STUDY ON WATER QUALITY AND HEAVY METALS IN RELATION TO LANDUSE ACTIVITIES OF SELANGOR RIVER

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FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
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ABSTRACT

The Selangor River is very important from the viewpoint of water supply and multipurpose water use in Malaysia. Rapid development, population growth, urbanization and industrialization are being undertaken in the state of Selangor and the city of Kuala Lumpur, Malaysia. As a result of these changes, the character of the major pollutant sources may evolve from rural type sources to industrial type sources, which results in many environmental troubles and contradictory interests of water users. This study focuses on a comprehensive water quality assessment and models the impact of point and non-point sources of pollution on the Selangor River water quality. Water quality Index (WQI) consists of six parameters, viz. DO, pH, BOD, COD, AN, TSS and it is used to define the status of river water quality. Thirteen heavy metals viz. Arsenic(As), Aluminum(Al), Cadmium (Cd), Chromium (Cr) , Copper (Cu), Cobalt (Co), Iron(Fe), Lead (Pb), Magnesium (Mg), Manganese (Mn), Nickel (Ni), Silver (Ag) and Zinc (Zn) were analysed using inductively coupled plasma optical emission spectroscopy (ICP-OES). Total coliform and Escherichia coli (*E.coli*) were analyzed for microbial pollution assessment. In order to predict and assess the water quality status in Selangor River basin, QUAL2K was used as a simulation model. Water quality parameters DO, BOD and NH_3-N have been chosen for modeling. In addition, different model scenarios were simulated in order to assess the impact of point and non-point sources on the Selangor River water quality.

The results showed that Selangor River is affected in terms of high concentrations of COD, BOD and NH_3-N. Most of the stations in these river basins recorded water inferior to Class III. Significantly lower water quality was found in areas downstream from high human impact areas, where urban land was dominant or near point sources of pollution. The water quality parameters exhibited significant variation between built-up and mining sites. The Rawang sub-basin within the study area was identified as the main contributor of pollutants. A river pollution level map was developed based on this information for better visualization and spatial indication of the polluted areas. Metals analysis showed As, Mn and Fe exceeded the admissible limit of Malaysian National Standard Water Quality at some of the sampling stations. Heavy metal pollution index (HPI) was below the critical pollution index value of 100. Anthropogenic metal concentrations in the Selangor River water were low, indicating that the Selangor River does not experience extreme pollution. Concentration of ions viz. sodium, potassium, calcium and nitrate were significantly high in some tributaries, whereas forested areas showed low values of these parameters. The highest *E*.coli was found in the urban area followed by industry, residential and agricultural area respectively. The water quality model presented different scenarios for changes of Selangor River water quality. From scenarios it was found that, the river water quality issue in the Rawang sub basin within the study area is considered crucial to create significant improvement within the sub basin and in the downstream area of Selangor river basin.

Key words: Water quality, Heavy metal, Land use, Pollution, Selangor River, WQI, GIS, QUAL2K.

ABSTRAK

Sungai Selangor adalah sangat penting untuk bekalan air dan kepelbagaian penggunaan air di Malaysia. Aktiviti pembangunan yang pesat, pertumbuhan penduduk, perbandaran dan perindustrian sedang giat dijalankan di negeri Selangor dan bandar Kuala Lumpur, Malaysia. Hasil daripada aktiviti ini, penyebab utama pencemaran berubah dari sumber luar bandar kepada sumber industri yang mendatangkan pelbagai masalah kepada alam sekitar. Kajian ini, memberi fokus kepada penilaian kualiti air yang menyeluruh dan membangunkan model bagi kesan punca tetap dan punca tidak tetap untuk kualiti air Sungai Selangor. Indeks Kualiti Air (IKA) terdiri daripada enam parameter, iaitu DO, pH, BOD, COD, AN dan TSS dan ia digunakan untuk menentukan status kualiti air sungai. Tiga belas logam berat iaitu Arsenik (As), Aluminium (Al), Kadmium (Cd), Chromium (Cr), tembaga (Cu), Kobalt (Co), Besi (Fe), plumbum (Pb), Magnesium (Mg), Mangan (Mn), nikel (Ni), Perak (Ag) dan zink (Zn) telah dianalisis dengan menggunakan penduaan induktif plasma secara pelepasan optik spektroskopi (ICP-OES). Jumlah koliform dan Escherichia coli (E.coli) dianalisis untuk penilaian pencemaran mikroorganisma. Bagi menjangka dan menilai tahap kualiti air di lembangan Sungai Selangor, QUAL2K telah digunakan sebagai model simulasi. Parameter kualiti air DO, BOD dan NH_3-N telah dipilih untuk permodelan. Tambahan pula, pelbagai model senario telah disimulasi bagi menilai kesan punca tetap dan punca tidak tetap bagi kualiti air Sungai Selangor. Sebanyak 132 sampel air telah diambil dari 11 stesen persampelan pada setiap bulan selama setahun.

Keputusan menunjukkan bahawa Sungai Selangor terjejas kerana kepekatan COD, BOD, dan NH_3-N yang tinggi. Kebanyakan stesen di dalam lembangan sungai ini berada di Kelas III, yang menunjukkan bahawa air ini tidak sesuai untuk digunakan sebagai sumber air mentah, terutama di kawasan sungai yang berhampiran dengan pembangunan dan perlombongan. Lembangan Rawang telah dikenal pasti sebagai punca utama pencemaran. Satu peta tahap pencemaran sungai telah dihasilkan berdasarkan hasil kajian ini untuk visualisasi lebih baik dan petunjuk spatial satu kawasan yang tercemar. Kajian logam berat menunjukkan As, Mn dan Fe melebihi tahap yang dibenarkan oleh Standard Kualiti Air Kebangsaan Malaysia di beberapa stesen. Indeks Pencemaran Logam Berat (HPI) adalah di bawah indeks pencemaran kritikal, 100. Logam antropogenik di Sungai Selangor adalah rendah, menyatakn bahawa Sungai Selangor tidak mengalami pencemaran yang melampau. Kepekatan ion seperti natrium, kalium, kalsium dan nitrat adalah tinggi di sesetengah anak sungai, manakala di kawasan Bandar menunjukkan nilai yang rendah bagi parameter ini. E.coli yang tertinggi dicatatkan di kawasan bandar diikuti kawasan industri, kediaman dan pertanian. Model kualiti air dibentangkan menggunakan senario yang berbeza untuk mengkaji perubahan kualiti air Sungai Selangor. Daripada senario yang dijana dicadangkan bahawa, isu kualiti air sungai di lembangan Rawang dianggap penting untuk mewujudkan peningkatan yang ketara dalam lembangan tersebut dan juga di kawasan hilir lembangan sungai Selangor.

Kata kunci: Kualiti air, Logam berat, guna tanah, pencemaran, Sungai Selangor, IKA, GIS, QUAL2K

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LIST OF SYMBOLS AND ABBREVIATIONS

Ag	:	Silver
Al	:	Aluminum
AN	:	Ammonical Nitrogen
As	:	Arsenic
Cd	:	Cadmium
Fe	:	Iron
BOD	:	Bio-chemical Oxygen demand
CBOD	:	Carbonaceous Bio-chemical Oxygen demand
COD	:	Chemical Oxygen demand
Cu	:	Copper
Zn	:	Zinc
Pb	:	Lead
Ni	:	Nickel
ND	:	Not detected
E.coli	:	Escherichia coli
Eq.	:	Equation
Mn	:	Manganese
WQI	:	Water Quality Index
ICP-OES	:	Inductively coupled plasma optical emission spectroscopy
IWK	:	Indah Water Konsortium
DO	:	Dissolve Oxygen
Cr	:	Chromium
Co	:	Cobalt
Mg	:	Magnesium
MPN	:	Most probable number
NH_3-N	:	Ammonical Nitrogen
LOD	:	Limit of detection
HPI	:	Heavy metal pollution index
PS	:	Point source
NPS	:	Non-point source
TDS	:	Total dissolved solid
TCU	:	True color unit
EC	:	Electric conductivity
NTU	:	Nephelometric Turbidity Units
NWQS	:	National water quality standard
EQA	:	Environmental quality act
MWA	:	Malaysian Water Association’s
Na^+	:	Sodium ion
K^+	:	Potassium ion
NO_3^-	:	Nitrate ion
Ca^{2+}	:	Calcium ion
WQ	:	Water Quality
PCA	:	Principal component analysis
PE	:	Population Equivalent
HCA	:	Hierarchal cluster analysis
RSD	:	Relative standard errors
LOQ	:	Limit of quantitation
SI	:	Sub index
HW	:	Head water

R	:	Reach
GIS	:	Geographic Information System
Sg.	:	Sungai/River
St.	:	Station
D/S	:	Downstream
U/P	:	Upstream
SC	:	Scenario
mg	:	milligram
L	:	Liter
µg	:	Micro gram
Q	:	Discharge/ Flow
^0C	:	Degree Celsius
s	:	Conductivity
m_i	:	Inorganic suspended solids
o	:	Dissolved oxygen
c_s	:	Slowly reacting CBOD
c_f	:	Fast reacting CBOD
n_o	:	Organic nitrogen
n_a	:	Ammonia nitrogen
n_n	:	Nitrate nitrogen
p_o	:	Organic phosphorus
p_i	:	Inorganic phosphorus
a_p	:	Phytoplankton
IN_p	:	Phytoplankton nitrogen
IP_p	:	Phytoplankton phosphorus
m_o	:	Detritus
X	:	Pathogen
Alk	:	Alkalinity
c_T	:	Total inorganic carbon
a_b	:	Bottom algae biomass
IN_b	:	Bottom algae nitrogen
IP_b	:	Bottom algae phosphorus

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CHAPTER 1: INTRODUCTION

1.1 Background

Rivers are the main sources of fresh water for all human activities (Hema & Subramani, 2013). Rivers at their source are unpolluted, but as water flow downstream, the river is receiving point and non-point pollutant sources, resulting in negative impacts on river water quality. The degradation of water resources has increased the need for determining the ambient status of water quality, in order to provide an indication of changes induced by anthropogenic activities.

River basin management is an interdisciplinary task and includes both components from the natural sciences (hydrology, erosion and sediment transport, landscape assessment, hydrogeology, etc.) and the social sciences (socio-economics, ecological economics, behavioral theory, etc.)(Rode, Klauer, Krause, & Lindenschmidt, 2002). Water quality management is essential in ensuring the water supply to the entire population is adequate and safe to be consumed. An important component in the management of a river basin is the river itself since all the water resource activities that are carried out in the basin will have, in most cases, a direct impact on the ecological status of the river. Hence, we need to know the river's present ecological functioning and how human activities impact the quality of the water. Malaysia is blessed with plentiful rainfall of over 2000 mm per year and has 1800 rivers in the whole territory. Water sources in Malaysia are 97% from surface water and 3% from ground water (NAHRIM, 2009). In Malaysia, water demands increased from 9,543 m^3/day in 1995 to 15,285 m^3/day in 2010. This means that the increment is approximately 60% for 15 years which will give a projection of 20,338 m^3/day in 2020 or 113% during 25 years (DOE, 2003). It can be said that the increment of water demand is due to the increase in population over the years. In order to cater with the increment of the demand by the population, several control and maintenance operations need to be done so that the population will receive safe water.

The total population in Malaysia is 29.2 million people in 2012 which has increased 256 percent from 1960 when the population was smaller with 8.2 million people (DOSM 2013). In Malaysia, about 12 billion cubic meters of water are currently abstracted annually from the rivers, of which 22% is for water supply, 75% for irrigation and 3% for other uses(Mohamed, 1993).However, it is still facing water shortages; and has an irregular water supply (DOE, 2009).

There are about 468 water treatment plants (WTPs) in Malaysia. Most of the WTPs are using conventional treatment methods. As conventional method have limitations in treating polluted water for potable use, the availability of water supply in the country can be affected due to the issue of raw water quality, despite availability of adequate amount of polluted water in the rivers. According to the Department of Environment's (DOE) report in 2009, there are 116 rivers monitored, of which 42 are rated as clean, 61 are rated as slightly polluted and 13 rated as polluted(DOE, 2009). It is important to control and maintain the raw water quality in the river to ensure the safe quality of available water for multi-stakeholders (Fulazzaky, 2005).

The surface water resources are being polluted due to urbanization, increased industrial activities, intensive farming and over use of fertilizers in agricultural productions, discharge of untreated waste water and sewage outlets(Dhanalekshmy;, V, & MeeraBhaskar, 2014). Fresh water demand has increased tremendously due to the accelerated pace of industrial development and progressive growth of population (Ramakrishnaiah, Sadashivaiah, & Ranganna, 2009). To explain in more detail, squatter areas continue to use rivers as an open wastewater sewer and residential, commercial and industrial owners use drains and rivers as solid and liquid waste disposal sites.

The control practices are mostly focused on managing water shortages, floods, and pollution(Chan, 2012). To protect valuable water resources, one must understand the natural evolution of water chemistry under natural water circulation processes in combination with knowledge of the background of the study area(Mokhtar et al., 2009). Water quality management has been an important issue for decades, nevertheless, the current situation of water quality management in the world is quite far from satisfactory(Biswas, 1991). This is due to increasing pressure of economic development to facilitate the rapidly because the increasing population (Falkenmark, 1997).

Pollution generated by sewage water is one of the main problems of river pollutions. Sewage water is the water that flows after its use for domestic, industrial and other purposes. Water pollution happening from sewage is mostly detected in rising nations. The bacteriological quality of drinking water is of paramount importance and monitoring must be given the highest priority (S & D, 2012). Thoughtless clearance of sewage water leads to formation of a chain of problems like distribution of diseases, eutrophication and increase in biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO) and turbidity.

River water is also exposed to heavy metal contamination such as mercury, cadmium, iron and lead. 24 rivers exceeded the mercury limit of 0.0001mg/L, 36 rivers exceeded the lead limit of 0.01 mg/l, 44 rivers exceeded the iron limit of 1.00 mg/L and 55 rivers are polluted with cadmium that exceed the maximum limit of 0.001 mg/L(DID, 2010).Metal contamination has been shown to have serious effects on both the environment and humans. In the aquatic environment, the minute quantities of some metals, such as: copper, zinc, iron, manganese and nickel are essential for biological systems to function, but their excessive concentration can be toxic to living organisms. Other metals such as cadmium, mercury, arsenic and lead are non-essential and therefore have toxic effects on living organisms (Amiard, Amiard-Triquet, C., & Metayer, 1987; Barka, Pavillon, & Amiard, 2001; Hanna, Peters, Wiley, Clegg, & Keen, 1997).

The Water Quality Index (WQI) has been considered as one of the possible criterion for river water classifications based on the use of standard parameters for water characterization. The WQI is a numeric expression used to transform large quantities of water categorization data into a single number, which represents the level of water quality(Bordalo, Teixeira, & Wiebe, 2006; Sánchez et al., 2006). The Department of Environment, Malaysia are using the six parameters DO, pH, BOD, COD, SS and NH_3-N to determine WQI to define the status of river water quality (DOE, 2003; Sari & Wan Omar, 2008; Shuhaimi-Othman, M., C., & Mushrifah, 2007).

This research focused on the Selangor River basin which is an important surface water source for water supply in Malaysia. The Selangor River basin is the third largest river basin after the Langat and Bernam basins. The Selangor River basin, Malaysia - functions as the main source of water for the State of Selangor for domestic, industrial and irrigation purposes. The main and longest river that flows through the entire basin is the Selangor River, with tributaries from other sub-catchments converging with the Selangor River at various points of the basin. Approximately 60% of water consumption in Selangor and Kuala Lumpur is sourced from the Selangor River (Subramaniam, 2004). The Selangor River basin is characteristically rich with animal and plant life. Upstream of the basin, there is a green and pristine ecosystem with unique flora and fauna, and the world-renowned white-water rafting at Kuala Kubu Bharu (now obliterated by Selangor River Dam). The downstream area is blessed with the natural wonder of firefly colonies along the riverbanks of Selangor River from Kg. Kuantan to Kg. Belimbing, which is an internationally renowned tourist spot. However, the on-going rapid urbanization in the Selangor River basin has resulted in many environmental problems and conflicting interests of water use. Top help combat these consequences, a comprehensive water quality assessment study is crucial for this river basin to provide reliable information on pollution level of water quality and to identify the problematic areas.

Solving the water resource problems will require an improved understanding of the fundamental physical, biological, economic and social processes, and a better knowledge of how all these components operate together within watersheds. Computer technology has provided useful tools such as the Geographic Information System (GIS) in the process of achieving sustainable development. GIS offers powerful new tools for the collection, storage, management, and display of map-related information, whereas simulation models can provide decision-makers with interactive tools for understanding the physical system and judging how management actions might affect that system. It also supplies open and unclouded information to generate dependence and a collaboration among all parties involved in river basin management(Nyon, 1999). Land use impact on water quality and water quality trends analysis was carried out for the Han River basin, South Korea by generated thematic water quality maps using the spatial analyst tool of GIS(Chang, 2008). Recently, GIS has been used in the classification of a Brazilian watershed, based on thematic maps of water quality parameters(Borges, dos Santos, Caldas, & Lapa, 2015). Such GIS applications on spatial water quality analysis and understanding the land use impacts on water quality helps water resource managers target appropriate scales and factors for the improvement of water quality management efforts. Therefore, to assist the local environmental policy makers in preparing well-informed action plans, it is important that a GIS-based water quality assessment tool can be usefully developed for the spatial river water quality assessment system to assess pollution levels. However, no studies have been carried out so far on determining the level of contamination contributed by different land uses to the water quality parameters and WQI.

To better understand and manage the river, it is often helpful to use a water quality model. An intensive water quality modelling exercise is yet to be carried out to evaluate the current status and predict the effects of the available or proposed water quality control methods on the river basin. A proper and accurate water quality model can be used as an assessment and monitoring tool. Water quality modelling is the development of abstractions of phenomena of river systems. The main objective of river water quality modelling is to describe and to predict the observed effects of a change in the river system. The usual application of a water quality model is for forecasting changes in water quality parameters resulting from changes in the quality, discharge or location of the point or non-point input sources(Crabtree, Cluckie, Forster, & Crockett, 1986).

1.2 Problem Statement

Environmental issues in the Selangor river basin include pollution from both point sources and non-point sources. STPs, industrial and domestic wastewater are examples of point sources. However, nonpoint sources such as agricultural activities and erosion. As mentioned in the Selangor River Basin Management Plan 2007–2012, the pollutant loads of 10.5 tons BOD/day discharge the main river and its tributaries from the outlet of public and private sewerage treatment plants, individual septic tanks, industrial estates, wet markets, landfills, and aquacultures. The industrial estates release a major part of the metal loads. It was estimated that the respective metal loads of 181.4 and 912 kg/day are from discharged mineral micro pollutants (As, B, Cd, Cr, Cu, Hg, Ni, Pb, Sn, and Zn) and mineral pollutants (Fe and Mn), respectively, coming from 11 industrial estates (DID 2007).

The major use of water resources in the Selangor River basin is for portable water supply. More than two third of the Selangor population inhabit the floodplain, which provides highly fertile land for agriculture and land for housing, recreation, and industrial developments. This scenario has brought a conflict of harmony between human development, river environment and consequently increases the degree of pollution into river channels (Juahir et al., 2011). Currently, Selangor has a total population of 5,785,200 (M.D.O.S., 2013). Increases of population have increased the water demand for fresh water resources intake from the river.

The water shortage that occurs in Malaysia especially in urban area such as Selangor state has seriously affected by the large population. Rapid urbanization with increasing numbers of industries, sewage treatment plants (STPs), wet markets, mining activities and agriculture have had a significant negative impact on the Selangor River's water quality and its associated ecosystems. Consequently, water becomes polluted, losing its clarity, transparency and its self-purification rate decreases year by year. Air, and soil pollution and accumulated wastes in catchment areas, are transferred by surface runoff and flood channels to rivers and have a significant impact on water quality.

Water crisis issues in the Selangor river basin was highlighted in many newspaper articles. The article in the water supply situation in Selangor, Kuala Lumpur and Putrajaya dated 20 February 2013 with the title of "Water Supply Situation in Worrying Condition" has discussed about the water shortage problem that occur. The Star daily newspaper dated 19 March 2014, discussed about water crisis with the title "water crisis caused by over development and lack of planning". The Sun daily newspaper dated 7 July 2015 discussed about water supply problem with the title of "Level of water supply in Kalang Valley worrying".

1.3 Scope of Research

The scope of the study focused on water quality of the Selangor River basin which is an important surface water source for water supply in Malaysia. The analysis scope covers the analysis of water quality parameters as such in-situ analysis conducted for dissolved oxygen (DO), pH, turbidity, temperature, electrical conductivity (EC), total dissolve solid (TDS), sodium ions (Na^+), potassium ions, calcium ions (Ca) and nitrate ions (NO_3) while laboratory analysis were conducted for Biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonaical nitrogen (NH_3-N), total suspended solid(TSS), total coliforms and *E.coli* and heavy metals (As, Ag, Cd, Co, Cr, Cu. Ni, Pb, Fe, Al, Mg, Zn and Mn). WQI was calculated based on six parameters i.e. DO, pH, BOD, COD, NH_3N and TSS. Finally, a one dimensional (1-D) water quality model has been developed using the QUAL2K model.

1.4 Significance of Research

Evidently, the contamination of the Selangor River basin has been continuously increasing during the last decade due to the increment of urban activities, industrial activities, agricultural activities, and commercial activities, and residential areas. The identification of vulnerable tributaries of the Selangor River basin by water quality index with GIS application and predictive scenarios modeling by QUAL2K enhanced the significance of the research. The GIS and the application of water quality model that was considered in this research are important and required for the decision makers of sustainable water quality monitoring. A spatial correlation between prevailing water quality and potential pollution sources has been established based on the spatial and temporal water quality trends with GIS application. The developed map is more convenient, interactive and efficient than traditional paper maps. It is a physical map that can be easily edited and modified at any time using GIS tools. In addition, the developed map connects the features' spatial data with their tabular databases, which makes it easy to analyze the data for better results that can assist with decision making. Water quality model provides a clear understanding on the control of point sources to maintain a reasonable water quality class at the downstream of the Selangor River. This will assist decision makers to identify the spatial levels and reasons for water quality problems, such as land use practices and their effects on the water body of the Selangor River Basin. Furthermore, the outcomes of the research can provide a benchmark level to be used in the exploration of strategies to protect human health and the ecosystem and an environmental reference for water pollution control of the Selangor River basin.

1.5 Research Objectives

This research aims to achieve the main goal through the following objectives:

1. To study the status and trends of water quality parameters of Selangor River's water bodies.
2. To determine heavy metal concentrations in Selangor River's water.
3. To establish the relationship between land use and the river water quality.
4. To develop a water quality model for the Selangor River basin for sustainable management.

1.6 Research Outline

The background of the research, a recent problem statement, significant of the research, objectives of the research and scope of the research are included in the main subjects of Chapter 1. Chapter 2 provides a review on the water quality monitoring, water quality parameters, pollution sources, water quality status of study area, standards, guide lines and previous studies. 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. Chapter 4 concentrates on the in-situ and laboratory analysis results, data analysis, assessment and discussion of the research, the results of the water quality model calibration, validation and different scenarios of the model, while 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 research are discussed in detail based on the existing studies. The references used are mostly recent papers, however; some references predating, 2008 are used due to their major contribution to the field and their global recognition.

2.2 River Network System

A river is part of a large natural stream system. A river network is a dynamic part that drains a watershed and transports sediment. It can also be defined as a large natural stream of water flowing in channels or large bodies. The river network system is a group of rivers draining water into the sea. Alternatively, it can also be defined as a watershed that drains into a large water body by a group of rivers. A river system consists of a river source (head water), a main river, tributaries, confluence, a river mouth and a sub-basin. Water flowing near the source is referred to as ‘upstream’, while water near the mouth is called ‘downstream’. Figure 2.1 illustrates a sample river system (Lord, Germanoski, & Allmendinger, 2009). The river is begins at a river source also known as head water; the river source is commonly located in mountains or hilly areas. The river starts from a source and continues to flow into a lake or an ocean, with the main body being called the main river. A smaller stream or river that joins a main river is known as a tributary. The point where a tributary meet the main river is known as confluence. The location where the river meets the lake or an ocean is called the river mouth. The direction of or nearer to the source of a river is known as upstream and the direction of or nearer to the river mouth is call downstream.

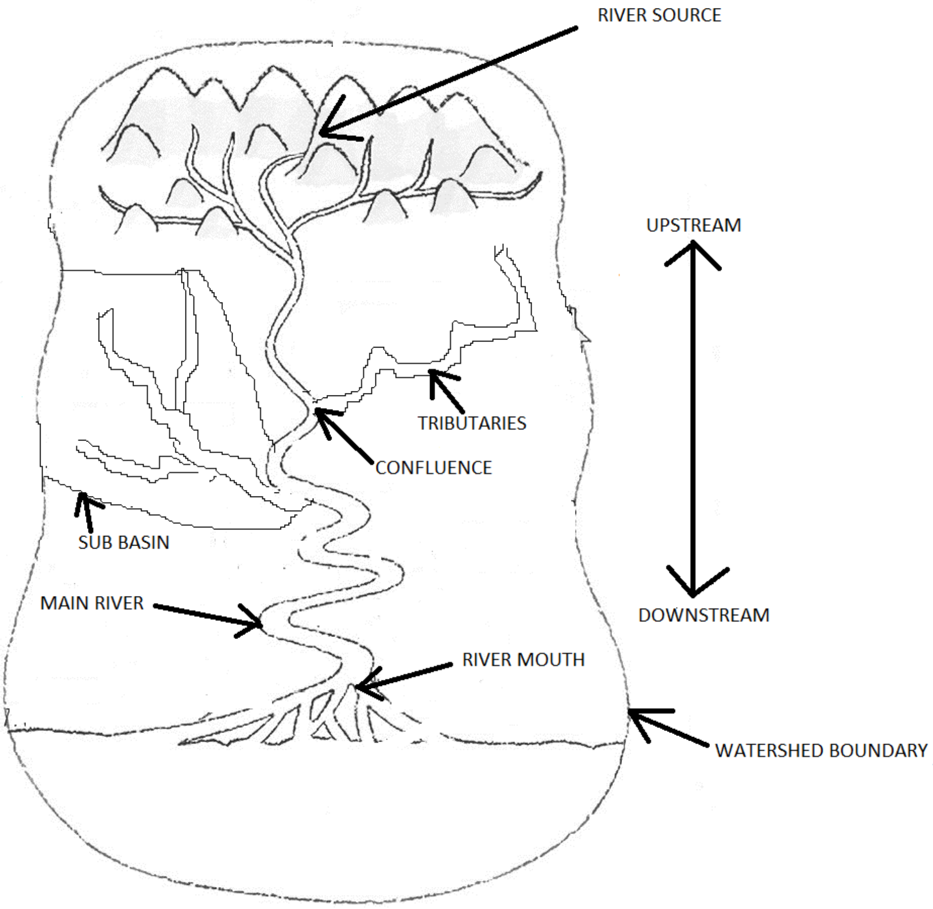


Figure 2.1: River network system

2.3 Water quality monitoring

River water quality has become a crucial issue in many countries, In the future, freshwater will be a scarcer resource so a river water quality monitoring program is necessary for the protection of freshwater resources (Pesce & Wunderlin, 2000). Water quality monitoring is a key component in efforts to protect water resources. Information provided by water quality monitoring can help identify the actual environmental impacts resulting from pollution, detect trends in water quality, warn of potential problems, and, at times, locate sources of pollution and stimulate corrective action in problem areas (Keeney, 1996; US, 1990). Table 2.1 tabulates the natural processes that affecting water quality.

Table 2.1: Important natural processes affecting water quality (Bartram & Balance., 1996).

Process type	Major process within water body	Water body
Hydrological	Dilution Evaporation Percolation and leaching Suspension and settling	All water bodies Surface waters Groundwater Surface waters
Physical	Gas exchange with atmosphere Volatilization Adsorption/desorption Heating and cooling Diffusion	Mostly rivers and lakes Mostly rivers and lakes All water bodies Mostly rivers and lakes Lakes and groundwater
Chemical	Photo degradation Acid–base reactions Redox reactions Dissolution of particles Precipitation of minerals Ionic exchange	Lakes and rivers All water bodies All water bodies All water bodies All water bodies Groundwater
Biological	Primary production Microbial die-off and growth Decomposition of organic matter Bioaccumulation Bio magnification	Surface waters All water bodies Mostly rivers and lake Mostly rivers and lakes Mostly rivers and lakes

Besides natural processes affecting water quality, there are also anthropogenic impacts, such as man-induced point and non-point sources and alteration of water quality due to water use and river engineering projects (e.g., irrigation, damming, etc.) (Chapman, 1996). The degradation of water resources has increased the need for determining the ambient status of water quality, in order to provide an indication of changes induced by anthropogenic activities. Water quality monitoring refers to the acquisition of quantitative and representative information on the physical, chemical, and biological characteristics of a water body over time and space(Sanders et al., 1983).

2.4 Monitoring Network Design

The purposed of water quality monitoring design is to capture data from which management and restoration information is extracted. It generally involves a vast number of activities, which are extensively described in (Sanders et al., 1983) and are summarized in Table 2.2.

Table 2.2: Water quality monitoring activities (Sanders et al., 1983)

Main Activity	Specific activities
1. Network design	Station locations; Variable selection; Sampling frequencies.
2. Sample collection	Sampling techniques; Field measurements; Sample preservation; Sampling points; Sample transport
3. Laboratory analysis	Analysis techniques; Operational procedures; Quality control; Data recording
4. Data handling	Data reception; Screening and verification; Storage and retrieval; Reporting; Dissemination
5. Data analysis	Basic summary statistics; Regression analysis; Water quality indices; ‘‘Quality control’’ interpretation; Time series analysis; Water quality models
6. Information utilization	Information needs; Reporting formats; Operational procedures; Utilization evaluation

The basic principles of monitoring network design and site selection criteria for individual monitoring stations have been evaluated and applied (Esterby, El-Shaarawi, & A.H., 1992; Lettenmaier, Anderson, & Brenner, 1986; Loftis, McBride, & G.B. Ellis; Skalski & Mackenzie, 1982; Smith & McBride, 1990).Later studies have focused greater attention on the effective design of water quality monitoring networks using various types of statistical and/or programming techniques, such as integer programming, multi-objective programming, kriging theory and optimization analysis (Cieniawski, Eheart, & Ranjithan, 1995; Dixon & Chiswell, 1996; Dixon, Smyth, & Chiswell, 1999; Harmancioglu & Alpaslan, 1992; Hudak, Loaiciga, & Marino, 1995; Timmerman et al., 1997).

A review of monitoring approaches shows that many water quality monitoring network designs use a conceptual network as a guide in the design of the actual network (Woolfenden, 1984). A conceptual network represents an ideal network, in which the network is free from all budgetary constraints and, hence, where the network is solely based on hydrologic conditions, land use, existing water quantity and quality data, and the location of contamination sources. An ideal network can serve as a basis for future expansion of the actual network. For example, sampling stations can be added to the actual network if additional financial resources become available (W.E.Templin, 1984).

The monitoring objectives can be set based on operational and management requirements for monitoring programs and may include helping to establish water quality standards, determining water quality status and trends, identifying impaired waters, identifying the causes and sources of water quality problems, implementing water quality management programs and evaluating program effectiveness(U.S. Environmental Protection Agency, 2003).The periodic reviews of a water quality monitoring program should therefore, not only take into account changes in hydrologic conditions, but also shifts in management objectives (Herricks, 1982; Kohonen, 1984) as well as changes in technology and data analysis methods.

2.5 Water Quality Parameters

Water from natural sources almost always contains living organisms that are integral components of the biogeochemical cycles in aquatic ecosystems. However, some of these, particularly bacteria, protists, parasitic worms, fungi, and viruses, can be harmful to humans if present in water used for drinking. The availability of water and its physical, chemical, and biological composition affect the ability of aquatic environments to sustain healthy ecosystems: as water quality and quantity are eroded, organisms suffer and ecosystem services may be lost. The health of a river and ecosystem is completely dependent on good water quality. If the basic conditions that are needed for aquatic life to survive are not adequate, populations become stressed. Water living organisms may die due to poor water quality. Therefore, in order to determine the health of the river water various water quality parameters need to be measured so that it is safe to use for any purpose. To assess the water quality of rivers several parameters need to be considered: physical, chemical, biological and radioactive.

2.5.1 Physical Parameters

The physical parameters that are consided for water quality assessment are turbidity, total suspended solids, total dissolved solids, temperature, etc. All of these physical parameters have a significant impact on water quality. Temperature is an important parameter which influences the growth rate and survivability of aquatic life. Physical, biological, and chemical characteristics of river water are directly affected by temperature. An optimum temperature and tolerances of extreme temperatures vary for different species (Davis & McCuen, 2005).

Within a specific range of water temperatures most waterborne animals and plant life can survive while some of them can tolerate extreme changes of temperature (WSDE, 2002). Turbidity is a measure of the fine particles that are suspended in water. There is a possibility of harm of the habitats for fish and other aquatic organisms due to high concentration of particles in the water (Said, Stevens, & Sehlke, 2004). In the water treatment process, filtering processes take a long time for highly turbid water. The disinfectant process also become hampered as many pathogenic organisms may be encased in the particles (Avvannavar & Shrihari, 2008). Particles of sizes larger than 0.45 μm are generally referred to as total suspended solids (TSS). Many pollutants (e.g. toxic heavy metals) can be attached to TSS, which is harmful for the aquatic habitat and aquatic organisms. The amount of sunlight that can penetrate the water can also be reduced due to a high amount of suspended solids. TDS refers to dissolved minerals into the water and indicates the presence of dissolved materials which cannot be removed by conventional filtration.

2.5.2 Chemical Parameters

The common chemical parameters that are used to assess the water quality are pH, DO, BOD, COD, NO_3, TP and metals. The pH is a measure of the acid balance of a solution and is defined as the negative of the logarithm to the base 10 of the hydrogen ion concentration. pH is an important variable in a water quality assessment as it influences many biological and chemical processes within the water body as well as all processes associated with **w**ater supply and treatment. A high value of pH indicate high alkalinity which may be present due to carbonates of calcium and magnesium in the sample water (DOE., 2010). A high concentration of H^+ activity causes lowering of the pH value, meaning the water is acidic (Davis and McCuen, 2005).

DO is important to the respiration activities of the aquatic organisms and effluents, yet very low DO may have a negative impact on the sustainability of the rivers in the basin(Dadolahi-Sohrab, A., & Fadaei-Nassb, 2012). Oxygen is essential to all forms of aquatic life, including those organisms responsible for the self-purification processes in natural waters. The oxygen content of natural waters varies with temperature, salinity turbulence, the photosynthetic activity of algae and plants and atmospheric pressure. The solubility of oxygen decreases as temperature and salinity increase. Biological Oxygen Demand (BOD) is an indication of the organic load and it is a pollution index for water bodies receiving organic effluents (Ndimele, 2012).BOD is used as the index of organic pollution of waste water that can be decomposed by bacteria under anaerobic conditions (Dzwairo Bloodless, Otieno Fred A.O., & Ochieng George M., 2010). In natural water, a minimum of 2 to 7 mg/L of DO should be available for the degradation of an oxidizable organic (Avvannavar and Shrihari, 2008).The BOD results gives amount of biodegradable waste present in the water (WSDE, 2002). COD is a measure of the amount of organic and inorganic oxydizable compounds in the water. COD is a useful measure of water quality, as the amount of total oxidizable pollutants can be determined in surface water by a COD test.

Nitrates are important in aquatic environments as these compounds, which contain nitrogen, act as nutrients in streams and rivers. Thus, nitrites can cause serious illnesses in fish (Davis and McCuen, 2005). Phosphorus is essential to all living organisms, but at high concentrations in water it can speed up eutrophication and causes algae blooms which are harmful to most aquatic organisms. This can result in a fish kill and the death of any organisms (Said *et al.*, 2004). Heavy metals are introduced into river water through surface runoffs and wastewater discharge from industries. Some heavy metals such as Cu, Zn, Fe, Mn and Ni are vital for biological systems to function in the aquatic environment, but excessive concentrations can be toxic to living organisms. Metal nutritional requirements differ substantially among animal or plant species and also vary with element types(Adepoju & Adekoya, 2014). Human activities such as mining and heavy industry can result in higher concentrations than those that would be found naturally(Carr & Neary, 2006).

2.5.3 Biological Parameters

The biological parameters that should be considered to assess the quality of water are fecal coliform and groups of microorganism. Fecal coliform are bacteria whose presence indicates that the water may have been contaminated with human or animal fecal material. If fecal coliform counts are high in a site, it is very likely that pathogenic organisms are also present, and this site is not recommended for swimming and other contact recreation (Said *et al.*, 2004). Various health related problems due to contaminated waters are diarrhea, abdominal cramps and vomiting due to salmonella; cholera due to vibrio cholera; and, infection of lungs due to mycobacterium (Avvannavar and Shrihari, 2008).

2.6 River Water Pollution

In general, river water pollution means that unexpected changes of physio-chemical and bio-chemical properties of river water which may cause harm to human health. Pollution also may be defined as a change in the environment caused by man's discharge of matter or energy into it , which alters the natural function of an ecosystem(Kendeigh, 1961). By dilution and self-purification factors rivers are able to assimilate a certain amount of pollution without serious effects. Due to urbanization, industrialization and rapid population growth, excessive pollutant discharge into a river causes it to be unable to integrate pollutants. River pollution affects water supply, plants and organisms living in and around these water bodies.

Most of the Malaysian rivers are degraded by both point and non-point sources of pollution. The major sources of point sources pollution are sewage treatment plants, agro-based industries, manufacturing industries, sullage or grey-water from commercial and residential premises, and pig farms whereas NPS sources are mainly diffused sources such as agricultural activities and surface runoff (DOE., 2010).

2.7 Point Sources (PS)

The point sources included discharge of treated wastewater from sewage treatment plants and industrial water treatment plants. The amount of pollutant that could be discharge by an organization is based on the site specific and region-specific characteristics of the water body. In the year 2006, DOE recorded 18,956 water pollution point sources comprising mainly of sewage treatment plants (9,060: 47.79% inclusive of 601 Network Pump Stations), manufacturing industries (8543: 45.07%), animal farms (869: 4.58%) and agro-based industries (484:2.25%). The number of sewage treatment plants under the management of Indah Water Konsortium Sdn. Bhd (IWK) had increased to 9,060 in 2006 compared to 8,782 plants in 2005. Selangor had the largest number of sewage treatment plants (2,563:28.3%) followed by Perak and Johor.

2.7.1 Sewage

One of the main pollutants originates from point sources sewage. Domestic sewage refers to wastewater that is discarded from households. Sewage, also known as waste water, is the mix of water and waste from domestic and industrial sources, which are flushed into the sewer. It is also referred to as sanitary sewage if the water contains a wide variety of dissolved and suspended impurities. The content of sewage includes organic matter, animal and human excreta. Since sewage is full of organic matter, the numbers of microorganisms in it are numerous. These organisms consume oxygen to complete aerobic digestion of organic matter. Increase in organic matter might contribute to imbalance in the aquatic ecosystems known as oxygen depletion. Depending on their origin, wastewater can be classed as domestic waste, industrial or commercial, agricultural or surface runoff. If it is not properly treated before being discharge into river, it can severely affect the water quality primarily with organic and pathogenic pollution.

In the case of organic pollution such as that contributed by BOD, it amounts to a very small fraction of the sewage by weight. However, it is large by volume and contains impurities such as organic materials and plant nutrients that tend to rot. It is among the most important parameters for the design and operation of STPs.

2.7.2 Industry

The industry sector in Selangor expands every year. The premises (manufacturing industrial premises) which are subject to EQA 1974 have increased from 1,308 in 2006 to 1,508 in 2007. Therefore, increasing environmental enforcement is needed to control the industrial effluents. According to environmental enforcement data in Annual Report 2007 by DOE Selangor, 1,828 enforcement visits were carried out at 1,508 premises. It was found that 65% of the premises had complied with the EQA 1974 where as 35% of the premises had not complied with it.

The industry of metal and electric planting (44%) has the highest non-compliance with Environmental Quality (sewage and industrial effluents) Regulation 1979, followed by the food and beverage (25%), paper (16%) and electronic (10%) industries. Besides this, the plastic, metal fabrication/engineering, automotive/ workshop, paint-based, and manufacturing industries have the minimum non-compliance between 2 and 5%. Heavy metal and oil and grease (O&G) were the major parameters causing metal and electric plating manufacturing to fail to comply with the said regulation. Meanwhile, food and beverage manufacturing industries failed because of BOD, SS and O&G.

2.7.3 Landfill

All non-hazardous solid wastes such as food residues, glass, metals, papers, plastic, diapers and garden waste generated by households, commercials sites, institutional sites and industrial premises are disposed of at landfill sites (at either sanitary or non-sanitary landfills), except for some which have been put aside for recycling before being disposed of.

Various factors together create condition causing tremendous leachate from solid waste disposed of at the landfill sites. These factors include the fact that more than 50% of solid waste in Malaysia comprises of food residues, the hot and humid climate, and time. Leachate is highly contaminated with hundreds types of contaminants such as dissolved organic matter, inorganic macro components, heavy metals, xenobiotic organic compounds, etc. Of the 3 operating landfill sites within the Sungai Selangor basin areas, only Bukit Tagar Sanitary landfill has proper leachate treatment system in place. Without proper leachate treatment facilities, contaminant from the leachate that enters the rivers from landfill sites could be significant.

2.7.4 Illegal Dumping

Many cases of illegal dumping of solid waste were reported in the Selangor basin area. Yet, there is no specific way to detect and control the illegally dumped activities. The actual amount of solid waste being illegal dumping is unknown. Most of the illegal dumping of solid waste was small scale, and they were mainly found by the road side of some outskirt areas as well as around abandoned housing and industrial areas.

2.7.5 Log Boom

Besides illegal dumping in rural areas, solid waste has also been dumped into the river. As the waste flows along the river, it will be trapped in drains and this can cause flash floods. To minimize flash flood occurrences, DID have installed waste traps at various locations. Three log booms have been installed within the basin, i.e., Sungai Buloh (Kampung ljok), Sungai Selangor (Kampung Rantau Panjang) and Sungai Sembah (Rawang) . It was reported that an average of 90 tons of solid waste have been removed from the three log booms monthly since between 2004 and 2008. The volume of solid waste trapped was high as compared to log booms in other river basins, excluding the log boom located at Sungai Klang, Harper Road.

2.7.6 Sand Mining

Sand mining is becoming an increasingly relevant environmental issue as the demand for sand increases in industry and construction sectors. Being a direct and obvious cause of erosion, it also has a great impact on nature. Disturbance of underwater sand causes the water to become turbid which is harmful for water abstraction at water intake points. Besides that, it also destroys fisheries and thus, people who rely on fishing for their livelihoods are faced with problems. Although the law regulates sand mining, many illegal activities are still carried out which have subsequently doubled the determined quantity. It was found that increased turbidity was not only caused by sand mining activities due to the river bank erosion but was also contributed to by the oil/diesel spill from the machineries used for sand dredging and washing.

2.7.7 Livestock Farming

The dominate livestock farming in Sungai Selangor basin areas is cattle farming followed by poultry. The main environmental problem coming from livestock farming appears to be from cattle farming where waste management is almost absent and animal manure is directly washed into the river, discharged into the streams or seeped into the ground. Unlike cattle farms, waste from poultry farms is better managed: manure is collected and sold as fertilizers by the farmers. However, pollution from poultry farms is still caused by other activities such as washing of cages and surface run-off after the rain. Information on the pollution caused by animal husbandry activities is very limited and difficult to estimate. The common indicators such as BOD, COD, and NH_3-N and bacteria counts (especially E. coli and total coli form) are important parameters to be analyzed in order to determine the pollution level caused by farm waste.

2.7.8 Wet Markets/ Restaurants/Food Outlets

Apart from the pollution sources mentioned above, wastewater discharged from restaurants, food stalls and wet markets will also pollute the water body. Restaurants and wet markets at Bukit Sentosa have been selected as one of the 8 water-related pilot projects under IRBM. The storm drain in Bukit Sentosa of Hulu Selangor has been polluted by the wastewater discharged from 3 restaurants and wet markets where around 650 chickens are slaughtered daily. An ecological and almost invisible wetland was constructed to treat the dry weather flow from the storm drain. The system is run without any power supply and does not occupy land as it is located on the banks along the monsoon drain.

2.8 Non-point Source Pollution (NPS)

The pollution that caused due to rainstorm is known as non-point source pollution. The pollutant are washed away through rain water and accumulated on surface of the land and finally drains into the water bodies. Human activities cause the most of the pollutants while the rests are due to natural degradation of soil and other components of the urban environment.

2.8.1 Chemo-Physical Pollutants

Turbidity, TSS, TDS, conductivity and pH may significantly influence by chemo-physical pollutants. In the heavy industrial area pH may be a problem due to the potential of generating acid rain and runoff.

2.8.2 Organic Pollutants

These pollutants are composed of organic matter, which is degraded rapidly and has the potential to cause oxygen depletion in the receiving water bodies. These pollutants are expressed in terms of BOD, COD, total organic carbon (TOC), O&G, etc. However, BOD and COD are the most common parameters studied the NPS pollution monitoring and control (US EPA, 1983; Pitt *et al.*, 1993).

2.8.3 Inorganic Pollutants

Inorganic pollutants are mainly metals. Contamination of natural environmental components such as soil, sediment, water resources and biota by heavy metals is one of the major concerns impacting environmental problems worldwide as these metals are indestructible and most of them have toxic effects on living organisms when they exceed a certain concentration(Arnous & Hassan, 2015).

The increasing tendency of heavy metal concentrations being present in the environment has caused great concerns worldwide(Tang, Huang, & Pan, 2014). Water bodies may consistently hold anthropogenic metals ultimately transferred to humans through the food chain. Surface water quality is an essential component of the natural environment and is considered the main factor for controlling environmental health and potential hazards(Wan Ying Lim, Ahmad Zaharin Aris, & Sarva Mangala Praveena, 2013). Both industrial activities and urbanization have greatly increased the heavy metal burden in the environment(Shikazono, Tatewaki, Mohiuddin, Nakano, & Zakir, 2012).

Some of Malaysian's river water is contaminated with As, Ag, Cd, Cu, Pb, and Zn, while some coastal sediments are contaminated with Pb, Zn and Cd as reported in previous studies (DOE, 2009; Kamaruzzaman, Waznah, & Nurulnadia, 2011; C. K. Yap et al., 2011; Zulkifli, 2010). The common sources of metal pollution in developing countries including Malaysia are from anthropogenic activities such as manufacturing, agriculture, sewage, and motor vehicle emissions (Shazili, Yunus, Ahmad, Abdullah, & Rashid, 2006). Recent reports of elevated total dissolved metal levels in aquatic environments have attracted worldwide attention (Idriss & Ahmad, 2012; Kamaruzzaman et al., 2011; W.Y. Lim, A.Z. Aris, & S.M. Praveena, 2013; J. Wang et al., 2012; C. K. Yap, Pang, B.H., , 2011).

Pollution of water sources by heavy metals are well documented in the literature (Brown-Adiuku & Ogezi, 1991; Edet & Ntekim, 1996; Xibao, Shen, & Licheng, 1996; Yiping & Min, 1996; Zhongyi, 1996), with almost all studies concluding that regular monitoring and assessing water quality is essential because of the increasing concentrations of heavy metals in potable water, which increase the threat to health and the environment.

2.8.4 Toxic Pollutants

Besides heavy metals, toxic pollutants in urban runoff are mainly referred to as herbicides, pesticides, PAHs, PCBs and other carcinogenic elements including the most common heavy metals (Pitt *et al*. 1993; Lee and Lee, 1993).

2.8.5 Microbial Pollutants

Pathogenic bacteria in water sources are a risk to human health and microbial study of them is essential. The goals of river water quality monitoring consist in directly targeting the sources of contamination, by using simple and quick indicators. The main parameters of river water quality monitoring are measurements of faecal bacteria such as (*E. coli* or *Enterococci*). Enteric viruses, which play a major role in waterborne diseases, are rarely investigated due to the detection limits of commonly applied methods (Hundesa, Maluquer de Motes, Bofill-Mas, Binana-Gimenez, & Girones, 2006; Poma, Gutiérrez Cacciabue, Garcé, Gonzo, & Rajal, 2012). Microbial contamination the water is often of faecal nature related to humans such as water sewage treatment plants, combined sewage overflow, non-collective sewage systems, domesticated animals (manure spreading, pit stock overflow), or wildlife.

The main origins of microbial contamination of natural aquatic resources are point sources such as discharge of water treatment plants, decontamination stations, hospitals, and industries. Correlation between pathogens concentrations and urban activities is well documented (Marsalek & Rochfort, 2004; Selvakumar & Borst, 2006) and non-point sources are also considered. The abundance and importance of pathogens in water depend on factors such as the contamination level, pathogens' persistence in water bodies, biological reservoirs (including aquatic plants and sediments) and the ability of pathogens to be transported (Dechesne et al., 2006). The land use management practices and the size of the watershed also influence the survival of microorganisms (Ferguson, Charles, & Deere, 2008; Harmel, Karthikeyan Gentry, & Srinivasan, 2010; James & Joyce, 2004).

2.9 Malaysian Standards, Regulation and River Water Classification

In relation to the water quality Malaysian guidelines produced include the National Water Quality Standard (NWQS), Environmental Quality Act (EQA) and the Malaysian Water Association's (MWA) criteria for raw water intakes. The water quality parameters standards and a description of the classes in terms of utility are given in Appendix -A. The Water Act 1920 states that "the entire property and control of all rivers in any State is and shall be vested solely in the Ruler of such State". If required, the Federal Government shall play its role only for the water bodies shared or bordered by several states. The other legislations to control water pollution are the Mining Act 1929, the Forest Enactment 1935, the Drainage Works Ordinance 1954 and the Land Conservation Act 1960. The latest is the Environmental Quality Act 1974 (revised in 1979 and 2009), which provides the regulatory control of point pollution sources.

The DOE, Malaysia developed a WQI system to analyse trends in river water quality based on six parameters which are DO, pH, BOD, COD, SS and AN. Fundamentally, the WQI and the NWQS of Malaysia serve as the basis for environmental assessment of a watercourse in relation to pollution load categorization and designation of classes for beneficial uses. The NWQS, which was developed by the DOE, classifies rivers into 5 classes (I-V) according to beneficial usage. The classes are related to the values of WQI. WQI is a numeric expression used to express different water quality parameters into a single number which represents the water quality level. The WQI is simply a general indicator to the health of a river at a specific site.

2.10 Water Quality Modeling

Water quality modeling and simulation is rapidly becoming an integral part of environmental management. Water shade management planning requires a range of analytical techniques that assess the present status the environment and also provide predictions of various strategies to control pollutants. In this respect, the Environmental Protection Agency of United States developed management or engineering tools to control pollution and help to improve water quality goals (Bowie et al., 1985).River water quality models are generally used to predict the water quality parameters along the river system reaches, resulting from the interactions of the physical , chemical and biological processes of oxygen demand. The model can be utilized to predict the effect of the available or proposed water quality control methods on water quality. Therefore, the water quality models can be used to assist watershed management decision-making in achieving the designated water quality objectives. The common surface water quality models are listed in Table 2.3.

Table 2.3: Main surface water quality models and their versions and characteristics(Q. Wang, Li, Jia, Qi, & Ding, 2013).

Models	Characteristics	Model version
Streeter-helps models	Streeter and Phelps established the first S-P model in 1925. S-P models focus on oxygen balance and one-order decay of BOD and they are one-dimensional steady-state models.	S-P model ; Thomas BOD-DO model; O'Connor BOD-DO model; Dobbins-Camp BOD-DO model
QUAL models	The USEPA developed QUAL I in 1970. QUAL models are suitable for dendritic river and non-point source pollution, including one-dimensional steady-state or dynamic models.	QUAL I,QUAL II, QUAL2E, QUAL2E UNCAS, QUAL 2K
WASP models	The USEPA developed the WASP model in 1983.WASP models are suitable for water quality simulation in rivers, lakes, estuaries, coastal wetlands, and reservoirs, including one-, two-, or three-dimensional models.	WASP1-7 models
QUASAR model	Whitehead established this model in 1997. QUASAR model is suitable for dissolved oxygen simulation in larger rivers, and it is a one-dimensional dynamic model including PC QUA SAR, HERMES, and QUESTOR modes.	QUASAR model
MIKE models	Denmark Hydrology Institute developed these MIKE models, which are suitable for water quality simulation in rivers, estuaries, and tidal wetlands, including one-, two-, or three dimensional models.	MIKE11, MIKE 21, MIKE 31
BASINS models	The USEPA developed these models in 1996. BASINS models are multipurpose environmental analysis systems, and they integrate point and nonpoint source pollution. BASINS models are suitable for water quality analysis at watershed scale.	BASINS 1, BASINS 2,BASINS3,BASINS 4
EFDC model	Virginia Institute of Marine Science developed this model. The USEPA has listed the EFDC model as a tool for water quality management in 1997. EFDC model is suitable for water quality simulation in rivers, lakes, reservoirs, estuaries, and wetlands, including one-, two-, or three-dimensional models.	EFDC model

In connection to water quality management, water quality modeling tools have been used in a wide variety of applications in many countries throughout the world. The QUAL2K model has been utilized in other areas for simulation of river water quality and is found throughout the literature (Bottino, Ferraz, Mendiondo, & Calijuri, 2010; Cho & Ha, 2010; Fan, Ko, & Wang, 2009; Kannel, Lee, Lee, Kanel, & Pelletier, 2007; Ma, Nambi, & Suresh Kumar, 2011; Marzouni et al., 2014; Moalla, Mirsanjari, & Zarekar, 2013; Park & Lee, 2002; Zhang, Qian, Li, Yuan, & Ye, 2012; Zhang et al., 2014). In recent decades, QUAL2K has been used to develop a surface water quality model. For example, a QUAL2K model for river water quality was used to simulate the effects of a range of pollution load reduction scenarios in the Wujin River. Results from this simulation showed that controlling the emission of pollutants from their sources is the best course of action for pollution prevention and control (Zhang et al., 2014). A QUAL2K model of the water quality of the Taihu Lake basin was investigated and researchers concluded that the water quality of this lake was impacted by discharge of wastewater and effluent in the Hongqi River that flows into Taihu Lake (Zhang et al., 2012). (Z. Zainudin, N.A. Rahman, &, & Mazlan, 2010), investigated the effect of pollution from industrial areas to the Tebrau River, Malaysia using a QUAL2K model and concluded that industrial discharge was the major contributor of pollutants downstream. They recommended the QUAL2K model as an outstanding tool in managing the river basin. However, no study has been carried out so far on a water quality model for the Selangor River using QUAL2K. Thus, a QUAL-2K model will be run and calibrated for this study.

2.10.1 Description of QUAL2K model

QUAL2K (or Q2K) is a river and stream water quality model that is intended to represent a modernized version of the QUAL2E (or Q2E) model (Brown & Barnwell, 1987). The following features characterize QUAL2K:

(i) one dimensional (the channel is well-mixed vertically and laterally);

(ii) steady-state hydraulics (non-uniform, steady flow is simulated);

(iii) diurnal heat budget (the heat budget and temperature are simulated as a function of meteorology on a diurnal time scale);

(iv) diurnal water-quality kinetics (all water-quality variables are simulated on a diurnal time scale);

(v) heat and mass inputs (point and non-point loads and abstractions are simulated).

2.10.2 River segmentation in QUAL2K

In a river system consisting of one river only (no tributaries), the QUAL2K model divided the river as a series of reaches. These represent stretches of river that have constant hydraulic characteristics (e.g., slope, bottom width, etc.). As represented in Figure 2.2, starting from the headwater of the river's main stem, the reaches are numbered in ascending order. In such a way, both point and non-point sources along with point and non-point withdrawals (abstractions) can be positioned anywhere along the channel's length.

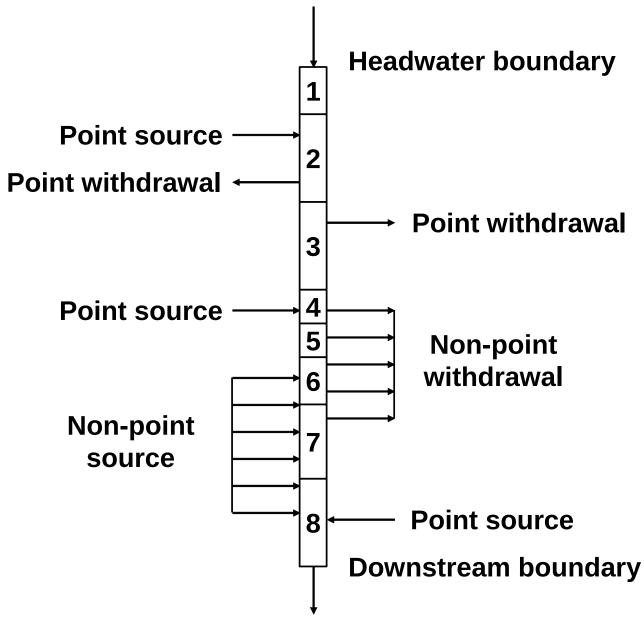


Figure 2.2: Segmentation of river network in QUAL2K (river without tributaries)

In river systems with tributaries, the reaches start with reach 1 at the headwater of the main stem, followed by reaches in ascending order (Figure 2.3). The numbering continues at that tributary's headwater when a junction with a tributary is reached. Both the headwaters and the tributaries are also numbered consecutively following a sequencing scheme similar to the reaches. Furthermore, a river system's major branches (i.e. the main stem and each of the tributaries) are referred to as segments.

The output of the model is on a segment basis. It runs individual plots for the main stem as well as each of the tributaries. Therefore, any reach of the model can be divided into a series of equally-spaced elements (Figure 2.4).

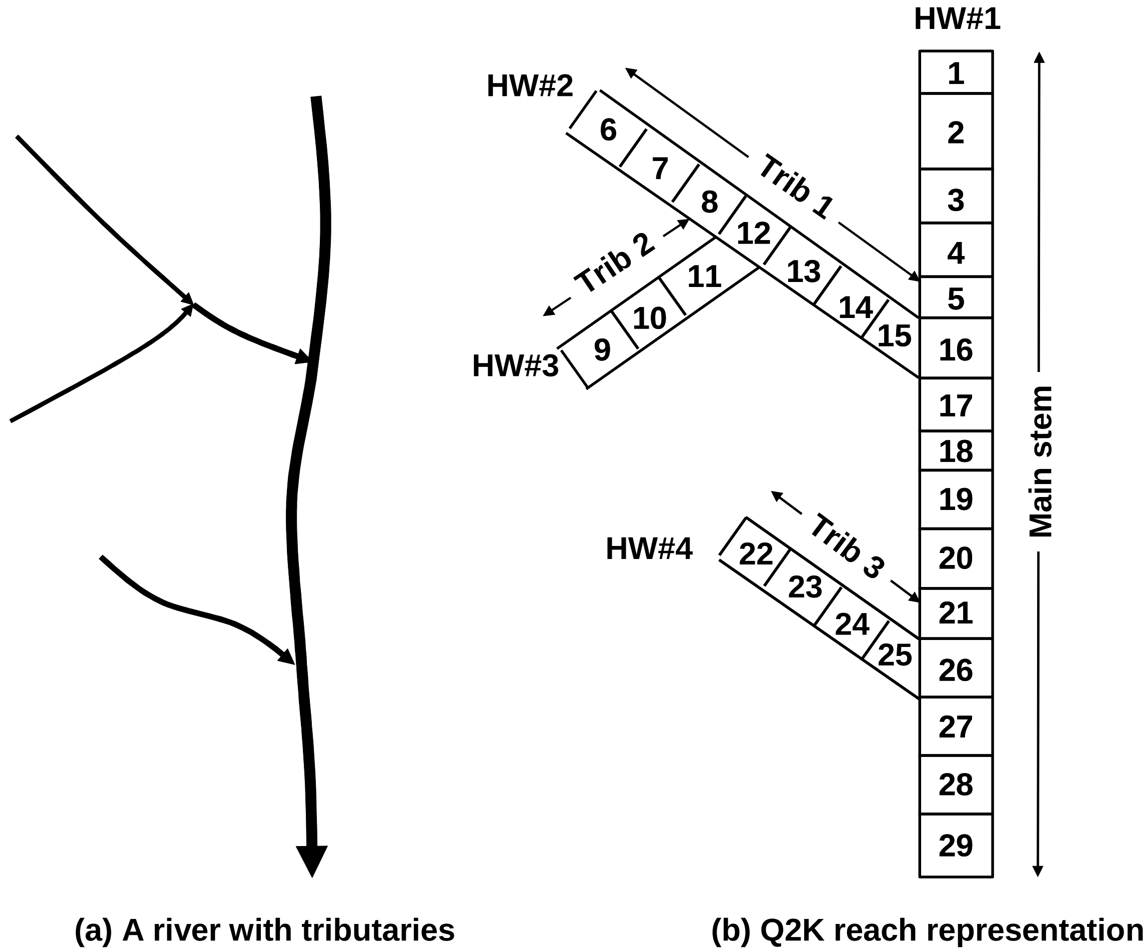


Figure 2.3: Segmentation of river network in QUAL2K (river with tributaries)

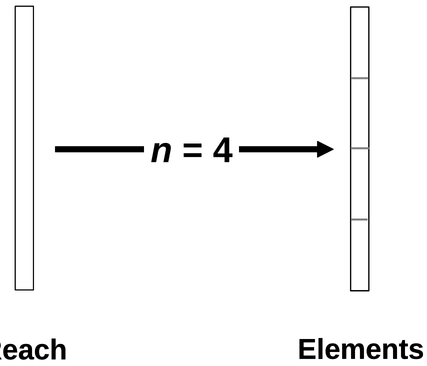


Figure 2.4: Reach and elements in QUAL2K model

2.10.3 Flow calculation in QUAL2K

Flow calculation in the QUAL2K model is based on one of three formulas, which are: the Manning formula, Rating curves or weirs. In this study, flow calculation was performed based on Manning's formula. Each element in a particular reach can be idealized as a trapezoidal channel in Manning's formula (Figure 2.5). Manning's formula can be expressed as Eq. 2.1 under steady flow conditions:

$$Q = \frac{S_0^{1/2} A_c^{5/3}}{n\, P^{2/3}} \qquad Eq. 2.1$$

where Q = flow (m3/s), S0 = bottom slope (m/m), n = the Manning roughness coefficient, Ac = the cross-sectional area (m2), and P = the wetted perimeter (m).

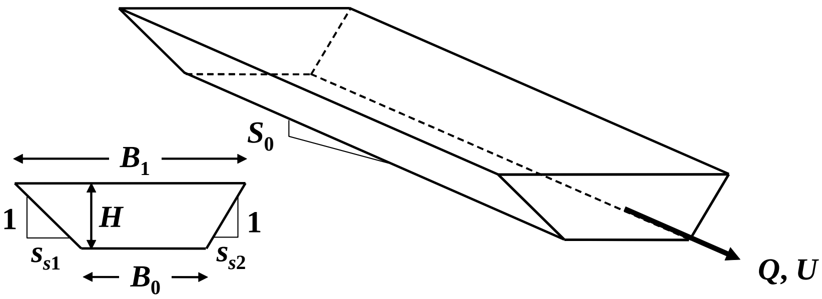


Figure 2.5: Trapezoidal channel

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

$$A_c = \left[B_0 + 0.5(s_{s1} + s_{s2})H\right]H \quad \text{Eq. 2.2}$$

where B_0 = bottom width (m), s_{s1} and s_{s2} = the two side slopes as shown in Figure 2.5 (m/m), and H = element depth (m).

The wetted perimeter is computed as follows:

$$P = B_0 + H\sqrt{s_{s1}^2 + 1} + H\sqrt{s_{s2}^2 + 1} \quad \text{Eq. 2.3}$$

After substituting Eq.2.2 and Eq. 2.3, Eq.2.1 can be solved iteratively for depth(Chapra & Canale, 2006),

$$H_k = \frac{(Qn)^{3/5}\left(B_0 + H_{k-1}\sqrt{s_{s1}^2 + 1} + H_{k-1}\sqrt{s_{s2}^2 + 1}\right)^{2/5}}{S^{3/10}\left[B_0 + 0.5(s_{s1} + s_{s2})H_{k-1}\right]} \quad \text{Eq. 2.4}$$

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

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

As presented in Figure 2.6, the steady-state flow balance is implemented for each model reach according to Eq.2.5 :

$$Q_i = Q_{i-1} + Q_{in,i} - Q_{out,i} \quad \text{Eq. 2.5}$$

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

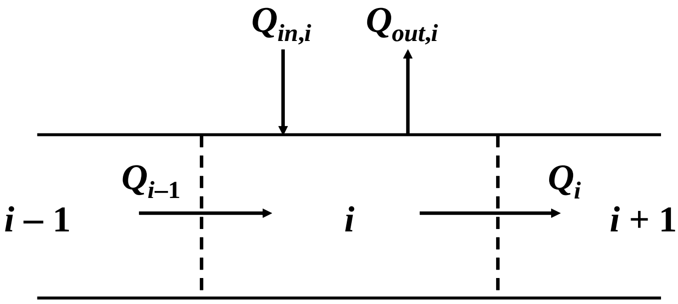


Figure 2.6: Element flow balance

The total inflow from the sources is computed with Eq. 2.6 :

$$Q_{in,i} = \sum_{j=1}^{psi} Q_{ps,i,j} + \sum_{j=1}^{npsi} Q_{nps,i,j} \qquad \text{Eq.2.6}$$

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

The total outflow from withdrawals is computed as Eq.2.7:

$$Q_{\mathrm{out},i} = \sum_{j=1}^{pai} Q_{pa,i,j} + \sum_{j=1}^{npai} Q_{npa,i,j} \qquad \text{Eq.2.7}$$

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

The non-point sources and withdrawals are modeled as line sources. As shown in Figure 2.7, the non-point source or withdrawal is demarcated by its starting and ending kilometer points. Its flow is then distributed to or from each element in a length-weighted fashion.

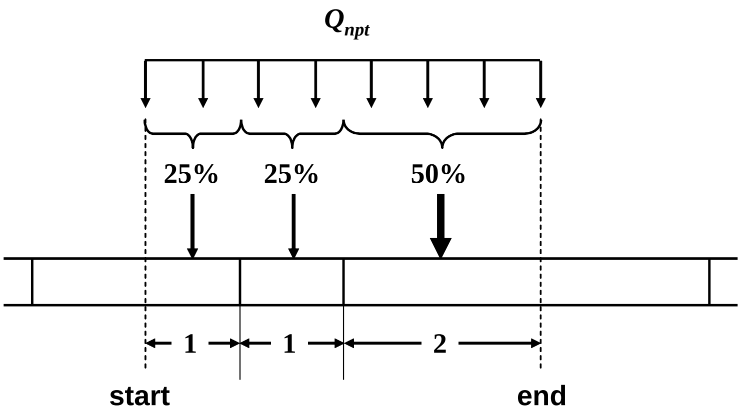


Figure 2.7: The distribution of non-point source flow to an element.

2.10.4 Water Quality Calculations

This model can simulate fate and transport of many parameters and contaminants including temperature, pH, carbonaceous biochemical demand, sediment oxygen demand, dissolved oxygen, various kinds of nutrients, phytoplankton and bottom algae. In this study, DO, BOD and NH3-N were chosen as river water quality measurement parameters along the Selangor River basin. QUAL2K calculates the DO according to the following formula:

$$\begin{aligned} S_o = {} & r_{oa}\mathrm{PhytoPhoto} + r_{oa}\frac{\mathrm{BotAlgPhoto}}{H} - r_{oc}\mathrm{FastCOxid} - r_{on}\mathrm{NH4Nitr} \\ & - r_{oa}\mathrm{PhytoResp} - r_{oa}\frac{\mathrm{BotAlgResp}}{H} + \mathrm{OxReaer} \end{aligned} \qquad \text{Eq. 2.8}$$

Where r_{oa}PhytoPhoto= phytoplankton oxygen produced (g $O_2 d^{-1}$), r_{oa}BotAlhPhoto= bottom phytoplankton oxygen produced (g $O_2 d^{-1}$), r_{oc}FastOxid = O_2 required for carbon decay ($gO_2 gC^{-1}$), r_{on}NH4Nitr = O_2 required for NH_4 nitrification (gO_2 gN^{-1}), r_{oa}PhytoResp = phytoplankton oxygen consumption (dO_2 d^{-1}), r_{oa}BotAlgResp = bottom phytoplankton oxygen consumption(gO_2 d^{-1}) and roa, roc, rod and ron are parameters whose values were suggested by (Chapra &Canale,2006).

OxReaer as calculated by Eq. 2.9

$$\text{OxReaer} = k_a(T)\left(o_s(T, elev) - o\right) \quad \text{Eq.2.9}$$

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

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

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

2.10.5 Hydraulic Characteristics in QUAL2K

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

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

2.10.6 QUAL2K Model Simulation

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

2.10.7 Data input in QUAL2K

Water quality models generally require physiographic data, such as channel network, slopes, soil and other geometric of the catchment (Srinivasa Vittala, Govindaiah, & Honne Gowda, 2006). The Qual2K model necessitates several input data distribution into many Excel worksheets, namely hydraulic data, rates and constants as well as the quality data of the pollution sources. Hydraulic data consist of elevations, channel lengths, channel slopes, widths and roughness coefficient. Flow rate are calculated from these parameters using Minning’s equation. The Qual2K model requires the flow rates of the river entering and for each pollution sources. The rate and constants data needed includes the processes to be simulated such as re-aeration rate, CBOD decay coefficients, turbulent eddy diffusivity, algal growth rate and settling velocity. Several parameters are indicators of pollutant source quality, such as CBOD, dissolved oxygen, pH, alkalinity, and nitrogen and phosphorus species.

2.10.8 QUAL2K Output

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

2.10.9 Performance Evaluation Criteria of Model

The R^2 coefficient is the measure that shows how well the trends in the measured data are reproduced by the model simulated results. It provides the ratio of the variance of one variable that is predictable from the other variable. The value of R^2 ranges from 0 to 1($0 \leq R^2 \leq 1$). The R^2 for n number of measured and simulated data can be calculated using Eq. 2.10:

$$R^2 = \frac{(n\sum_i^n M_i * S_i - \sum_i^n M_i * \sum_i^n S_i)^2}{[n\sum_i^n (M_i)^2 - (\sum_i^n M_i)^2] * [n\sum_i^n (S_i)^2 - (\sum_i^n S_i)^2]} \qquad \text{Eq. 2.10}$$

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

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter describes the materials and the methodologies that were applied to achieved the objectives of the research. The Figure 3.1 below shows the methodology flows chart for this research study. Literature review was the first step of the methodology in which review of journals, reports, books, and guidelines related with water quality assessment, heavy metals, application of GIS and water quality modeling issues were studied. The research methodology includes the details information of the study area, data collection, the sampling procedure, data analysis and water quality model setup.

Field survey was involved selection of sampling stations, collection of water samples from each stations monthly basis for one year following standard method, measurement of *In-situ* parameters pH, DO, EC, Turbidity, salinity, TDS. Laboratory analysis of chemical variables BOD5, COD, NH3-N, TSS, E-coli, heavy metals and total coliforms, were analyzed in laboratory. Data collection consist of gathering the available data such as water quality data, hydrological data, topographic map, hydro-chemical datasets from previous years, from different organization in Malaysia. In data analysis part, all data which are collected and measured during sampling assessed and classified according to NWQS Malaysia. Thematic maps for spatial and temporal changes of water quality index (WQI) and six parameters visualized using Arcview GIS software. Water quality model was developed using QUAL 2 K software. Modeling includes hydraulic (discharge) and water quality (DO, BOD and NH3-N).

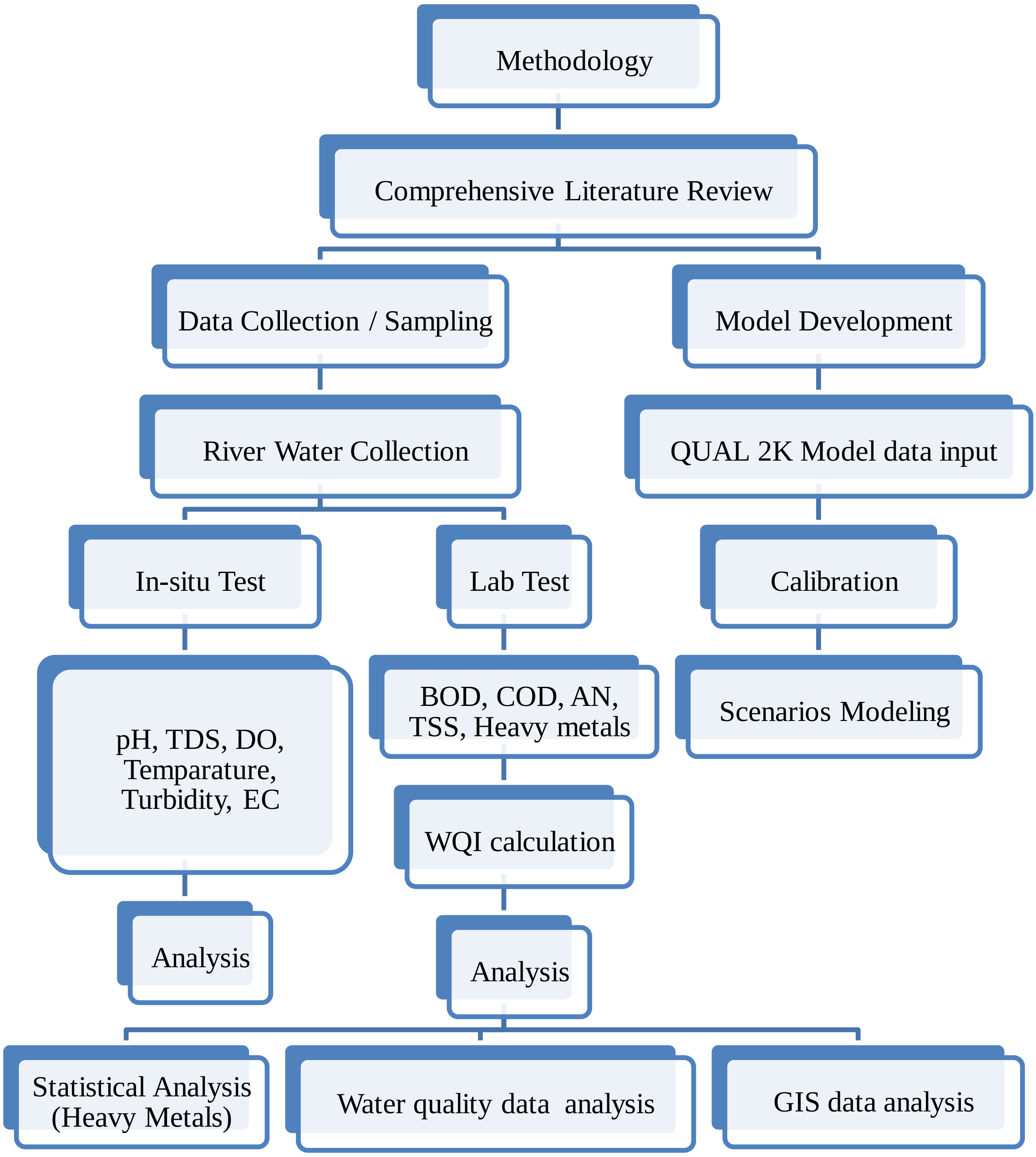


Figure 3.1: Methodology Flow chart

3.2 Study area

3.2.1 Spatial information

The study area is the Selangor River basin located within the state of Selangor, Malaysia. The location map of the Selangor River basin can be seen from Figure 3.2. The catchment area is about 2200 km^2, covering approximately 25% of Selangor. The basin is approximately 70 km long and 30 km wide, and generally lies in the longitude-latitude quadrangle of 101.10E, 3.08N and 101.84E, 3.81N. The main tributary of the Selangor River starts at the border between the states of Selangor and Pahang at an elevation of 1700m. The elevation map is presented in Figure 3.3.

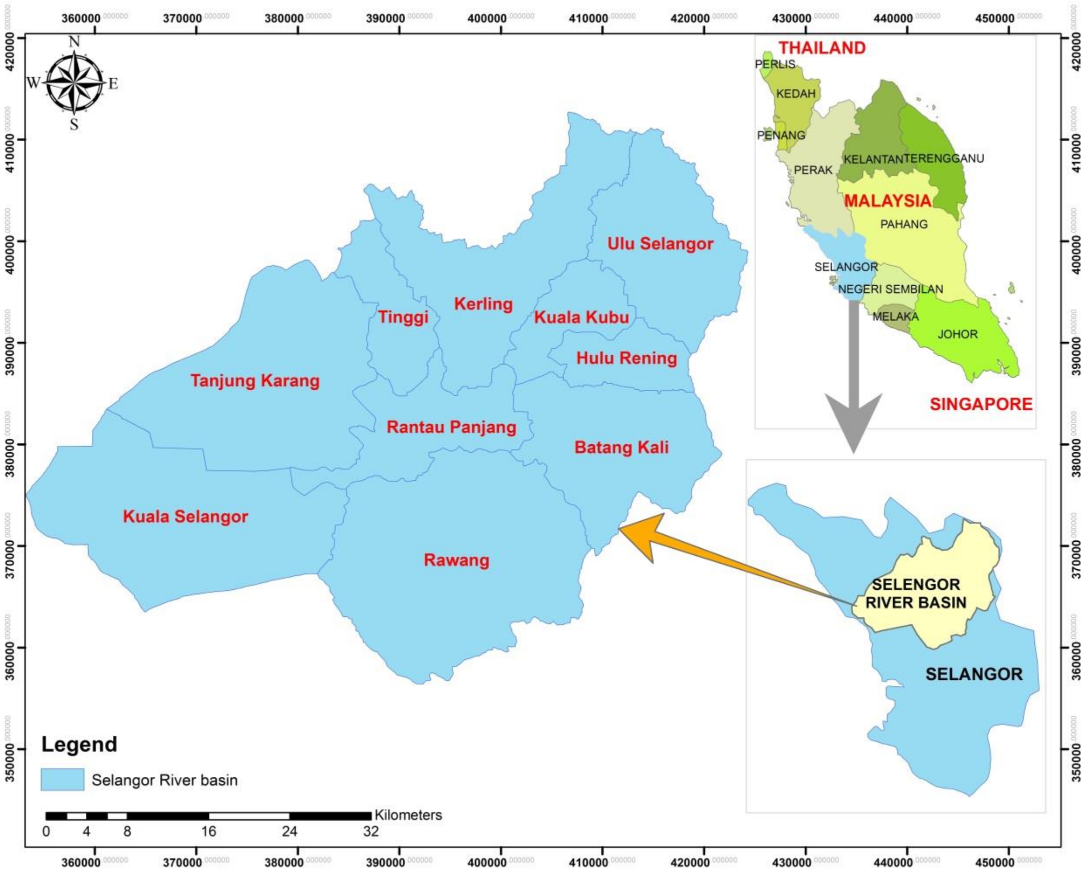


Figure 3.2: Location map of Selangor River Basin with sub-basins

The Selangor River flows in a southwesterly direction traversing a total distance of about 110 km before discharging into the Straits of Malacca at the town of Kuala Selangor. Among the main tributaries are Sungai Batang Kali, Sungai Serendah, Sungai Buloh, Sungai Kerling, Sungai Sembah, Sg Kundang and Sungai Rawang. The basin encompasses three main districts of Kuala Selangor, Gombak and Hulu Selangor with 6 major towns, i.e. Kuala KubuBaru, Rasa, Rawang, Serendah, Bestrai Jaya (Batang Berjuntai), and Kuala Selangor. A seaside town of Kuala Selangor is a seafood haven and the hillside town known as Fraser’s Hill is a popular hill resort for many local and foreign tourists. The Sungai Selangor is recognized as the largest source of water supply for the state of Selangor and the city of Kuala Lumpur. Approximately 60% of water consumption in Selangor and Kuala Lumpur is sourced from the Selangor River (Subramaniam, 2004). It also provides haven to many species of fish and prawn and this form a source of income to the fisherman and market traders. Popular tourist areas can be located at Kampung Kuantan and Bukit Belimbing, home to one of the largest population of fireflies in the world.

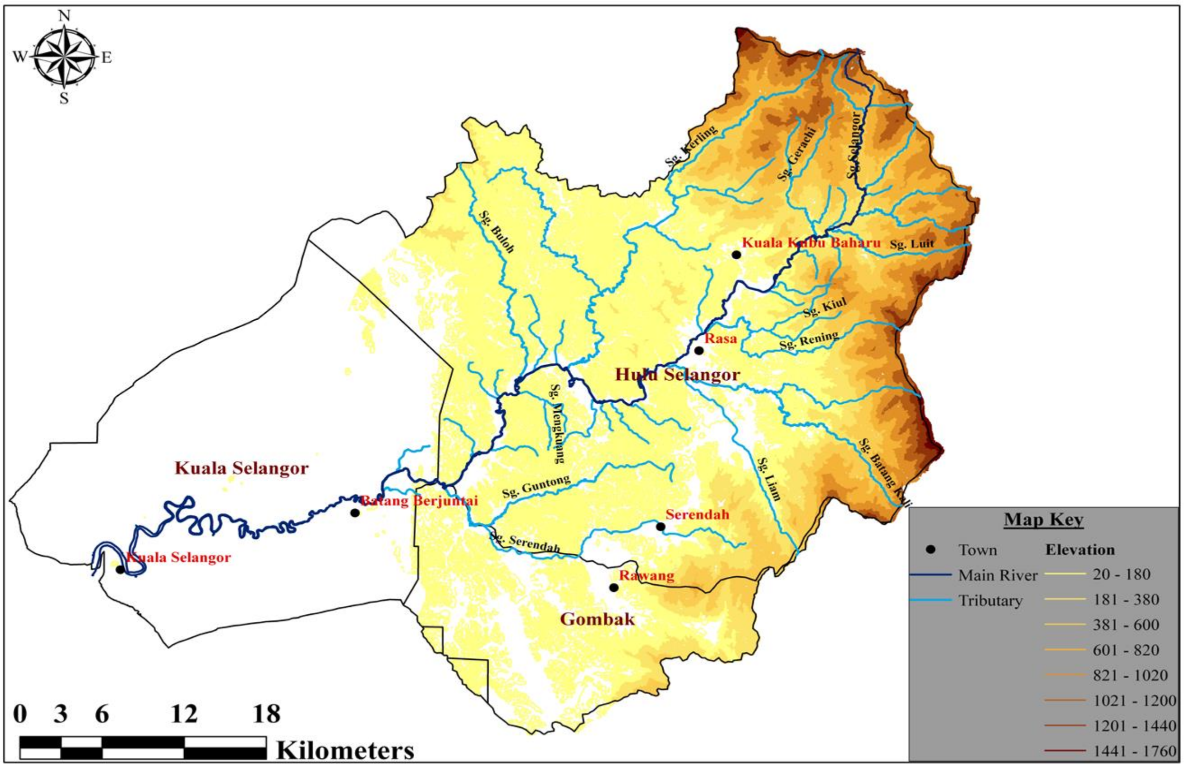


Figure 3.3: Elevation map with Main River and tributaries of the study area (Source LUAS 2007)

3.2.2 Land use

Selangor River basin is still largely a rural catchment. The dominant land uses in the basin are forest and agriculture. About 57% of the basin area is still covered by natural forest area. This includes a forest reserve catchment for Sungai Selangor Dam in the northeast and swampy forest in the middle and low-lying area. Agricultural activities take another 23% of the basin area. This is predominantly rubber estates and oil palm plantations. Some paddy fields could be found in the low laying area near the coastal region. There are 8 main classifications of land use in the basin shown in Table 3.1 and Figure 3.4.

Table 3.1: Major land use within Selangor River basin(Source: (UPUM, 2007).

Land use classification	Area (km^2)	Percent
Agriculture	510.46	23.09
Build-up Area	239.82	10.84
Cleared land	3.62	0.16
Forest	1271.94	57.53
Grassland	2.41	0.11
Mining	27.85	1.26
Water bodies	78.42	3.55
Wet land	76.43	3.46

Selangor has the largest built-up area among the stats of Malaysia. Urban development which includes housing, commercial services and industrial areas are concentrated in the central area of the basin. The urbanized area extends in a general corridor from Kung, Rawang, Sungai Choh, Serendah and Batang Kali. This corridor follows the old KL-Ipoh route. The economy of the river is based predominantly on agriculture and primary industries. Areas that are still undergoing major development are those around Bestari Jaya and between the Hulu Selangor and Kuala Selangor districts.

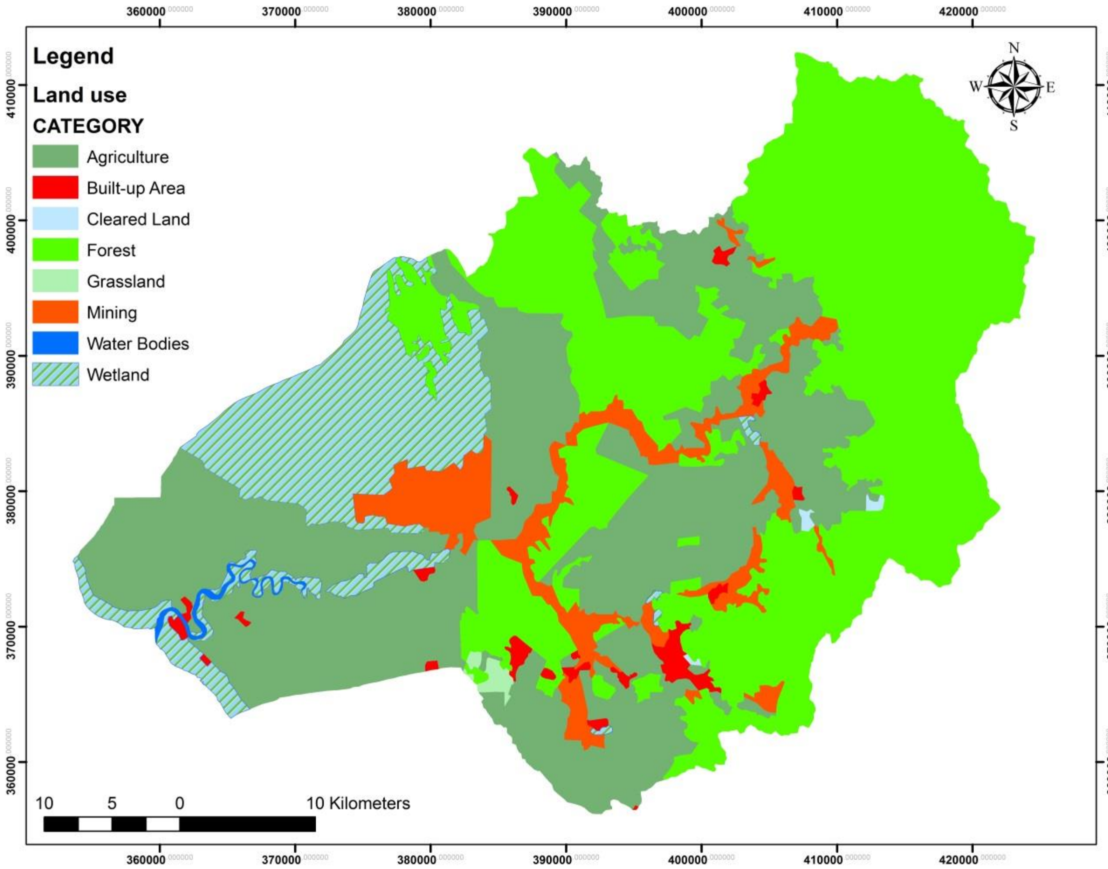


Figure 3.4: The land use map of Selangor river basin

3.2.3 Hydrological information

The Sungai Selangor watershed has a humid, tropical climate much like Peninsular Malaysia in general. The characteristic climate featured here is uniform temperature with minimal variation throughout the year. Rainy season i.e. North monsoon usually from October to April and dry season i.e. South monsoon is from May to September. Beginning of the southwest monsoon in May however do not has heavy rain(Chong, Sasekumar, Leh, M.U.C., & D'Cruz, 1990). The highest monthly rainfalls occur in the months of October and November and in the months of April and May. Average daytime temperature can reach 32˚C and drop to 23˚C at night. The average annual rainfall varies between 2000-3000 mm throughout the watershed. The highest amount of precipitation falls in the upper section while the least amount of precipitation falls towards the coastal areas at Kuala Selangor. Open water evaporation ranges from 1600 mm to 1800 mm, while the relative humidity is 80 percent on average each year

(Breemen, 2008; Shafie & Julien, 2009; Zin, Jemain, & Ibrahim, 2013).The Selangor river experiences an average discharge of 57 m3/s, with seasonal rainfall variations causing the flow to exceed 122 m3/s or to fall below 23 m3/s about 10 percent of the time (Nelson, 2002).

3.3 Data Collection

In order to know the present water quality status of Selangor River, sampling was conducted. Water samples were collected from 11 sampling stations of the Selangor River and its tributaries on a monthly basis from October 2013 to September 2014. The samples were analyzed and the results were recorded. In order to know the water quality trends, historical water quality data (2000 - 2010) of the Selangor River basin were collected from DOE, Malaysia.

3.4 Sampling Methods and Analytical Procedures

The Selangor River passed through rural area, forested area and some of the developing area. A site visit was conducted to check the accessibility of the sampling station. During site visit the longitude and latitude was recorded by using GPS. Other factors such as anthropogenic activity, point sources, Nonpoint sources, overlapping with DOE, DID station was also took into account during the selection of the sampling stations. Eleven sampling stations were selected along the Selangor River and its tributaries. Location of the sampling station is presented in Figure 3.5.

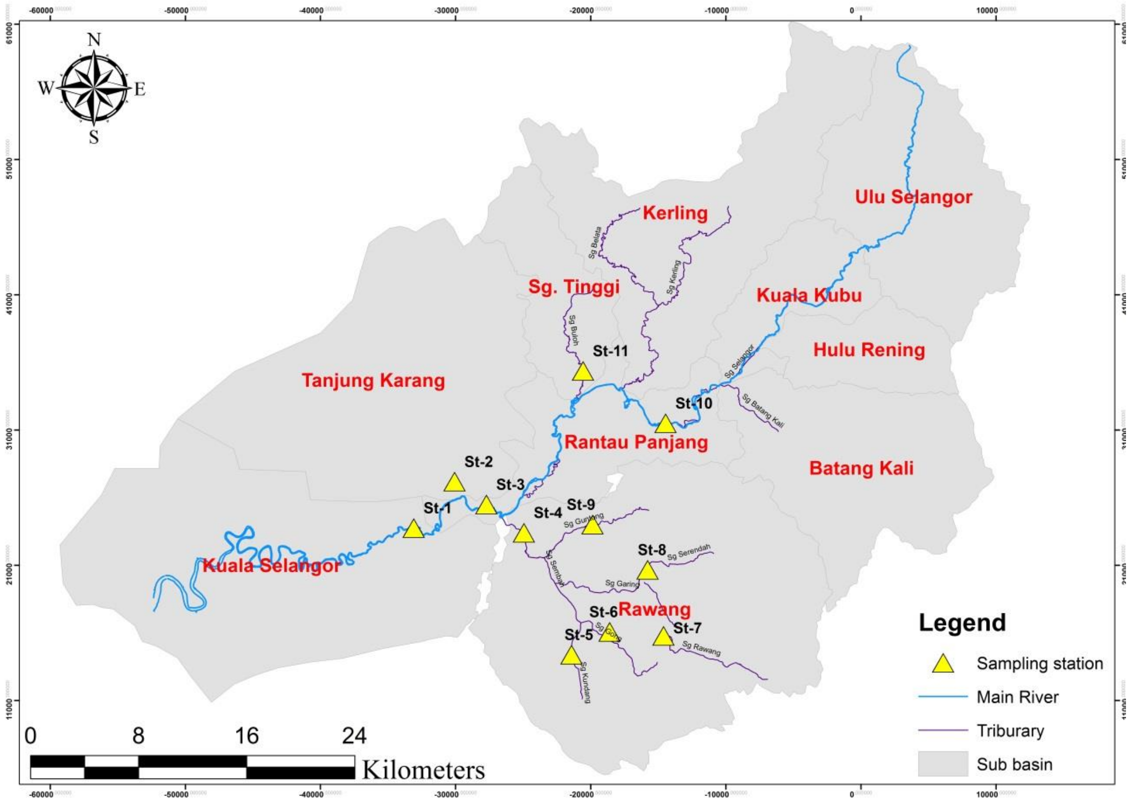


Figure 3.5: Location of the sampling station

Water samples were collected during the period of October 2013 to September 2014. Table 3.2 tabulates the description of the sampling stations and pictures of the sampling stations are presented in Appendix F. International Organization for Standardization (ISO 1985) was followed for sample handling and preservation. Sampling stations St-1 is located at the downstream while St-11 is the upstream of the river basin. Sampling stations St-1 is located downstream while St-11 is upstream of the river basin. Sampling station St-2 is located in the former tin mining catchment Bestari Jaya (previously known as Batang Berjuntai. Bestari Jaya was one of the most important tin mining sites in Selangor and is now a sand mining site. Sampling stations St-4, 5, 6, 7, 8 and 9 are located in the Rawang sub-basin. The Rawang sub-basin is the most populated, urbanized and industrial area of the river.

Table 3.2: Sampling stations detailed.

Stations	Longitude	Latitude	River Name	Sub-basin	Major activity
St-1	101’24”54E	3’23”03N	Selangor	Kuala Selangor	Close to a sanitary landfill.
St-2	101’25”55E	3’24”30N	Ayer Hitam	Kuala Selangor	Former tin mining catchment, peat land is in the surrounding area and palm oil plantations.
St-3	101’26”30E	3’24”08N	Selangor	Kuala Selangor	Sand mining.
St-4	101’27”56E	3’23”33N	Sembah	Rawang	Livestock farming and sand mining.
St-5	101’30”53E	3’19”08N	Kuang	Rawang	Industry effluent and former tin mining catchment.
St-6	101’31”34E	3’19”22N	Gong	Rawang	Industry effluent, restaurants, wet markets and former tin mining catchment.
St-7	101’34”16E	3’19”00N	Rawang	Rawang	Industrial effluent
St-8	101’33”38E	3’21”39N	Serendah	Rawang	Residential wastewater
St-9	101’31”26E	3’23”28N	Guntong	Rawang	Residential wastewater
St-10	101’34”21E	3’27”32N	Selangor	Rantan Panjang	Agricultural activities.
St-11	101’31”03E	3’29”38N	Buloh	Tinggi	Residential wastewater

3.4.1 In-Situ Analysis

Analyses for many important physical, chemical and microbiological variables were carried out in the field using apparatus made specifically for field use. Temperature, dissolved oxygen (DO), DO%, conductivity, Total Dissolved Solid (TDS), Salinity and pH were measured *in-situ* as field parameters by Handheld Multi parameter Instrument (YSI, Inc.), Turbidity was measured by Turbidity meter 2100P (HACH, Inc.) Furthermore, compact handy meters (LAQUAtwin) were used to measure various ions (Na^+, K^+, NO_3^-, Ca^{2+}). All these field apparatus were calibrated prior to use based on the manufacturer’s directions.

3.4.2 Laboratory Analysis

Laboratory analysis was conducted for Bio-chemical oxygen demand (BOD), Chemical oxygen demand(COD) Ammonical nitrogen(NH_3-N), Total suspended solid(TSS), Heavy metals, Total coliforms, *E.coli* and also some ions which showed below limit of quantitation during the on-site analysis.

3.4.2.1 Bio-Chemical Oxygen Demand (BOD)

The BOD is an empirical test to determine the relative oxygen requirements of river water. Dilution is done to bring the high BOD to a readable amount, to bring oxygen demand and supply into balance. Dilution is also done to add nutrients to samples for the microbial growth. Buffer solution is used during the dilution to ensure pH suitable for growth of microbes. The BOD tests were performed by following the standard method APHA 5210: 5-Day BOD test. The DO determination used is based on the addition of manganese solution followed by alkali iodide azide reagent to the samples in the BOD that has been filled with sample and aerated water. The DO rapidly oxidizes the manganous hydroxide to form higher hydroxides. After the addition of iodide, acidification occurred where iodine is liberated and is equivalent to the original DO in the sample. The iodine is then titrated with standard thiosulphate solution.

BOD value is determined based on formula given by equation 3.1 where the results are expressed in mg/l and the value is round off to the nearest whole number. High BOD value means high level of microorganisms in water and this gives an assumption that the river is polluted.

$$BOD_5 = \frac{DOi - DOf}{P} \qquad \text{Eq. 3.1}$$

Where, DO_i = Initial dissolved oxygen at day one

DO_f = Final dissolved oxygen at day five

P = Dilution factor.

3.4.2.2 Chemical Oxygen Demand (COD)

COD is a measure of the oxygen equivalent of that portion of the organic matter in a sample that is susceptible to oxidation by a strong chemical oxidant. The COD tests were performed by following standard method APHA 5220B: Open Relflux Method.

$$COD = \frac{(a-b)M \times 8000}{ml\ sample} mg/L \qquad \text{Eq. 3.2}$$

$$M = \frac{Volume\ of\ K_2Cr_2O_7\ \times 0.10}{Volume\ FAS\ used\ in\ titration} \qquad \text{Eq. 3.3}$$

Where:

a = ml FAS used for blank

b = ml FAS used for sample

M = Molarity of FAS

3.4.2.3 Ammonical Nitrogen (NH_3-N)

In NH_3-N test, the sample is buffered at pH 9.5 and distilled into boric solution. The ammonia in the distillate is determined by titration with a standard solution of an acid. NH_3-N tests were performed following standard method APHA 4500. Borate buffer solution, Mixed indicator solution, Sodium carbonate solution were prepared as per standard method (A.P.H.A,2003).

$$\text{Ammonia as N mg/L} = \frac{(X-Y) \times 280}{ml\ sample} \qquad \text{Eq. 3.4}$$

Where,

X= ml of sulfuric acid (0.02 N) used for titrating the sample

Y= ml sulfuric acid (0.02 N) used for titrating the blank

3.4.2.4 Total Suspended Solid (TSS)

Total suspended solid (TSS) are materials that are retained on a standard glass fiber filter paper when a sample of water is filtered. The residue on the filter paper is dried at 105 ^{0}C.TSS tests were performed by following APHA 2540D: Total Suspended Solids Dried 103-105 ^{0}C.

$$TSS = \frac{(A - B) \times 1000}{C} \; mg/l \qquad \text{Eq. 3.5}$$

Where,

A = weight of filter paper + residue (mg)

B = weight of filter paper (mg)

C = ml of sample taken

3.5 Data Analysis

To best characterize of water quality data, statistical techniques like Box and whisker plots, correlation analysis, principal component analysis (PCA) and agglomerative hierarchal cluster analysis (AHCA) were applied in this study. The results of water quality parameters of each station were distributed by Box and whisker plots. The main reason of PCA is data reduction to better describe the relationship among the variables. Cluster analysis was done for identifying relatively homogeneous groups of variables based on their similarities. In agglomerative hierarchal cluster method each variables first forms a separate cluster which combine repeatedly until all the variables come under a single cluster. SPSS 22 was used for Box and whisker plots, PCA and AHCA. ArcGIS version 10.1 was used to develop the geographic information system (GIS) map.

3.5.1 Box and whisker plots

In order to graphically present water quality and heavy metals data, box and whisker or box plots were used. Box and whisker plots represent the shape of the distribution, spread and its central value. It also illustrates minimum and maximum values, the lower and upper quartiles, and the median (Figure 3.6). On the boxplot Figure 3.6 shown here outliers are identified, note the different markers for "out" values (small **circle**) and "far out" or as SPSS calls them "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.

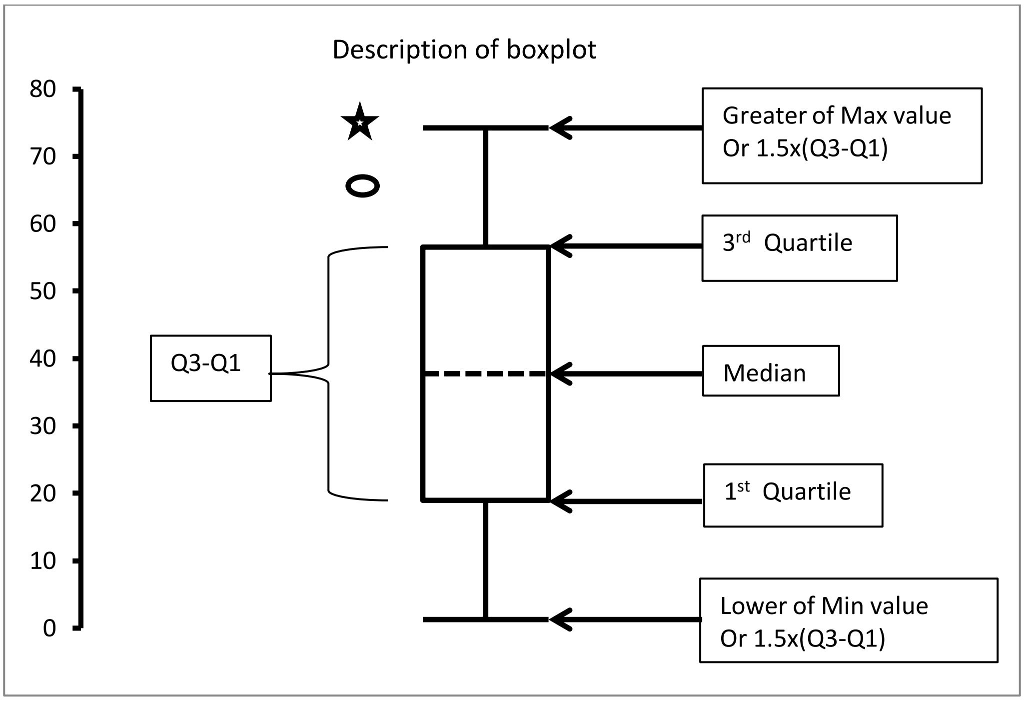


Figure 3.6: Box Plot Chart

3.5.2 Heavy Metals Analysis

The samples preparation had been completed following USEPA-2007. 20 ml of each sample was dispensed into a 50 ml centrifuge tube, after which 0.4 ml of nitric acid (1+1) was dispensed into the samples. The centrifuge tubes were then put into a water bath at 85°C for 2 hours (Ashraf, J.Maah, & Yusoff, 2012). The centrifuge tubes were 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 dissolved metal while avoiding the clogging of spectrometry instrument during analysis. A quality control (QC) sample was also prepared to check the recovery following guideline USEPA-2010. The reproducibility and recovery of the metal analysis in the water samples spiked with appropriate amount of metals Digested samples were analyzed for most of the metal concentrations by an ICP-optical atomic emission spectrometry. For this evaluation of water quality, 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 were analyzed in order to float the calibration curves. The wavelengths of the each element and their corresponding limit of detection (LOD), including the quantitative limits, are listed in Table 4.3. Environmental risk assessment was conducted by comparing the heavy metal pollution index (HPI) within the study area. The HPI was obtained with the following equation (Venkata Mohan S, and, & S, 1996) is given by Eq. (3.6)

$$HPI = \sum Q_i W_i \quad \text{Eq. 3.6}$$

Where, *Wi* is the rating or unit weightage for each parameter selected for heavy metal evaluation and is inversely proportional to the recommended standard i.e. highest permissible value for the drinking water (*Si*) of the heavy metals.

The rating is a value between zero and one. *Qi*, is the Subindex of the *ith* parameter and was calculated as Eq. (3.7) shown below.

$$Q_i = \frac{(M_i - I_i)}{(S_i - I_i)} \times 100 \quad \text{Eq. 3.7}$$

Where, *Mi* is the observed value of the *ith* parameter, *Ii* is the maximum desirable value (ideal) of the *ith* parameter and *Si* is the recommended standard of the *ith* parameter. The critical pollution index value is taken to be 100. For the present study the *Si and Ii* values were taken from the Malaysian national water quality standard.

3.5.2.1 Correlation Analysis (C.A)

Correlation between metals was analyzed by using the Pearson's correlation coefficients. Correlation between sets of data is a measure of how well they are related. The most common measure of correlation is stats in the Pearson correlation. It shows the linear relationship between two sets of data. The letter "r" is used to represent the Pearson correlation.

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2]\,[n\sum y^2 - (\sum y)^2]}} \qquad \text{Eq. 3.8}$$

r value 0.7-1.0 : Very strong correlation

r value 0.4-0.7 : Moderate correlation

r value 0.2-0.4 : Weak correlation

r value <0.2 : No correlation

3.5.2.2 Hierarchical Cluster Analysis (HCA)

HCA classifies variables or observations into classes (clusters) on the basis of similarities within a class and dissimilarities between different classes from the dataset with respect to predetermined characteristics (Boyacioglu & Boyacioglu, 2008). The result of an HCA can be displayed graphically using a tree diagram which is known as a dendrogram. A dendrogram distinguishes groups of high similarity that have small distances between clusters while the dissimilarity between groups is represented by the maximum of all possible distances between clusters. It is a useful technique to investigate spatial and temporal variations (Praveena, Abdullah, Bidin, & Aris, 2011).In order to investigate the groupings of the sampling station within the Selangor River basin HCA was performed on the heavy metals data.

3.5.2.3 Principal Component Analysis (PCA)

PCA is an exploratory, multivariate, statistical technique that can be used to examine data variability (Osman R, Saim N, Juahir H, & M, 2012). The main reason of

PCA is data reduction to better describe the relationship among the variables. PCA explains the variance of a large set of inter correlated variables by transforming them into a smaller set of independent variables and reducing the complexity of data into principal components (Singh, Malik, Singh, Mohan, & Sinha, 2005). A principal component provides information on the most meaningful parameters, which describes a whole dataset, affording data reduction with a minimum loss of the original information (Shrestha & Kazama, 2007). In this study, components were selected in such a way that the first PC explains most of the variance in the data, and each subsequent one accounts for the largest proportion of variability that has not been accounted for by its predecessors. This was to clearly differentiate potential factors or metals sources contributing to the variation of Selangor River's water.

3.5.3 Microbiological Analysis

Microbiological tests were carried out no later than 24 hours from the sampling by following the MPN method (IDEXX). Autoclaved distilled water was prepared for dilution of the water samples. The medium (Colilert®) was added to each 120 ml shrink-banded vessels without sodium thiosulfate containing sample, and the bottles were sealed and shaken to dissolve the medium. Each bottle was then poured into a 97-well Quanti-Tray/2000 and sealed with a Quanti-tray sealer. The trays were incubated at 36 °C for 24 hours, and the number of positive wells was counted which stands for those which emit fluorescence in UV light for E. coli and which are colorized yellowish in visible light for total coliform. The number of positive wells was converted into a most-probable number (MPN) using an IDEXX-supplied calculation sheet.

3.5.4 Ions Analysis

Sodium ions, potassium ions, calcium ions and nitrate ions were analyzed by a standard addition method since some sampling stations showed limit of quantitation in the on-site analysis LAQUAtwin was calibrated by using a standard solution of 150 ppm and 2000 ppm. About 0.40 ml of sample was put into its sensor, and values were recorded after 10 to 20 seconds. The standard solutions were diluted to 5 ppm, 10 ppm, 20 ppm and 40 ppm in each analyte, and 0.2 ml of this was added to 0.2 ml of sample to make a calibration curve. The concentrations in the sample water were calculated from the calibration curve.

3.5.5 Water Quality Index (WQI) Calculation

Pollution level of river water quality assessment was conducted by calculated WQI. The water quality index was obtained with the following equation (DOE, 2009) is given by Eq. (3.8)

$$WQI = 0.22SI_{DO} + 0.19SI_{BOD} + 0.16SI_{COD} + 0.16SI_{SS} + 0.15SI_{AN} + 0.12SI_{pH} \quad \text{Eq. 3.9}$$

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

SIDO	$=0$	for	$DO < 8$	Eq.3.10a
	$=100$	for	$DO > 92$	Eq.3.10b
	$= -0.395 + 0.030DO^2 - 0.00020DO^3$	for	$8 < DO < 92$	Eq.3.10c
SIBOD	$= 100.4 - 4.23BOD$	for	$BOD < 5$	Eq.3.11a
	$=108e^{-0.055BOD} - 0.1BOD$	for	$BOD > 5$	Eq.3.11b
SICOD	$= -1.33COD + 99.1$	for	$COD < 20$	Eq.3.12a
	$= 103e^{-0.0157COD} - 0.04COD$	for	$COD > 20$	Eq.3.12b
SIAN	$= 100.5 - 105AN$	for	$AN < 0.3$	Eq.3.13a
	$= 94e^{-0.573AN} - 5 \lvert AN - 2 \rvert$	for	$0.3 < AN < 4$	Eq.3.13b
	$= 0$	for	$AN > 4$	Eq.3.13c
SISS	$= 97.5e^{-0.00676SS} + 0.05SS$	for	$SS < 100$	Eq.3.14a

	$= 71e^{-0.0016SS} - 0.015SS$	for	$100 < SS < 1000$	Eq.3.14b
	$= 0$	for	$SS > 1000$	Eq.3.14c
SIpH	$= 17.2 - 17.2pH + 5.02pH^2$	for	$pH < 5.5$	Eq.3.15a
	$= -242 + 95.5pH - 6.67pH^2$	for	$5.5 < pH < 7$	Eq.3.15b
	$= -181 + 82.4pH - 6.05pH^2$	for	$7 < pH < 8.75$	Eq.3.15c
	$= 536 - 77.0pH + 2.76pH^2$	for	$pH > 8.75$	Eq.3.15d

The DOE water quality classification based on WQI value are presented in (Appendix-A).

3.5.6 Geographic Information System (GIS) Data Analysis

The combined approach of using GIS and water quality model helps researchers carry out quantitative analysis of spatially distributed pollution processes (F. Othman, ME, & Mohamed, 2012). ArcGIS has been used for the development of the GIS of the Selangor River basin. A GIS technique was applied to create the digital elevation model (DEM) for the Selangor River basin from the contour line map. From the DEM information, the Selangor River basin was subdivided into small sub-catchment units using the GIS technique. A series of operations were performed to produce the map of pit removal, flow direction, flow-accumulation, and stream-network of the Selangor River basin. The base map of the Selangor River basin consists of three layers:

a) A point map that includes all sampling data in the specified Sampling locations.

b) Polygon map that includes the body of Selangor river basin.

c) Line map that includes main river and tributaries of Selangor river basin.

The water quality parameters results of the Selangor River basin are distributed over the constructed base map. The spatial calculation of water quality parameters of the

Selangor River basin were carried for the estimation of unknown values using the moving average method. With the application of the GIS technique in ArcView, pollution level maps for DO, BOD, COD, NH3-N, TSS and WQI were generated.

3.6 QUAL 2 K Model Setup

The sequence of steps needed to develop a water quality model using QUAL2K is illustrated in Figure 3.7.

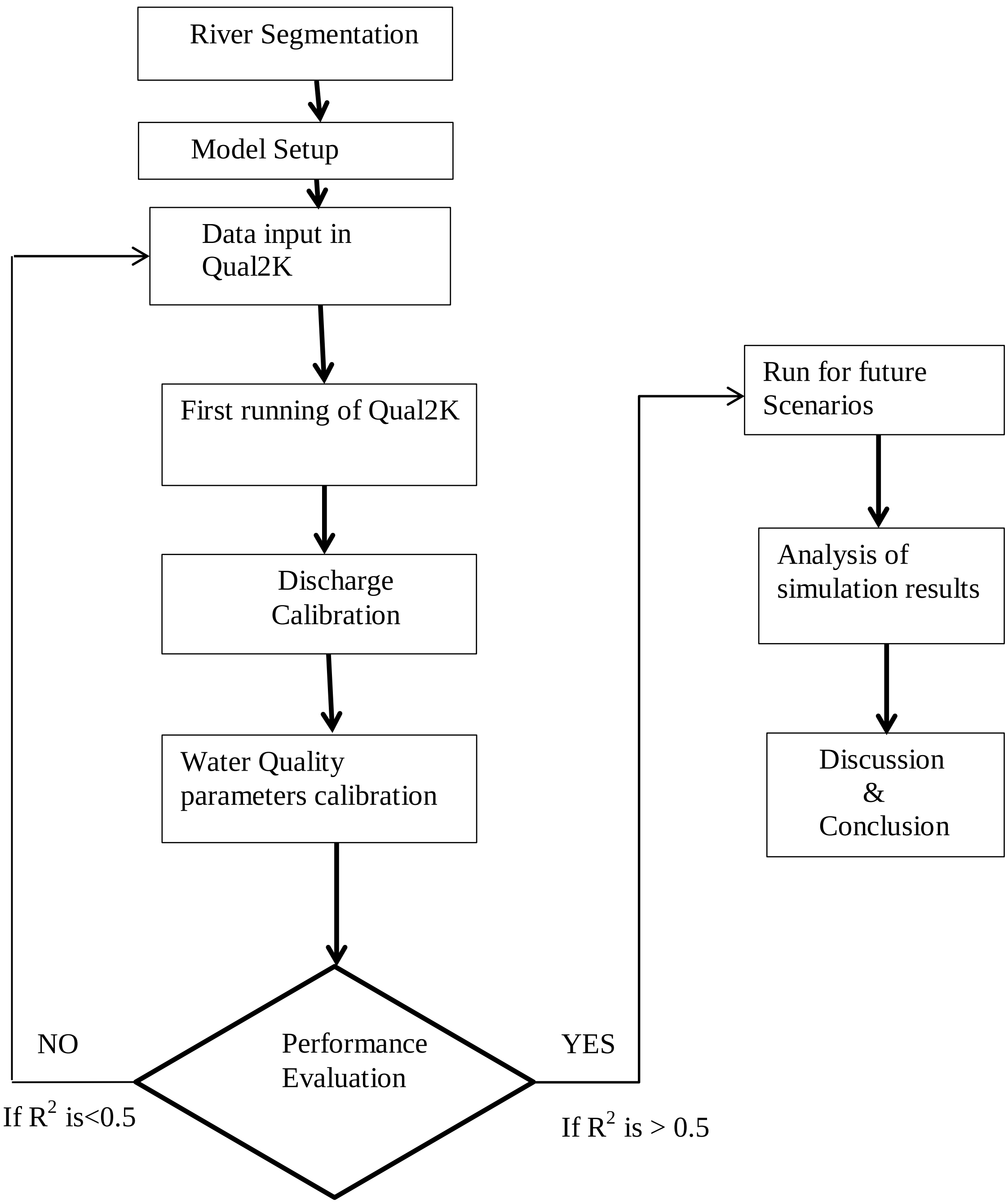


Figure 3.7: Flow chart of QUAL 2 K model

3.6.1 River System of Selangor River Basin

Due to the complexity of the tributaries of the Selangor River basin, two models were developed. First of all, the Rawang sub-basin was modelled and calibrated and secondly, Selangor River's basing was modelled and calibrated while the main river of the Rawang sub-basin was connected as a tributary. Selangor River has been divided into 13 reaches with 6 junctions to accommodate all the sub-basins and the river tributaries within the Selangor sub-basin. Figure 3.8 shows the schematic diagram of the Selangor River basin and illustrates the reaches, the junction system, the sampling stations and the head water. The upstream border is just after Selangor Dam, while the downstream border is limited to 15 km upstream from the coastal region. The Rawang sub-basin has been divided into 9 reaches with 4 junctions to accommodate all the river tributaries within the Rawang sub-basin. Figure 3.9 shows the schematic diagram of the Rawang sub-basin representing the reaches, the junction system, the sampling stations and the head water.

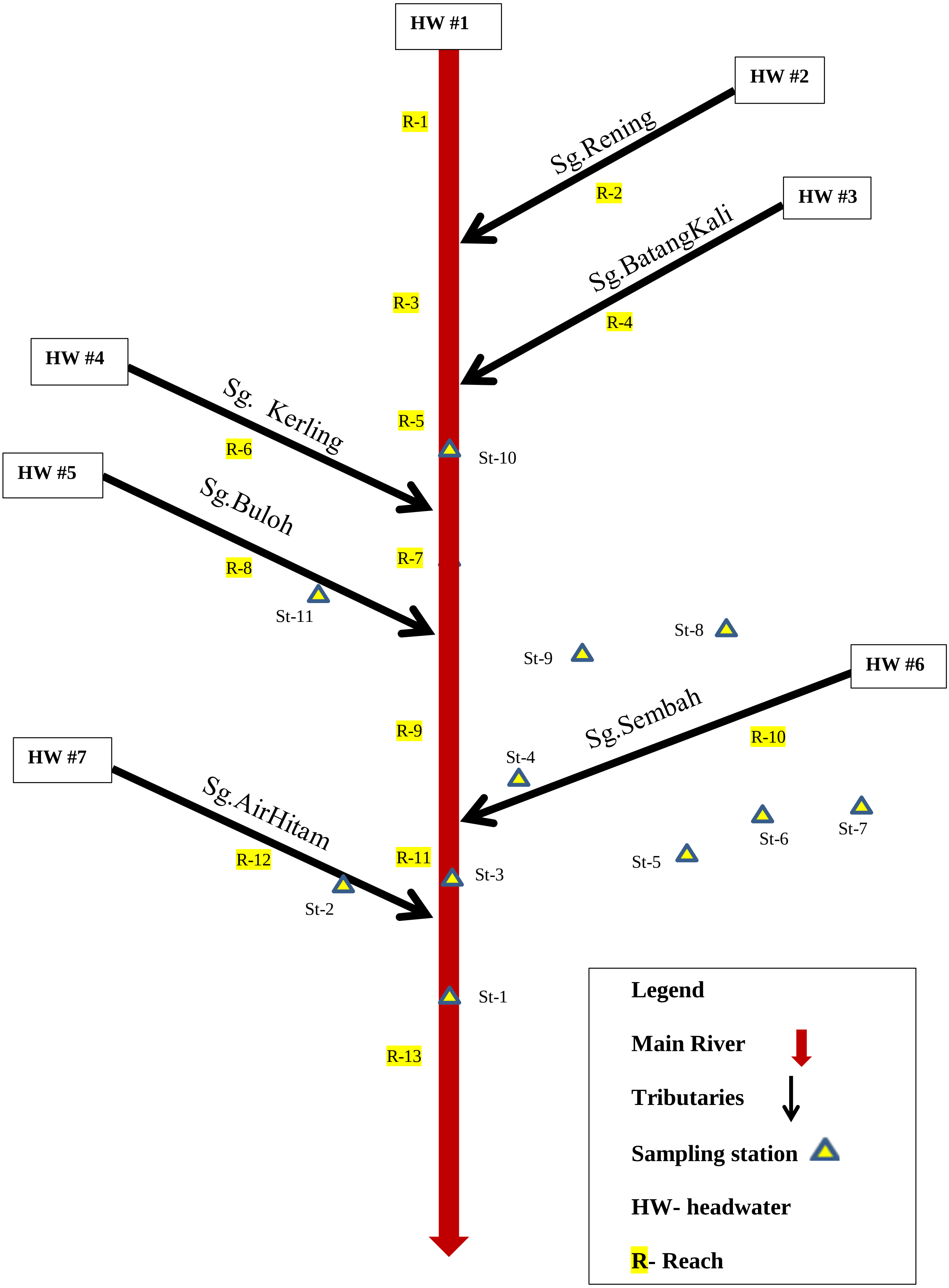


Figure 3.8: River reaches, headwaters and junction system for Sg Selangor River Basin

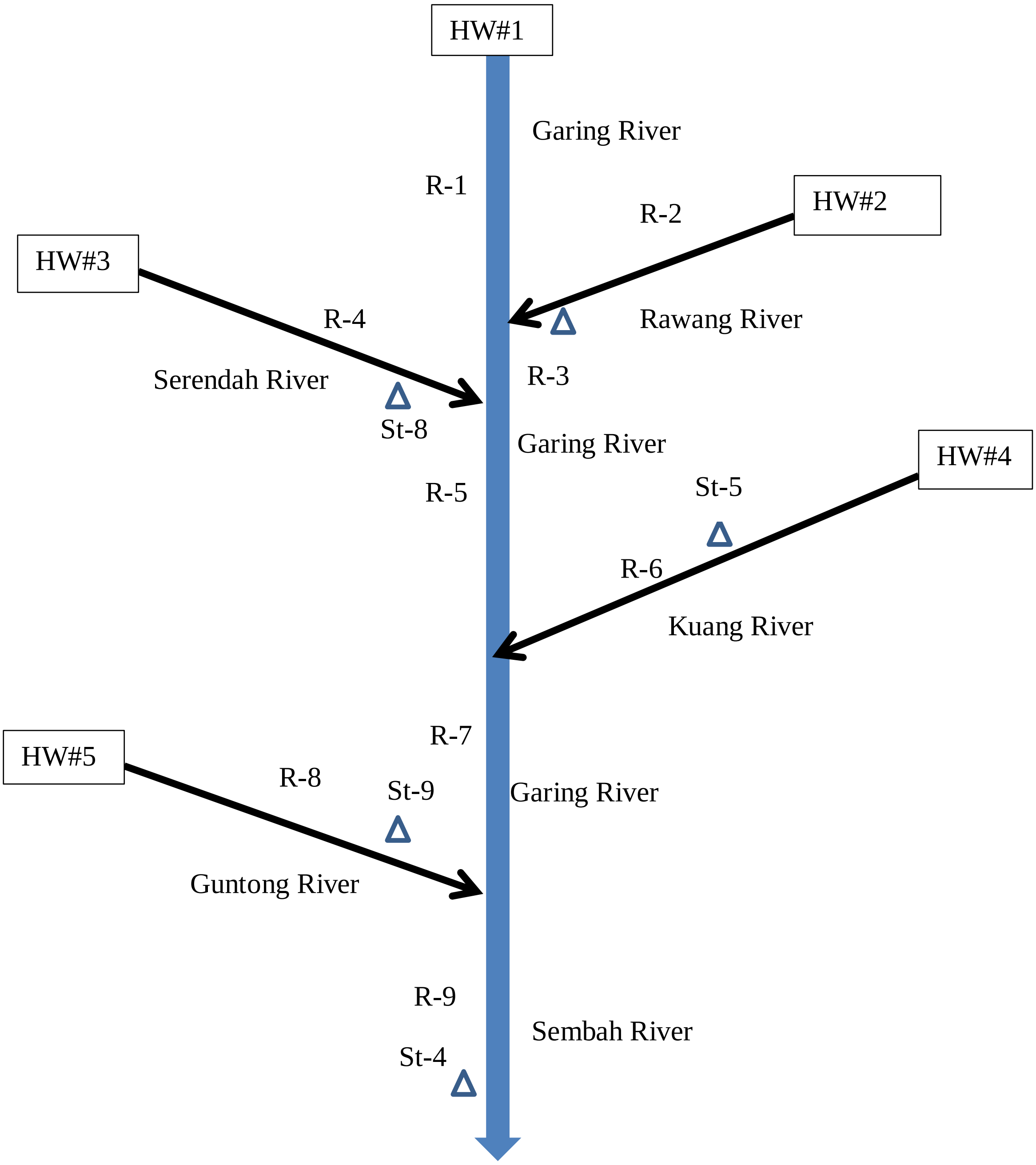


Figure 3.9 : River reaches, headwaters and junction system for Rawang Sub-basin

3.6.2 Data Input in QUAL 2 K Model

QUAL2K requires several data spread on several worksheets. There are two types of worksheet data input in QUAL2K, i.e. simulation data worksheets and calibration data worksheets. Simulation data worksheets are headwater, reach, diffuse sources, point sources, while calibration data worksheets are hydraulic data and water quality data. Table 3.4 shows the data input of the worksheets and their sources.

Table 3.4: QUAL 2 K data input in the worksheets and their sources

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

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

Table 3.5: The used reach data for Qual2K model (Selangor River)

Reach Level	Reach No	Reach length (km)	Location		Number of Elements
			Up-stream (km)	Downstream (km)	
Selangor-1	1	14.50	115.500	101.000	15
Sg. Rening	2	21.00	21.000	0.000	21
Selangor-2	3	4.50	101.000	96.500	5
Sg. Batang Kali	4	18.00	18.000	0.000	18
Selangor-3	5	13.00	96.500	83.500	13
Kerling	6	21	21.000	0.000	21
Selangor-4	7	4.00	83.500	79.500	4
Sg. Buloh	8	17.50	17.500	0.000	18
Selangor-5	9	14.50	79.500	65.000	15
Sg.Sembah	10	17.00	17.000	0.000	17
Selangor-6	11	5.00	65.000	60.000	5
Sg. Air Hitam	12	3.50	3.500	0.000	4
Selangor-7	13	60.00	60.000	0.000	60

Table 3.6 : The used reach data for Qual2K model (Rawang Sub-basin)

Reach Level	Reach No	Reach length (km)	Location		Number of Elements
			Up-stream (km)	Downstream (km)	
Garing-1	1	10.50	24.500	14.00	11
Rawang	2	7.50	7.500	0.00	8
Garing-2	3	0.50	14.000	13.50	1
Serendah	4	15.50	15.500	0.00	16
Garing-3	5	6.50	13.500	7.00	7
Kuang	6	9.00	9.000	0.00	9
Garing-4	7	2.50	7.000	4.50	3
Guntong	8	18.00	18.000	0.00	18
Garing-5	9	4.50	4.500	0.00	5

The model represents the non-point sources as two points based on their distance from the reach's downstream. Therefore, the locations of the pollution sources are determined using GIS tools. NPS was distributed according to the land use distribution in each sub-basin and tributaries of the Selangor River basin. The land use distributions are summarized in Appendix E.

With respect to the point sources, the model defines the location as a single point based on its distance from the reach's downstream. Thus, GIS tools were used to determine the location of the point sources. The average daily flow design of sewerage systems depends on the daily wastewater produced by people. It was assumed previously that a person generates about 0.225 m^3 or 225 liters of wastewater per day (M. A. R. Othman et al., 2006). Thus, the daily flow design of a sewerage plant can be calculated using the following equation:

$$Q = 0.225*PE(m^3/day) \qquad \text{Eq.3.16}$$

Where Q = the design of daily flow and PE= the population equivalent. The IWK company determines the PE values according to the Table 3.7.

Table 3.7: PE values for different establishments (Source: IWK, 2011)

Type of Establishment	Population Equivalent
Residential	5 per house
Commercial : Includes offices, shopping complex, entertainment / recreational centres, restaurants, cafeteria and theatres	3 per 100m2 gross area
School / Educational Institutions : 1- Day schools / Institutions 2- Fully residential 3- Partial residential	1- 0.2 per student 2- 1 per student 3- 0.2 per non-residential student& 1 per residential student
Hospitals	4 per bed
Hotel with dining and laundry facilities	4 per room
Factories, excluding process water	0.3 per staff
Market (Wet Type)	3 per stall
Market (Dry Type)	1 per stall
Petrol kiosks / Service stations	15 per toilet
Bus Terminal	4 per bus bay
Taxi Terminal	4 per taxi bay
Mosque / Church / Temple	0.2 per person
Stadium	0.2 per person
Swimming Pool or Sports Complex	0.5 per person
Public Toilet	15 per toilet
Airport	0.2 per passenger/day 0.3 per employee
Laundry	10 per machine
Prison	1 per person
Golf Course	20 per hole

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

This chapter consists of three main sections. First section provides results and discussion of one year sampling In-situ and laboratory analysis of water quality parameters obtained from Selangor River basin. The water quality results are then compared to the historical results that were collected from DOE. The results were classified based on the national water quality standard. The reasons for variation of results, the potential sources of pollution and the impact of land use on the water quality of Selangor River were discussed. Second section includes results and discussion on heavy metals. Distribution of heavy metals, statistical analysis and HPI were included in this section. Third section provides results and discussion on water quality model. Calibration and scenarios modeling were included in this part.

4.2 Water Quality Results

4.2.1 In-Situ Analysis

The physico-chemical parameters of the water column such as temperature, DO, conductivity, pH, TDS, turbidity and salinity are important because they have a significant effect on the river water quality. Furthermore, aquatic life will also suffer due to degradation of river water quality and the river will be unable to support healthy aquatic life. Thus, it is essential that the physico-chemical parameters of a river to be studied. As for the water quality studies, water samples were taken for laboratory tests and also done in-situ to get the existing environmental information. The sampling had been done for the whole day, thus many factors such as the sampling time, weather conditions, and location impacted the increase or decrease of temperature, which in turn affected the percentage of DO, biological activities, and other parameters (Shuhaimi-Othman et al., 2007).

pH:

The pH of most natural water is between 6.0 and 8.5, although lower values can occur in dilute waters high in organic content and higher values in eutrophic waters, groundwater brines and salt lakes. Figure 4.1 represents the pH results of the 11 sampling stations. The pH of this study was almost stable. The maximum pH value was 8.42 at St-9 and the minimum value was 5.01 at St-2. Due to peat land surrounding the area of Air Hitam River at St-2, the pH value was low. The area of peat swamp is known to have low water pH values and has an extremely acidic environment (Satrio & Majid, 2009b). This is due to the acidification process which occurs in the peat: pyrite oxidation occurs where pyrite reacts with oxygen and water to discharge the acidity, sulfate and iron (Klapper, Geller, & Schultze, 1996).

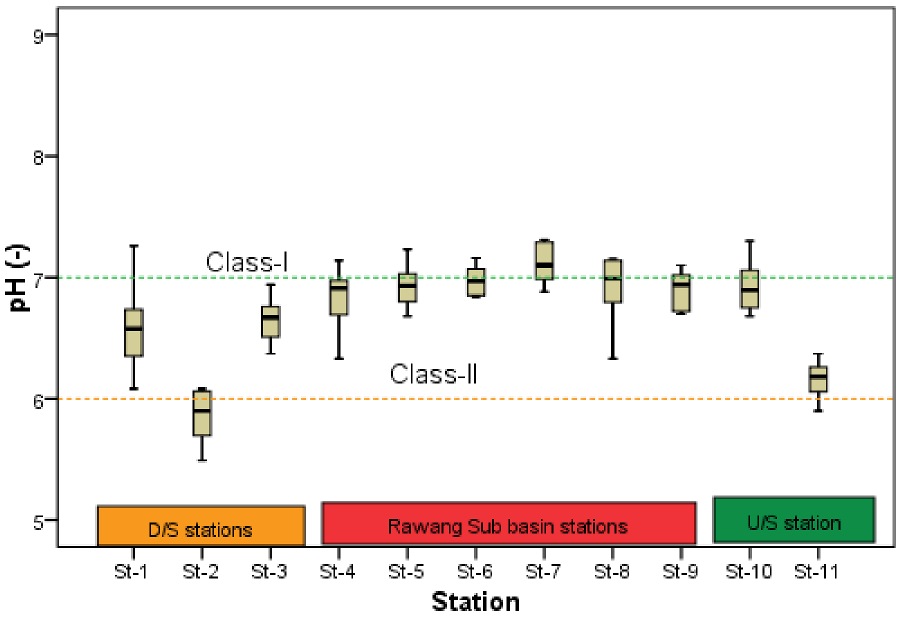


Figure 4.1: Variations of average pH among the sampling stations

Temperature:

The temperature of surface water is influenced by latitude, altitude, season, time of day, air circulation, cloud cover, and flow and the depth of the water body. Temperature affects the physical, chemical and biological processes in water bodies. As water's temperature increases, the rate of chemical reactions generally increases together with the evaporation and volatilization of substances in the water. The metabolic rate of aquatic organisms is also related to temperature, and in warm waters, respiration rates increase leading to increased oxygen consumption and an increase in decomposition of organic matter. Selangor River's water temperature varied between 28.63°C to 31.61°C (Figure 4.2).

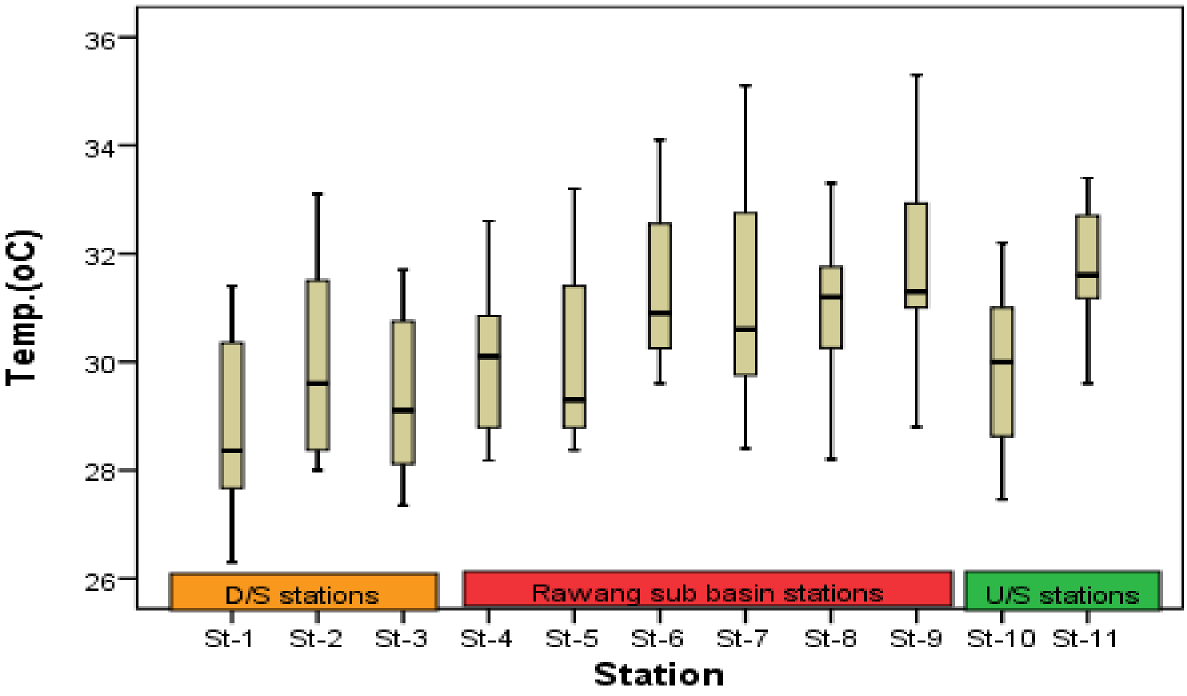


Figure 4.2: Variations of average temperature among the sampling stations

Turbidity:

Figure 4.3 shows the variation of turbidity at the sampling stations during sampling. The graph shows that most sampling stations exceeded the turbidity value of 50 NTU. The highest average value was 471.96 NTU at station St-5 and the lowest average value was 23.18 NTU at station St-11. The reason behind such high turbidity at station St-5 lies in the fact that sand mining is being carried out in this area, and wastewater from the construction site around stations St-5 flowed to the river. Another reason behind high turbidity at station St-5 is sludge from the contraction site (especially piling sludge) is directly discharging into the river. Another elevation of turbidity was noticed at St-8 and St-9, the reason being heavy rainfall during sampling. This turbidity results show that, turbidity varies with rainfall, high tide, low tide and human activities such as wastewater from construction sites. Adverse impacts of construction work, such as those caused by erosion and sedimentation, result in deterioration of the colour and turbidity of the water (Purcell, Bruen, O'sullivan, J., & Kelly-quninn, 2012).

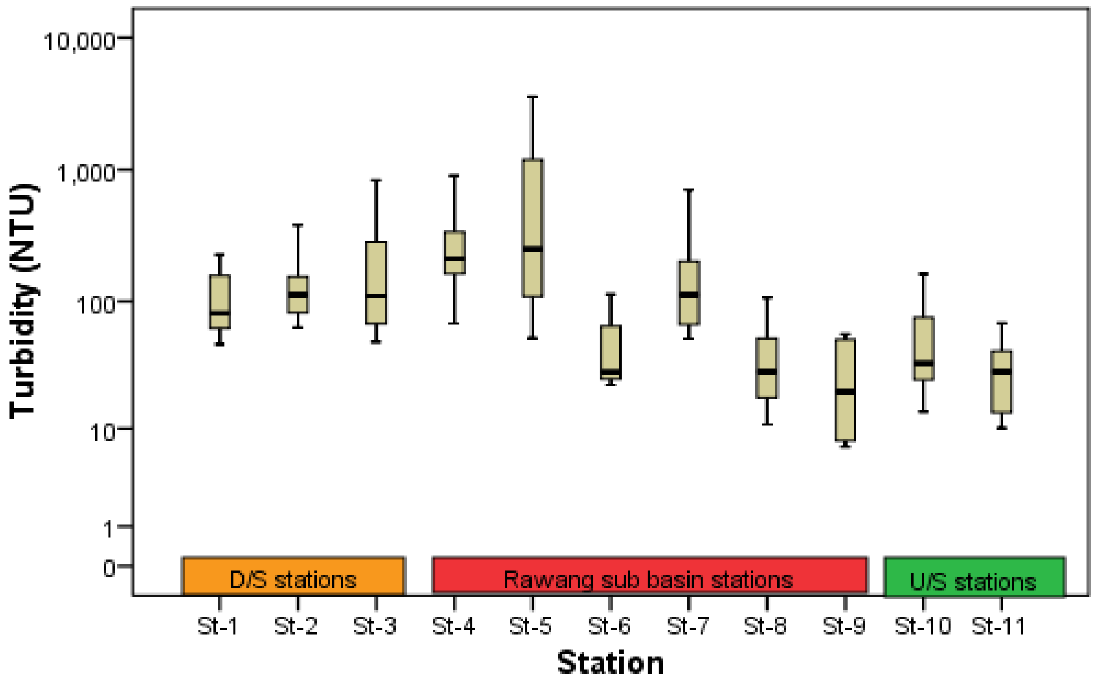


Figure 4.3: Variation of Turbidity among the sampling stations

Dissolve Oxygen (DO):

Figure 4.4 shows the variation of DO among the sampling stations. The average lowest and highest values 2.80 mg/L and 7.11mg/L of DO was register at St-6 and St-10 respectively. It can be noticed that significantly lowers of DO followed by St-2, St-5 and St-6. These three stations are located in the Rawang sub basin. The potential reasons of low value of DO are wastwater from restaurants, septic tanks and wet merkets are directly discharing to the river also many construction works along these tributaries, which resulted in high TSS concentration, suspended solids absorb heat from sunlight, increasing the water temperature and subsequently decreasing the DO level necessary for aquatic life(Ginting & Mamo, 2006). In addition, these tributaries are narrow and have a low flow rate, and as a result, stream self-purification does not occur properly. St-2, St-4, St-5, St-6 fall into class IV and all almost stations varies from Class-II to Class-III.

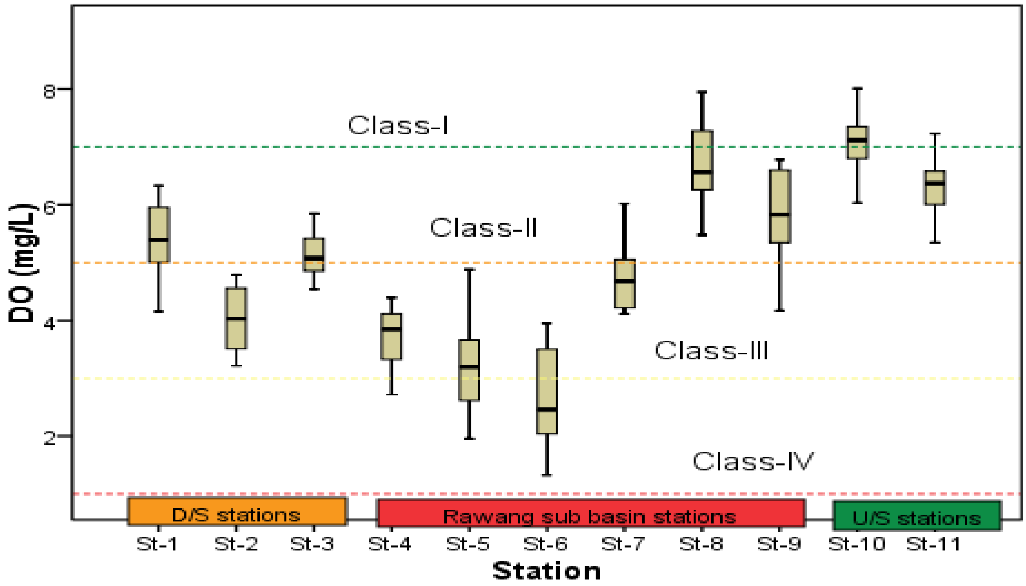


Figure 4.4: Variation of DO among the sampling stations

Overall, in-situ results indicated that, St- 2, 4, 5, 6, 7, 9 are more polluted than others stations. Station St- 4, 5, 6, 7 and 9 are within the Rawang sub-basin. The potential sources of pollution of the Rawang sub-basin are STPs, industrial wastewater, illegal dumping, and sullage from restaurants, food stalls and wet markets.

Ions Analysis:

The result of on-site analysis is shown in Table 4.1. Na+ was detected at stations St-2, St-5 and St-9. Ca+ was detected at stations St-2, St-4, St-5, St-6, St-7 and St-9. K+ was detected at station St-2 only. NO_3^- was detected at stations St-2, St-5 and St-9. However, the on-site result shows that the ion concentration was below the limit of quantitation at most of the sampling stations as the measurement range of the four ions (i.e. Na+ at 23 -

2300 ppm, K^+ at 39 - 3900 ppm, NO^3- at 62 - 6200 ppm and Ca+ at 40 - 4000 ppm) was higher than the existing level. In addition, salinity at all the stations was considerably lower than limit of quantitation (i.e. 0.1 %) and could not be analyzed effectively even with the standard addition method.

Table 4.1: On-site analysis results

Station	Na^+	Ca^+	K^+	NO_3^-	Salt
St-1	ND	ND	ND	ND	0%
St-2	120	43	73	80	0.03%
St-3	ND	ND	ND	ND	0%
St-4	ND	44	ND	ND	0%
St-5	61	91	ND	81	0.02%
St-6	ND	50	ND	ND	0.01%
St-7	ND	61	ND	ND	0%
St-8	ND	ND	ND	ND	0%
St-9	25	70	ND	62	0.01%
St-10	ND	ND	ND	ND	0%
St-11	ND	ND	ND	ND	0%

ND = Not detected

4.2.2 Laboratory Analysis

Biochemical Oxygen Demand (BOD):

Figure 4.5 shows the variations of BOD among the sampling stations. The highest BOD value was 29.23 mg/L, measured at St-6. During sampling, it was observed at St-6, a large quantity of organic waste such as dead plants, leaves, grass clippings, sewage and food waste meant that there would also be a lot of bacteria present working to decompose this waste. So, the demand for oxygen was high (due to all the bacteria), which may be the reason of such high BOD at St-6. A significantly high BOD was detected at stations St-4, St-5, St-6, St-7 and St-9 while St-1, St-2, St-3, St-8, St-10 and St-11 showed low BOD values. The BOD concentration of this study was directly correlated with the DO concentration. The sampling stations where elevated values of BOD were found showed declining levels of DO. This correlation phenomenon is common as reported in many previous research works (Rosli, Gandaseca, Ismail, & M. I. Jailan, 2010). The average BOD values show that St-10 is in class-I, St-11 is in class-II, St-1, St-2, St-3, St-8 and St-9 are in class-III, St-4, St-5 and St-7 are in class-IV and St-6 is in class-V as per DOE classification.

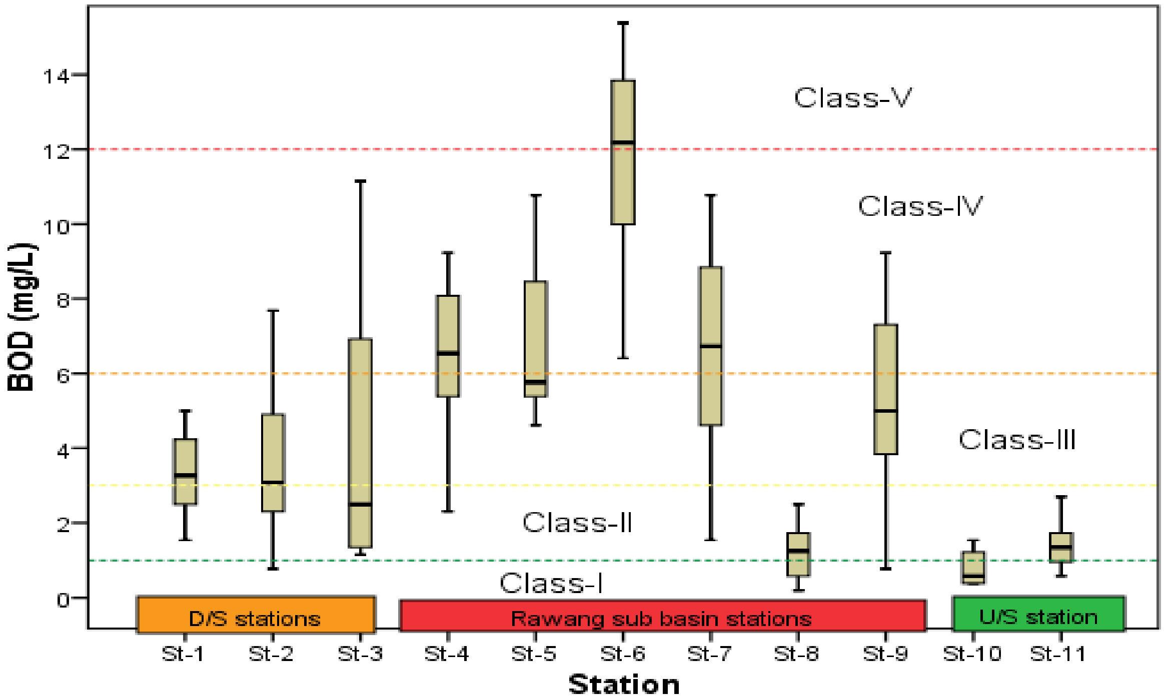


Figure 4.5: Variation of BOD among the sampling stations.

Chemical Oxygen Demand (COD):

Figure 4.6 shows the COD variation among the sampling stations. The COD concentrations of water samples fluctuated from 1.36 mg/l at St-10 and 116.4 mg/l at St-7. From Figure 4.6, it is clear that the COD was significantly higher at St-7 than other stations, indicating that the decomposition of matter in the water causes a high consumption of oxygen. This means that there would have been little oxygen left to support other aquatic organisms. The COD range at St-7 was 5.44 - 116.4 mg/l and the average value was 50.07mg/l. As per DOE classification, the average value at St-7 can be categorized as class-IV. St-1, St-3, St-8, St-10 and St-11 are in class-II, while St-2, St-4, St-5, St-6 and St-9 are in class-III. The higher values of BOD and COD indicate that the samples contained ammonia, sludge or other waste which largely came from untreated or partially treated sewage and discharges from agro-based and manufacturing industries. Generally, a lower COD level indicates a low level of pollution, while a high level of COD points to a high level of pollution in water (Waziri & Ogugbuaja, 2010). Moreover, the wide usage of chemicals and organic fertilizers, along with discharge of sewage affect COD levels, A high COD points to a deterioration of the water quality and is attributed to the discharge of municipal effluent (Al-Sabahi, 2007).

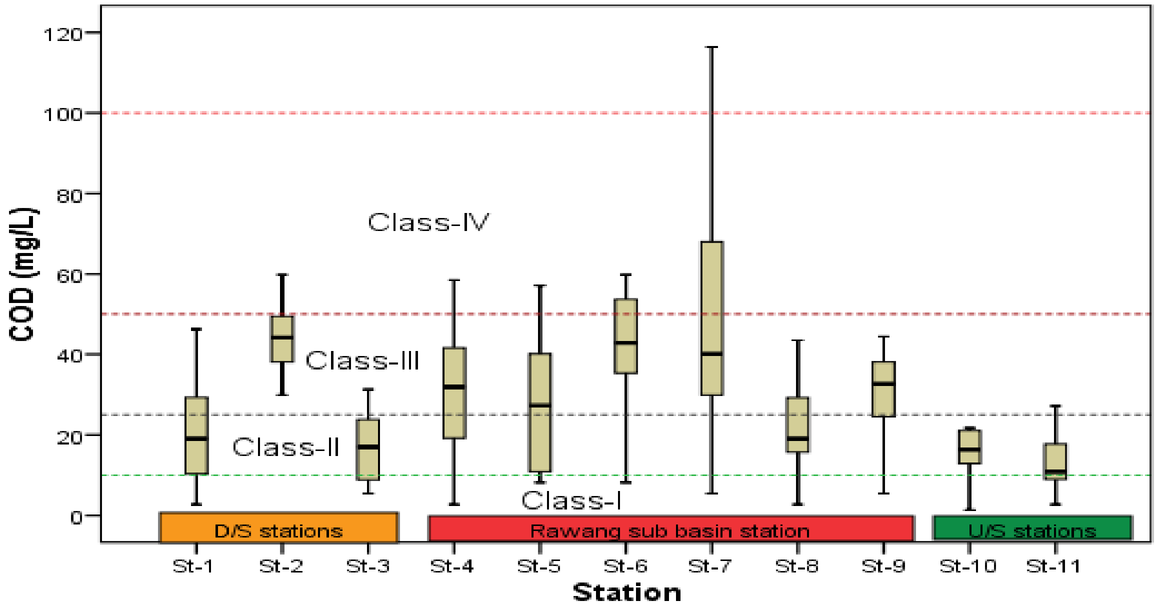


Figure 4.6 : Variation of COD among the sampling stations

Ammoniacal Nitrogen (NH_3-N):

The contribution of ammoniacal nitrogen to water quality degradation is a crucial environmental and public concern worldwide; this is because it can cause eutrophication (F. Wang, Ding, Ge, Ren, & Ding, 2010). Figure 4.7 shows the variation of NH_3-N among the sampling stations. The NH_3-N concentrations of water samples were high at St-5, St-6, St-7 and St-9 while other stations showed lower values. The range of NH_3-N at St-6 was 3.75 mg/l to 8.71 mg/l during the one year of sampling. The highest NH_3-N concentration of 8.71 mg/l was detected at St-6. The NH_3-N result was extremely high at St-6 throughout the sampling period, meaning the station can be categorized as class-V according to NWQS. A high concentration of NH_3-N is a cause of concern due to its effect on living organisms in river water. The main sources of ammonia in the Gong River (at St-6) probably come from septic tanks, waste from food stalls and sewerage outlets. The concentrations of NH_3-N at St-5, St-7 and St-9 were in the ranges of 0.028 - 3.164 mg/l, 0.028 - 2.44 mg/l and 0.672 - 3.08mg/l, respectively. From the average results St-1, St-2, St-3, St-4, St-8, St-10 and St-11 can be categorized as class-III, while St-5, St-7 and St-9 can be categorized as class-IV according to NWQS.

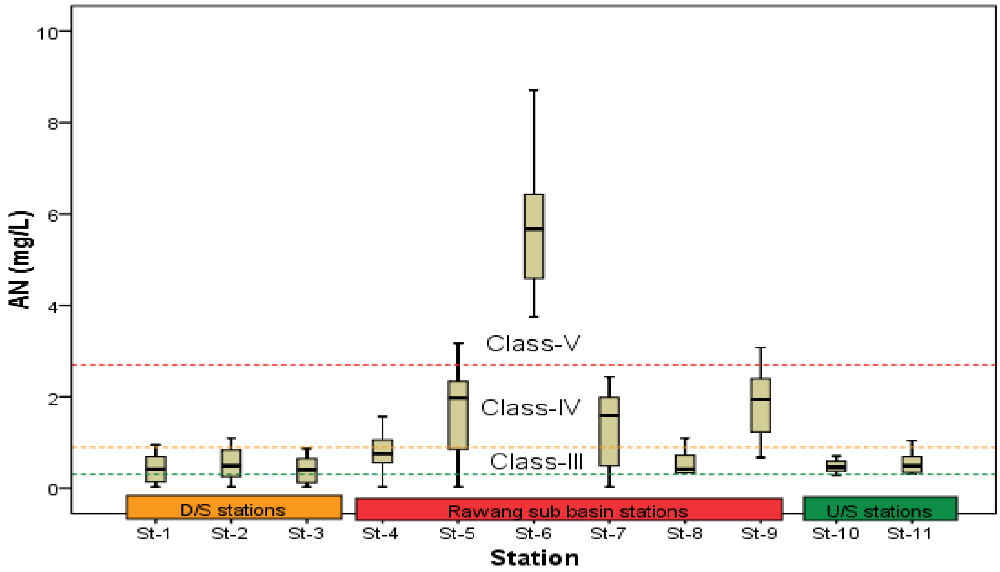


Figure 4.7: Variation of NH_3-N among the sampling stations.

Total Suspended Solid (TSS):

Figure 4.8 represents the variation of TSS among the sampling stations. The TSS values of water samples ranged between 1 mg/L at St-8 and 2234 mg/L at St-5. Based on the NWQS, the maximum threshold limit of TSS for Malaysian rivers which support aquatic life is 150mg/L (DOE, 2006; Rosli, Gandaseca, Ismail, & Jailan, 2010). However, the average TSS values in this study were within this limit and were categorized as class-III (except stations St-4 and St-5). The average value of TSS at St-4 and St-5 were 318 mg/l and 459 mg/l, respectively, therefore they can be categorized as class-V as per NWQS.

The trend of the TSS results of this study was the same as the trend of turbidity. Normally, soil erosion is the source of suspended solids, coming from surrounding areas and caused by human activities. For example, rainy season stations recorded the highest value of TSS due to rainy days which stimulated serious erosion on the two sides of the riverbanks along the river. In addition, the TSS concentrations increased at St-4 and St-5, this increment value of TSS possibly being due to land clearing activities or land erosion, sand mining, quarries, and earthworks along the study area (SecaGandaseca, NorainiRosli, JohinNgayop, & ImanArianto, 2011).

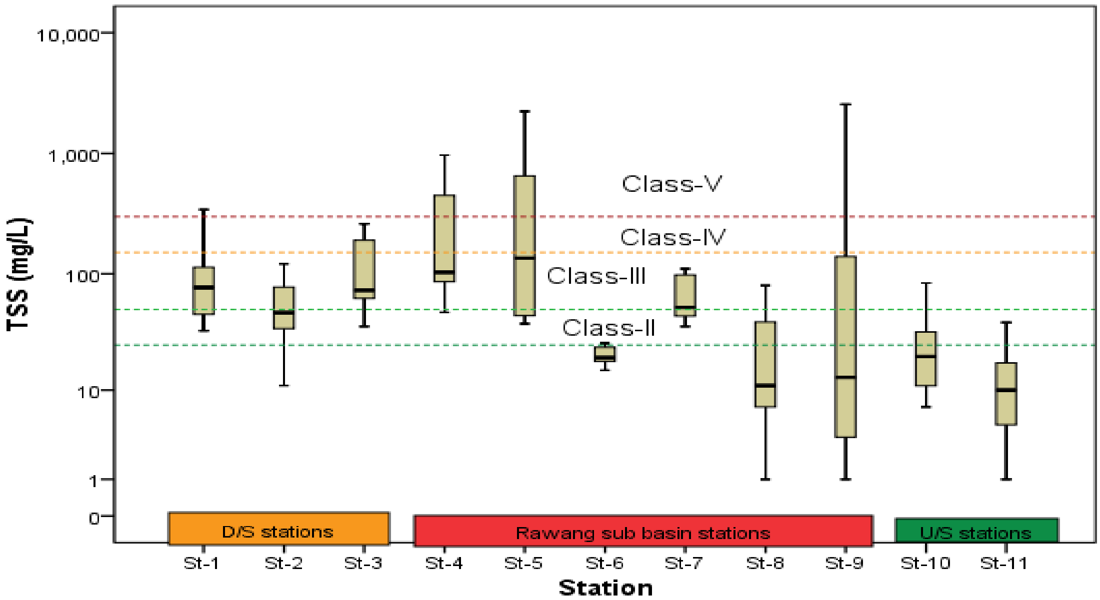


Figure 4.8: Variation of TSS among the sampling stations

Ions Concentration Analysis:

The concentration of Na, Ca, K, and NO_3 was high at stations St-2, St-4, St-5, St-6, St-7, and St-9, and low at stations St-1, St-3, St-8, St-10 and St-11. The results indicate that chemical compositions of dissolved ions in Selangor River are in the increasing order of Ca^{2+}, NO_3^-, Na^+, and K^+. It can be seen from Table 4.2 that St-2 shows the highest reading, followed by the stations located in the Rawang sub-basin (namely St-5, St-6, St-7,St-9), which registered high values of pollutant loading. On the other hand St-1, St-10, and St-11 showed a small loading of pollutants. St-2, is at the confluence of the Ayer Hitam River and Selangor River. During the sampling exercise it was observed that black water from Ayer Hitam River had mixed with Selangor River. The stations in the Rawang sub-basin also registered a higher pollutant loading. The Rawang sub-basin is the most developed area within the Selangor river basin where a lot of point and non-point sources would be generated from industries, urbanization activities, and large population. Potential sources of contamination in these waterways would include septic effluent (private and municipal), animal waste, and agrochemicals. Discharge from municipal landfills usually enhances Na^+, K^+, Ca^{2+}, Mg^{2+}, Sr^{2+}, Cl^-, HCO_3^-, NH_4^+, Fe and ^3H (Baedecker & Back, 1979; Hackley, Liu, & Coleman, 1996). A similar case was reported in which effluent was discharged from municipal septic and private septic systems in Illinois, and contained anomalously high concentrations of Na^+, K^+, $NO3^-$, as well as ammonium ions, chlorine ions and phosphate ions with maximum concentrations of 255, 281, 29, 66, 618 and 9 mg/L, respectively (Panno, Hackley, & H.H. Hwang, 2002).

Table 4.2: Lab analysis results of ions.

Station	Na^+(ppm)	Ca^+(ppm)	K^+(ppm)	NO_3^-(ppm)
St-1	2.60	2.80	1.20	5.20
St-2	118.70	39.00	71.20	80.00
St-3	3.10	3.70	1.00	9.90
St-4	7.90	41.10	1.80	16.40
St-5	58.26	87.00	5.00	81.70
St-6	11.70	48.00	3.40	6.10
St-7	6.40	61.00	2.80	7.40
St-8	6.90	4.50	0.70	6.70
St-9	23.90	68.60	4.50	62.40
St-10	0.30	4.70	2.20	4.70
St-11	0.30	0.50	0.70	4.40

4.2.3 Total Coliform and E.Coli

Total bacteria and *E. coli* were detected and the results are given in Figure 4.9. The number of total coliform at all stations was in the range of $5.4x10^2$ MPN/100ml to

6.4x10^5 MPN/100ml. The number of fecal coliform (FC) or *E. coli*, was between 1.4x10^2 MPN/100ml to 1.0 x 10^6 MPN/100ml. The number of *E. coli* was generally low upstream of the Selangor river basin, but in some of the stations of the middle of the stream it was extremely high. The highest number of total coliforms (6.48 x 10^5 MPN/100ml) and *E. coli* (1.00 x 10^5 MPN/100ml) were observed in the St-8. Figure 4.9 shows the *E.coli* results varied widely among the sampling stations.

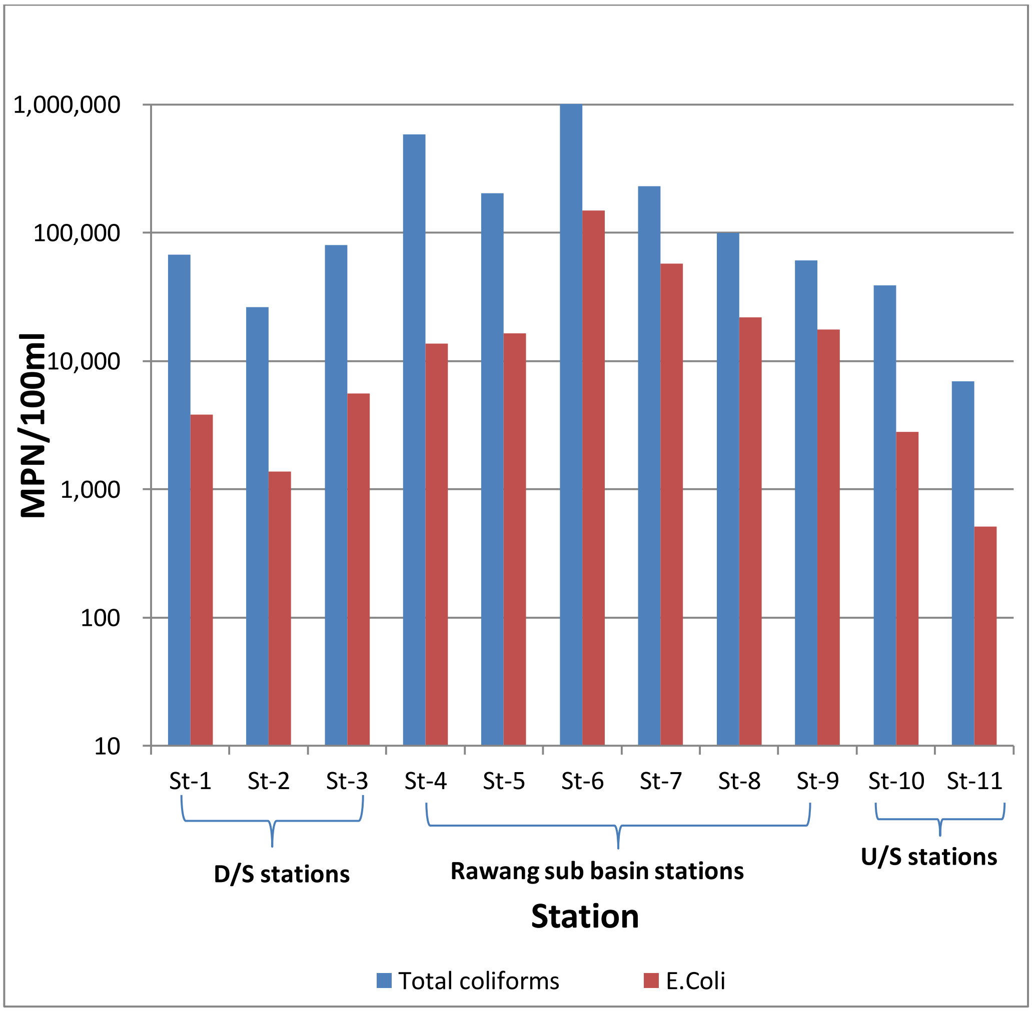


Figure 4.9: Variation of total coliform and *E. coli*; among the sampling stations

The *E.coli* number was significantly high at St-5, St-7, St-8, St-9 and St-11. The maximum number of *E.coli* was detected at St-8 (1.00 x 10^6 MPN/100ml). St-5, St-7, St-8, St-9 and St-11 are located at the Rawang sub basin which contains the main river for urban wastewater discharge, effluents from septic tanks and industrial effluents within Rawang industrial areas. The reasons of such high *E.coli* may be due to the direct discharge of wastewater from septic tanks, STPs and industrial wastewater to the river from the surrounding area. The lowest *E.coli* was detected at St-11 as it is located upstream of Selangor River.

4.2.4 Water Quality Index (WQI)

The WQI trend of the sampling results shows that the water quality varies from upstream to downstream (Figure 4.10). Upstream of Selangor River is located in a rural area and the area is still covered by natural forest according to land use. Generally, the water quality at St-6 as depicted by the relatively low DO and high BOD, and NH_3-N. The WQI values ranged from 41.80 at St-6 to 92.47 at St-10. Figure 4.10 shows that, St-6 was clearly the most polluted station among the sampling stations, as indicated by the WQI. This low WQI was contributed towards by DO, AN and BOD. The range of WQI at St-6 was from 41.80 during the 6th sampling to 57.62 during the 2nd sampling. The average WQI value at St-6 was 50.80, which means this station can be categorized as class-IV according to NWQS. The average WQI results indicated stations St-2, St-3, St-4, St-5, St-7 and St-9 all fall into class-III, while stations St- 1, St-8, St-10 and St-11 fall into class-II as per NWQS classification. It can be seen from Figure 4.10 the lower WQI values, followed by the stations located in the Rawang sub basin.

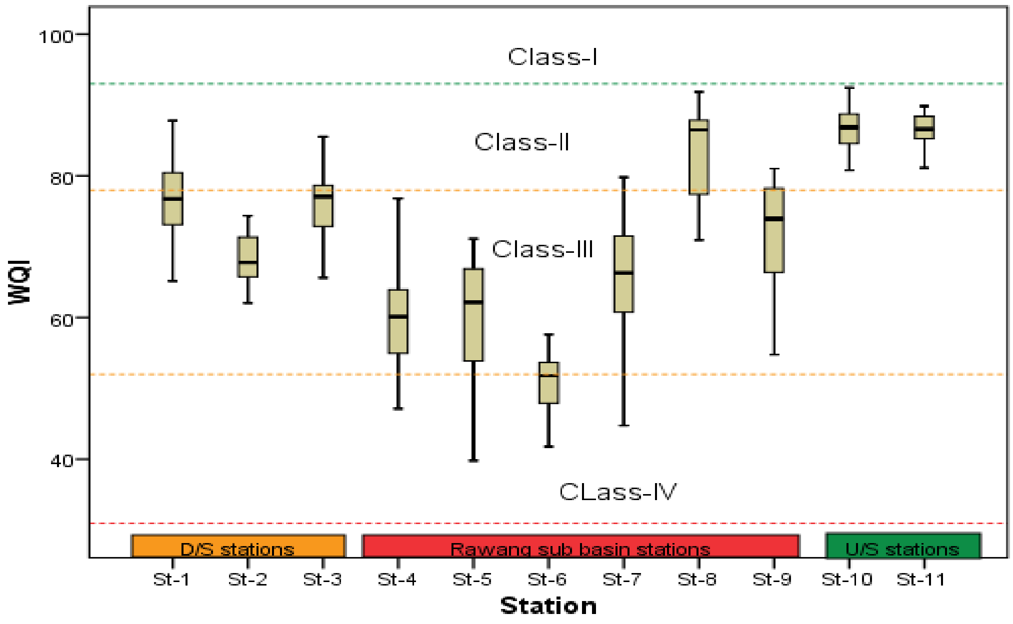


Figure 4.10: Variation of WQI among the sampling stations

The variations in average WQI values according to point source and land use are visualized in Figure 4.11. Several more point sources are located in the Rawang sub-basin compared with other sub-basins. The stations located in the Rawang sub-basin receive wastewater from industries, STPs, food stalls, and domestic effluents from unsewered areas. The degraded WQI can be linked with land use as seen in Figure 4. 12. According to analysis, catchments with more forests and less urbanization have better water quality. Forest land is mostly related to good water quality and it plays an important role in keeping water clean in different watersheds around the world (R. Wang, Xu, Yu, Zhu, & Li, 2013). The water quality parameters (e.g., NH_3-N, BOD, COD, DO) had lower values in forested areas within the Selangor River basin. Forested land use generally acts as a nutrient detention zone as nutrients move downstream, which suggests a strong biological nutrient retention (e.g., microbial and plant assimilation and microbial denitrification) (Gardner & McGlynn, 2009). In contrast, built-up land use was identified as the strongest contributor of NH_3-N, BOD and COD to the Selangor River basin, which may be highly influenced by point sources as well as non-point sources of pollution. This is further supported by high concentrations of NH_3-

N (5.72 mg/l) and BOD (12.82 mg/L) in urban-dominated rivers, which suggests chronic sewer leakage or illicit discharges (Paul & Meyer, 2008). Large amounts of incompletely treated sewage (e.g., municipal wastewater and industrial effluents) are discharged into rivers, which is a particular problem in tropical Asian watersheds with dense populations and many industries (Dudgeon, 1992). The analysis suggests that built-up land use has substantial impact on water quality in the study area. About 80% of built-up areas are located in the Rawang sub-basin, which is the most developed and highly populated area within the Selangor River basin and where a lot of point and non-point sources are generated by industries and urbanization activities. WQI values were much lower in built-up areas and higher in forested areas. With the rapid development of Selangor State, the urban population reached 91.4% in 2010, signifying the high urbanization level with the growing population (M.D.O.S., 2013). Therefore, this sub-basin is a major pollution contributor to the Selangor River. The upstream regions of the Selangor River are rural areas that are still covered by natural forests in terms of land use.

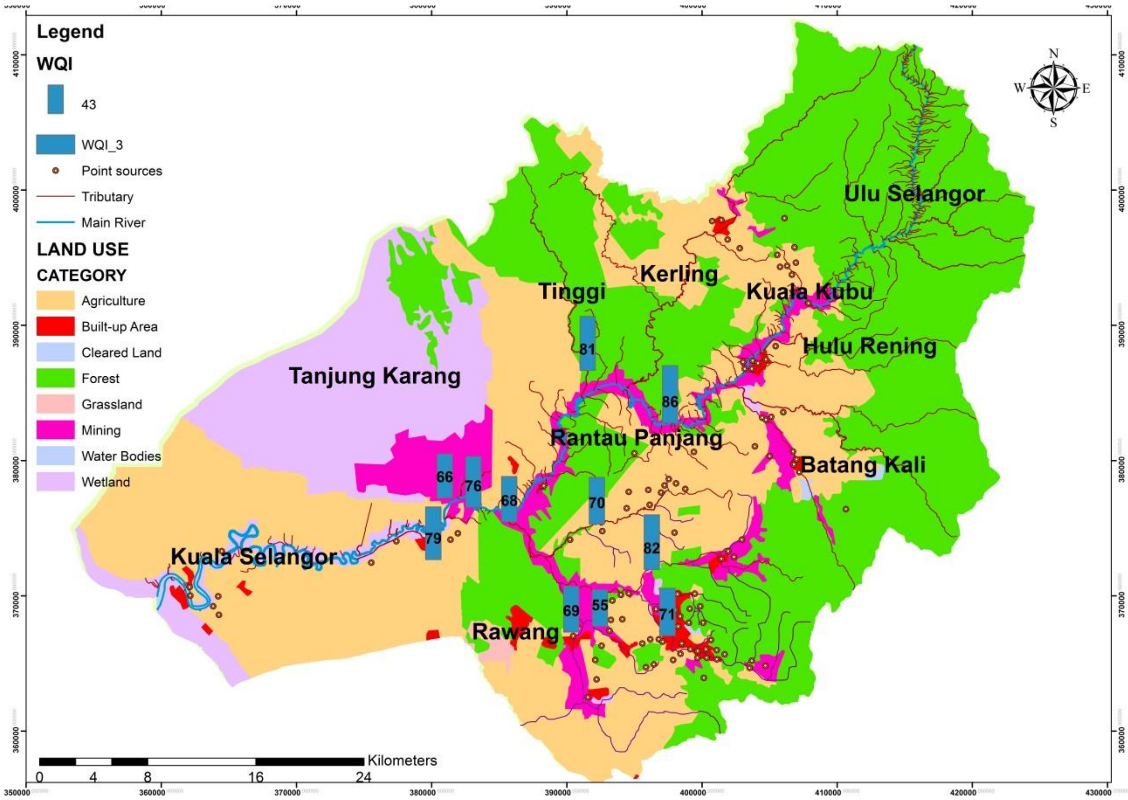


Figure 4.11: . Land use, pollution sources and WQI for the Selangor River basin

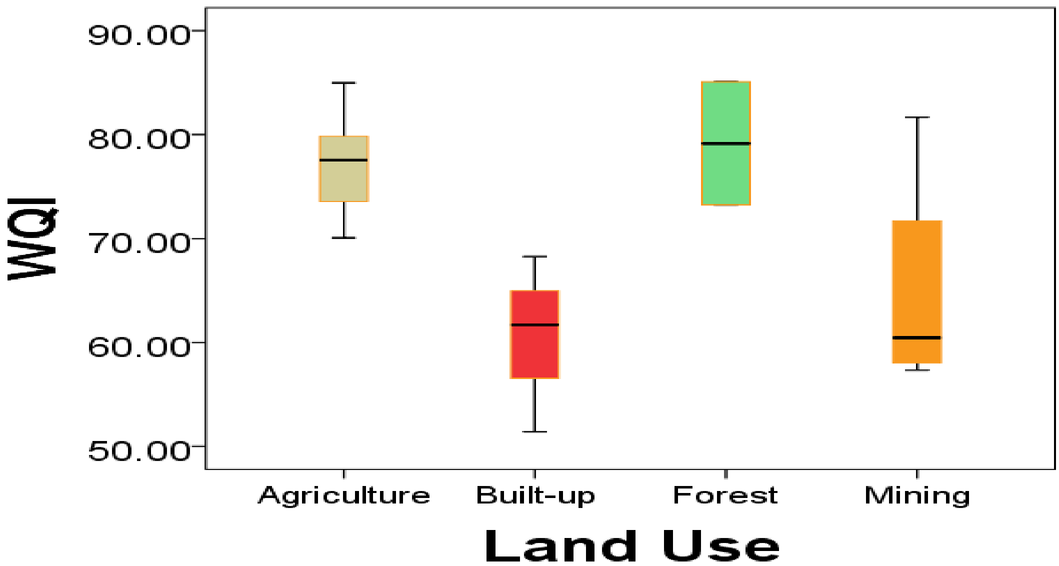


Figure 4. 12 : Impact of land use on WQI

4.2.4.1 Impact of land Use on WQI Parameters

The impact of land use on water quality parameters is presented in the box plots in Figure 4.13. These box plots were drawn based on the sampling results for water quality parameters and the stations' locations with different land uses. There are eight categories of land use in the Selangor River basin, but most sampling stations fall within four categories, i.e. agriculture, forest, built-up areas and mining. Agricultural activities are mostly carried out around St-1, St-2, St-3 and St-4, and these stations show lower river water contamination. Figure 4.13 also represents high DO values and low BOD, COD, ammonical nitrogen (AN) and TSS values for agricultural areas. St-5, St-6, St-7, St-8 and St-9 are located within built-up and mining areas. These stations receive wastewater from industries, STPs, sand mining and former tin mining activities. Figure 4.13 indicates that built-up areas significantly affect water quality parameters. DO was low in built-up areas, while COD, BOD and AN were high. TSS is influenced by mining as well as built-up areas. St-10 and St-11 are located upstream of Selangor River, which is covered with dense forest and has less agricultural activities and limited human activities with the exception of recreational activities upstream of the Selangor River dam. Therefore, the water quality of these stations was optimal. According to Figure 4.13, DO was high and COD, BOD and AN were low with respect to the forested areas.

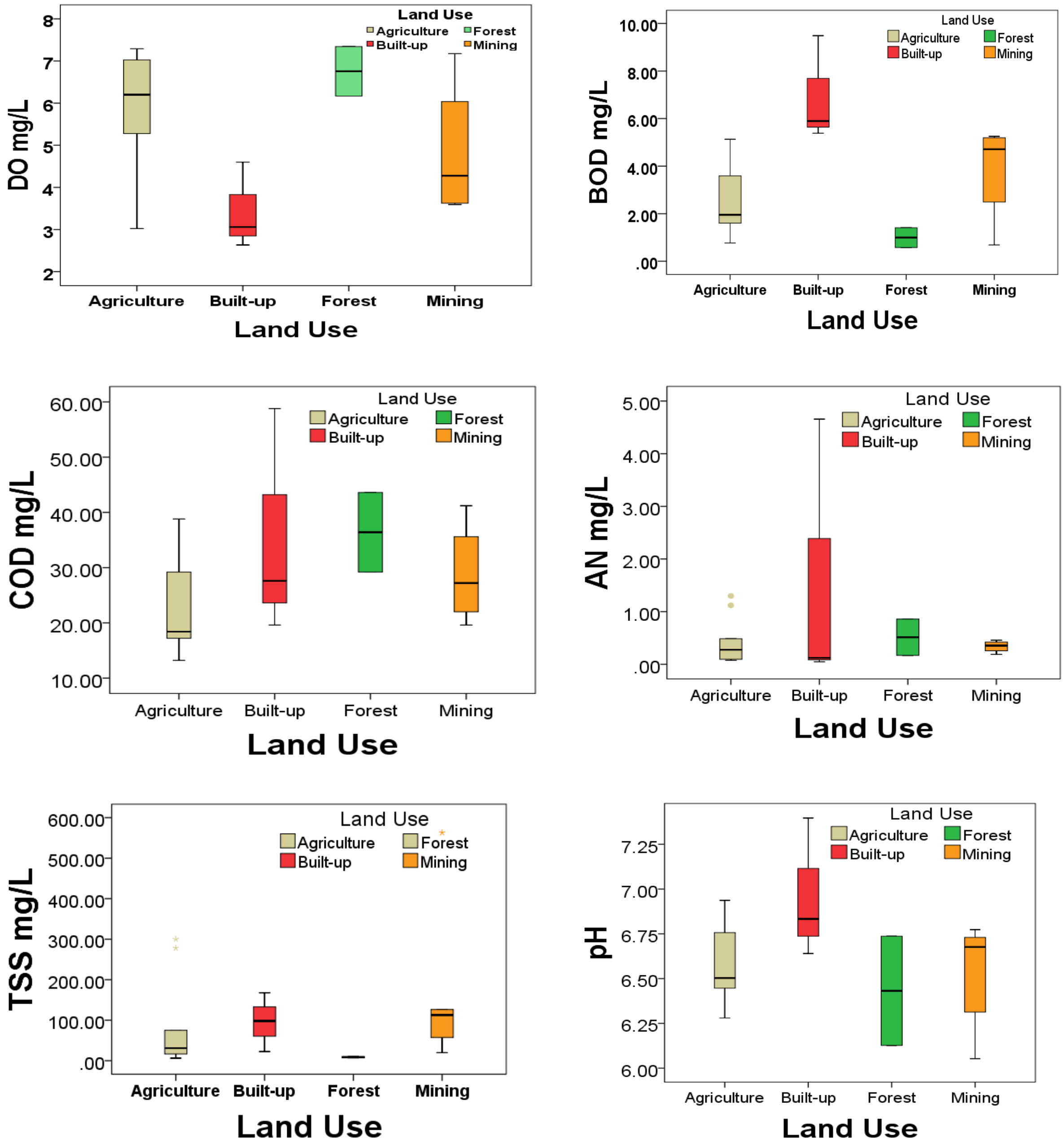
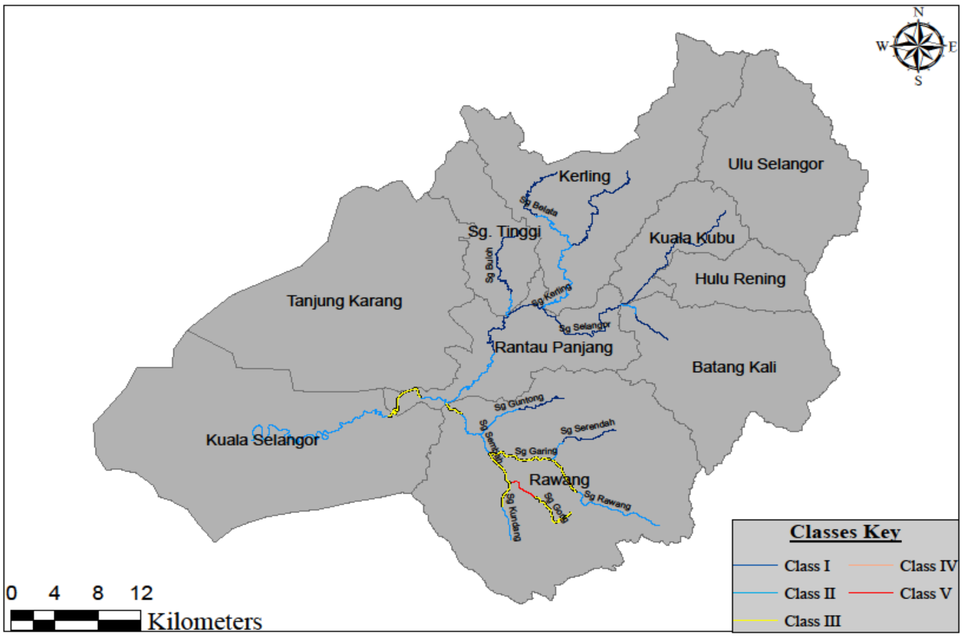


Figure 4.13: Variations in water quality parameters among land use categories

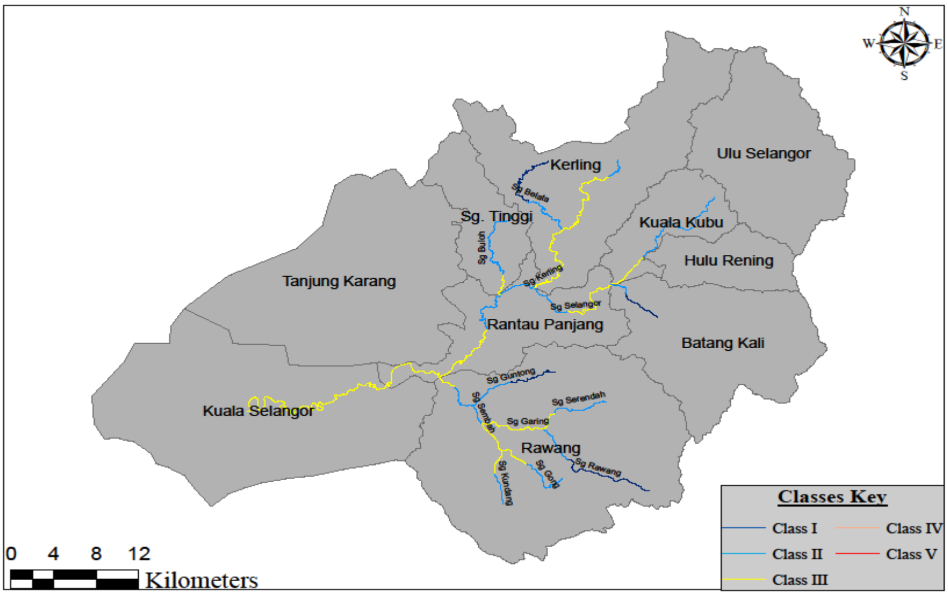
4.2.5 Spatial Water Quality Assessment

The river water quality of sampling stations depends on many factors (WHO, 1996), including :i) the proportion of surface run-off and groundwater, ii) reactions within the river system governed by internal processes, iii) the mixing of water from tributaries of different quality (in the case of heterogeneous river basins), and (iv) inputs of pollution.

Figure 4.14(f) displays the spatial pollution level map related to water quality in the form of WQI at the tributaries and the main river of the Selangor River basin, while Figure 4.14 (a), (b), (c), (d) and (e) show the corresponding spatial pollution level maps for the DO, BOD, COD, AN and SS sub-indices. The spatial GIS map of DO signifies that the upstream tributaries and main river are in class I and class II. However, the Gong River in the Rawang sub-basin is class IV and other tributaries, namely the Garing River, Kuang River and Sumbah River are in class III of DO. The lower DO value in the Rawang sub-basin caused the class III classification of DO downstream of the Selangor River. The lower DO was potentially because of the construction work along these tributaries, which resulted in a high TSS concentration. Suspended solids absorb heat from sunlight, increasing the water temperature and subsequently decreasing the DO level necessary for aquatic life (Ginting & Mamo, 2006). In addition, these tributaries are narrow and have a low flow rate, and as a result, stream self-purification does not occur properly. Figure 4.14 (b) shows that the downstream tributaries of the Selangor River fall into class III BOD category. It is evident that upstream, some portions of the main river also fall into class- III because point sources, especially untreated wastewater from STPs, are found around the area. The Rawang River within the Rawang sub-basin exhibited class IV and most tributaries in this sub-basin were class III. The Gong River and Gontong River in the Rawang sub-basin fall into class V and Class IV of AN, respectively. A potential cause of such high AN in the Rawang sub-basin is the abundant sewage discharge along the river, which carries effluents from septic tanks, including industrial effluents that have not undergone a disinfection process. The AN level is class-III at the confluence of the Kerling and Selangor Rivers. The upstream part of the Selangor River was identified as class I and class II categories of TSS, but within the Rawang sub-basin some tributaries were in class V, class IV and class III categories of TSS. The factors potentially contributing to the increasing TSS trend are on-going construction and sand mining activities within the Rawang sub-basin. Although the effects of these activities on the river are transient, the increase in TSS in the Selangor River is evident. The WQI map indicates that upstream is class II and downstream is class III. The Rawang sub-basin is very clearly the most polluted within the basin, as pointed out on the WQI pollution level map. Most tributaries within the Rawang sub-basin are classified as class III and class IV WQI. The DO, BOD and AN contributions are shown on the spatial maps in Figure 4.14 (a), (b) and (c), respectively.



(a)



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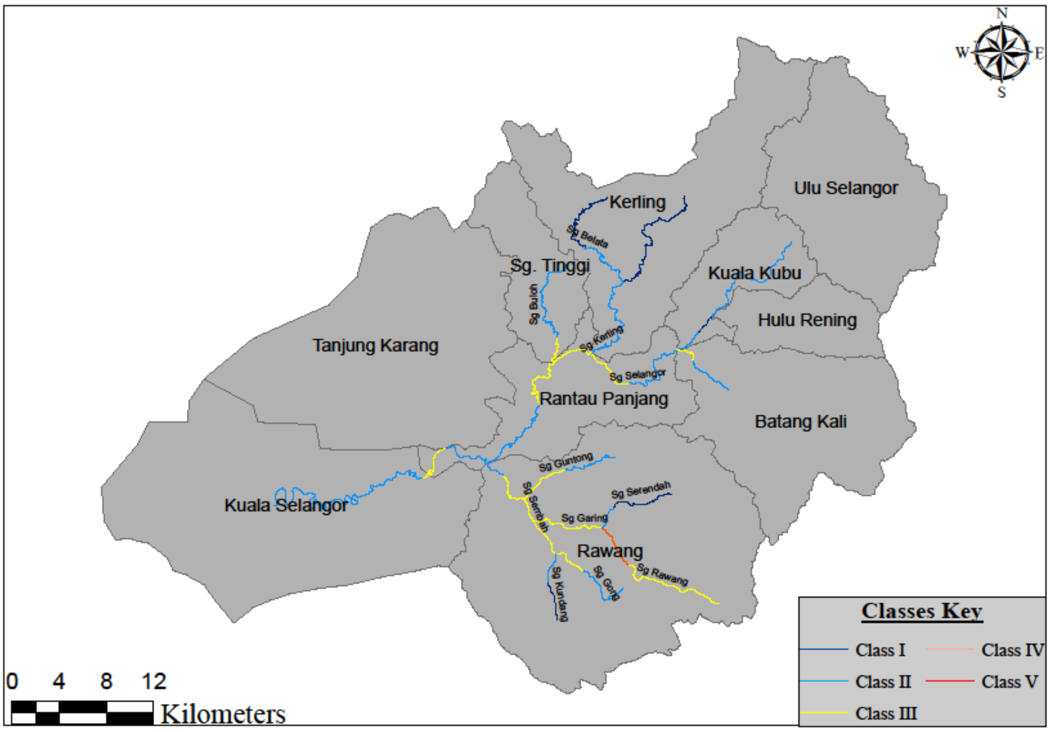
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Sg Buloh
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Kuala Kubu
Hulu Rening
Tanjung Karang
Sg Kerling
Sg Selangor
Rantau Panjang
Batang Kali
Sg Guntong
Kuala Selangor
Sg Serendah
Sg Sembah
Sg Garing
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Sg Gong
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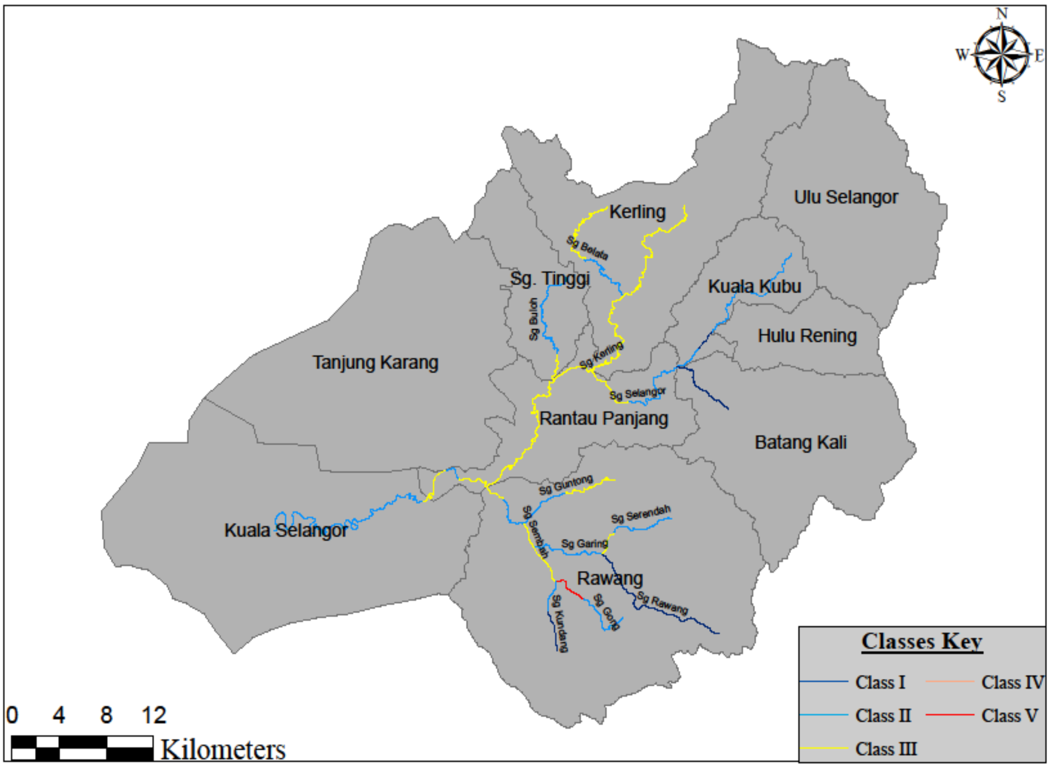
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Rantau Panjang
Batang Kali
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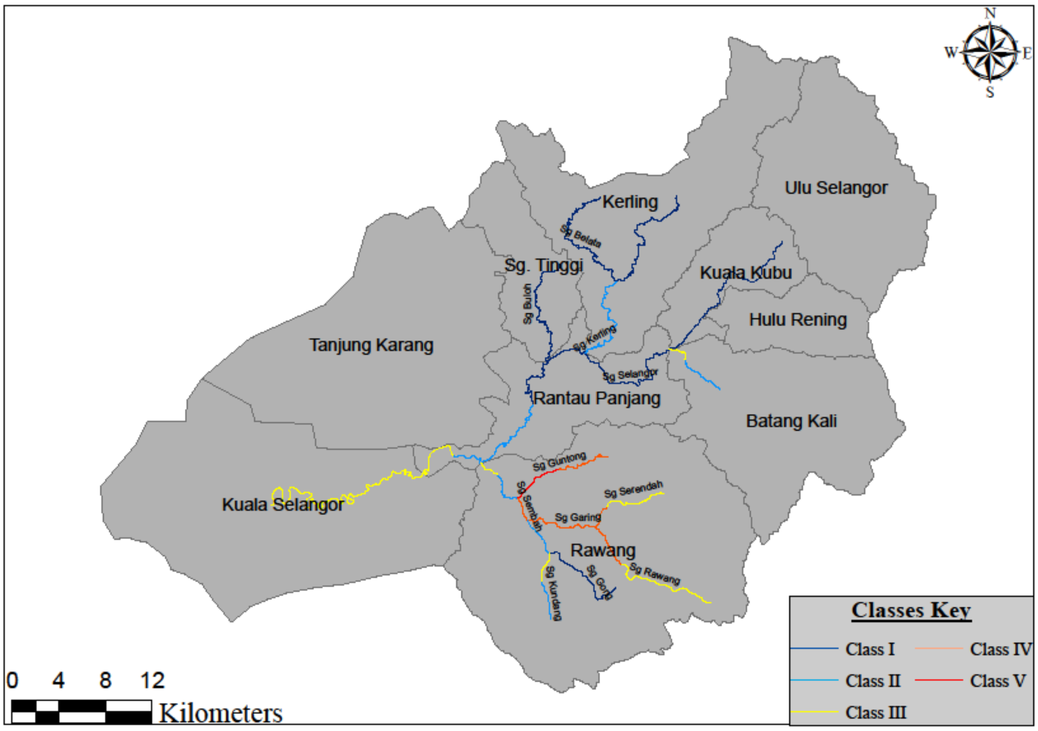
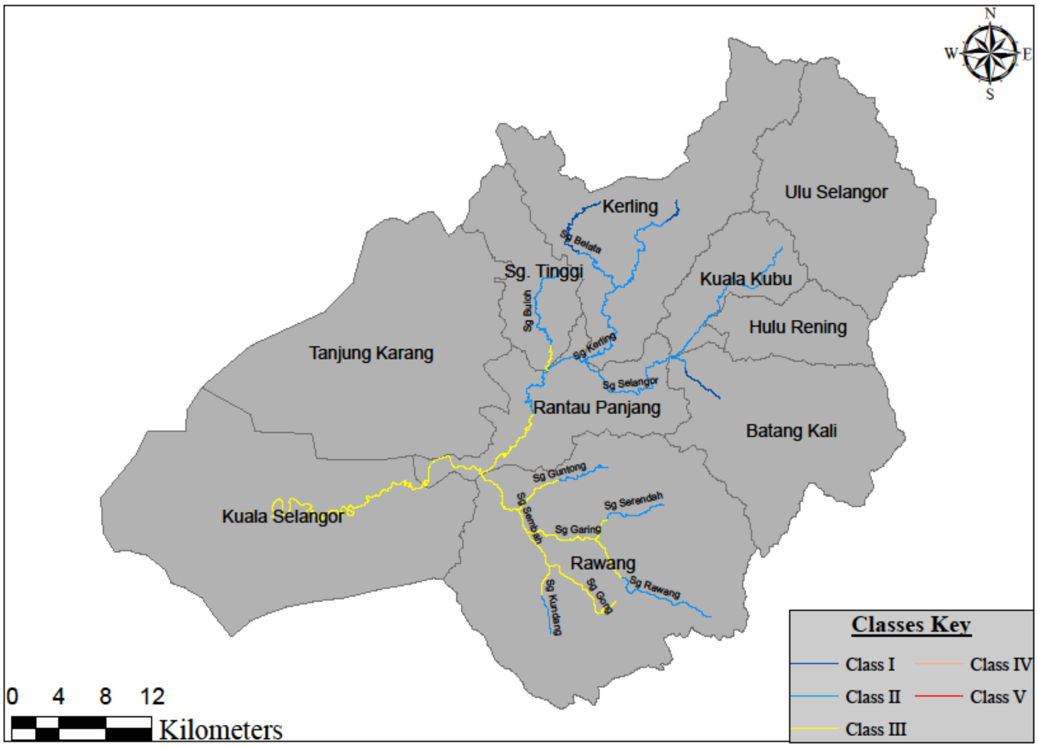


(e)



(f)

Figure 4.14: a) DO b) BOD c) COD d) AN e) TSS f) WQI

Generally, the water quality of the Selangor River varies from the upstream to the downstream region, and it is also dependent on different land uses. The water quality result shows that Selangor River is affected in terms of high concentrations of BOD, COD and NH_3-N. WQI results show that sampling stations located upstream and middle stream registered as classes- II, while in the Rawang sub basin and downstream of Selangor River the water quality falls into class-III based on the NWQS for Malaysian rivers. BOD, COD and NH_3-N registered as class-IV and class-V at some of the tributaries within the Rawang sub-basin. Based on the water quality result, St-6 is the most polluted station located within the Rawang sub basin while St-11 is the cleanest station located upstream of Selangor River. The high pollution level in the Rawang sub-basin is due to substantial dumping or leakage of industrial waste, and sullage from restaurants, food stalls, wet markets and construction sites along the river. The current study results indicate that the main sources of pollution for the Selangor River basin are anthropogenic in nature and comprise of STPs, industrial waste and effluents, slaughter houses and abattoirs, agricultural activities and landfills. Topography of upstream of the Selangor River basin shows that the river runs through mountainous areas, resulting in it having a high velocity and high turbulence. Hence, the upstream part of the river has more oxidization potential, re-aeration and self-purification. As one goes further downstream, natural conditions change from mountainous regions to valley-like area. In the valleys, the velocity and turbulence of the river decreases, resulting in reduced capability of oxidization, re-aeration and self-purification of the river. This is the natural factors of possibility to store contaminant elements in the river water a longer time and distance (Altansukh, 2000).

4.2.6 Temporal Water Quality Assessment

DOE Malaysia has been monitoring the Selangor river basin water quality at thirteen monitoring stations throughout the basin. Out of the thirteen monitoring stations eight monitoring stations (WQ-1, WQ-2, WQ-3, WQ-4, WQ-5, WQ-6, WQ-7 and WQ-8) of water quality data from the year 2005 to 2010 were available for analysis. The location of these eight stations of DOE can be seen on Figure 4.15.Station WQ-1 is located at the sub-basin Kuala Selangor and is the most downstream of Selangor River. WQ-6, WQ-7 and WQ-8 are located at the Rawang sub-basin while WQ-2, WQ-3, WQ-4 and WQ-5 are located upstream of the Selangor River.

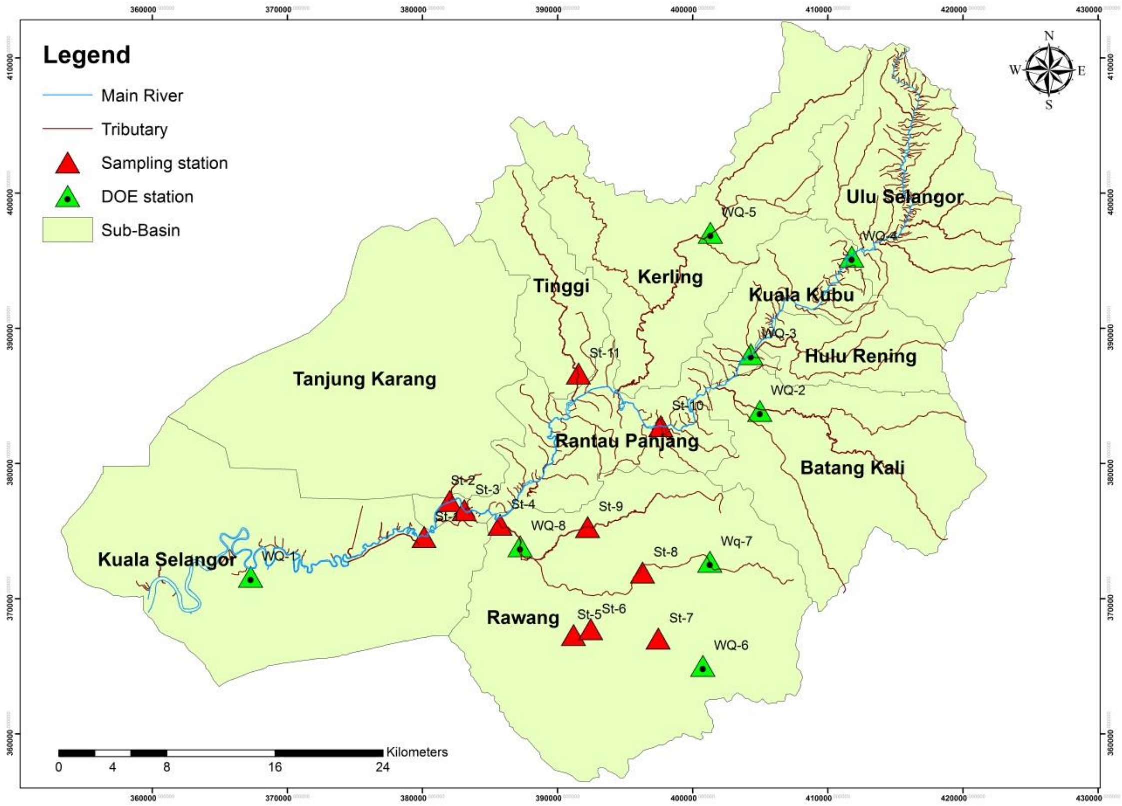


Figure 4.15: Location map of DOE stations

Figure 4.16 shows the comparison of the temporal average annual trends related to the water quality results (2005-2010) in the form of WQI at the DOE stations and our sampling results (2014). The comparison shows the WQI of the Selangor River significantly decreasing from DOE (2005-2010) data to our average sampling results in 2014. DOE monitoring station WQ-2, WQ-3, WQ-4, WQ-5, WQ-6 and WQ-7 was almost stable 2005 to 2010.However, WQ-1 and WQ-8 shows increasing and decreasing trend throughout the year 2005 to 2010. WQ- 1shows an increasing trend and was register under class-II of WQI from 2005 to 2007. However, WQI values of this station start to decreasing trend and fall under class-III from 2007 to 2010. The WQI values of WQ-8 increased from 2005 to 2007 and this station again shows decreasing trend from 2007 to 2010. The WQI values of WQ-8 was under class-II during 2007 and 2008 while during 2005, 2006, 2009 and 2010 this station categorized as class-III. WQ-1 is the most downstream station and WQ-8 located within the Rawang sub-basin. This DOE results analysis indicate that the Rawang sub-basin is the main contributor of pollutants to the Selangor River. This scenario further supported by WQI trend of our sampling stations. Most of our sampling stations located within the Rawang sub-basin are register class-III of WQI values.

Populations are increasing year by year. Increases of population have increased the water demand for fresh water resources intake from the river. The degradation of the water quality from 2005 to 2014 is mainly due to rapid urbanization, increased industrial activities, intensive farming, over use of fertilizers in agriculture, discharge of untreated waste water and sewage outlets.

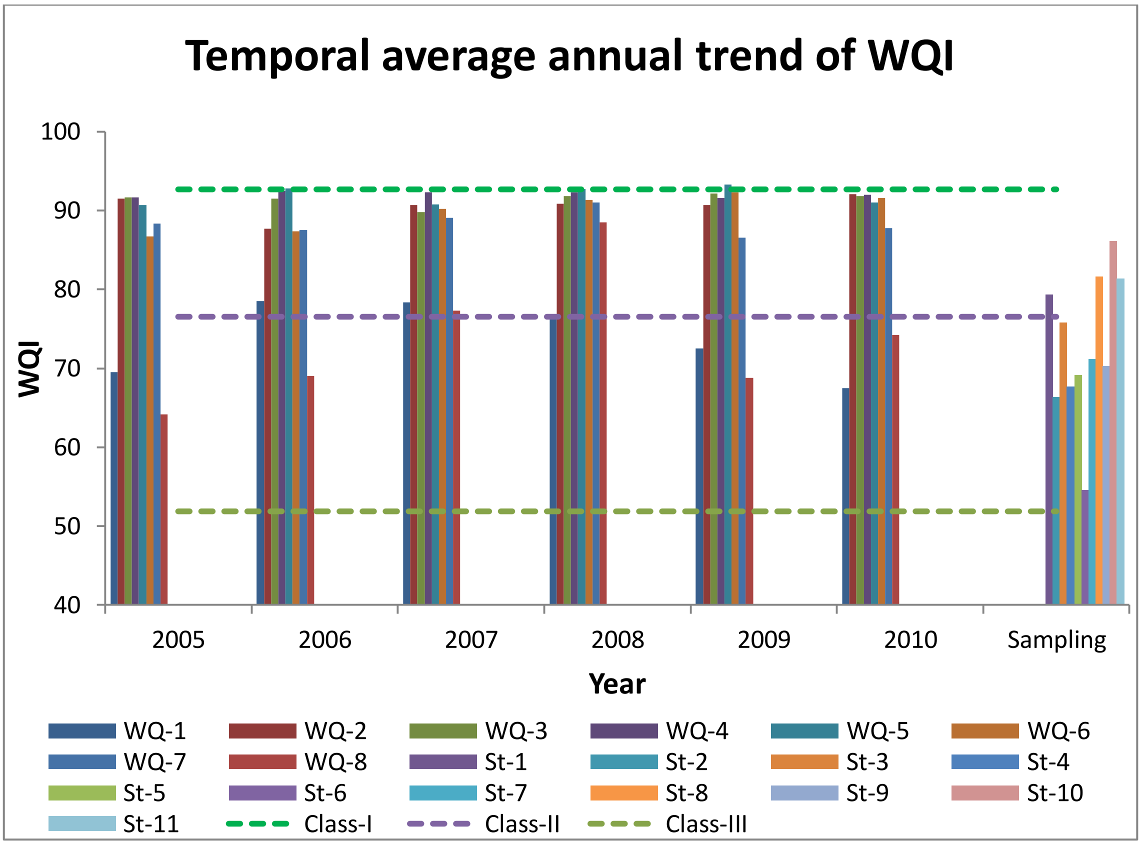


Figure 4.16: Comparison of WQI of DOE monitoring stations and sampling stations

4.3 Heavy Metals

The recovery of the analytical procedure of heavy metal analysis is presented in Table 4.3.The recovery of the procedure for water samples metal analysis was within the range of 80-120% for all metals. This implies that the extraction procedure used was satisfactory in extraction of acid soluble metal compounds from river water (U.S. EPA Method 200.7). The analysis of seven replicates of each water samples demonstrated relative standard errors (RSD) below 10% in general (USEPA-2010).

Table 4.3 : Percentage recovery of metals for water analysis by ICP-OES

Metals	Wave length (nm)	Detections limit (µg/L)	Quantitative limits(µg/L)	Calibrations Curve(r)	Recovery (%)
Ag	328.068	0.17	0.57	0.9998	98.10
As	188.979	0.97	3.27	0.9922	83.47
Cd	228.802	0.39	1.30	0.9999	86.12
Co	228.616	0.21	0.70	0.9997	88.72
Cr	262.716	0.12	0.40	0.9999	91.46
Cu	327.393	0.48	1.60	0.9998	100.47
Pb	220.353	1.20	4.00	0.9993	89.13
Ni	231.604	0.21	0.70	0.9998	92.17
Fe	238.204	0.16	0.53	0.9992	118.45
Mn	257.610	0.02	0.07	0.9991	115.65
Al	396.153	0.28	0.93	0.9998	88.60
Mg	285.213	0.11	0.37	0.9999	106.38
Zn	206.200	0.10	0.33	0.9996	107.85

The descriptive statistics of heavy metals are summarized in Table 4.4.The MOH and NWQS limits are presented in Appendix B. Standard deviation (SD) and coefficient of variance (CV) are statistical measures of dispersion in a data series around its average; and the CV denotes the ratio of standard deviation to the metals concentration. The average concentrations of As, Fe and Mn exceeded limit of Malaysian National Standard Water Quality and standard proposed by the Ministry of Health(MOH, 2004), while all other studied metals had average concentrations below of the standards. The mean and maximum value of Fe crossed both limits. The average concentration of Mn was below the MOH's limit and NWQS limit however, the maximum value of Mn exceeded both limits. The mean value of As exceeded the MOH limit but was below the NWQS limit. The maximum value of As exceeded both standards. The mean, maximum and minimum values of Mg, Al, Zn, Ag, Cd, Co, Cr, Cu, Pb and Ni were well below the NWQS and MOH limit.

Table 4.4: Descriptive statistics of heavy metal concentrations in water samples from the Selangor River

Metal	Present Study					MOH (µg/L)	NWQS (µg/L)
	Max (µg/L)	Min (µg/L)	Mean (µg/L)	SD	CV (%)		
Fe	3356.20	947.45	1733.76	767.51	40	1000	1000
Mg	1946.47	312.95	808.46	533.25	55	150000	-
Al	4368.84	98.13	571.21	2231.49	137	-	-
Mn	430.27	45.04	93.32	111.64	80	200	100
Zn	235.22	53.11	85.44	62.16	58	3000	5000
Ag	3.18	0.51	1.05	0.99	69	50	50
Cd	1.27	0.20	0.37	0.31	66	3	10
Co	4.56	0.83	1.41	1.05	63	-	-
Cr	5.39	1.61	3.08	1.07	34	50	50
Cu	35.60	6.20	9.37	8.93	70	1000	20
Pb	20.60	0.62	3.87	5.92	70	10	50
Ni	6.87	0.72	1.15	1.79	98	20	50
As	128.34	3.03	29.49	35.71	95	10	50

4.3.1 Distribution of Heavy Metals

Box and whisker plots were drawn to observe the distribution of As, Mn and Fe among the sampling stations (Figure 4.17). The concentrations of Fe, Mn and As varied widely at each station. Fe was the dominant metal in the Selangor River, exceeding the limit of 1000µg/L at nearly all sampling stations. The highest concentration of Fe was found at St-9 (9741.52µg/L) and the lowest at St-11 (285.97µg/L). The Fe concentration was significantly high at St-5, St-2 and St-9. Stations St-5 and St-9 are located in the Rawang Sub-basin, which is an industrial area and also former tin mining region. Therefore, the potential sources of Fe in the Rawang Sub-basin are industrial estates and mining waste water from the former tin mining catchment. St-2 is located at the Air Hitam River where the surrounding area is peat land and palm oil plantations as well as palm oil factories. The pH was low at station St-2, because the toxicity of Fe(attributed to the peat land) increases as pH decreases(Decker, 1974).

Mn exceeded the limit (200µg/L) at St-5 and St-9. The highest concentration of Mn was found at St-5 (2619.36µg/L) and the lowest at St-7 (9.27µg/L). The possible source of Mn is industrial estates around the Rawang Sub-basin. Mineral pollutants (Fe and Mn) of 912kg/day are discharged from 11 industrial estates to Selangor River and its tributaries(DID, 2007).

Arsenic concentration was highest at St-2 (369.78µg/L) and lowest at St-11 (2.11µg/L). The highest value of As was found at St-2, which is located in the former tin mining catchment of Bestari Jaya (previously known as Batang Berjuntai) at the Rantau Panjang sub-basin. The source of As may be mining wastewater from the former tin mining catchment of Bestari Jaya, Peninsular Malaysia. A previous study also reported that As in the catchment of Bestari Jaya, Peninsular Malaysia, is sourced from the former tin mining area (Ashraf, Maah, & Ghararibrez, 2012).

The sampling stations which are located at the Rawang sub-basin of Selangor River basin were found to have a high concentration of metals. Industrial and formal tin mining activities at the Rawang sub-basin increased the metal concentration within the Selangor River basin. This indicates that land use of the Selangor River basin could have had negative influences on the metal concentrations of the river water. Rapid urbanization and industrialization surrounding the area of the Selangor basin has resulted in an overall increase in heavy metal concentration in the river water. The standard guideline values of heavy metals has had a significant role in ensuring proper management of water resources (Bulat Nadmitov et al., 2015).

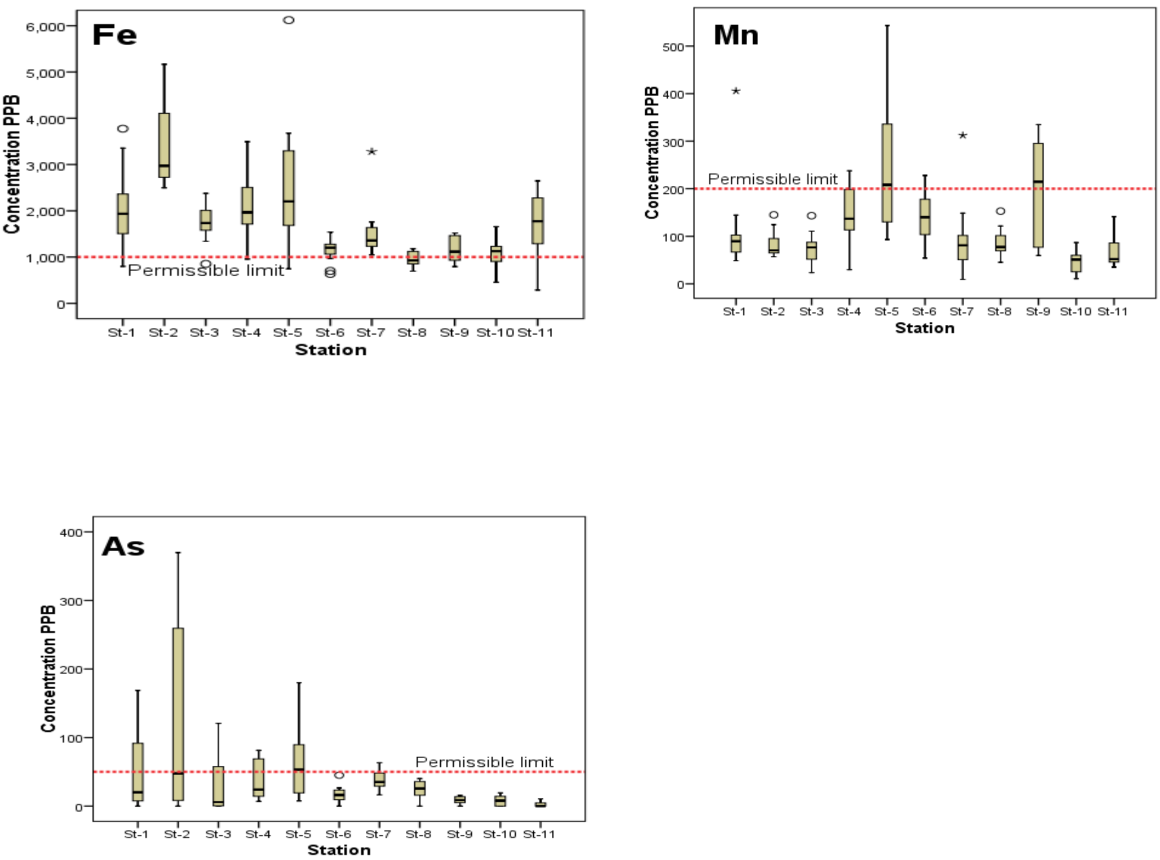
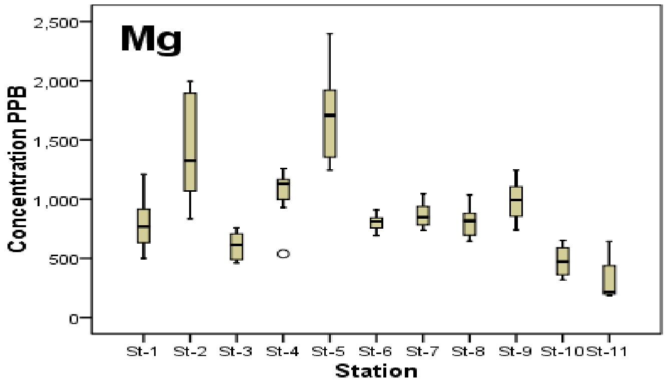
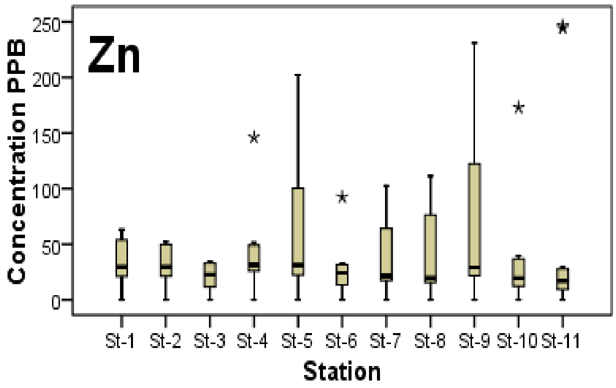
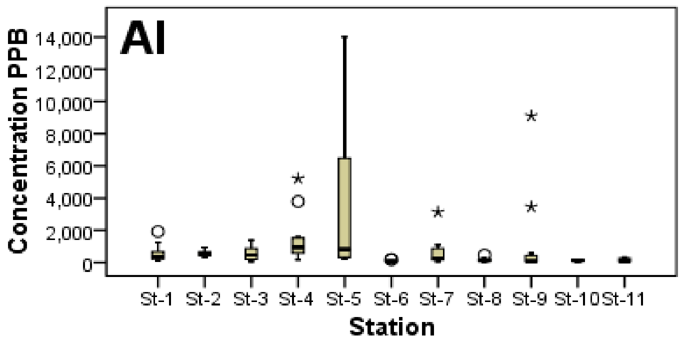


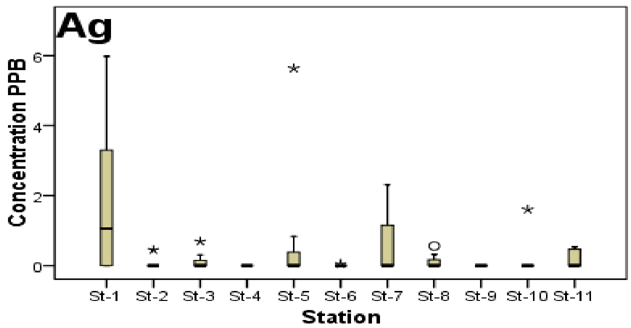
Figure 4.17: Box and whisker plots of the distribution of Fe, Mn and As

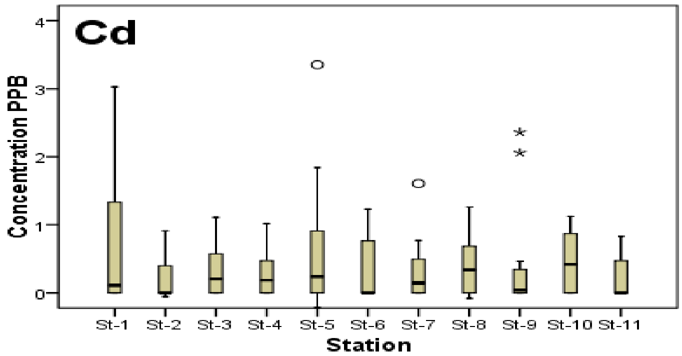
Figure 4.18 represent the box and whisker plots of the metals which were well below the standards limit. Elevated metal concentrations of Mg, Al, Zn, Ag, Cd, Co, Cr, Cu, Pb and Ni were found at St-5, St-6 and St-9, though these metal concentrations were well below the standards limit. St-5, St-6 and St-9 are located at the Rawang sub-basin which is an industrial area within the Selangor River basin. Therefore potential reasons of increasing concentrations of heavy metals at St-5, St-6 and St-9 are from point sources such as industrial waste and also non-point sources such as mining wastewater from the former tin mining catchment.

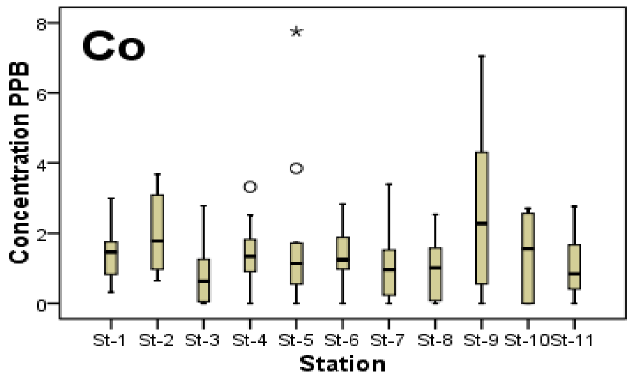

Mg
Concentration PPB
0
500
1,000
1,500
2,000
2,500
St-1 St-2 St-3 St-4 St-5 St-6 St-7 St-8 St-9 St-10 St-11
Station

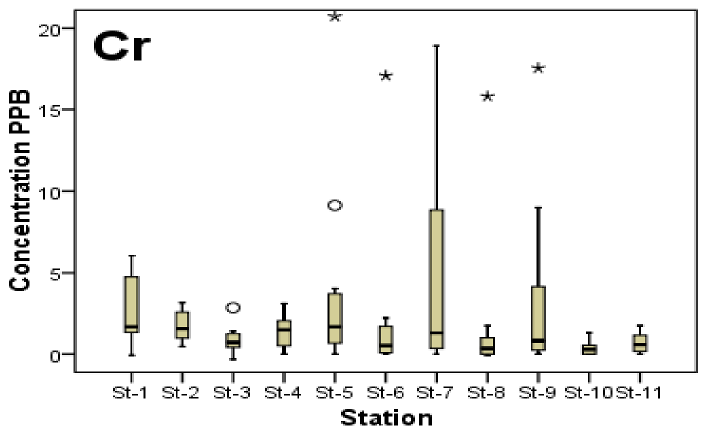

Zn
Concentration PPB
0
50
100
150
200
250
St-1 St-2 St-3 St-4 St-5 St-6 St-7 St-8 St-9 St-10 St-11
Station

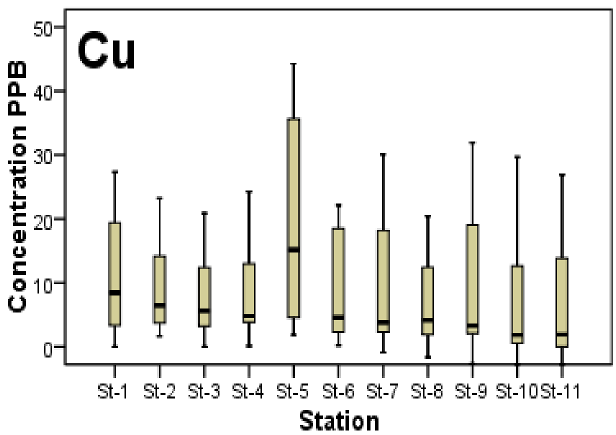

Al
Concentration PPB
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
St-1 St-2 St-3 St-4 St-5 St-6 St-7 St-8 St-9 St-10 St-11
Station


Ag
Concentration PPB
0
2
4
6
St-1 St-2 St-3 St-4 St-5 St-6 St-7 St-8 St-9 St-10 St-11
Station


Cd
Concentration PPB
0
1
2
3
4
St-1 St-2 St-3 St-4 St-5 St-6 St-7 St-8 St-9 St-10 St-11
Station


Co
Concentration PPB
0
2
4
6
8
St-1 St-2 St-3 St-4 St-5 St-6 St-7 St-8 St-9 St-10 St-11
Station


Cr
Concentration PPB
0
5
10
15
20
St-1 St-2 St-3 St-4 St-5 St-6 St-7 St-8 St-9 St-10 St-11
Station


Cu
Concentration PPB
0
10
20
30
40
50
St-1 St-2 St-3 St-4 St-5 St-6 St-7 St-8 St-9 St-10 St-11
Station

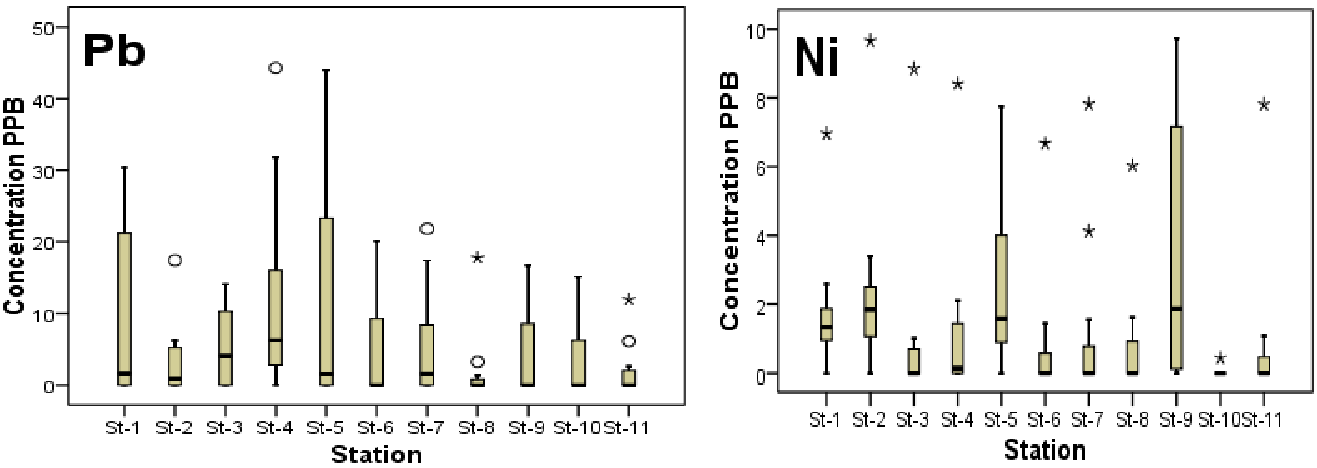


Figure 4.18: Box and whisker plots of the distribution of heavy metal which were below standards

4.3.2 Statistical Analysis of Heavy metals

4.3.2.1 Pearson Correlation Analysis

Table 4.5 present Pearson's correlation coefficients of studied heavy metals Selangor River's water. Fe showed very strong correlation between Fe-Mn (r=0.80); Fe-Mg (r=0.86); Fe-Al (0.88); Fe-Pb (r=0.77) at *P*<0.01, which indicate that this group of metals may be from the same source. Fe,-Mn,-Mg,-Al and Pb are mainly sourced from industrial activities, untreated domestic sewage and also from traffic sources. The correlation between metal concentration and physicochemical parameters was a major concern of this study. The concentrations of Fe, Mn, Mg, Al, Pb and As in water were positively correlated with turbidity (r = 0.83, *P* <0.01 for Fe, r = 0.87, *P* <0.01 for Mn, r = 0.65, *P* <0.01 for Mg, r=0.98 *P*<0.01 for Al, r=0.73, *P*<0.01 for Pb and r=0.96, *P*<0.01 for As).

Turbidity was high at sampling stations St-5, St-9, St-3 and St-4 while elevated metal concentrations were also observed at the same sampling stations. This signifies that the metals do not have a strong bond with the crystal structure of minerals that comprise sediment; thus, dilution due to rain largely affects metal concentration in river water.

Wastewater from construction sites, industry effluent, mining activities, agricultural activities and rainfall runoff contribute to the high turbidity of river water, which increases the influx of metals into the Selangor River.

Table 4.5: Pearson correlation analysis between heavy metals and pH, EC, Turbidity, and Temperature

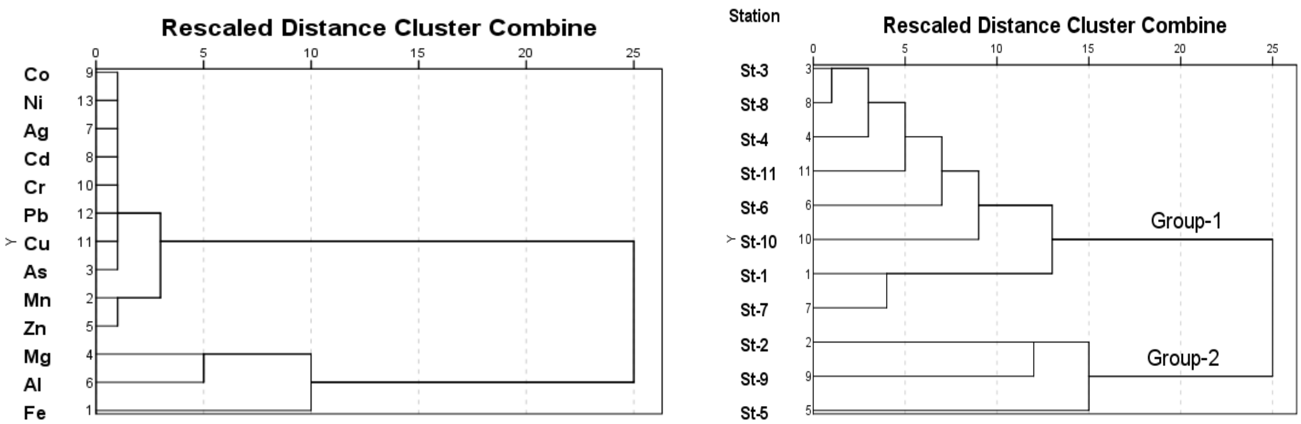
	Fe	*Mn*	*Mg*	*Zn*	*Al*	*Ag*	*Cd*	*Co*	*Cr*	*Cu*	*Pb*	*Ni*	*As*	*pH*	*EC*	*Turbi.*	*TEMP*
Fe	1																
Mn	**0.80**	1															
Mg	**0.86**	0.64	1														
Zn	-0.20	-0.07	-0.11	1													
Al	**0.88**	**0.92**	0.67	-0.22	1												
Ag	-0.29	-0.44	-0.43	0.08	-0.35	1											
Cd	0.00	0.12	-0.10	-0.06	0.16	-0.26	1										
Co	0.28	0.40	0.31	-0.20	0.18	-0.37	0.20	1									
Cr	0.42	0.25	0.38	0.13	0.37	0.42	-0.05	0.05	1								
Cu	0.66	**0.89**	0.54	0.15	0.79	-0.45	0.18	0.18	0.14	1							
Pb	**0.77**	**0.83**	0.57	-0.07	**0.95**	-0.32	0.13	-0.03	0.37	0.75	1						
Ni	0.37	0.49	0.37	-0.18	0.29	-0.31	0.07	**0.96**	0.16	0.22	0.05	1					
As	0.45	0.24	0.42	0.54	0.35	0.03	0.07	-0.19	0.47	0.19	0.43	-0.09	1				
pH	-0.27	0.21	-0.19	0.19	0.15	-0.11	0.20	-0.10	0.17	0.24	0.24	-0.06	-0.08	1			
EC	0.32	0.56	0.46	0.15	0.50	-0.25	-0.21	0.20	0.49	0.50	0.58	0.26	0.14	0.59	1		
Turbi.	**0.83**	**0.87**	**0.65**	-0.20	**0.98**	-0.35	0.12	0.04	0.36	0.41	**0.73**	0.16	**0.96**	0.21	0.50	1	
TEMP	-0.25	0.08	-0.20	-0.19	-0.15	0.20	-0.34	0.21	-0.20	0.13	-0.24	0.20	-0.70	0.22	0.18	-0.23	1

0.7-1.0 Strong correlation
0.4-0.7 Moderate correlation
0.2-0.4 Weak correlation
<0.2 No correlation

4.3.2.2 Hierarchal Cluster Analysis (HCA)

HCA was applied to evaluate the degree of association between various heavy metals and to detect similarities between the sampling stations. Sampling results for a total of 13 trace metals over a period of one year (October'-2013 toSeptember'-2014) were used for HCA. The dendrogram was obtained by Ward's method depicted in Figure 4.19. Thirteen metals formed two clusters whereas Co- Ni-Ag-Cd-Cr-Pb-Cu-As-Mn-Zn formed one cluster and Fe-Al-Mg formed another cluster. The degree of association is high between the elements of the same cluster as compared to the elements of the different clusters. The joining of two clusters with a significantly large linkage distance indicates each cluster is highly independent(M.G Yalcin, A. Tumuklu, M. Sonmez, & D.S.Erdag, 2010).

Metals belonging to the same cluster are likely to have originated from a common source. Cluster-1 may be attributed to the anthropogenic sources and Cluster-2 to both the natural and anthropogenic sources. The HCA categorized eleven sampling stations in to two clusters (Group-1 and Group-2) which were statistically significant. St-2, St-9 and St-5 are under Group-1. The similarity among the stations under Group-1 was that concentrations of some metals were high at these three stations. Elevated concentration were registered for Fe, As and Mg at St- 2, Fe, As, Mn, Mg, Zn, Al at St-5 and Mn, Zn, Co, Ni at St-9. This indicates that sampling station under Group-1 received metals from common sources. The potential contributing sources of Group-1 stations may be from formal tin mining and industrial waste. St-1, St-3, St-4, St-6, St-7, St-8, St-10, St-11 are under Group-2. The similarity among the stations under Group-2 was that all studied metals showed a low concentration. The potential source of metals at station in Group-2 may be of natural origin. From the analysis, HCA multivariate technique was used to assess and classify the metal's concentrations in the Selangor River basin.



(A) (B)

Figure 4.19: Dendrogram showing clusters: (A) heavy metals parameters (B) sampling station

4.3.2.3 Principal Component Analysis (PCA)

PCA was applied on one year sampling heavy metals data set for each station to identify the spatial sources of metals in the Selangor River basin. The variables of this analysis are interrelated with two principal components of the variance in the data set. These two significant principal components are designated on the basis of eigenvalue higher than 1(one) and the Kaiser criterion. Eigenvalue of a specific factor calculates the variance in all the variables accounted for by that factor. Eigenvalue's ratio is the explanatory importance of the factors associated with the variables. The factor having a low eigenvalue contributes little to the explanation of variances in the variables. In accordance to the eigenvalues (greater than 1), two components were extracted and explained 51.45%, 56.02%, 58.2%, 52.34%, 69.17%, 48.97%, 65.52%, 48.86%, 77.16%, 61.11% and 50.73% of the total variance for the station St-1, St- 2, St-3, St-4, St-5, St-6, St-7, St-8, St-9, St-10 and St-11, respectively. These variances exhibit sufficient information of data structure.

Among the stations, the variance is higher for stations St-2, St-3, St-5, St-7, St-9 and St-10 in which the principal component 1 represents 29%, 33%, 49%, 42%, 52% and

43%, respectively, having a higher number of significant variables than others. The classification factor loading values of > 0.75, between 0.75 – 0.5 and 0.5 – 0.3 are strong, moderate and weak based on their absolute values(Nair. I.V, K. Singh, M. Arumugam, and, & D. Clarson, 2010). Principal component-1 was characterized by strong loading of Ni (r=0.88), Cu (r=0.86), Cr (r=0.80) and Zn (r=0.70) for St-2; Mg (r=0.98), Mn (r=0.97), Pb (r=0.97), Co (r=0.96), Ag (r=0.91), Cd (r=0.90) and Al (r=0.88) for St-5; Al (r=0.96), Ni (r=0.91), Co (r=0.91), Mn (r=0.90), Cu (r=0.90), Fe (r=0.89), Mg (r=0.88) and Pb (r=0.72) for St-9; Cd (r=0.99), Ni (r=0.98), Cr (r=0.98), Co (r=0.95), Zn (r=0.85) and Cu (r=0.68) for St-10. Others metals in principal component-1 demonstrated low factor loadings indicating their independence within this group. In principal component-2 the variance for the stations St-2, St-5, St-7, St-9 and St-10 represent 27%, 20%, 23%, 26% and 18%, respectively. Principal component-2 was characterized by strong loading of Al (r=0.92), As (r=0.87), Mn (r=0.67) and Cd (r=0.66) for St-2; Zn (r=0.94), Cr (r=0.89) and Ni (r=0.81) for St-5; Ni (r=0.94), Cr (r=0.87), Zn (r=0.74), and Cu (r=0.62) for St-7; Cr (r=0.93), Cd (r=0.85), Zn (r=0.79) and As (r=0.73) for St-9; Al (r=0.69), Mg (r=0.69), Mn (r=0.68), As (r=0.59) and Ag (r=0.53) for St-10.

These analyses summarize the heavy metals into two major components representing the group of heavy metals and their different sources. It can be seen from Figure 4. 20 that the metals loading patterns are similar at St-5, St-7 and St-9 and the total variance of component-1 is significantly higher at St-2, St-5, St-7, St-9 and St-10 as compared to other stations. This is in agreement with the findings of the cluster analysis which indicates that metals sources are common for these stations. These five stations are located in mining, industrial and agriculture land as can be seen from the land use map (Figure 4. 21). In consideration of this land use, the observed high loading of component-1 metals also implies the possible contribution from mining, industrial and agriculture. From the above statistical analysis, correlation, cluster analysis and PCA show that stations St-2, St-5, St-7 and St-9 can be clustered together based on their common source and controlling factors. This analysis clearly indicates that the anthropogenic influence on the Selangor River water with respect to the studied heavy metals. There are a lot of points sources located in the Rawang sub-basin which discharge their effluents directly into the river. Apart from this, some of the tributaries also pass through formal tin mining belts and carry effluents that ultimately drain into the river increasing the heavy metals load.

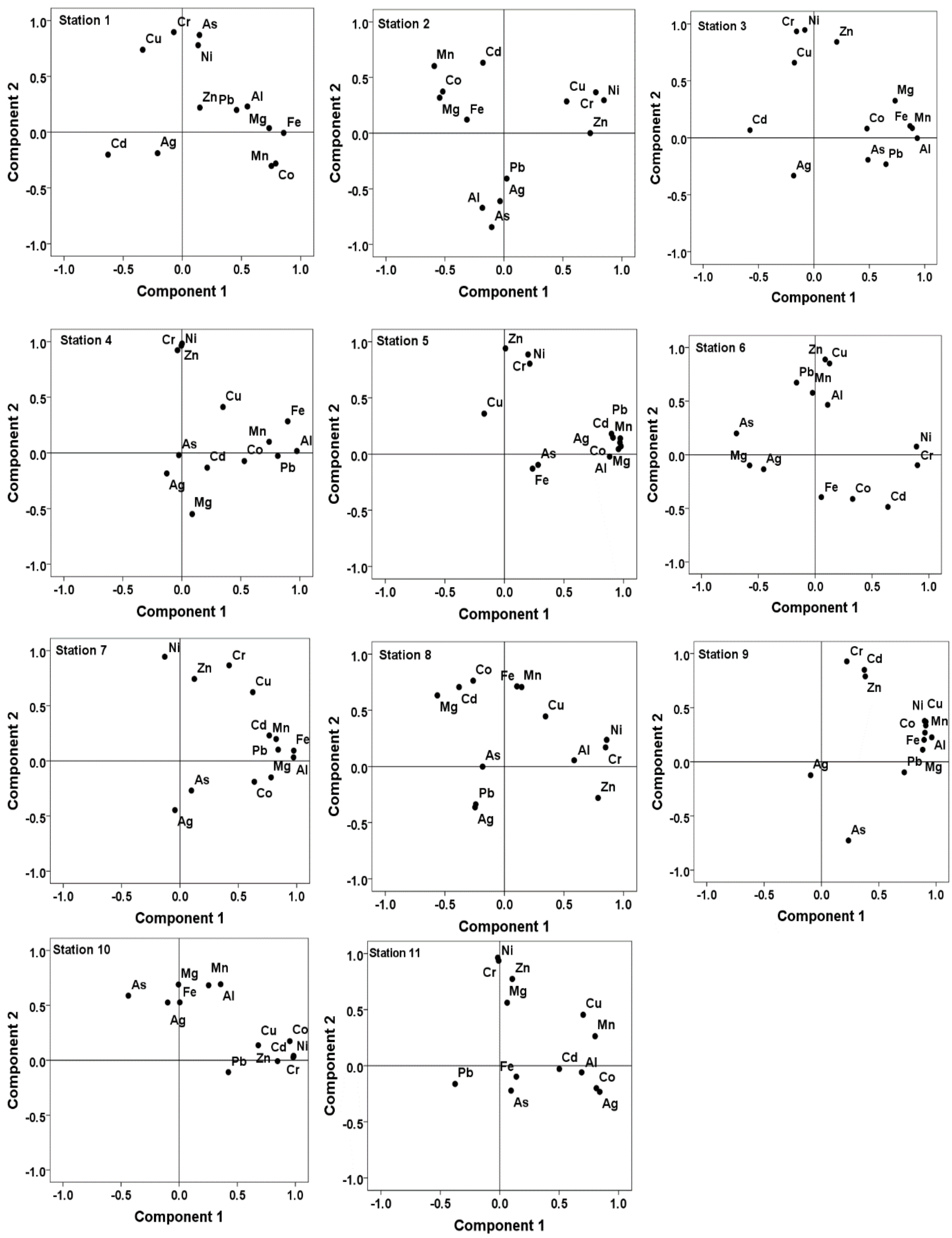


Figure 4. 20: The principal component analysis plot in rotated space for heavy metals at eleven sampling stations

4.3.3 Metal Pollution Index

In order to assess the risk of metals in the Selangor River basin, HPI was calculated based on the studied metal concentration and the NWQS, Malaysia. The critical pollution index value is 100 above this value the metal pollution level should be considered unacceptable for an aquatic ecosystem (Prasad & Bose, 2001; Venkata

Mohan S et al., 1996). The HPI value for Selangor River basin was below the critical value of 100.

However, considering the classes put forward by (A. Edet & Offiong, 2002), sampling stations St-2(HPI-48.83), St-5(HPI-57.12) and St-7 (HPI-37.13) fall into the high class (HPI > 30) with regards to water quality and metal concentration. St-1(HPI-22.26) St-4(HPI-27.01), St-6(HPI-16.70) and St-8(HPI-29.73) fall into the medium class (HPI 15–30) while St-3(HPI-8.72), St-9(HPI-10.44) and St-11(HPI-0.33) fall into the low class (HPI < 15). The increased HPI was especially marked in the presence of high Fe, Mn, Mg, Zn and As levels. An increasing trend ($P < 0.05$; ANOVA) was observed in heavy metal concentration near the industrial area in the Rawang sub-basin. This is mainly due to anthropogenic activities from upstream of the river as it flows through industrial areas, urban areas, and agricultural areas(Caeiro, Costa, & T. B. Ramos et al., 2005; Marchand, Verg`es, Baltzer, P. Alb´eric, & P. Baillif, 2006). The Rawang sub basin is an industrial zone located adjacent to the river, which increases the frequency of metal pollution occurrence within this area.

Hence, the variation of HPI was influenced greatly by the location of sampling stations. HPI values in the Selangor River basin showed good agreement with the degree of point sources and non-point sources (land use map) in surrounding sub basin, indicating that HPI were directly related to human activities and land-based activities (Figure 4. 21). So, it can be inferred that the composite influence of all the considered metals on the overall quality of the water is alarming and is due to the mining and industrial activities near some of the locations. This can be visualized while evaluating the HPI for each location.

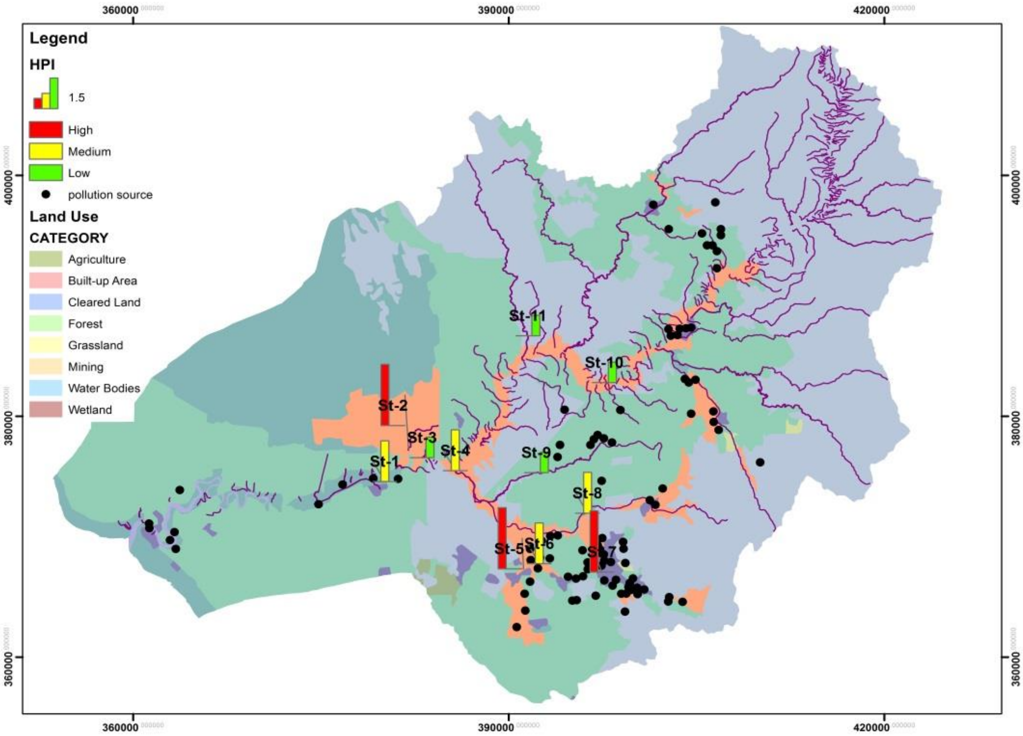


Figure 4. 21: Land use, point sources map of Selangor River basin and Heavy metal pollution index (HPI) variations among the sampling stations.

4.4 Water Quality Model

An essential aspect of the present study is to provide a water quality model for the study area that can simulate the quantity and quality of the water following various forms of pollution discharge along the river. In seeking a water quality model, the QUAL 2 K model was employed to conduct a water quality simulation for the Selangor River basin. QUAL2K simulates flow and water quality in rivers and streams. Compared to the higher dimensional models, the 1-D model does not require a comprehensive effort in the determination of relationships between parameters in the model development. Therefore, adopting the 1-D simplifies the need for carrying out complicated parameter measurement and determination during field data collection. This is important, as there were not many suitable data available for modeling purposes. Another factor that governed the selection of the 1-D modeling is the limited time frame available for model development. The 1-D modeling technique is the only method able to produce a model with an acceptable degree of accuracy within the time frame. The model uses a finite-difference solution of the advective-dispersive mass transport and reaction equations. A stream reach is divided into a number of computational elements, and for each computational elements, the model calculates a flow and mass balance. QUAL2K is typically used to assess the environmental impact of multiple pollution discharges along rivers. It is also able to predict the concentration levels of selected pollutants at different stretches (reaches) along rivers.

4.4.1 Results of Calibration and Validation of the Model

Calibration and validation of a model are the most crucial steps needed to gain adequate performance of the model. Model calibration is the process of justifying the parameters input data until the model output matches the observed data set. Model validation, on the other hand, is the process of testing a model using an independent data set without further parameter adjustment. This is important to obtain an agreement between the simulated result and the observed data set. According to (Henriksen et al., 2003), R^2 value of ≥ 0.85 considered an excellent, between 0.65 and 0.85 considered very good, between 0.5 and 0.65 considered good, between 0.2 and 0.5 considered poor, while the values less that 0.2 considered very poor. Several water quality and hydraulic parameters can be simulates by a QUAL2K model. In this study two model calibration stages i.e. water quality and hydraulic parameters have been done. DO, BOD and AN were selected as water quality parameters for calibration while discharge was chosen for hydraulic calibration.

The Selangor River QUAL2K model was calibrated and validated using the average one year sampling data collected from October'2013 – September' 2014. Average (October'2013-Decmber'2013) water quality sampling data was used as headwater water input data. Sampling data (discharge) for the month of October'14 was used for headwater input data. Average (October’2013-December’2013) discharge data was used for discharge calibration. The sampling stations that were used for calibration and validation along the Selangor River were St-1, St-3, and St-10, while St-4 was used for the Rawang sub-basin. In this study, three water quality parameters i.e. DO, BOD and AN were calibrated as water quality parameters. Average yearly (October'2013-September'2014) sampling water quality data was used as observed data. During model calibration, an adjustment was made for the missing water quality data at the headwaters. In addition, an adjustment was done in model calibration for the water quality variables at the pollution sources to achieve a reasonable match between observed and calculation data. According to (Edward, 1992), the adjusted variables data can be entered either by direct measurements or by using the input parameters and constant values of a model accomplished for a study area similar to that of the current study. The rate and coefficient values (Appendix C) of the water quality parameters were adjusted using values from literature as a first approximation, after which the values were fine-tuned through the process of QUAL2K calibration.

Generally, the simulated values show a reasonable agreement with the measured values, except for certain stations where the model underestimates or overestimate certain values.

4.4.1.1 Calibration of the Model

Calibration of Discharge:

In this study, discharge calibration was made on the observed discharge at the sampling stations. In order to attain a reasonable match between measured and simulated discharge, an adjustment was made for the discharge rates at the headwaters and diffuse sources. Figure 4.22 represents the comparison between the observed and simulated discharge for the main stream of Selangor River. It shows that the pattern of observed discharge is similar to that of the simulated discharge. As shown in Figure 4.23, the correlation between the observed and simulated discharge (R^2) is 0.9934, which can be considered as excellent according to Henriksen et al. (2003).

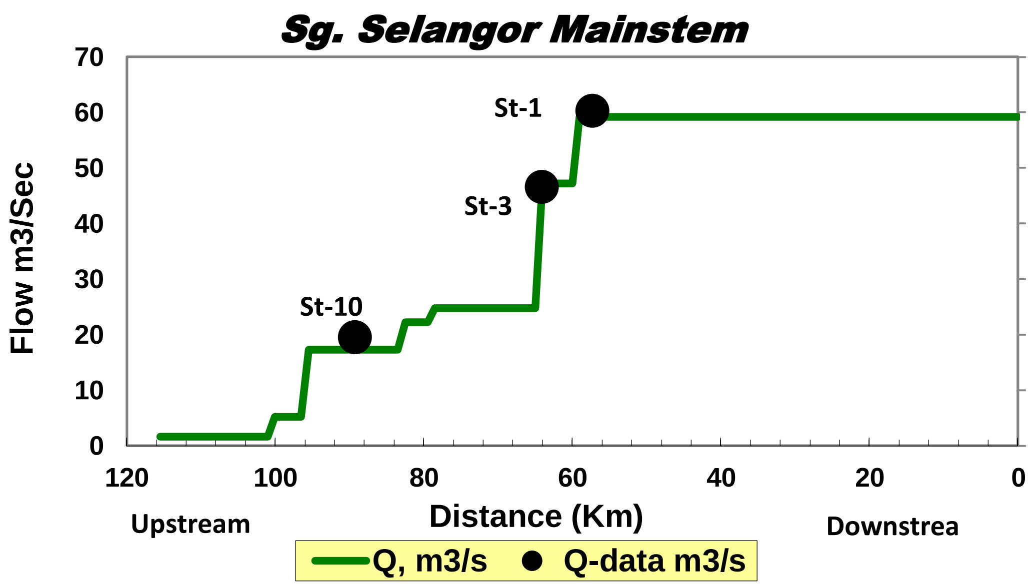


Figure 4.22: Flow calibration of the main stream of Selangor River

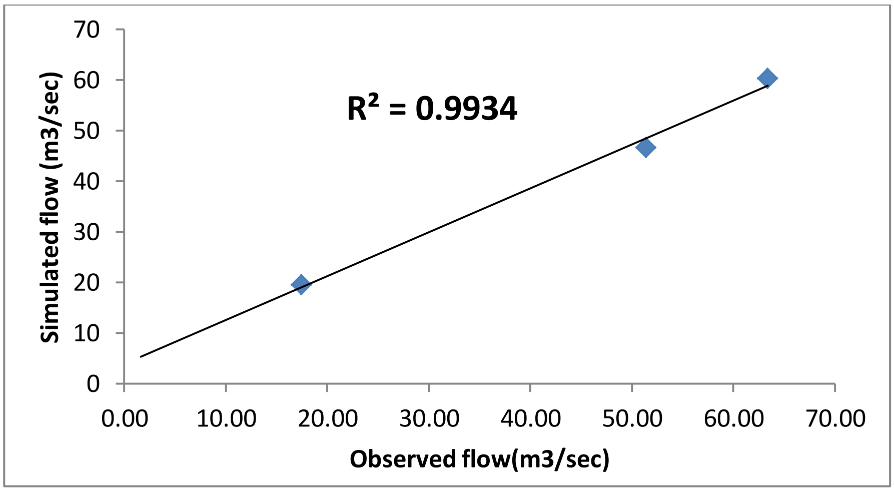


Figure 4.23: Graph of discharge calibration for the main stream of Selangor River

Calibration of Dissolve Oxygen: `

Figure 4.24 presents the calibration results of DO concentration levels along the Selangor River. The observed DO pattern is comparable to that of the simulated DO upstream and downstream of the river. The correlation between the observed and simulated DO (R^2), as per Figure 4.25, is 0.517. (Henriksen et al., 2003) indicate that this correlation value is deemed good. The model seems to have overestimating the DO values near station St-3. Such errors in this DO modeling are unavoidable because the fieldwork involved gathering a water sample at each monitoring point. Nevertheless, the simulation results were acceptable to realize water environmental management targets under the conditions of limited data (Zhang et al., 2012).

The DO concentration level shows a decreasing trend from upstream to downstream. There are three remarkable observations of DO that decrease, the first decrease was at the confluence of Batang Kali River and. Selangor River, secondly at the confluence of Buloh River and Selangor River and finally third a decrease at the confluence of Sambah River and Selangor River. The lowest decrease was at the confluence of Sambah River and Selangor River. The DO upstream started at 6.88 mg/L and increased to 9.04 mg/L just before Batang Kali enters into the main stream . Subsequently it dropped to 8 mg/l and it was steady until just before Buloh River entered into the main stream. Thereafter, there was a small drop to 7.89 mg/l. Subsequently, a significant drop of DO was noticed at the confluence of Sembah River and Selangor River. The point that shows sharp decreases of DO is the point where Sembah River (in the Rawang sun-basin) meets the Selangor River. Downstream of this junction, the DO level comes to around 2.5 mg/L, i.e. at the threshold level of class IV.

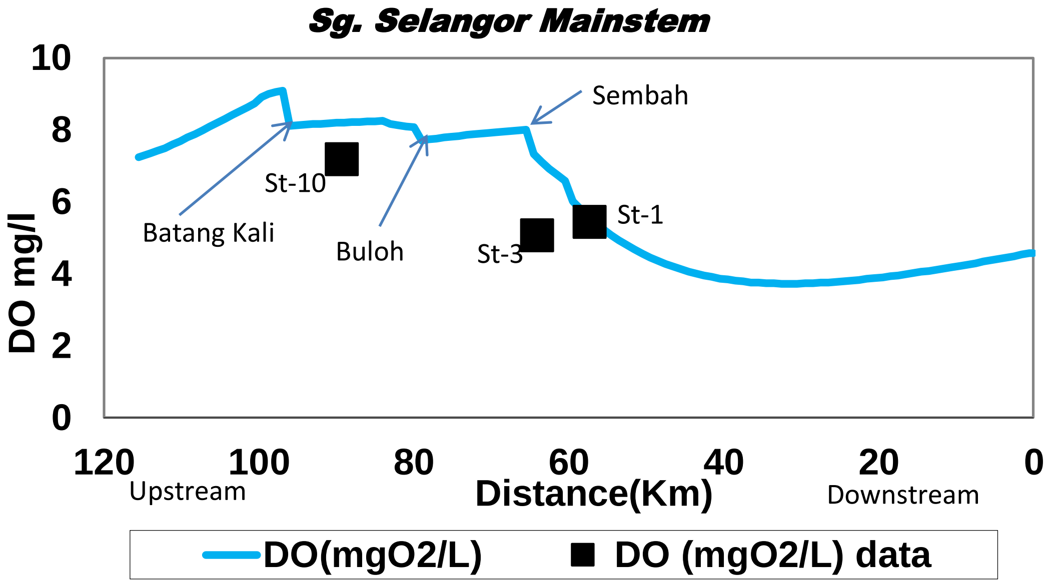


Figure 4.24: Comparison between observed and simulated DO for the Selangor River

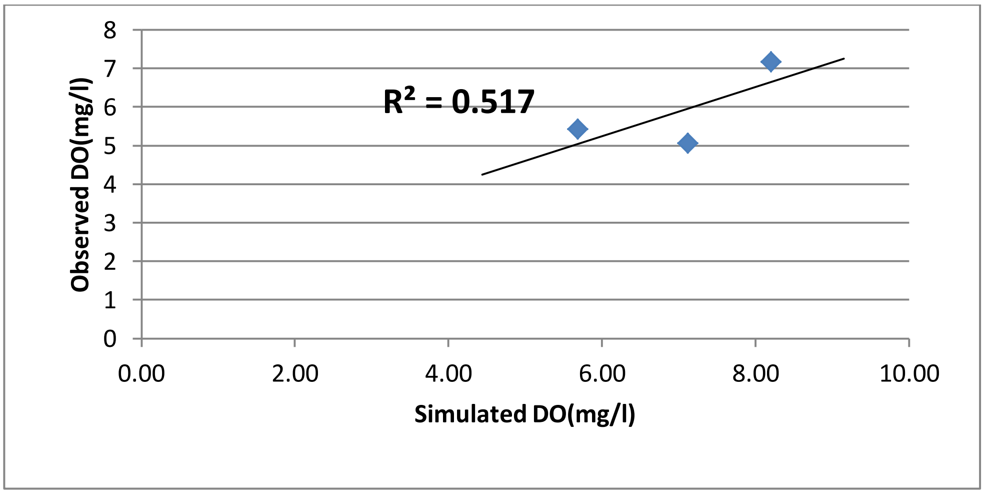


Figure 4.25: Plot DO calibration for the main stream of the Selangor River

Figure 4.26 shows the DO calibration and validation results along the main river in the Rawang sub-basin. The DO starts at 4.8 mg/l upstream and increases to 8.17 mg/l just before the Rawang River. A sharp decrease in the DO value (6.31 mg/L) was observed when the Rawang River entered into the main river, thereafter the value remained steady until the Kuang River met the main stream whereby the DO value decreased to 5.68 mg/l at the confluence of the Kuang River and the main stream. Henceforth, it shows a steadily decreasing trend as it flows downstream along the Sembah River before meeting Selangor River. The value obtained at Sambah River by the model was 6.02 mg/L whereas the observed value is about 3.83 mg/L at the same point.

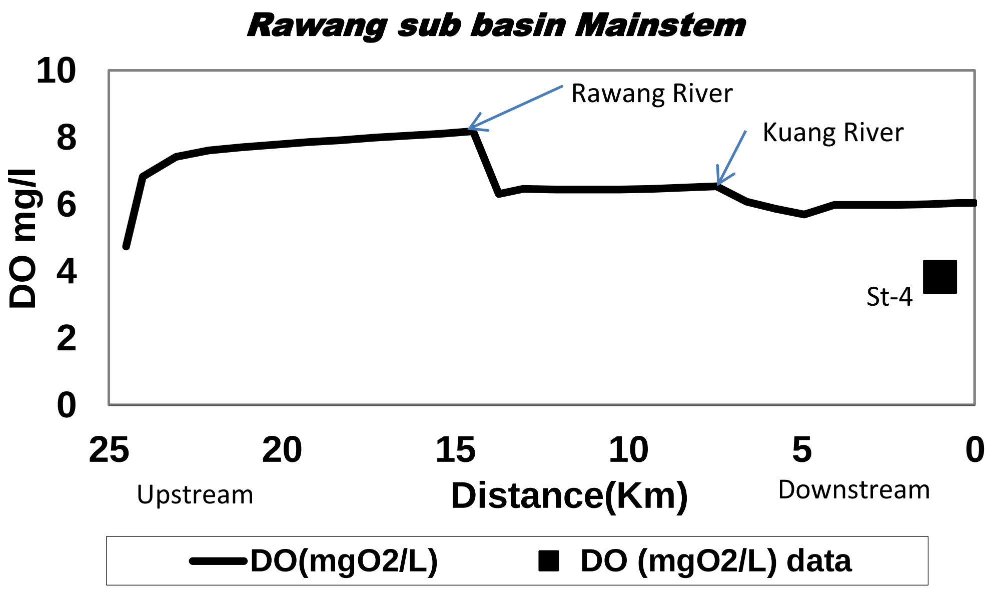


Figure 4.26: Plot DO calibration for the main stream of the Rawang sub-basin.

Calibration of Biochemical Oxygen Demand:

The calibration results of the BOD level are presented in Figure 4.27 while Figure 4.28 represent the correlation between the observed and simulated BOD (R^2) at 0.82. This correlation value is seen as very good according to (Henriksen et al., 2003) The level of BOD shows an increasing trend as the river flows downstream. The first increase in the BOD of 1.54 mg/l occurred at the confluence of Bantang Kali River and Selangor River and another slight increment of 1.01 mg/L occurred at the confluence of Buloh River and Selangor River. Finally, a BOD value of 6.97 mg/L was seen at the confluence of the Sambah River and Selangor River. The highest simulated value of 10.48 mg/L BOD along the Selangor River was at the point where Sembah River (in the Rawang sub-basin) meets the Selangor River. Such high BOD at the confluence of Selangor River and Sembah River was due to the contribution of point sources located in the Rawang sub-basin. Although similar patterns can be seen between the modeled and observed values, the model seems to overestimate the BOD values at St-1. BOD levels fall under class III and class IV downstream.

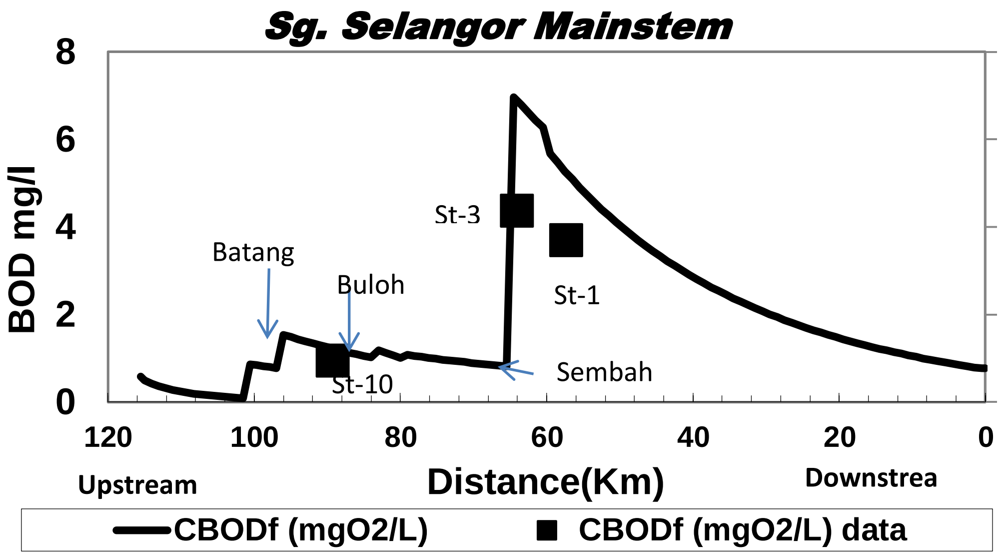


Figure 4.27: Comparison between observed and simulated BOD for the Selangor River

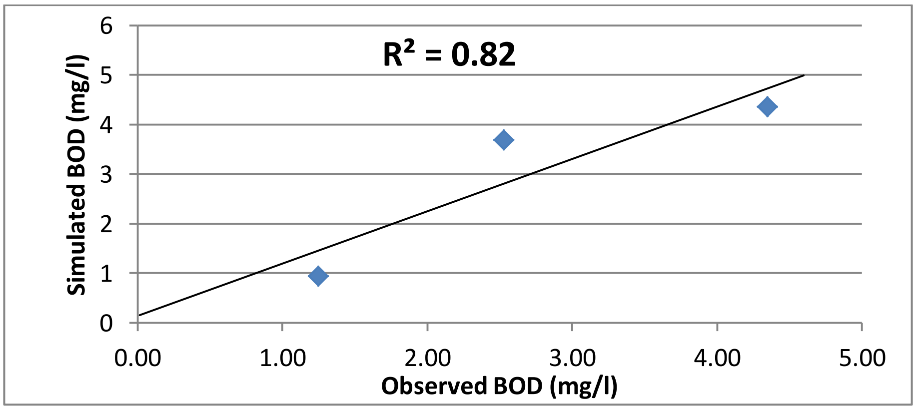


Figure 4.28: Plot BOD calibration for the main stream of the Selangor River

In Figure 4.29, the BOD model calibration results are provided. As a general observation, the level of BOD loads only become significant as the river passes through the populated area. It can be seen from Figure 4.29 that a sharp increase of BOD from 4 mg/l to 13 mg/l occurs at the confluence of Rawang River and the main stem .Thereafter, this value gradually decreases to 5.58 mg/l downstream of the main stem of the Rawang sub basin. The observed BOD value and simulated value at the Sambah River were 7.15 mg/l and 6.15 mg/L respectively.

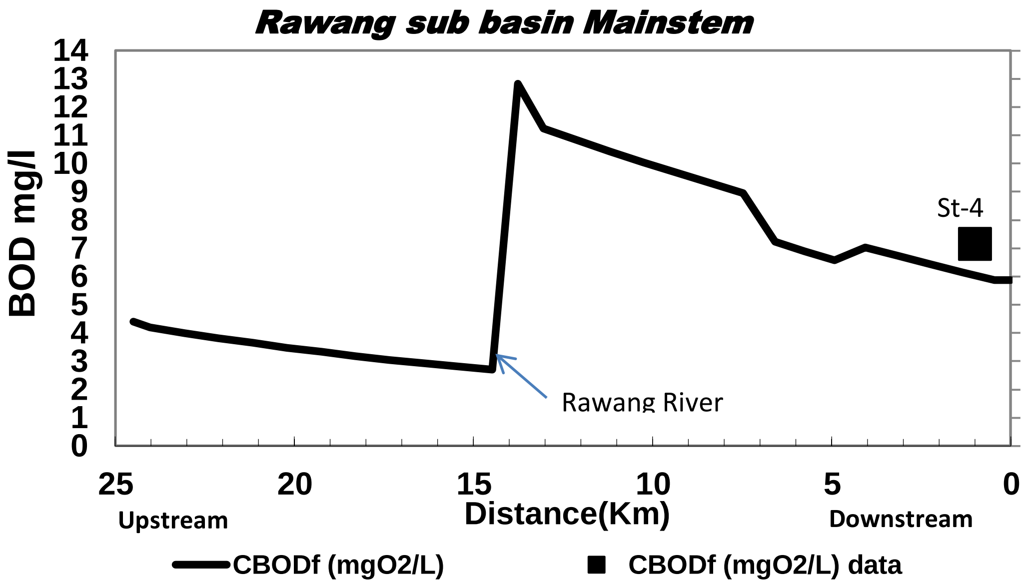


Figure 4.29 Plot BOD calibration for the main stream of the Rawang sub-basin

Ammonical Nitrogen

The calibration results of the NH_3-N level are presented in Figure 4.30.The agreement between the modeled and observed NH_3-N is generally very good as the correlation between the observed and simulated NH_3-N (R^2) is **0.8321** as can be seen from Figure 4.31. This correlation value is seen as very good according to (Henriksen et al., 2003). The highest concentration of NH_3-N predicted by the model is around 1.58 mg/L at the confluence of Selangor River and Sembah River. The trend of a sudden increase NH_3-N levels downstream of this junction was predicted by the model. The main reason for this is the higher ammonia content coming in from the Rawang sub-basin, plus the compensation of SOD in the DO model calibration.

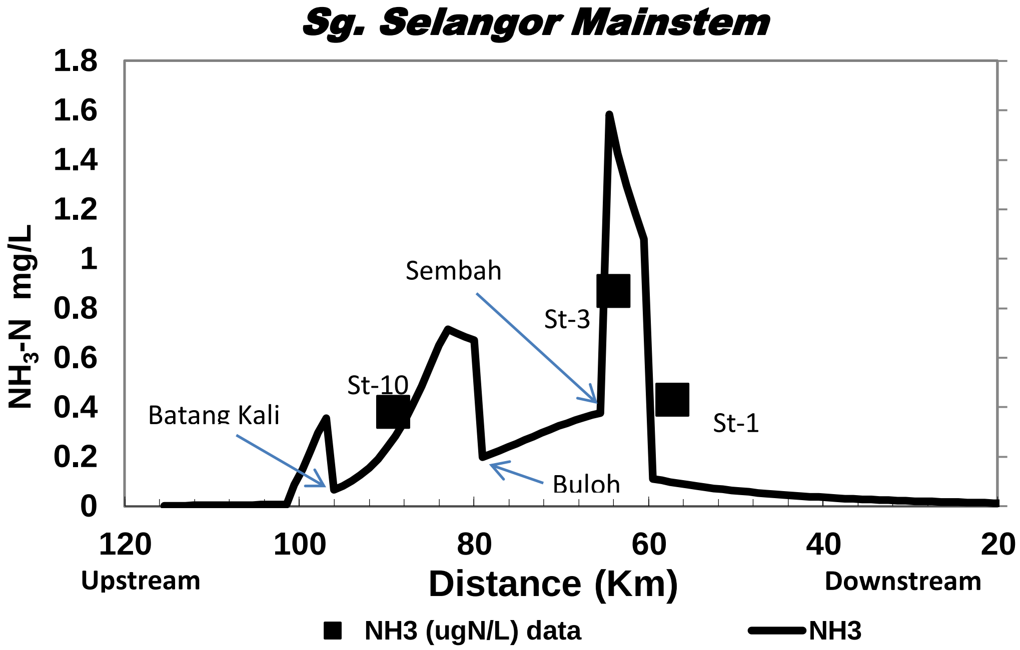


Figure 4.30: Comparison between observed and simulated NH_3-N for the Selangor River

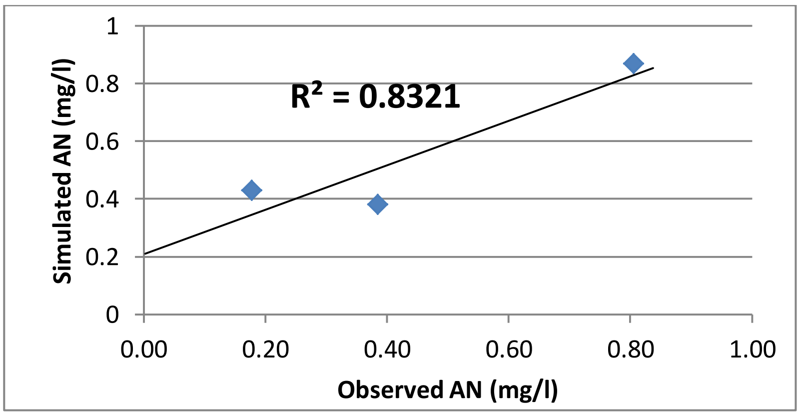


Figure 4.31: Plot NH_3-N calibration for the main stream of the Selangor River

The NH_3-N shows an increasing trend from upstream to downstream (Figure 4.32). It starts increasing from the confluence of Rawang River and the main stem of the Rawang sub- basin. The increasing trend starts from the confluence of Rawang River and the main stem until the confluence of Kuang River and mainstem of the Rawang sub- basin. This was mainly due to untreated waste from septic tank, wet markets and STPs along the said rivers. The NH_3-N value obtained at the Sambah River by the model is about 0.87 mg/L whereas the observed value is about 0.86 mg/L at the same point indicating that the model is reliable.

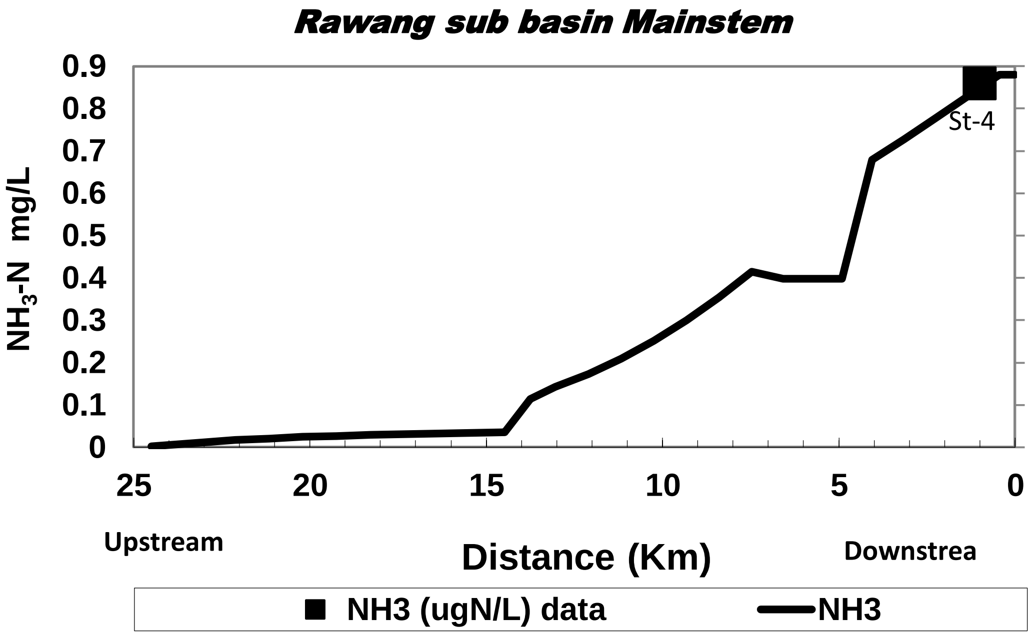
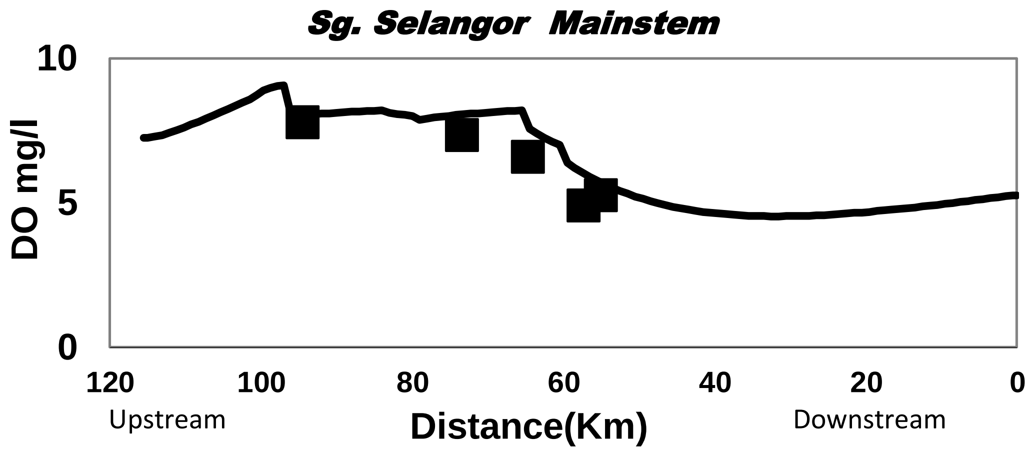


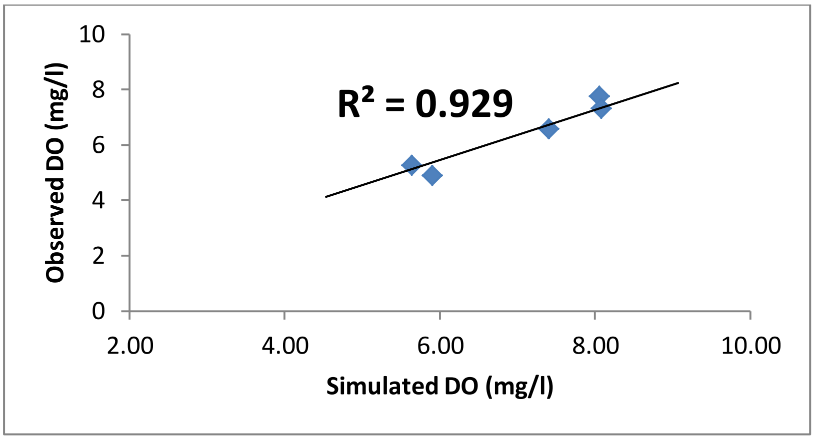
Figure 4.32 Plot NH_3-N calibration for the main stream of the Rawang sub-basin

It can be observed from the calibration results, the model exhibits a reasonable agreement against the observed values, although some disagreement can be seen. Three water quality parameters i.e DO, BOD and NH_3-N were modeled where DO showed a significant decrease (at the confluence of Sembah River and Selangor River). BOD and AN showed significant increase at the same point clearly indicating that the Rawang sub-basin is the major contributor to the degradation of water quality of the Selangor river basin. The Rawang sub basin model predicted an extremely high BOD which enters into the main stream of Selangor River through Sembah River, this impact of BOD was observed in the Selangor River basin model. Although several types of point sources are located along the Selangor River basin, only three types are spread along each reach of the river network, i.e. STP, industry and wet markets. STPs are the dominant point sources of pollution especially in the Rawang sub- basin. Therefore, a control of point sources at the Rawang sub basin possibly makes a significant decrease of BOD and AN while increasing the DO value.

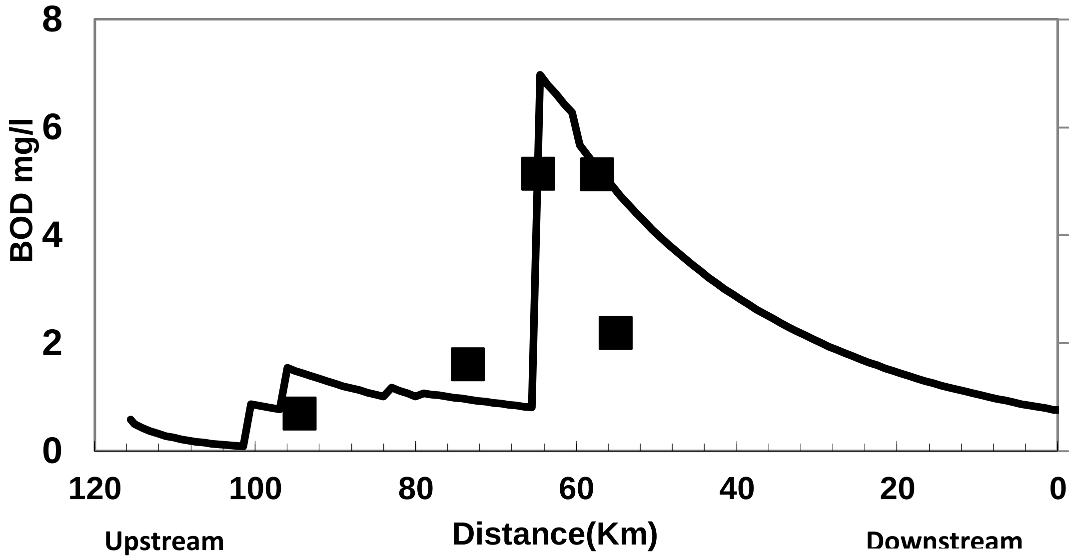
4.4.1.2 Validation of the Model

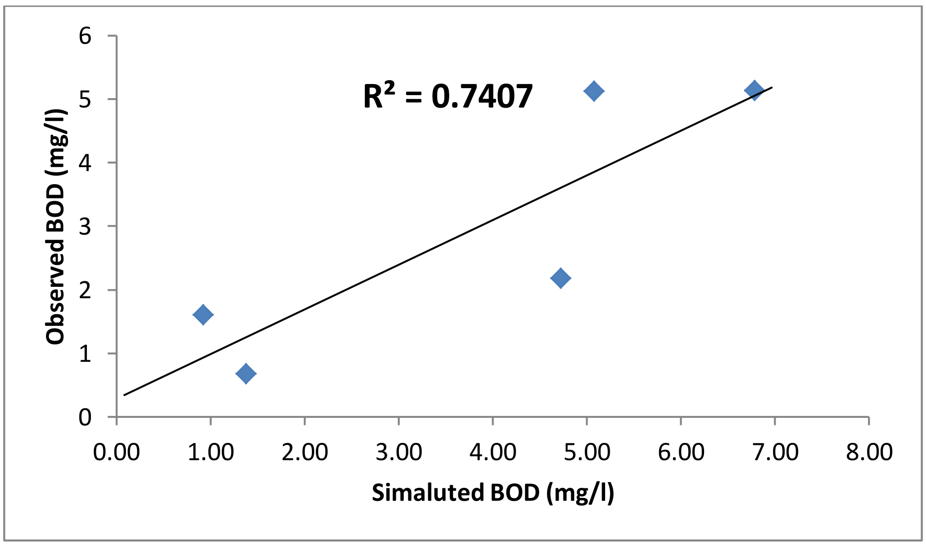
The sampling stations St-1, St-3, St-10 and in addition others two stations (upstream and downstream) along the Selangor River were used for validation of the model. Three months average data were used for validations. Figure 4. 33 display the results of validation of water quality parameters. The correlation (R^2) values between the observed and simulated of DO, BOD and AN are 0.929, 0.741 and 0.71 as per Figure 4. 33. According to (Henriksen et al., 2003), correlation (R^2) values for DO considered an excellent, for BOD considered very good and for AN considered very good. The validation results (Figure 4. 33) were very good indicated that the calibrated parameters are very reliable.

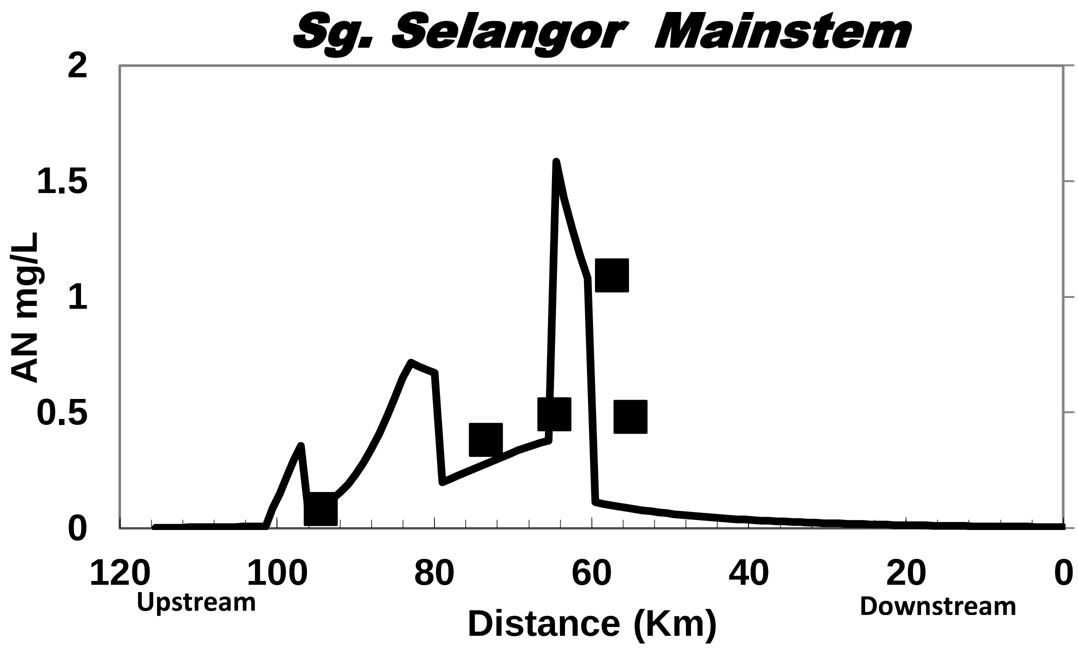




Sg. Selangor Mainstem







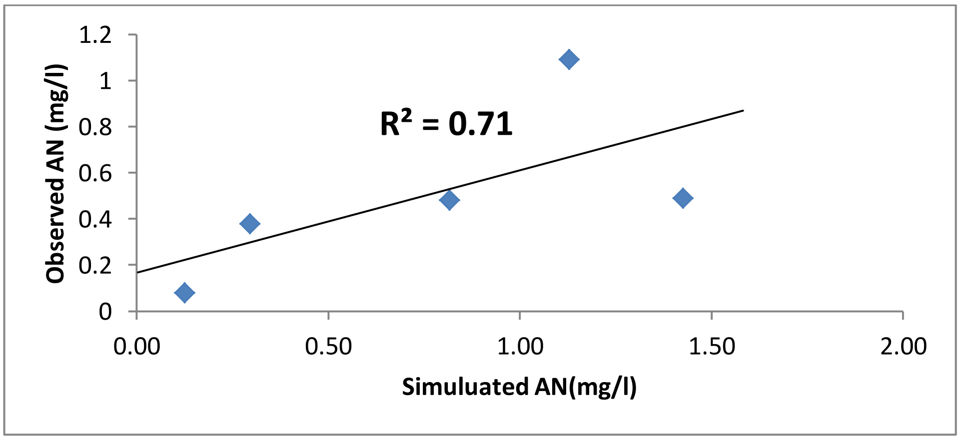


Figure 4. 33: Water quality validation results for the Selangor River

4.5 Predictive Scenario Modeling

As an improvement measure, the calibrated model was applied to predict the effects on water quality; in particular the changes in DO, BOD, and AN levels following the implementation of the recommended action plan. A number of scenarios were proposed and selected for the predictive scenario modeling. These scenarios are described in the Table 4.6 below.

Table 4.6: Description of scenarios

Scenario	Description
SC-1	Standard A compliance of all point sources within Rawang sub-basin
SC-2	Reduction of point sources pollution load within Rawang sub-basin.
SC-3	Installation of central STP with compliance of Standard A.
SC-4	Construction of wetland within Rawang sub-basin.
SC-5	Construction of wetland and Standard A compliance of all point sources within Rawang sub-basin.

Water quality downstream of Selangor River are class-III, thus the simulation of predictive scenarios were used with the aim of improving the water quality standard to class-II. By simulating different scenarios, the load reduction rate of different scenarios was obtained such that the water quality at the end of Selangor River reached the required standards.

Scenario-SC-1. In the scenario SC-1, simulation input pollution concentrations of water quality parameters were adjusted to Standard A according to Malaysian Environmental Quality Act 1974 (Appendix-B) for all point sources located in the Rawang sub basin.

Scenario-SC-2. In this scenario point sources pollution load within the Rawang sub-basin were reduced until the water quality simulation results met the class-II of water quality category.

Scenario-SC-3. In this simulation all STPs within the Rawang sub basin were omitted and replaced with a central STP in compliance to Standard A located at the Serendah River (Figure 4.34).

Scenario-SC-4. In SC-4, wetland performance on pollutant load is demonstrated and wetland effectiveness is identified. Wetland is one alternative for conservation practice not only for land management but also for water management. It is popular due to its effectiveness in reducing pollutant loads with minimal maintenance and at a low cost. In this scenario two wet lands were considered at Rawang River and Gontong River (Figure 4.35).

Scenario-SC-5. This scenario is a combination of SC-1 and SC-4. In other words, SC-5 involved the construction of wetland and Standard A compliance of all point sources within the Rawang sub-basin.

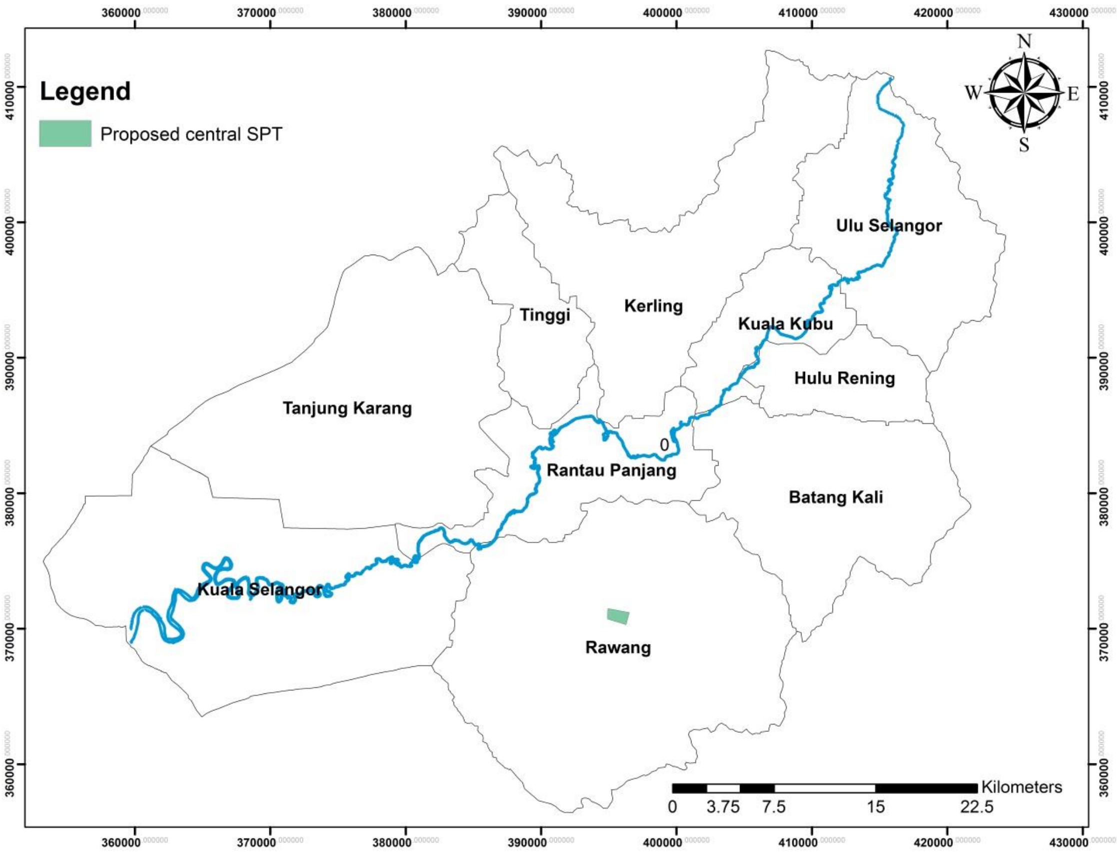


Figure 4.34: Location of the proposed central STP

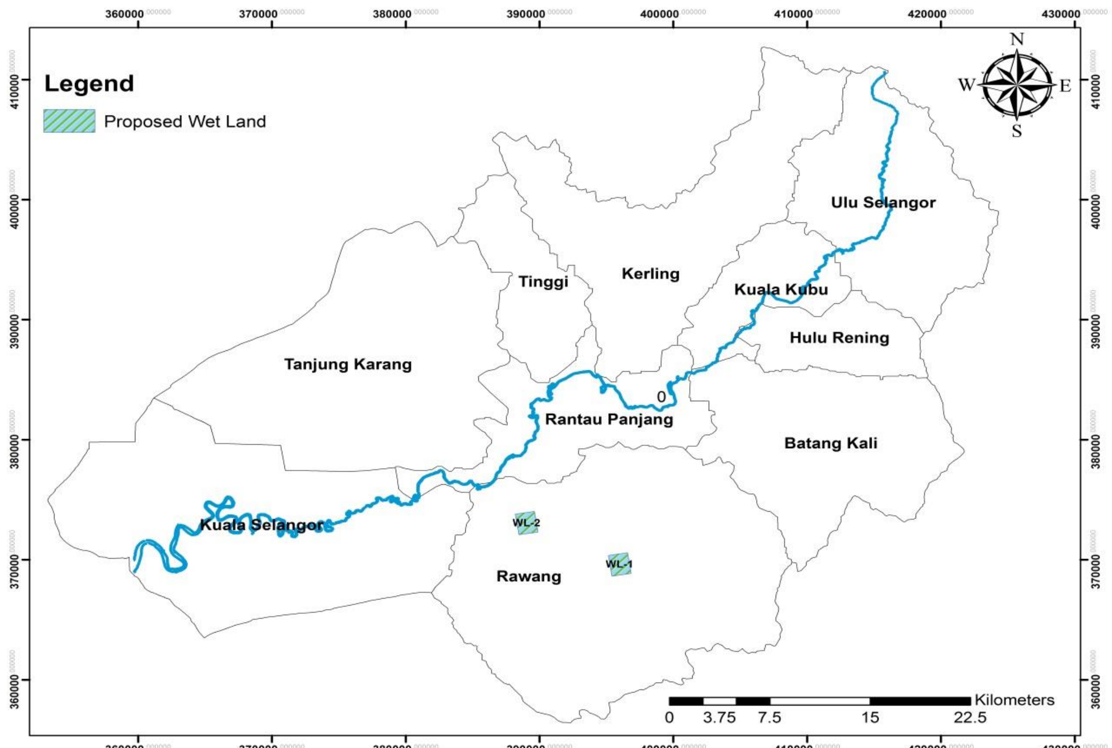


Figure 4.35 : Location of the proposed wetlands

4.5.1 Impact of Different Scenarios on DO

Variations in DO values due to the scenarios mentioned previously are presented in Figure 4.36, Figure 4.37 and percentage changes are summarized in Table 4.8 and Table 4.9. It can be observed from Figure 4.36 and Figure 4.37, upstream of the Rawang sub-basin, the DO values fall within class-II while downstream they fall under class-III (when Rawang River meets the main stem of the Rawang Sub-basin). Similarly, DO values upstream of the Selangor River fall within class-II and downstream, starting at the confluence of Sembah River and Selangor River, they fall under class-III. The DO results for the five scenarios did not differ very much, however in the Rawng sub-basin, the impact of SC-2 caused the highest increase the DO out of all the scenarios put forward. Due to SC-2, DO increased to 15.49% and 13.39% downstream, at reach-7 and reach-9 of the Rawang sub-basin, respectively. These values meet the class-II standard. On the other hand, the maximum increase of DO was 21.6% at the downstream reach-13 of the Selangor River in SC-2. The results show that the pollution load of point sources needed to be reduced by 80% for DO concentrations to meet class-II standard downstream of the Rawang sub-basin and at the Selangor River.

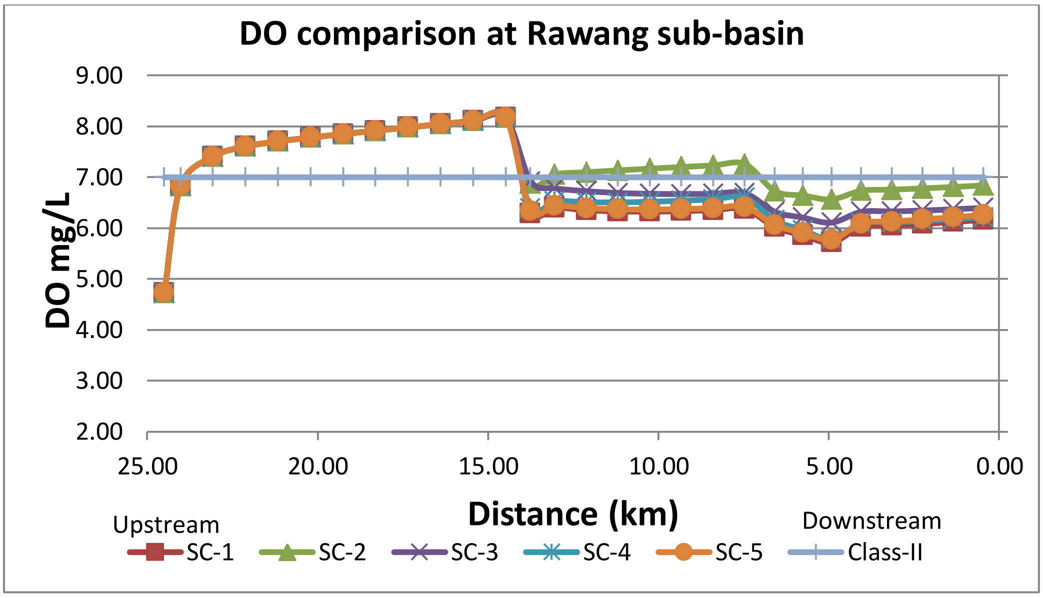


Figure 4.36: Variation of DO at Rawang sub-basin

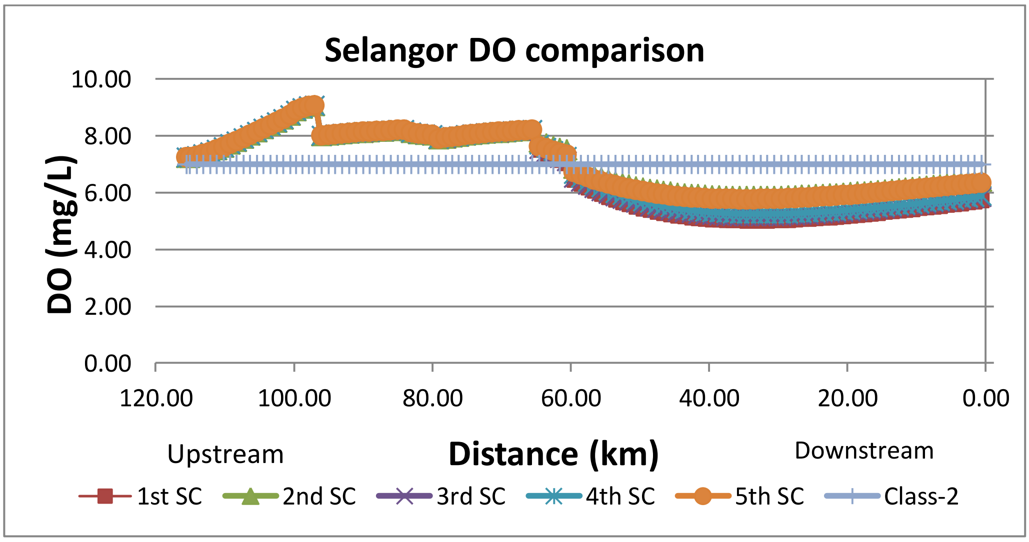


Figure 4.37: Variation of DO values along the Selangor River

4.5.2 Impact of Different scenarios on BOD

Variation of BOD due to the scenarios presented in Figure 4.38 and 4.39 while initial condition and percentage changes are summarized in Table 4.7, 4.8 and 4.9

respectively. The BOD concentration upstream of the Rawang main stem was low but at the confluence of the Rawang River and the main stream of the Rawang sub-basin it suddenly increased and gradually decreased again further downstream. The impact of scenarios SC-1, SC-2, SC-3 and SC-5 caused the reduction of BOD, allowing the BOD to come under class-II standard downstream of the Rawang sub-basin. A significant BOD decrease of 51.81% and 43.50% at the downstream reach-9 of the Rawang sub-basin was achieved due to scenarios SC-2 and SC-5, respectively. Despite this BOD only achieved class-II for SC-5. A reduction of BOD to 51.10% can be achieved at the downstream reach-13 of Selangor River for SC-5.

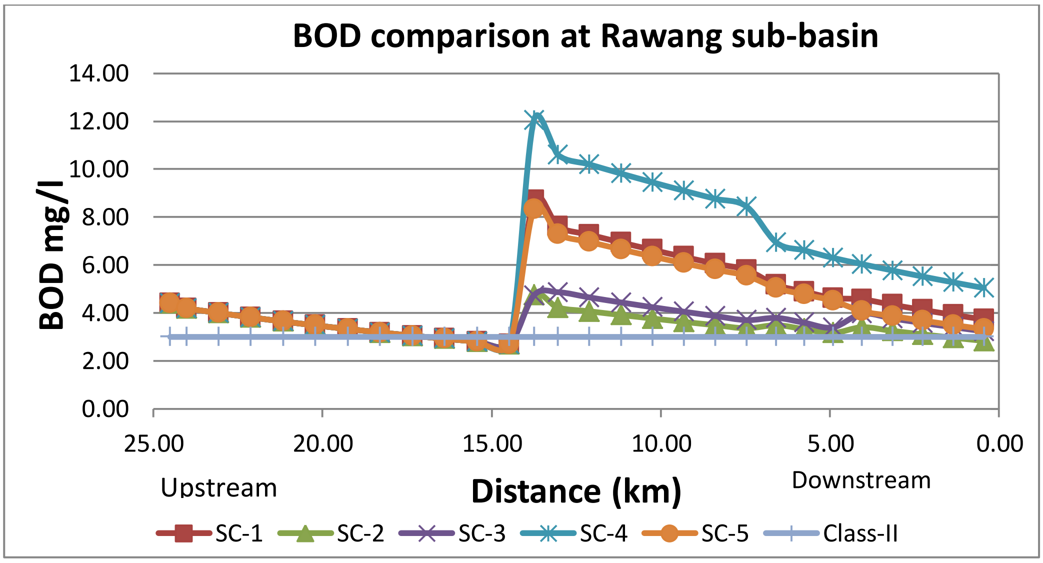


Figure 4.38: Variation of BOD at Rawang sub-basin

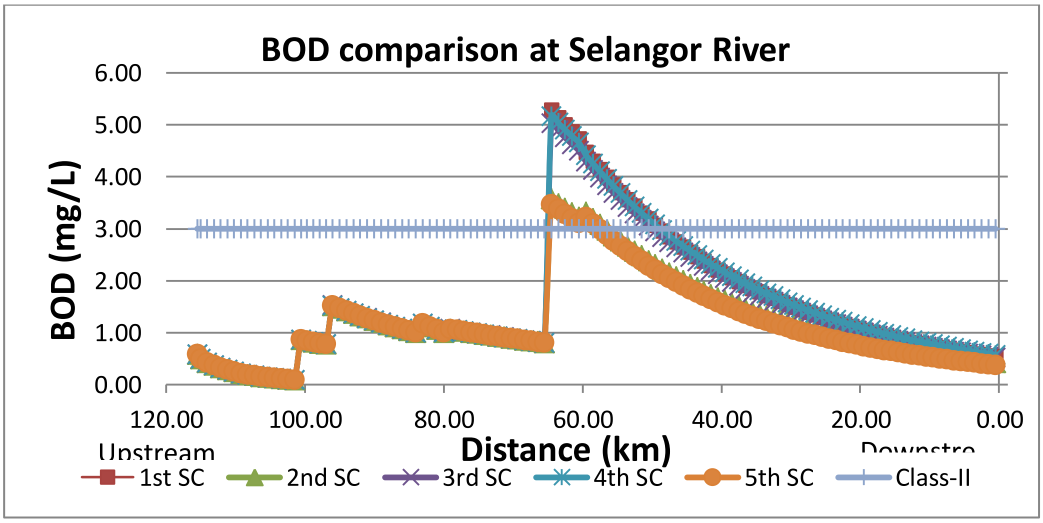


Figure 4.39 : Variation of BOD along the Selangor River

4.5.3 Impact of Different scenarios on NH_3-N

Variation of NH_3-N at the Rawang sub-basin is shown in Figure 4.40 and 4.41. It can be seen from the figures that a substantial reduction of NH_3-N downstream of the Rawang main stem can be possible if SC-5 is employed. The level of NH_3-N drops from 0.90 mg/L to 0.4 mg/L downstream of the Rawang main stem. It can be seen from Table-4.8 that NH_3-N decreases to 8.79%, 31.47%, 22.76%, 41.61%, and 43.76% at reach-9 of the Rawang main stem due to the SC-1, SC-2, SC-3, SC-4 and SC-5 respectively. The decrease of NH_3-N in the Rawang sub-basin leads to the reduction of this parameter at the confluence of the Sembah River and the Selangor River. The maximum decreased to 66.18% of NH_3-N at the downstream reach-13 of the Selangor River was seen in SC-5.

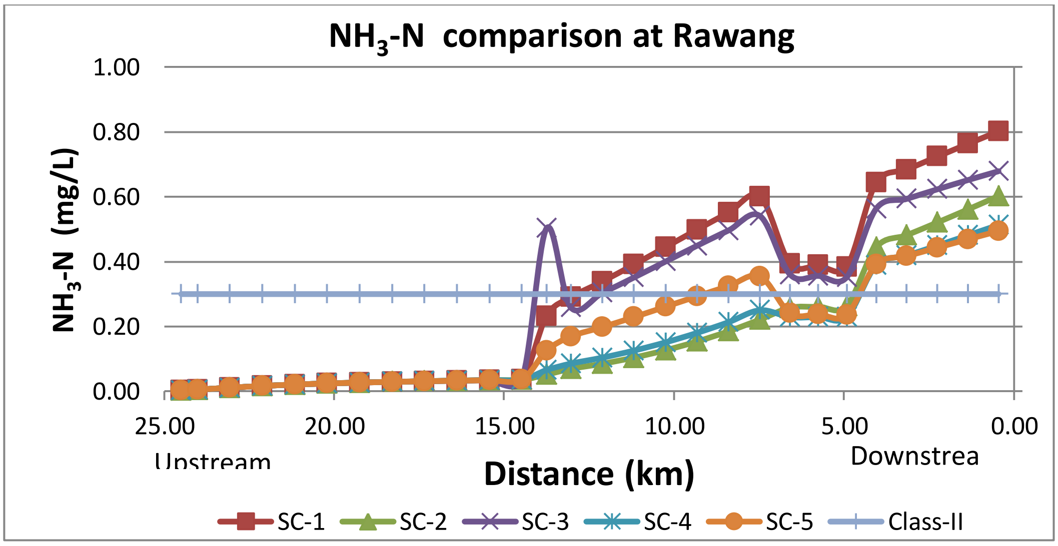


Figure 4.40: Variation of NH_3-N at Rawang sub-basin

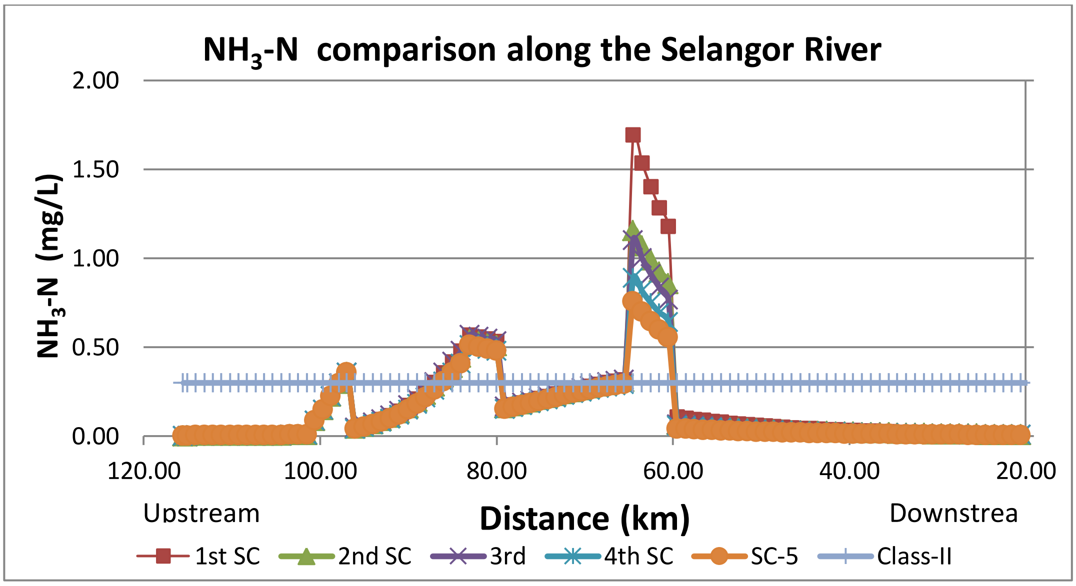


Figure 4.41 : Variation of NH_3-N along the Selangor River

From the simulation, the effect of different scenarios on the DO, BOD and NH_3-N levels can be seen, especially in the Rawang sub-basin. SC-1 investigated whether the point sources within the Rawang sub basin have an effective role on the water quality of the Selangor river main stem, where all point sources were adjusted to Standard A. The results showed an improvement in the water quality in terms of DO, BOD and NH_3-N. Due to simulation of SC-1, there was an increase of 1% of DO while BOD and NH_3-N decreased to 21.1% and 41.31% respectively at the downstream reach-13 of the Selangor River. Due to simulation of scenario SC-1, DO and NH_3-N came under class – II at the downstream reach-13 of the Selangor River but BOD was in class-III.

The impact of SC-2 was an increase of DO to 21.6% while BOD and NH_3-N decreased 45.20% and 38.82% respectively at the downstream reach-13 of Selangor River. Point sources reductions of 80% were required for the BOD concentration to fall under class-II, however, NH_3-N did not meet the standards with a 100% point source pollution load reduction. This is may be because of non-point source pollutants including domestic sewage and agricultural non-point source pollutants. Therefore, reducing only the point source pollution load did not achieve the desired water quality standards.

Due to simulation of SC-3, 93.10% of NH_3-N increased at reach-3 of the Rawang sub-basin. However, NH_3-N decreased to 22.76% at reach-9, downstream of Rawang sub-basin. DO increased to10.80% while BOD and NH3-N decreased to 32.6% and 49.67%, respectively at the downstream reach-13 of Selangor River.DO and NH_3-N improved and came under class-II and class-I, respectively, but BOD remained under class-III downstream of the Selangor River.

In scenario SC-4, DO increased to11.70 % while BOD and NH_3-N decreased to 25.30% and 45.16% respectively at the downstream reach-13 of Selangor River. DO and NH_3-N improved and came under class-II and class-I, respectively, but BOD was class-III downstream of the Selangor River.

Due to simulation of SC-5, DO increases to 20.40% while BOD and NH_3-N decreased to 51.10% and 66.18% at the downstream reach-13 of Selangor River. The highest performance of pollutants reduction was achieved by SC-5. DO, BOD and NH_3-N improved and came under class-II, class-II and class-I, respectively, downstream of the Selangor River. SC-5 performed best in terms of improvement of water quality compare to other scenarios.

Table 4.7: Initial condition of water quality parameters along the Selangor River

Reach	Location	DO		BOD		NH_3-N	
		mg/L	class	mg/L	class	mg/L	class
R-1	U/S	7.24	I	0.58	I	0.01	I
	D/S	8.58	I	0.09	I	0.01	I
R-3	U/S	8.72	I	0.86	I	0.09	I
	D/S	9.07	I	0.77	I	0.36	III
R-5	U/S	7.98	I	1.54	II	0.07	I
	D/S	8.20	I	1.01	II	0.65	III
R-7	U/S	8.10	I	1.18	II	0.71	III
	D/S	8.01	I	1.01	II	0.67	III
R-9	U/S	7.88	I	1.07	II	0.20	II
	D/S	8.20	I	0.81	I	0.38	III
R-11	U/S	7.57	I	6.97	IV	1.58	IV
	D/S	6.99	II	6.28	IV	1.08	IV
R-13	U/S	6.39	II	5.67	III	0.11	II
	D/S	5.26	II	6.76	IV	0.36	III

Table 4.8 : Improvement of water quality parameters along the Rawang subbasin main stem due to simulation of Scenarios

Rawang Sub-basin (Change in percentage)																
Reach		**DO**					**BOD**					**NH_3-N**				
		SC-1	SC-2	SC-3	SC-4	SC-5	SC-1	SC-2	SC-3	SC-4	SC-5	SC-1	SC-2	SC-3	SC-4	SC-5
Reach-1	U/S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.19	0.00	-0.17	0.00	-0.19
	D/S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.87	0.00	-0.80	0.00	-0.87
Reach-3	-	0.27	9.08	9.61	1.15	0.37	-32.15	-62.98	-63.06	-5.99	-35.08	-0.82	-54.43	93.10	-42.17	10.36
Reach-5	U/S	0.90	9.31	5.07	1.08	0.30	-32.37	-62.41	-56.73	-5.82	-35.19	-0.77	-51.51	81.05	-40.21	18.29
	D/S	2.25	11.28	2.48	1.14	1.65	-35.40	-62.51	-58.72	-5.84	-38.10	-0.88	-46.61	30.37	-39.65	-14.52
Reach-7	U/S	0.86	10.82	4.10	1.40	0.13	-28.47	-51.72	-47.51	-4.00	-30.30	-1.04	-35.15	-9.34	-42.40	-39.50
	D/S	0.58	15.49	7.48	1.80	1.52	-29.48	-51.80	-48.25	-4.02	-31.29	-3.47	-33.73	-11.46	-42.26	-40.88
Reach-9	U/S	0.93	12.86	5.89	2.14	2.07	-35.10	-51.65	-43.67	-14.20	-42.13	-5.15	-34.56	-16.98	-42.73	-42.40
	D/S	2.16	13.39	6.09	3.06	3.79	-36.62	-51.81	-44.97	-14.24	-43.50	-8.79	-31.47	-22.76	-41.61	-43.76

Table 4.9 : Improvement of water quality parameters along the Selangor River main stem due to simulation of Scenarios

Selangor River (Change in percentage)																
Reach		**DO**					**BOD**					**NH_3-N**				
		SC-1	SC-2	SC-3	SC-4	SC-5	SC-1	SC-2	SC-3	SC-4	SC-5	SC-1	SC-2	SC-3	SC-4	SC-5
R-1	U/S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.07	0.00	-0.07	0.00	-0.07
	D/S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.72	0.04	-0.61	0.04	-0.67
R-3	U/S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.06	0.00	-0.05	0.00	-0.05
	D/S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.06	0.00	-0.05	0.00	-0.06
R-5	U/S	0.2	0.2	0.2	0.2	0.2	-0.8	-1.0	-0.8	-1.2	-1.2	-26.07	-31.39	-26.07	-36.75	-36.75
	D/S	0.1	0.1	0.1	0.1	0.1	-0.9	-1.1	-0.9	-1.2	-1.2	-26.34	-31.69	-26.34	-37.07	-37.07
R-7	U/S	0.1	0.1	0.1	0.1	0.1	-0.5	-0.6	-0.5	-0.7	-0.7	-20.22	-24.31	-20.22	-28.42	-28.43
	D/S	0.1	0.1	0.1	0.1	0.1	-0.5	-0.6	-0.5	-0.7	-0.7	-20.24	-24.33	-20.23	-28.44	-28.45
R-9	U/S	0.1	0.1	0.1	0.1	0.1	-0.4	-0.5	-0.4	-0.5	-0.5	-16.12	-19.34	-16.12	-22.57	-22.58
	D/S	0.1	0.1	0.1	0.1	0.1	-0.4	-0.5	-0.4	-0.6	-0.6	-16.02	-19.22	-16.01	-22.43	-22.44
R-11	U/S	0.9	2.9	0.4	1.6	0.8	-24.1	-48.8	-27.9	-25.8	-50.2	7.07	-27.05	-30.31	-43.76	-52.20
	D/S	0.6	7.2	1.7	3.9	4.9	-24.6	-48.8	-28.4	-25.9	-50.6	9.13	-20.57	-29.04	-40.59	-48.66
R-13	U/S	1.0	7.4	2.0	4.0	5.4	-21.1	-41.6	-24.3	-22.1	-43.2	-2.69	-41.31	-41.53	-46.90	-62.62
	D/S	8.7	21.6	10.8	11.7	20.4	-29.5	-45.2	-32.6	-25.3	-51.1	-20.30	-38.82	-49.67	-45.16	-66.18

Table 4.10 : Summary of DO, BOD and NH_3-N class along the Selangor River main stem due to simulation of Scenarios

		DO Class					**BOD Class**					NH_3-N **Class**				
Reach	Location	SC-1	SC-2	SC-3	SC-4	SC-5	SC-1	SC-2	SC-3	SC-4	SC-5	SC-1	SC-2	SC-3	SC-4	SC-5
R-1	**U/S**	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
	D/S	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
R-3	**U/S**	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
	D/S	I	I	I	I	I	I	I	I	I	I	III	III	III	III	III
R-5	**U/S**	I	I	I	I	I	II	II	II	II	II	I	I	I	I	I
	D/S	I	I	I	I	I	II	II	II	II	II	III	III	III	III	III
R-7	**U/S**	I	I	I	I	I	II	II	II	II	II	III	III	III	III	III
	D/S	I	I	I	I	I	II	II	II	II	II	III	III	III	III	III
R-9	**U/S**	I	I	I	I	I	II	II	II	II	II	II	II	II	II	II
	D/S	I	I	I	I	I	I	I	I	I	I	III	III	III	II	II
R-11	**U/S**	I	I	I	I	I	III	III	III	III	III	IV	IV	IV	III	III
	D/S	I	I	I	I	I	III	III	III	III	III	II	II	II	II	II
R-13	**U/S**	II	II	II	II	II	III	III	III	III	II	II	I	I	I	I

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

Based on the results of this research, many conclusions, recommendations and suggestions for future work related to the research topic were obtained.

5.2 Conclusions

The following conclusions were obtained based on the results of the research.

1. In this research, investigating the water quality status of the Selangor River basin has been implemented to enhance the understanding of the current water pollution status of the river basin, and water quality results have been included in QUAL2K modelling to improve the measurement of DO, BOD and NH_3-N .

2. A spatial correlation between the prevailing water quality and potential pollution sources was established in this study based on the spatial water quality trends observed with the application of GIS. The sampling stations located upstream and mid-stream registered as Classes II and III, while in the Rawang sub-basin the water quality falls in Class IV based on the NWQS for Malaysian rivers. The basin's upstream region is relatively clean and deteriorates progressively further downstream. Based on the current study results, land use within the Selangor River basin has a direct impact on the river network. The Selangor River water quality varied with different land use categories. The water quality of the Selangor River basin much lower in built-up areas and higher in forested areas. Most of the land use categories with Built-up and mining sites are located within the Rawang sub basin, therefore poor water quality was observed within this sub basin and the upstream of Selangor River with more forests and less urbanization have better water quality. As far as water quality is concerned, the worst situation was observed in the Rawang

sub-basin compared to other sub-basins. The water quality is affected, as is the riparian ecosystem along with all of its biologically diverse inhabitants, which includes humans as well. In light of this, a holistic approach to sustainable land use within the river basin is necessary.

3. From the heavy metals results, it is evident that Fe, Mn and As exceed the standard limits at some of the sampling stations, while the concentrations of Ag, Cd, Co, Cr, Cu, Ni, Pb, Al, Mg and Zn were well below the Malaysian National Standard for water quality and were also below the recommended limit of MOH. The elevated concentrations of Fe, Mn and As may be due to point source input from the nearby industrial zones and also from non-point sources of mining wastewater from former tin mining catchments that increase the frequency of pollution occurrence within this study area. Although the heavy metal concentration in the Selangor River water is not very serious at present, the elevated concentrations of certain metals may pose a threat in the future because of their accumulative nature and toxicity effects on organisms.

4. This study also showed that an urban area was greatly contaminated with excessive numbers of total coliform and *E. Coli*. The presence of contamination was due to the existence of many sewage discharges along the river, which carried effluents from septic tanks including industrial effluent which has no disinfection process. The results of this study indicated that the main sources of pollution of the Selangor River basin were from anthropogenic activities such as industrial wastes and effluents, slaughter houses or abattoirs, agricultural activities and landfills.

5. The simulations included in this study were designed to provide information on the present and future status of the Selangor River basin. The changes of Selangor water quality due to the introduction of different scenarios have also been presented.

From the simulation, the effect of different scenarios in the BOD and NH_3-N can be seen, especially in the Rawang sub-basin. A substantial reduction of NH_3-N and BOD levels has been predicted by the model after the implementation of scenarios SC-2 and SC-5. The simulation also showed that reduced levels of BOD and NH_3-N at 51.10% and 66.18% respectively, can be obtained if SC-5 is employed.

6. This is an important issue where proper measures need to be taken to protect and preserve natural water resources, so that sufficient and clean water can be provided to the urban population. Continuous monitoring, proper planning and control on human activities are needed to ensure that developments within the watershed do not contribute to the degradation of Selangor River's water quality. In addition, improvement efforts and policies as well as instilling people's awareness of the need to preserve and protect the vital water resources are timely required.

5.3 Recommendations

The following recommendations were obtained based on the results of the research.

1. There are a lot of point sources located along the Selangor River especially at the Rawang sub-basin. Untreated effluent from industries, STPs, septic tanks, and animal husbandries are discharged into waterways which threaten the Selangor River with poor water quality. To maintain a reasonable water quality, proper treatment of the effluent is recommended before final discharge into receiving waters. All effluents have to be treated prior to final discharge under the Environmental Quality(Sewage and Industrial Effluents) Regulations, 1979; and Environmental Quality(Prescribed Premises) (Scheduled Wastes, Treatment and Disposal Facilities) order 1989. Legislative controls are: Pig farming enactment, 1980; and Irrigation Areas Act, 1953. Performance reviews by relevant authorities

to ensure companies abide by the legislations under which they have to treat their effluents to the standards required are needed.

2. Partial and raw sewage have caused high BOD and *E.coli* in many segments of the river systems. There is a need to monitor the water quality to ensure that any exceptionally high levels of BOD and *E.coli* are detected early to reduce outbreaks of water-bone diseases. STPs are some of the main pollution sources at Rawang sub-basin. This sub-basin area has not been served with centralized STP. Therefore, a central STP is recommended.

3. On-going construction and sand mining activities within the Selangor River basin are some of the main pollution sources. Although the effects of these activities on the river are only transient, the increase in TSS in the Selangor River is evident. These areas are at Buaya River, Serendah River and Rawang River. Constant monitoring of developmental activities is recommended.

4. In related to assess the water quality characteristics benthic macroinvertebrates is a good biological indicator which was not considered in this study. Therefore, further analysis of benthic macroinvertebrates is really suggested such as calculation for Biological Monitoring Working Parties Index (BMWP). Scientifically it is now considerable proof that heavy metals can be taken up and concentrated by sediments. In this study heavy metals analysis was conducted for river water samples only and sediment analysis was not considered in this study. According to the heavy metals results analysis some area along the Selangor rive under risk of metals pollution, so sediment analysis for heavy metals is recommended for further study.

5. This is aimed at establishing a level of protection required for water quality for beneficial uses. Point source discharges, particularly sewage and industrial effluents,

have significant detrimental impacts on the environmental quality of receiving waters, particularly when discharges occur at times of low flows as this is when the risk of algal blooms is highest. By maintaining control of point source pollution and protection through various legislations, the level of pollution is likely to be progressively reduced and eliminated in the long-term.

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LIST OF PUBLICATIONS AND PAPERS PRESENTED

Journal Article:

1. Faridah Othman, **Md.Sadek Uddin Chowdhury**,Nobumitsu Sakai, Md. Ghazaly Shaaban, Yoshihisa Shimizu(2014). Identification of pollution loading in a tropical river basin: A case study of Selangor River, Malaysia. "Journal of Environmental Science and Biological Engineering" WIT Transactions on The Built Environment, Vol. 156, © 2014 WIT Press.(**Scopus)**
2. Faridah Othman, **Md.Sadek Uddin Chowdhury** and Nobumitsu Sakai (2015). Assessment of microorganism pollution of Selangor River, Malaysia. Int'l Journal of Advances in Agricultural & Environmental Engg. (IJAAEE) Vol. 1, Issue 2 (2014) ISSN 2349-1523 EISSN 2349-1531
3. Faridah Othman, **Md. Sadek Uddin Chowdhury**, Wan Zurina binti Wan Jaafar, E.M. Mohammad Faresh, S.M. Shirazi: Assessment of risk and source of heavy metals in a tropical river basin:A case study of the Selangor River, Malaysia (**Accepted**, **Polish journal of Environmental studies, ISSN:1230-1485, Q-4, IF-0.790**)
4. **Md. Sadek Uddin Chowdhury,** Faridah Othman, Wan Zurina binti Wan Jaafar and Mohammad Ibrahim Adham: Assessment and Improvement measure of Water Quality parameters of Selangor River, Malaysia Using Scenarios Modeling **(Accepted, Sains Malaysiana, Q-3, IF 0.350)**
5. **Md. Sadek Uddin Chowdhury**, Faridah Othman, Wan Zurina binti Wan Jaafar and N.Che Mood: Generation of River Pollution map by linking Water quality and spatial information (To be submitted to ISI journal)

Conference Paper:

1. Faridah Othman, Alaa-Eldin, **Md.Sadekuddin Chowdhury** (2014). Assessing the impacts of non-point sources in the river water quality modeling: A case study for Klang River basin.1st National Conference On Nonpoint Sources Pollution (NPS 2014), 14-15 May 2014, Kuala Lumpur, Malaysia.

Poster:

1. Nobumitsu SAKAI, **Md Sadek UDDIN CHOWDHURY**, MohdRedzuan RAMRI, KalaiselviPALANI,Faridah OTHMAN, NikMeriam NIK SULAIMAN, Mustafa ALI MOHD, Minoru YONEDA(2013).Development of Eco-Heart Index for Water Quality: Case Study in Selangor River Basin. 3rd Comprehensive Symposium (CS-3), 28-29, October 2013, JSPA Asian core program, Kyoto University, Japan
2. Faridah OTHMAN, **Md Sadek uddin CHOWDHURY** and Nuzaima che MOOD(2015). Pollution Level Map for Selangor River Using Water Quality Index and GIS Technique. 5th Comprehensive Symposium (CS-5), 19-21, November 2015, JSPA Asian core program, Kyoto University, Japan
3. Faridah Othman, **Md Sadek Uddin Chowdhury**, Mohammed Seyam and Alaa-Eldin (2016). River Basin Network System for Sustainable Water Quality Assessment. Sustainability Science Research Cluster (SuSci) Symposium 2016, 21–22nd April 2016 at Research Management and Innovation Complex (RMIC), University of Malaya.

Book Chapter:

1. Faridah Othman, Alaa-Eldin, **Md.Sadekuddin Chowdhury** and Mohamed Seyam(2015): An Overview of Resource and River Water Quality in Sungai Selangor Watershed, Land Use Dynamics and Governance in Sungai Selangor Watershed, University of Malaya Press, University of Malaya, 50603, Kuala Lumpur, Malaysia.