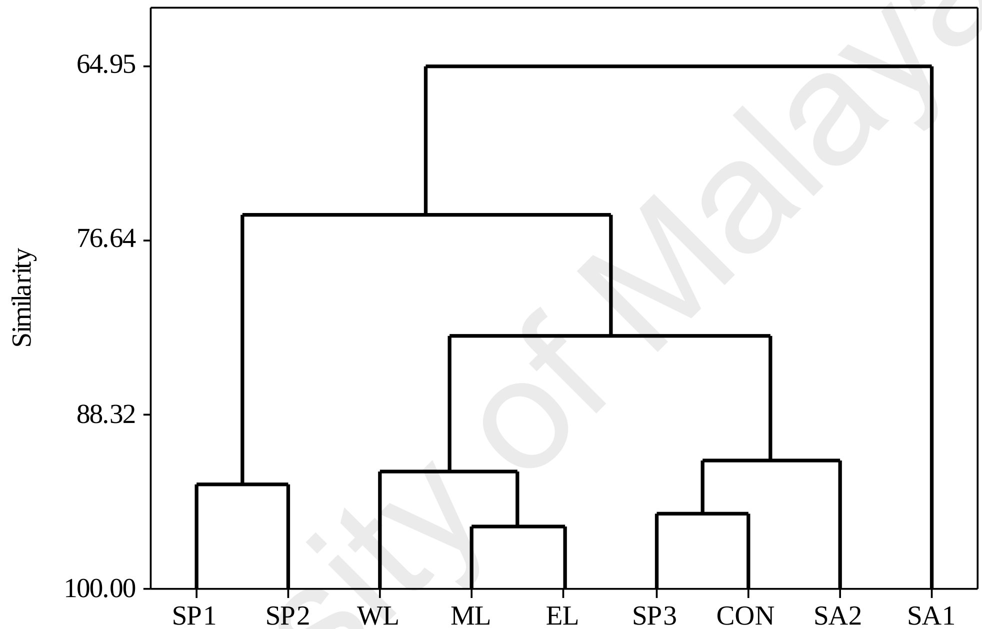

Figure 4. 17: The dendrogram for UM surface water

4.3 Effectiveness of Current Water Management Approach

The UM management authority has opened a wide step for improving the surface water quality in the Varsity Lake. This section discusses the impact of the rehabilitation work in the lake and the effectiveness of current water management towards surface water quality on the UM campus. This includes three sampling points in the Varsity Lake; Wetland (WL), Middle Lake (ML) and End of Lake (EL). The comparison is made based on the trend analysis for six pollutants indicators (DO, BOD, TSS, NH_3-N, NO_3-, and PO_4^{3-}) during pre-rehabilitation and post-rehabilitation of the lake. The mean and the standard deviation (SD) value are calculated to determine the dispersion of the data set.

The DO mean value in the pre-rehabilitation stage is 8.9 mg/L with SD of ±3.15 while the mean in the post-rehabilitation is 7.6 mg/L and SD of ±0.96. From Figure 4.18, the highest DO was recorded in July 2014 (12.1 mg/L) and the lowest was in April 2014 (3.8 mg/L). Both values are in the pre-rehabilitation stage. Figure 4.18 also shows that DO concentration is alternately increase and decrease from one month to the other month. This is due to the nature of eutrophication stage where rapid oxygen in produced from the photosynthesis process of the algae (Salenave, R., 2011). Likewise, if the large portions of the algae die off at once, bacteria will start to consume oxygen in order to decompose the dead algae and resulted to low DO concentration in the water body (Salenave, R., 2011). Thus, the extremely high DO in July 2014 is due to the rapid oxygen production from the algae and low DO in April 2014 is due to the die off algae in the lake.

The lower SD in the post-rehabilitation indicates that the DO is much more stable after the rehabilitation project has been applied to the lake. The unstable DO will affect the aquatic life in the lake as some species are sensitive towards DO changes. After the rehabilitation work, the DO is stable and the value is above the limit given by Class I of the NWQS, which is 7 mg/L.

Technically, the use of paddlewheel aerator in the lake after the rehabilitation work has helped to maintain a good DO concentration. Biologically, the use of Najas spp. as a biological control to solve the eutrophication problem has caused rapid oxygen production from photosynthesis of this species and thus, contributes to the stability of the DO concentration in the lake.

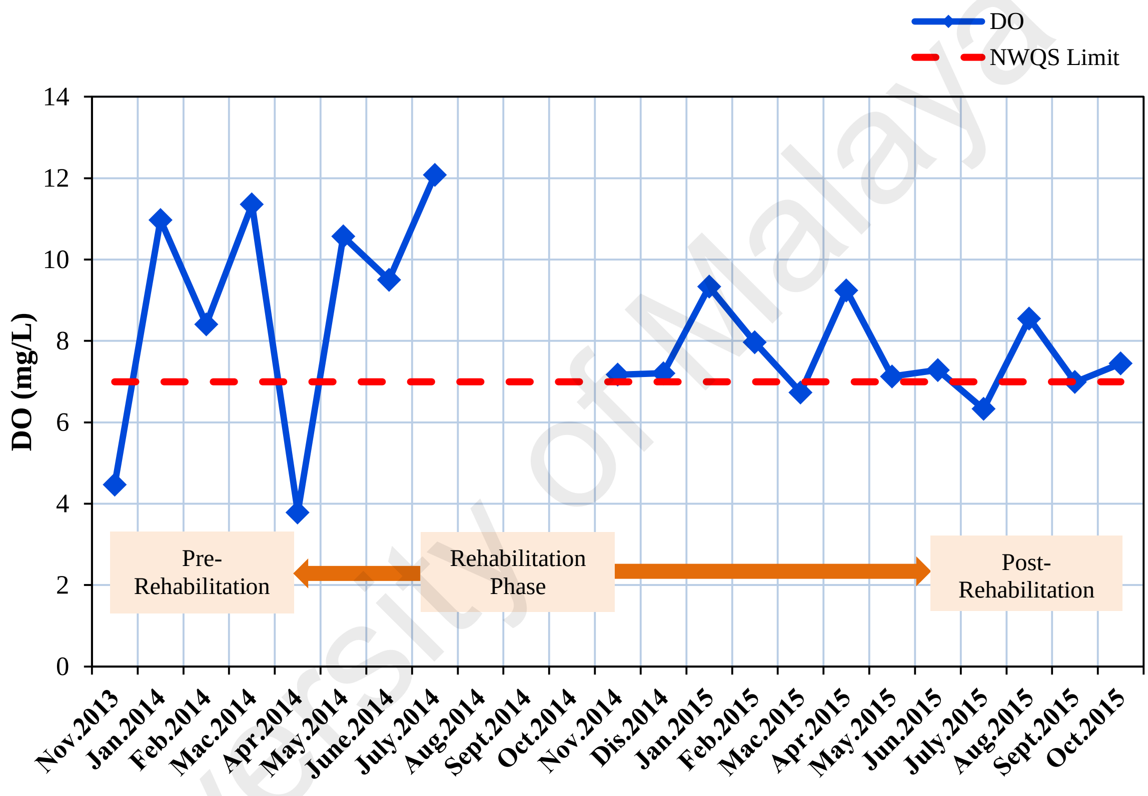

Figure 4. 18: The DO trend for pre-rehabilitation and post rehabilitation

BOD concentration also shows a good indication based on its concentration in the pre-rehabilitation and post-rehabilitation as shown in Figure 4.19. The average BOD concentration has reduced from 32.2 mg/L to 1.6 mg/L, and this shows that concentration of the post-rehabilitation has complied with the limit of 6 mg/L given by the NWQS. The BOD concentration in the pre-rehabilitation varies from 1.5 mg/L to 59.3 mg/L with SD of

±18.64. Meanwhile, the post- rehabilitation recorded a lower SD, ±0.67, which indicates that the BOD is more stable with low concentration dispersion.

The unstable BOD in the pre-rehabilitation stage is closely related to the discharge of wastewater into the lake as shown in Table 4.3. The high concentration of BOD from the wastewater has affected the BOD in the lake in the pre-rehabilitation stage. The stop of wastewater and rechanneling of drainage have contributed to the drastic improvement of BOD concentration in the lake. The BOD has improved from Class V to Class II of the NWQS.

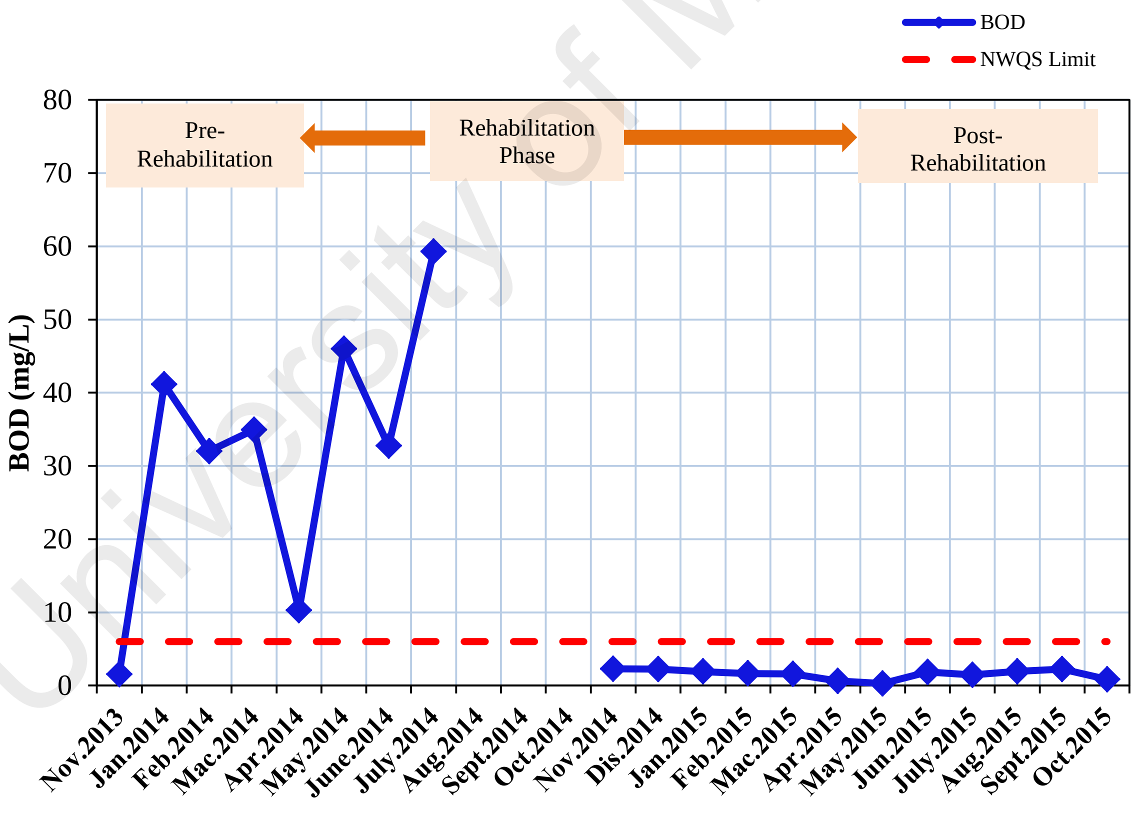

Figure 4. 19: The BOD trend for pre-rehabilitation and post rehabilitation

TSS is an important parameter for the water quality study because it is closely related to the DO where the oxygen will easily dissolve in a low suspended solids water. In the pre-rehabilitation stage, the average TSS was 66.1 mg/L, but after the rehabilitation begun, the average TSS reduced to 15.6 mg/L. The TSS has improved from Class III to Class I of the NWQS. From Figure 4.20, it can be seen that the TSS in the pre-rehabilitation stage is unstable with a value ranges from 12.3 mg/L to 184 mg/L. The SD recorded in the pre-rehabilitation stage was ±52.1, while after rehabilitation, the SD is only ±8.97. The standard limit for the TSS is 50 mg/L. This shows that the stopping of the wastewater discharge into the lake has reduced the TSS and the value is in the range of the standard limit given. The highest value was recorded in July 2014 and the value is significant with the BOD concentration. From the result, it can be interpreted that the wastewater has carried suspended solids, which consumed high oxygen during July 2014.

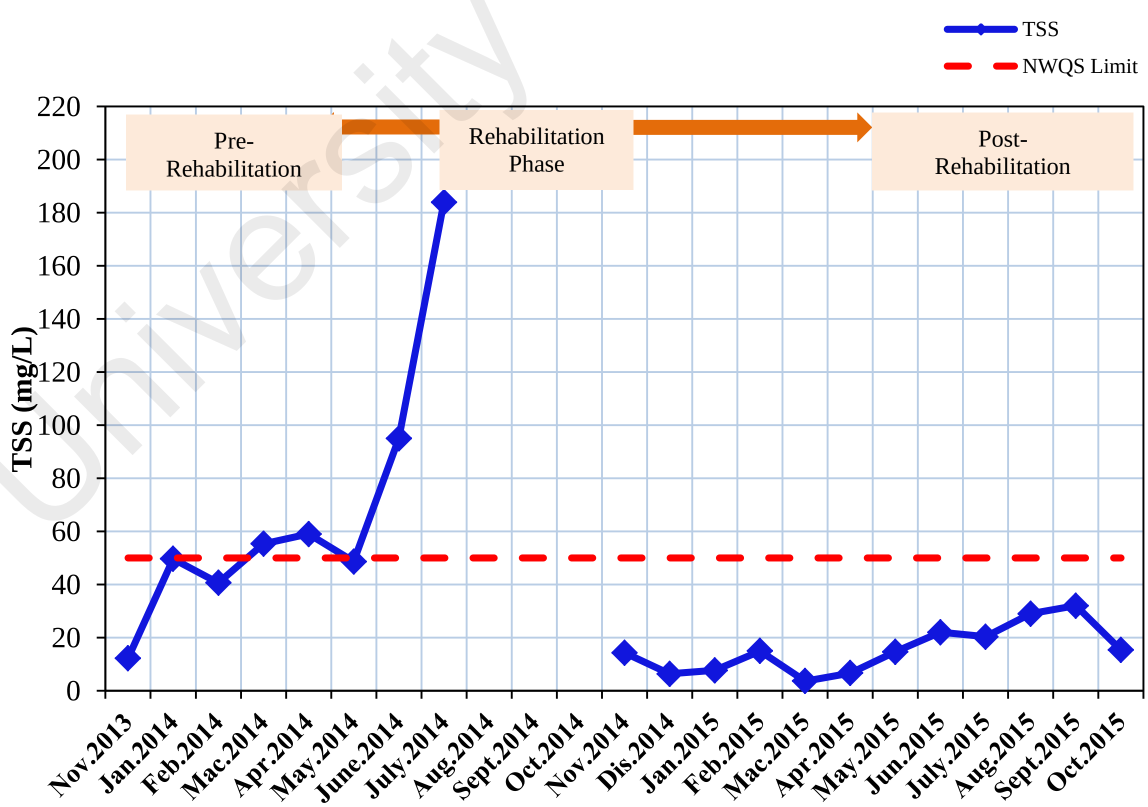

Figure 4. 20: The SS trend for pre-rehabilitation and post-rehabilitation

NH_3-N is present in the water due to the discharge from the waste products, such as the sewage. Figure 4.21 shows that NH_3-N in the pre-rehabilitation stage varies from 0.1 mg/L to 2.3 mg/L. The highest value was recorded in July 2014 and this is significant with the results obtained for the BOD and TSS. This indicates that the lake receives a high wastewater discharge during that month, which has extremely affected the lake water quality. The wastewater discharge has contributed to the unstable NH_3-N in the pre-rehabilitation stage with SD of ±0.8 while the SD in the post-rehabilitation is lower with a value of ±0.2. The rehabilitation has reduced the NH_3-N from Class IV to the safe limit of 0.9 mg/L, Class III of the NWQS.

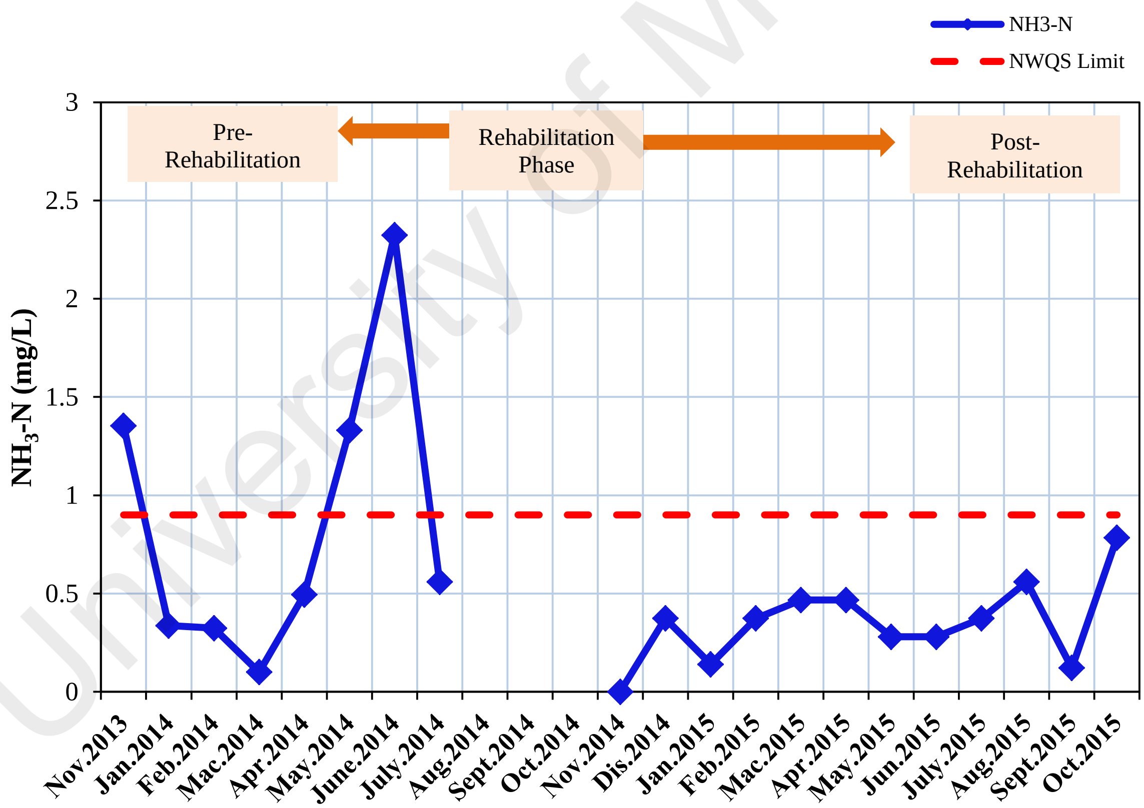

Figure 4. 21: The NH3-N trend for pre-rehabilitation and post-rehabilitation

The nutrient level is crucial in this study because the pollution in the lake is related to the eutrophication problem. Thus, the difference of NO_3^- and PO_4^{3-} concentration for the pre and post-rehabilitation were considered. These nutrients exist naturally in the water, however, the excessive amount will harm the aquatic life and cause eutrophication problem. Since there is no data available for the nutrient during November 2013 until July 2014, the pre-rehabilitation value was based on the average value reported by Ashraf, et. al (2009). The average NO^{3-} concentration in 2009 was 44 mg/L. Meanwhile, during the post-rehabilitation (November 2014-October 2015), the concentration drops to 2.0 mg/L (Figure 4.22a). The standard limit for nitrate is 7 mg/L. For PO_4^{3-}, the concentration in 2009 was 5.6 mg/L and after rehabilitation work, the concentration has reduced to an average value of 0.2 mg/L (Figure 4.22b). The standard allowable limit for PO_4^{3-} is 0.2 mg/L. Based on the results, it shows that the rehabilitation work has succeeded in bringing down the nutrients level to the safe level.

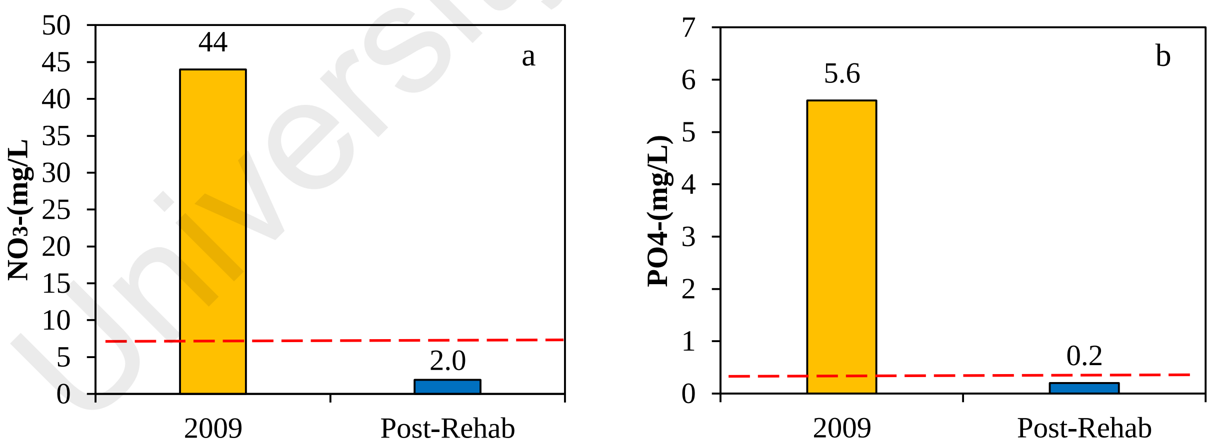

Figure 4.22: The comparison of water quality concentration in Varsity Lake before and after rehabilitation work. (a) NO_3^- concentration and (b) PO_4^{3-} concentration.

Table 4.4: The characteristic of wastewater discharge into Varsity Lake during pre-rehabilitation stage

Parameter	Concentration (mg/L)	
	Min	Max
DO	2.3	5.7
BOD	2.7	185.2
TSS	8.5	690
NH_3-N	4.0	20.6

The rehabilitation work, which includes the stopping of wastewater flow to the lake, pumping out the water from the lake, soil dredging, and installing the soil retainer have reduced the pollutants indicator concentration. The major changes can be seen especially when comparing the value of the post-rehabilitation with the value in July 2014.

This reveals that the water quality in the lake is improving from 2013 to 2015. However, each parameter has a different amount of reduction and in this study, the reduction is represented using the percentage change as shown in Figure 4.23. The equation used for the percentage change is as shown in Equation 4.1 and the clear picture for the rehabilitation work is shown in Appendix D.

$$\text{Percentage change} = \left(\frac{b-a}{a}\right) \times 100\% \qquad \text{……….Equation 4.1}$$

Where,

a = average concentration in pre-rehabilitation

b = average concentration in post-rehabilitation

The amount of BOD and TSS are normally high in wastewater composition, which is above 400 mg/L and 350 mg/L, respectively (Tchobanoglous, 1979). Also, the wastewater from the sewerage and septic line normally contains a high NO_3- and PO_4^{3-} concentrations (Tchobanoglous, 1979). From this study, PO_4^{3-} has the highest percentage change of 96.8% followed by NO_3^- with an improvement of 95.6 %, and the BOD of 95.2%. The TSS and NH_3-N has a lower percentage change with a value of 77.1% and 58.8%, respectively. Since NO_3^-, PO_4^{3-}, and the BOD concentrations have been reduced to nearly 100%, while the TSS and NH_3-N are reduced to over 50%, it shows that the rehabilitation work is very effective and truly helps in improving the water quality.

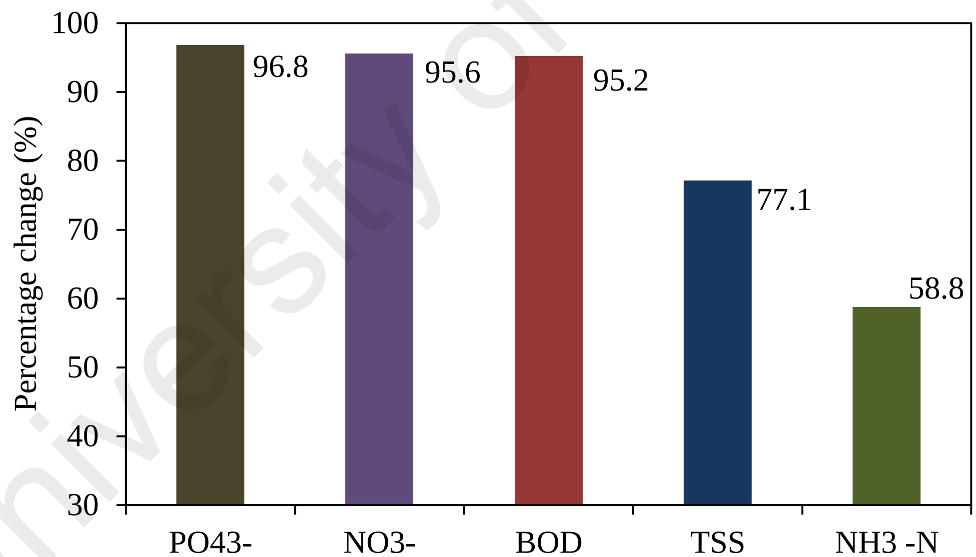

Figure 4.23: The percentage change of water quality parameters concentration before and after the rehabilitation work

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

The present study demonstrated the trend of the surface water quality in the University Malaya campus within a one year period.

5.1 Conclusion

In a nutshell, the general water quality trends for the University Malaya surface water indicate the following key findings:

a) The water quality in the river and lake exhibited different characteristics physically and chemically. On average of each water quality parameter, the lake water quality lies in a better class as compared to the rivers for DO, BOD and NH_3-N. The lake water quality for each parameters ranges from Class I to Class III whereas the river reported a wider range from Class I until Class V for NH_3-N. Hence, according to DOE classification for the individual water quality parameters, the river is classified as polluted while Varsity Lake is clean and suitable for recreational purposes.

b) Overall, the lake water has a better WQI and is classified as Class II, while the river has a lower water quality level, Class III. The outcomes indicate that the lake water is in a clean status and suitable for body contact where it can be utilized as a recreational site, while the river is slightly polluted. This study gives a better understanding that any pollution sources that flow into the river will not affect the lake water quality and clearly proved that there is no leakage from the river to the lake. The low water quality level in the river points out that it should be treated prior to be used as a lake water source in order to maintain the lake water level.

c) Apart from WQI classification, the study area is classified using statistical analysis, HCA. This analysis considering ten water quality parameters including nutrient concentration. The analysis shows that the water quality in UM surface water are divided into four different clusters and lake water has different chemical and physical characteristic as compare to the river.

d) Heavy metals distribution in the lake and river water has exceeded limit suggested by DOE(NWQS). However, the lake water has lower heavy metals concentration, while the river has recorded a higher average amount of Fe, Cd, Cu, and Pb. The high concentration of these metals is closely related to industrial activities outside the campus. The higher concentration of heavy metals in the river indicates that the river water should not be used as a lake water source.

e) As for the current water management, the focus is towards the Varsity Lake. The water quality trends for the pre-rehabilitation and post-rehabilitation shows that the current water quality is obviously better than before. However, the constructed wetland is found to be less functioning because it does not receive a specific discharge to be treated. Due to that, the effectiveness of the wetland could not be measured and is classified as less functioning in treating the water, but it is able to function as an aesthetical value. Thus, the major cause in the improvement of the lake water quality is due to the omission of wastewater discharge from faculties, residential college, and café. The stopping of pollution source into the lake has reduced the pollutant concentration up to 97%, proving that the rehabilitation is very effective.

f) In this study, among the two types of water sources in the UM campus; lakes and rivers, the rivers present as the greatest treatment challenge. The river receives the flow from outside of the campus and is exposed to numerous point sources and non-point sources. A master plan is required to improve the river water quality by ensuring a comprehensive river administration inside the campus and the integration between the UM stakeholders and the outside local authorities. Apart from that, the heavy metals concentration in the river should be focused.

5.2 Recommendations

Several recommendations are provided based on the result gathered in this study.

a) The Varsity Lake managers should focus on the capacity building on the water quality and monitoring of the physical, chemical, and bacteriological aspects. The systematic and continuous water quality data collection should be introduced in the lake by providing the sampling equipment and other scientific instruments. The availability of the equipment and such funding will encourage the researcher to get involved in the lake monitoring. A standard data sheets should be established to keep a record on the water quality of the lake. On top of that, the Varsity Lake managers should set a baseline data in order to determine the requirements for an appropriate water quality improvement in case of having water pollution in the future.

b) It is crucial to determine the lake water source since currently, the ground water source is insufficient to maintain the Varsity Lake water level. The river has a potential to supply water to the lake due to its abundant amount of water. However, the river obviously has a lower water quality. Thus, a proper raw water treatment should be applied prior to be used for the lake water source in maintaining the lake water level. The UM should upgrade the retention pond that is available in Anak Air Batu River should be upgraded to increase the effectiveness of the existing pond. The retention pond in the UM campus was designed and managed to allow the relatively large flows of water to enter and at the same time, limit the discharges during a high flow. However, supposedly a retention pond should has vegetation around its perimeter to act as a natural absorption, the bank stability and aesthetics will benefit. This is in contrast with the existing pond where the concrete embankment is used along the pond. Vegetation also provides water quality benefits by removing the soluble nutrient uptake. This might solve the high NH_3-N and PO_4^{3-} nutrient in the river.

c) Another option for the river water before utilizing it as a lake water source is the treatment by slow sand filtration, such as implementing the wetland system, which acts as an eco-friendly water treatment tool that is relatively simple and costs efficient. This will work by letting the water to percolate through a layer of sand. Even though this technique is time consuming, a sand filter is effective for a long period of time and most importantly, it is cost effective. Constructed wetland system applied to the Varsity Lake is a good approach, however, from this study, it is found that such wetland system is more appropriate to be applied in the river system to treat the water flowing from outside of the UM campus. The highly recommended area for the constructed wetland in the campus is at the existing retention pond in Anak Air Batu River. This is because of the available existing space and due to it receiving a considerable high pollutant loadings.

d) More research shall be done towards the river system by tracking the point source along the Pantai River and Anak Air Batu River from outside of the campus. The construction, industrial activities, and residential waste should be determined along the rivers and this is based on the outcomes of this study showing the high metals and nutrient concentration in this study. From that, a proper planning can be implemented and the most crucial thing is to get support, collaboration, and funding to bring the plan into a success. This support can be implemented under the Integrated Water Management by the combination of five key factors; institution, policy, participation, science, technology, and funding.

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APPENDICES

APPENDIX A: LIST OF PUBLICATION

A) Proceedings

- Che Mood.N, Othman.F, and S. Nobumitsu. Assessment of Physio-chemical Characteristics in Varsity Lake, University of Malaya, Kuala Lumpur. Paper presented at 3rd International Conference on Biological, Chemical & Environmental Sciences. Sept 21-22 (2015). Kuala Lumpur.

B) Poster

- F. Othman, W.Zurina, Nuroul Syuhada, Farahain, Che Mood.N, Zhoobin Rahimi. Hydrology and Water Quality Assessment of Bukit Fraser and Upstream of Sungai Selangor. Sustainable Symposium. 2016. University Malaya, Kuala Lumpur.

C) ISI Paper

- Che Mood,N., Othman,F. Adham, M.I., Muhammad Amin, N. (2017). Effectiveness of Lake Remediation towards Water Quality: Application in Varsity Lake University of Malaya, Kuala Lumpur. Sains Malaysiana. (Published).

- S.Chowdury, F. Othman, W.Zurina, N.Che Mood. Generation of River Pollution Map by Linking Water Quality and Spatial Information.

- S.Chowdury, F. Othman, W.Zurina, N.Che Mood., Adham, M.I. Assessment and Improvement Measure of Water Quality Parameters Using Scenarios Modeling for Selangor River Basin. Sains Malaysiana. (Accepted).