SEASONAL IMPACT ON WATER QUALITY AND MODEL DEVELOPMENT OF A TROPICAL URBAN RIVER

SITI ASIAH BINTI MUHAMMAD

DISERTATION SUBMITTED IN FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF ENGINEERING SCIENCE

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

2017

UNIVERSITY OF MALAYA

ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: **SITI ASIAH BINTI MUHAMMAD**

Matrix No.: **KGA130054**

Name of Degree: **MASTER**

Title of Thesis: **SEASONAL IMPACT ON WATER QUAITY AND MODEL DEVELOPMENT OF A TROPICAL URBAN RIVER.**

Field of Study: **WATER RESOURCES ENGINEERING**

I do solemnly and sincerely declare that:

(1) I am the sole author/writer of this Work;
(2) This Work is original:
(3) Any use of any work in which copyright exits was done by way of fair dealing and for permitted purposes and any excerpt or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledged in this Work;
(4) I do not have any actual knowledge nor ought I reasonably to know that the making of this work constitutes an infringement of any copyright work;
(5) I hereby assign all and every rights in the copyright to this Work to the University of Malaya (UM), who henceforth shall be owner of the copyright in this Work and that any reproduction or use in any form or any means whatsoever is prohibited without the written consent of UM having been first had and obtained;
(6) I am fully aware that if in the course of making this Work I have infringed any copyright whether intentionally or otherwise, I may be subject to legal action or any other action as may be determined by UM.

Candidate's Signature...................................... Date:

Subscribed and solemnly declared before,

Witness's Signature... Date:

Name: ....

Designation: ....

ABSTRACT

Seasonal climatic variations in Malaysia may contribute to inadequate water supply, unexpected flooding, and river pollution issues.The Penchala River Basin located in Petaling Jaya, Selangor, Malaysia, is noted as being under environmental stress due to several pollution sources, which has amplified the intention to assess the water quality. Therefore, this research aims to study the seasonal impact on water quality and to develop a river model. Four stations from upstream toward downstream were selected along the Penchala River and was monitored from November 2013 until October 2014 on monthly basis. The chemical parameters were analyzed in laboratory guided by the Standard Method. The water quality index (WQI) was calculated using the 6 parameters, namely the Biochemical Oxygen Demand, Chemical Oxygen Demand, Ammoniacal Nitrogen, Total Suspended Solid, Dissolved Oxygen and pH. The result showed physico-chemical parameters have a significant difference between sampling stations (ANOVA, $P<0.05$) except for pH, turbidity and velocity. WQI classifies Penchala River in Class II (clean) for upstream, Class III (slightly polluted) for middle stream and class IV (polluted) for downstream. The WQI shows better values during wet season compared to dry season by increasing the WQI class from Class IV to Class III at Station 4 during wet season and dragged the WQI class from Class III to Class IV at Station 3 during the dry season. Heavy metals which elements exceeded the limits are Arsenic, Iron and Aluminium. The three elements that have a significant difference between the stations are Manganese, Magnesium and Iron (ANOVA, $P<0.05$). The heavy metals value during wet season show good value compared to dry season whereby the Arsenic values exceed the limit at Station 2 to 4 during wet season compared to the whole Penchala River during dry season. Model development used the InfoWorks River Simulation for hydraulic and water quality river model. The calibration and verification of flow at Kg. Ghandi and Jalan 222 showed a good

agreement with the R^2 values greater than 0.85 whereas, the calibration and verification stage showed a very good agreement at Kg.Ghandi but very poor agreement at Jalan 222. For water quality model, the BOD calibration showed an excellent agreement while DO and pH showed a very good agreement at middle and downstream of the Penchala River. In conclusion, Penchala River can be considered as having clean water at upstream, slightly polluted water at middle stream and polluted water at downstream. Seasonal variations contribute significantly on water quality and metal contamination at the downstream of the river.

ABSTRAK

Perubahan iklim bermusim di Malaysia boleh menyumbang kepada kekurangan bekalan air, banjir yang tidak dijangka, dan isu-isu berkaitan pencemaran sungai. Kawasan tadahan Sungai Penchala terletak di Petaling Jaya, Selangor, Malaysia, terkenal sebagai berada di bawah tekanan alam sekitar disebabkan oleh beberapa punca pencemaran, yang telah menambahkan lagi niat untuk menilai kualiti air. Oleh itu, kajian ini adalah untuk mengkaji kesan bermusim kepada kualiti air dan untuk membangunkan model sungai. Empat stesen dari hulu ke arah hilir telah dipilih sepanjang Sungai Penchala dan dipantau dari bulan November 2013 hingga Oktober 2014 pada setiap bulan. Parameter kimia dianalisis di makmal berpandukan kaedah Standard. Indeks kualiti air (IKA) telah dikira menggunakan 6 parameter dinamakan permintaan oksigen biokimia, permintaan oksigen kimia, ammonia, jumlah pepejal terampai, oksigen terlarut dan pH. Hasil menunjukkan parameter fiziko-kimia mempunyai perbezaan yang signifikan antara stesen-stesen persampelan (ANOVA, $P <0.05$) kecuali untuk pH, keruhan dan halaju. IKA mengklasifikasikan Sungai Penchala berada dalam Kelas II (bersih) untuk huluan, Kelas III (sedikit tercemar) untuk aliran tengah dan IV kelas (tercemar) untuk hiliran. IKA menunjukkan nilai-nilai yang lebih baik pada musim hujan berbanding musim kering dengan meningkatkan kelas IKA dari Kelas IV kepada Kelas III di Stesen 4 pada musim hujan dan mengheret kelas IKA dari Kelas III kepada Kelas IV di Stesen 3 semasa musim kemarau. Logam berat yang mana melebihi had adalah Arsenic, Besi dan Aluminium. 3 unsur yang mempunyai perbezaan yang signifikan di antara stesen adalah Mangan, Magnesium dan Iron (ANOVA, $P <0.05$). Nilai logam berat semasa musim basah menunjukkan nilai-nilai yang lebih baik berbanding musim kering di mana nilai-nilai Arsenic melebihi had di Stesen 2-4 pada musim hujan berbanding keseluruhan Sungai Penchala semasa musim kering. Pembangunan model menggunakan InfoWorks simulasi sungai untuk model sungai hidraulik dan kualiti air. Aliran penentukuran dan

pengesahan di Kg. Ghandi dan Jalan 222 menunjukkan perjanjian yang bagus dengan nilai R^2 lebih besar daripada 0.85, manakala, peringkat penentukuran dan pengesahan yang menunjukkan perjanjian yang sangat baik di Kg.Ghandi tetapi perjanjian yang sangat buruk di Jalan 222. Untuk model kualiti air, penentukuran BOD menunjukkan perjanjian yang bagus manakala DO dan pH menunjukkan perjanjian yang sangat baik di tengah-tengah dan hilir Sungai Penchala. Kesimpulannya, Sungai Penchala boleh dianggap sebagai mempunyai air yang bersih di hulu, air sedikit tercemar di pertengahan dan air tercemar di hiliran. Variasi bermusim menyumbang secara signifikan kepada kualiti air dan pencemaran logam di hilir sungai.

ACKNOWLEDGEMENTS

First and foremost, I am grateful to my god, ALLAH, who has given me the strength, enablement, knowledge, and required understanding to complete this thesis.

Next, I wish to express my unreserved gratitude to my supervisor, Assoc. Prof. Dr Faridah Othman, for the help. Her constructive criticism and ideas have made this work worth reading. I would like to thank the University of Malaya and the Faculty of Engineering for providing me with the great opportunity of completing my Master.

I extend my gratitude to the Project Number LR006-2011A entitled an *"Urban Ecohydrology for Resilient Environment"* (Ucoren) and Project Number FL001-13SUS entitled *"Development of Integration Model for Sustainable Waste Management Impact Assessment"* for financial supporting. I would like to acknowledge the support of HR Wallingford technician Pn. Faezah Ahmad for helping me with the hydraulic and water quality modelling in this project.

I am most grateful to all those who have assisted, guided, and supported me in my studies leading to this thesis. Finally, I would like to extend my deepest gratitude to my parents, my husband, and my friends, who have always given me unremitting support during the preparation of this thesis.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Item
η	Manning coefficient
1-D	One dimensional
A	Area
Al	Aluminium
AN	Ammoniacal Nitrogen
As	Arsenic
BOD	Biochemical Oxygen Demand
BC	Boundary Condition
Cd	Cadmium
Co	Cobalt
COD	Chemical Oxygen Demand
CN	Curve number
Cr	Chromium
Cu	Cupper
DID	Drainage and Irrigation Department
DO	Dissolved Oxygen
DOA	Department of Agriculture Malaysia
DOE	Department of Environment
EC	Electrical Conductivity
Fe	Iron/Ferum
ICP	Atomic Emission Spectroscopy
INWQS	Interim National Water Quality Standards for Malaysia
IWK	Indah Water Konsortium
IWRS	InfoWorks River Simulation

L	Length
Mg	Magnesium
Mn	Manganese
MOH	Ministry of Health
MSMA	Manual Saliran Mesra Alam
n	Number of propeller
Ni	Nickel
P	Wetted perimeter
Pb	Lead
Q	Discharge/Flow rate
R	Hydraulic radius
RF	Rainfall
S	Channel gradient
Sw	Weighted slope
St	Station
T_c	Time to concentration
T_p	Time to peak
TDS	Total Dissolved Solid
TSS	Total Suspended Solid
V	Velocity
WL	Water level
WQI	Water Quality Index
Zn	Zinc

LIST OF APPENDICES

CHAPTER 1 INTRODUCTION

1.1 General background

Two major seasons are recognized in Malaysia, namely the southwest monsoon and northeast monsoon. The southwest monsoon is a dry season from May until September and the northeast monsoon is a wet season from November until March. April and October are considered intermonsoon periods when the weather is quite unstable. According to (Pejman, Bidhendi, Karbassi, Mehrdadi, & Bidhendi, 2009), seasonal variations in precipitation, surface run-off, ground water flow, interception and abstraction strongly affect river discharge and consequently, pollutant concentrations in river water.

Rivers are the sources of life in cases of providing water supply for the people, irrigation for agriculture, as a way of transportation, source of food for fisheries, hydroelectric power and water use for industries. Rivers also act as habitat for aquatic life and their environment supports a rich biodiversity of life forms. Unfortunately, rivers also provide an easy passage for the discharge of various domestic, commercial, industrial and agricultural effluents or waste via their natural function as drainage channels for flood mitigation.

Over the years, urbanisation in Selangor and Kuala Lumpur has increased rapidly together with agriculture expansion and industrialisation causing changes in land use from one of mainly forest and food crops to urban, commercial and industrial centres. All these developments have overstressed river systems and as a result, many river basins have reached their limits of water supply and are now susceptible to water stress and droughts. Rapid development also has produced greater amount of human waste as well as wastes from human activities, agriculture, industrial and also transportation. As a consequence, many rivers are highly polluted.

The Department of Environment (DOE) used Water Quality Index (WQI) to evaluate the status of the river water quality. The WQI serves as the basis for environment assessment of a water course in relation to pollution load categorization and designation of classes of beneficial uses as provided for under the Interim National Water Quality Standards for Malaysia (INWQS).

In 2006, a total of 1,064 water quality monitoring stations located within 146 river basins were monitored. Out of these 1,064 monitoring stations, 619 (58%) were found to be clean, 359 (34%) slightly polluted and 86 (8%) polluted. Stations located upstream were generally clean, while those downstream were either slightly polluted or polluted. In terms of river basin water quality, 80 river basins (55%) were clean, 59 (40%) slightly polluted and 7 (5%) were polluted (DOE, Malaysia).

The major pollutants in the river basin were Biochemical Oxygen Demand (BOD), Ammoniacal Nitrogen (AN) and Total Suspended Solids (TSS). In 2006, 22 river basins were categorized as being polluted by BOD, 41 river basins by AN and 42 river basins by TSS (DOE, Malaysia). High BOD was contributed largely by untreated or partially treated sewage and discharges from agro-based and manufacturing industries (DOE, Malaysia). The main sources of AN was domestic sewage and livestock farming, whilst the sources for TSS were mostly earthworks and land clearing activities (DOE, Malaysia).

1.2 Problems Statement

Issues in the Penchala river basin include pollution from both point sources and non-point sources such as industrial waste, wastewater run-off from drains, solid waste from the road and river banks as well as partially treated sewage from sewage treatment plants and septic tanks.

Penchala River is highly polluted by the factories' waste along the river. Other pollution sources are garbage disposal and invasion at river reserve and channel River, constructed by Drainage and Irrigation Department (DID, Malaysia), untreated sewage from Indah Water Konsortium (IWK) at Kampung Ghandi (Kg. Ghandi) and Section 19, Petaling Jaya, damage of Log-boom at Kg. Ghandi and trash screen at Sungai Way (Way River).

There are no river reserve areas for maintenance for the river. The depth of Penchala River became shallower yearly. This phenomenon causes flash flood to happen frequently at it surrounding area. Penchala River with brown and dirty channel hardly resembles a river. This is because almost 70% of the original river course, especially where it passes through residential and industrial areas, has been concrete-lined.

The quality of the river steadily deteriorates as it meanders further downstream, and begins to look more like an open sewer, its murky water laden with all kinds of waste and rubbish. The cause of pollution primarily has been attributed to rubbish, effluents from industries like iron and steel, saw-milling, battery production, clearing of land for development and overflows from manholes and septic tanks.

Inefficient drainage system and the fencing along rivers that has made the river unreachable for the residents to clean the river up are also factors contributing to the problem. The situation is made worse by the fast-growing population and industrialization within the river perimeter covering several townships.

In 1997, the river was already classified as Class IV based on the water quality parameters measured by Department of Environment (DOE, 2008). Measurements made up to 2003 showed that the river had fallen gradually to Class V. There was a slight improvement for the years thereafter but it still remained in Class IV. In 2008, the river again was classified as Class IV based on the water quality parameters measured by DOE (DOE, 2008). There is only one monitoring water quality station (1K14) from DOE along Penchala River.

Therefore, this study was conducted to assess the water quality (November 2013 to October 2014) along the Penchala River from upstream to downstream because only one station (IK14) had been monitored before this and it is located at downstream of the river. It is important to monitor throughout the river due to difference land use. At upstream of the Penchala River, it is forest if compared to middle stream and dowsntream, which are surrounded by factories, commercial and residential area.

In addition to that, this study focused on the Penchala River which is an urban river for water supply in Malaysia. The scarcity of water supply in the Selangor state is one of the main reasons why the Penchala River was chosen as the study area besides being one of the tributaries of Klang River.

1.3 Research Objectives

This research aims to achieve through the following objectives:

1. To assess water quality and to identify significant changes of water quality between stations along Penchala River.

2. To study the seasonal impacts on physico-chemical parameters, water quality index and heavy metals concentrations of the Penchala River.

3. To develop a river model for Penchala River by using InfoWorks River Simulation for assesment and simulating the selected water quality parameters.

1.4 Significant of Study

The significant of this study is to monitor the water quality of the Penchala River as it was reported as highly polluted since 1997 by previous study conducted by DOE, Malaysia and other researchers. Unfortunately, the monitoring of Penchala River was only done at downstream region, namely the IK14.

Therefore, this study aims to assess the water quality throughout the whole length of Penchala River to find out if there is any significant difference in terms of water quality or not along Penchala River. This research also studies the seasonal impacts on physico-chemical parameters, water quality index and heavy metals concentration. The results of the study will be compared with simulation result from the river model to make the calibration.

1.5 Scope of Works

The monitoring of the Penchala River water quality is according to the water quality parameters, WQI and heavy metals to find the significant change between stations and seasonal impacts on water quality at the Penchala River. The significant change between stations was analyzed by using one way of variance (ANOVA) and a seasonal impact was analyzed according to average of dry season and average of wet season, and also average of yearly data.

The monitoring of the water quality of Penchala River also includes in-situ testing and laboratory testing. Then, Water Quality Index (WQI) is calculated based on six parameters which are BOD, COD, DO, AN, TSS and pH. The six WQI parameters were classified according to the standard classification by DOE, Malaysia. From these classifications, the water quality of Penchala River then was identified either as clean water, slightly polluted water or as polluted water condition.

In addition to that, the hydraulic and water quality river model was developed by using the InfoWork River Simulation. The hydraulic river model can run in steady and unsteady state for more accurate result by following the natural condition. Water quality river model was run for 3 parameters are BOD, DO, and pH. Then, the simulation from river model was compared to the observation results to make the calibration. From these calibrations, the river model then was classified into modelling classification.

1.6 Thesis Outline

The thesis is organized in five chapters, beginning with the introduction as the first chapter, which includes a general background of the research topic, problem statement, objectives, significance and scope of the study.

The literature review is described in the second chapter, where many topics are viewed, such as the importance of the river as the main water resources for human being. Hydraulic, water quality and heavy metals are described in individual parameters characteristics. This chapter also includes the introduction of model development.

The third chapter presents the research methodology and briefly describes the study area includes sampling stations throughout the river, and procedure for data collection were consists in-situ and laboratory testing. This chapter covered the calculation of water quality index.The steps for hydraulic and water quality river model are briefly described in this chapter.

The results and discussion are found in the fourth chapter. This chapter presents a detailed of each parameter which includes physico-chemical, heavy metals, and water quality index. Discussion of output result hydraulic and water quality river modelling is described as the third objective of this research.

Finally, the conclusions and recommendations are presented in the fifth chapter, where various conclusions and recommendations derived from the research results are presented, as well as the proposed future research works related to the research topic.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Chapter 2 presents a general overview of the hydraulic, water quality, water quality index, heavy metals, and for developing the model.

2.2 Seasonal variation in Malaysia

The characteristic features of the climate of Malaysia are uniform temperature, high humidity and copious rainfall. The seasonal variation of rainfall in Peninsular Malaysia is of three main types according to the Malaysian Meteorological Department:

(a) Over the east coast states, November, December and January are the months with maximum rainfall, while June and July are the driest months in most districts.

(b) Over the rest of the Peninsula with the exception of the southwest coastal area, the monthly rainfall pattern shows two periods of maximum rainfall separated by two periods of minimum rainfall. The primary maximum generally occurs in October - November while the secondary maximum generally occurs in April - May. Over the northwestern region, the primary minimum occurs in January - February with the secondary minimum in June - July while elsewhere the primary minimum occurs in June - July with the secondary minimum in February.

(c) The rainfall pattern over the southwest coastal area is much affected by early morning " Sumatras" from May to August with the result that the double maxima and minima pattern is no longer distinguishable. October and November are the months with maximum rainfalls and February the month with the minimum rainfall. The March - April - May maximum and the June -July minimum rainfalls are absent.

2.3 Importance of the River

River is an essential for water resources not only in Malaysia but over the world. In Malaysia there are 189 river basins nationwide. Rivers in Peninsular Malaysia are highly diverse ecosystems and support extensive artisanal fisheries. More importantly, rivers are the main source of drinking water in the peninsular (Gorashi & Abdullah, 2012).

On average the Peninsular Malaysia receives 324 billion m^3 of rainwater annually, whereas the current demand is about 11 billion m^3 only (EPU, 2000). The demand in the year 2050 could be about 18 billion m^3 (Al-Mamun & Zainuddin, 2013). The tendency of water demands in Malaysia was estimated to increase from 9,543 m^3/day in 1995 to 15,285 m^3/day in 2010, or the increase of 60% during 15 years, to 20,338 m^3/day in 2020, or 113% during 25 years (DOE., 2003). The total fresh water is only 2.5% of all water of the earth that makes it as a scarce resource; and again the amount of available water for use is only 0.4% of total fresh water (Czarra F., 2003). However, experts have concluded that the main issue is not water scarcity but poor management which is precipitating a crisis (Ngai Weng Chan, 2012). In the last few decades, there has been a tremendous increase in the demand for fresh water due to rapid growth of population and the accelerated pace of industrialization (Ramakrishnaiah, Sadashivaiah, & Ranganna, 2009).

2.4 Water resources

Water is known as the Earth critical resources which are essential for all living things. Although our planet is covered by 70% of water, however the amount of freshwater that is ready for human consumption only covers a small percentage. Plus, freshwater resources vary widely both in space and time which often in conflict with water demand. Rivers as water resources, not only in terms of drinking water supply but also in terms of their function in recreational and sport activities such as water sports and fishing, are very important to man’s health (Shanbehzadeh, Vahid Dastjerdi, Hassanzadeh, & Kiyanizadeh, 2014)

Due to the increasing population growth and economic development in the recent years, the water demand for municipal, industrial, and agricultural uses is increasing, the surface and groundwater pollution is deteriorating, and freshwater supplies are going to run out. These, had caused water scarcity to become a critical issue in many countries worldwide. Based on the report from United Nations, approximately 700 million people in 43 countries are facing problem with water scarcity, and by 2025, it is estimated that 1.8 billion peoples will be living in countries or regions with absolute water scarcity. The research also predicted that 1.1 billion people will lack access to clean drinking water and 2.4 billion people will suffer with improper sanitation and perhaps can lead to loss of life. Thus a sustainable water resource is required to ensure a continuous water supply.

2.5 Hydraulics

Velocity is the time taken for the water in the river to travel a distance in particular time. The factor that affects the velocity is gradient and the roughness. The steeper the slope or gradient, the faster the velocity of water flows. The gradient of a stream or river can be expressed as the vertical drop of a stream over a fixed distance, in example 1 foot per mile. Resistance or roughness is determined by the nature of the substrate, the shape of channel, in stream vegetation and the distribution of woody debris such as logs and root wads. The unevenness distribution of streambed material and vegetation contributes resistance to stream flow and slows the velocity of water by causing friction to the water flow.

The main definition of discharge or flow is the amount of water that flows past a given point with a given amount of time. Mathematically, flow is the product of the cross-sectional area multiplied by the velocity. The unit of discharge is expressed as cubic feet per second (“cfs” or “ft3/sec”). High and low flow can affected the water quality of river in a few ways. Discharge or flows are much related to velocity and area since both of the parameter can cause a great impact on the flow. In a case of a river, the cross sectional area of the river is the width and depth of the river. Construction or alteration of the cross-sectional are of the river can cause a great impact on the river

2.6 Water quality

The water quality can be defined as a conventional ensemble of physical, biological and bacteriological features that are expressed as values and allow for the framing in a certain category, which expresses the possibility of its anthropogenic usage to meet a certain purpose (Sarala Thambavani & Uma Mageswari, 2013). And, the water quality is a measurement to determine the pollution level that happen in water, showing the reaction in water composition towards all the input whether is natural or manmade (Karanth, 1987; Krenkel, 2012).

Water quality is largely depends on the natural processes and anthropogenic activities like industrial activities, municipal waste management, homesteads and agricultural activities; which constitute a continuous polluting source (Hossain M.A., Sujaul I.M., & Nasly M.A., 2013; Kazi et al., 2009).

Therefore, the monitoring water quality is an important component of water resource conservation, management and treatment (MacDonald, Smart, & Wissmar, 1991; Mei et al., 2011; Othman, M. E, & Mohamed, 2012; Reduction, 2001). It is practiced to understand and evaluate water availability and quality to control and minimize the incidence of pollutant-oriented problems as well as provide water of appropriate quality to various water practices like urban water supply and irrigation (Boyacioglu, 2007; Loukas, 2010; Othman et al., 2012).

The Biochemical Oxygen Demand (BOD) is the amount of oxygen required to oxidize a substance to carbon dioxide and water by the microorganisms. In the simplest term, BOD is the amount of oxygen required for the microorganisms (bacteria) to eat the organic pollutant. The BOD is an empirical test to determine the relative oxygen requirements of wastewaters, polluted waters and effluents.

Chemical oxygen demand (COD) is defined as the amount of organic matter that is prone to oxidation by a strong chemical oxidant (Viessman, Hammer, & Perez, 2009). COD is an essential parameter for measuring water quality and is useful to determine the amount of organic pollutants found in surface water or waste water. The COD determination is a measure of the oxygen equivalent of the portion of the organic matter in a sample that is susceptible to oxidation by a strong chemical oxidant.

Ammoniacal Nitrogen (AN) is defined as the amount of ammonia and ammonium compounds. These compounds are transferred into the environment out of the different sources such as waste incineration, sewage treatment, cattle excrement and car exhausts.

A total suspended solid (TSS) is a measure of the particulate matter that is suspended within the water column. Values are reported in mg/L. High concentrations of TSS increase turbidity, thereby restricting light penetration (hindering photosynthetic activity). Suspended material can result in damage to fish gills. Settling suspended solids can cause impairment to spawning habitat by smothering fish eggs. Suspended solids also interfere with water treatment processes.

Dissolved oxygen (DO) is a measure of the amount of oxygen dissolved in water. Typically the concentration of dissolved oxygen in surface water is less than 10 mg/L. The DO concentration is subject to diurnal and seasonal fluctuations that are due, in part, to variations in temperature, photosynthetic activity and river discharge. The maximum solubility of oxygen (fully saturated) ranges from approximately 15 mg/L at 0°C to 8 mg/L at 25°C (at sea level). Natural sources of dissolved oxygen are derived from the atmosphere or through photosynthetic production by aquatic plants. Natural re-aeration of streams can take place in areas of waterfalls and rapids. Dissolved oxygen is essential to the respiratory metabolism of most aquatic organisms. It affects the solubility and availability of nutrients, and therefore the productivity of aquatic ecosystems. Low levels of dissolved oxygen facilitate the release of nutrients from the sediments. Oligotrophic (low nutrient) lakes tend to have increased concentrations of dissolved oxygen in the hypolimnion (deeper waters) relative to the epilimnion (defined as orthograde oxygen profiles). Eutrophic (high nutrient) lakes tend to have decreased concentrations of dissolved oxygen in the hypolimnion relative to the epilimnion (defined as clinograde oxygen profiles. Also, dissolved oxygen is consumed by the degradation of organic matter in water (Al-Badaii, Shuhaimi-Othman, & Gasim, 2013).

pH is the measurement of the hydrogen-ion concentration in the water. A pH below 7 is acidic (the lower the number, the more acidic the water, with a decrease of one full unit representing an increase in acidity of ten times) and a pH above 7 (to a maximum of 14) is basic (the higher the number, the more basic the water). Fresh waters have a pH range from 6.5 in to nearly 8.0. Higher pH values tend to facilitate the solubilisation of ammonia, heavy metals and salts. The precipitation of carbonate salts (marl) is encouraged when pH levels are high. Low pH levels tend to increase carbon dioxide and carbonic acid concentrations. Lethal effects of pH on aquatic life occur below pH 4.5 and above pH 9. Generally, the Ph concentrations increase as a result of the photosynthetic algae activities that consumes carbon dioxide dissolved in (Al-Badaii et al., 2013).

Temperature was affecting by many factors such as the weather condition, sampling time, and location impact on the increase and decrease of temperature by which its role effect on the percentage of dissolved oxygen, biological activities, and other parameters (Al-Badaii et al., 2013; Shuhaimi-Othman, Lim, & Mushrifah, 2007).

Normally, conductivity in the water was affected by the inorganic dissolved oxygen such as calcium, chloride, aluminium cations, nitrate, sulphate, iron, magnesium and sodium. Organic compounds such as oil, alcohol, phenol, and sugar also can influence the water conductivity as well as temperature. High temperature will be high in water conductivity. Most of the freshwaters conductivity is ranging from 10 to 1000 us/cm. but, the concentration can exceed about 1000us/cm in the water that receiving pollution (Al-Badaii et al., 2013; Harun, Abdullah, Mohamed, Fikri, & Jimmy, 2010).

The high total dissolved solid (TDS) concentration in the rivers is attributed to presence extreme anthropogenic activities along the river course and runoff with high suspended matter (Al-Badaii et al., 2013).

Commonly, the excessive turbidity is generally related to possible microbiological contamination because water disinfection contained elevated turbidity is very complicated. Turbidity is resulted from the presence of suspended particles such as silt, plankton, clay, organic matter, and other microscopic or decomposers organisms. Generally, the clarity of water decreased as a result of the presence of these suspended particles that deposited in the water. The murkier water in general was ascribed to the higher amounts of sediments. This can also be the indicator of a high measured turbidity, and stream flow, surface runoff, and overland flow in natural waters also increase the turbidity levels in the water (Yisa & Jimoh, 2010).

High concentrations of phosphate are generally indication of the pollution associated with eutrophication condition. Moreover, the domestic effluents particularly which contain detergents, fertilizer runoff, and industrial wastewater are the main reasons of high phosphate levels in surface water such as rivers and lakes (Al-Badaii et al., 2013).

2.7 Water quality index

Water quality indices appeared in the literature as early as 1965 (Horton, 1965). The general WQI was developed by (Brown, McClelland, Deininger, & Tozer, 1970). The WQI approach has many variations in the literature and comparative evaluations have been undertaken (A. Bordalo, Nilsumranchit, & Chalermwat, 2001).

The WQI was developed to give criteria for river water classification based on the use of standard parameters for water characterization (Gholikandi, Haddadi, Dehghanifard, & Tashayouie, 2012). The WQI has been used to quantify the quality of surface water based on measuring parameters for water specification (Sanchez et al., 2007). WQI is a mathematical instrument used to transform large quantities of water quality data into a single number (Stambuk-Giljanovic, 1999), which provides a simple and understandable tool for managers and decision makers on the quality and possible uses of a given water body (A. Bordalo et al., 2001). The WQI is a unitless number between 0 and 100 with the higher value indicating better quality of water (Cude, 2001).

WQI as a means of water quality assessment through the determination of physic-chemical parameters of surface water; it can act as an indicator of water pollution because of natural inputs and anthropogenic activities (Amadi, Olasehinde, Okosun, & Yisa, 2010; Hossain M.A. et al., 2013; Yisa & Jimoh, 2010). The WQI integrates complex data to generate a score that describes the status of water quality to the public as well as decision and policy makers (Massoud, 2012).

Many countries employ the WQI method to assess overall river status. These indices differ from country to country but share a similar concept, in that a few important parameters are selected and compounded to numerical rating for the evaluation of river water quality (Bhargava, 1983). There are several water quality indexes developed to evaluate river water quality all over the world. The common parameters used are DO, pH, turbidity, TSS, nitrates and phosphates (Fulazzaky, Seong, & Masirin, 2010; Lumb, Sharma, & Bibeault, 2011; Othman et al., 2012; Shuhaimi-Othman et al., 2007). While, (Al-Shujairi, 2013) proposed a WQI formula that used seven water quality parameters (TDS, total hardness, pH, DO, biochemical oxygen demand (BOD), nitrate (NO3), and phosphate) to evaluate water quality in the Tigris and Euphrates rivers in Iraq.

The results of the WQI allow the preliminary classification of river water for the purpose of various uses and provide a benchmark for evaluating management strategies (A. A. Bordalo, Teixeira, & Wiebe, 2006).). Based on the results of WQI, river water can be classified for the purpose of various uses. The evaluation of WQI requires many physical and chemical parameters be measured.

WQI is useful in assessing the suitability of river waters for a variety of uses such as agriculture, aquaculture, and domestic use. WQI is one of the most effective tools to provide feedback on the quality of water to the policy makers and environmentalists and it determines overall water quality status of a certain time and location.

2.8 Heavy metals

Heavy metals existed in the environment through natural process and human activities. The variation of natural sources such as acidification, erosion and weathering process are common ways of heavy metals brought into the environment (Abdullah, Louis, & Abas, 2015; Al-Badaii & Shuhaimi-Othman, 2014; Bidhendi, Karbassi, Nasrabadi, & Hoveidi, 2007; Mehrdadi et al., 2009; Mehrdadi, Ghobadi, Nasrabadi, & Hoveidi, 2006; T Nasrabadi, 2015; Touraj Nasrabadi, Bidhendi, Karbassi, & Mehrdadi, 2010; Shanbehzadeh et al., 2014).

As municipal, industrial, and agricultural waste enters the water, biological and chemical contaminants including heavy metals also enter into the river. Although some of these metals are essential as micronutrients, their high concentration in the food chain can cause toxicity and environmental impacts and endanger aquatic ecosystems and their users (Kane, Lazo, & Vlora, 2012; Shanbehzadeh et al., 2014). Pollution by heavy metals is considered to be a serious problem due to their toxicity and their ability to accumulate in the biota (Morillo, Usero, & Gracia, 2002). And, heavy metal contamination of sediments can critically degrade aquatic systems.

Monitoring the concentration levels would provide the preliminary baseline data for control of pollution (Ismail, Primasari, & Shirazi, 2011). Lots of studies in the literature have focused on heavy metal pollution of water resources all around the world (Abdullah Et Al., 2015; Al-Badaii & Shuhaimi-Othman, 2014; Bidhendi Et Al., 2007; Ismail Et Al., 2011; Ismail Et Al., 2013; Kane Et Al., 2012; Mehrdadi Et Al., 2009; Mehrdadi Et Al., 2006; T Nasrabadi, 2015; Touraj Nasrabadi Et Al., 2010; Prasad & Bose, 2001; Shanbehzadeh Et Al., 2014; Wang, Lu, Han, He, & Wang , 2007; Zhang, Guo, Meng, & Wang, 2009).

Arsenic contamination of groundwater is natural occurring with high concentration of arsenic in deeper levels and it is the most common cause of acute heavy metals poisoning in adults (Baharuddin, Ismail, Othman, Taib, & Hashim, 2013; Ismail et al., 2013; Shirazi, Imran, & Akib, 2012). Arsenic is released into the environment by the smelting process of copper, zinc, and lead, as well as by the manufacturing of chemicals and glasses. Other sources are paints, rat poisoning, fungicides, and wood preservatives. Arsenic is a carcinogen which causes many cancers including skin, lung, and bladder as well as cardiovascular disease and diabetes prevalence. Arsenic is detrimental to agriculture and its presence in drinking water may also compromise the immune function (Shirazi et al., 2011).

Industrial sources or toxic waste sites may cause the zinc amounts in drinking water to reach levels that can cause health problems. Zinc occurs naturally in air, water and soil, but zinc concentrations are rising unnaturally, due to addition of zinc through human activities. Most zinc is added during industrial activities, such as mining, coal and waste combustion and steel processing. Some soils are heavily contaminated with zinc, and these are to be found in areas where zinc has to be mined or refined, or were sewage sludge from industrial areas has been used as fertilizer (Ismail et al., 2013).

Lead is present in water sources. Lead and silver in river waters are commonly found together and associated with lead mining. Lead was once commonly used in gasoline (petrol), though its use is now restricted in some countries and is present in water sources. Today, the highest levels of lead in air are usually found near lead smelters. The major sources of lead emissions to the air today are ore and metals processing and piston-engine aircraft operating on leaded aviation gasoline (Gloag, 1981; Harrison, 2012).

Chromium is a carcinogen; the leather industry discharges chromium and other toxic substances into the river. The electroplating and textile industries also release relatively large amounts of chromium in surface waters. Leaching from topsoil and rocks is the most important natural source of chromium entry into bodies of water. Solid wastes from chromate-processing facilities, when disposed of improperly in landfills, can be sources of contamination for groundwater, where the chromium residence time might be several years according to Agency for Toxic Substances and Disease Registry (ATSDR) (Health & Services, 1993)

Iron makes up about five percent of the earth's crust. It can be a soluble or relatively insoluble form found in water. Soluble iron is found in groundwater, oxygen-free reservoirs, dead-ends in water distribution systems, and scale (hard mineral coatings) within pipes. The primary sources of iron in drinking water are from natural geologic sources and corroding distribution systems and household pipes. Iron-based materials, such as cast iron and galvanized steel, have been widely used in our water distribution systems and household plumbing (Colter & Mahler, 2006).

Calcium enters the freshwater system through the weathering of rocks, especially limestone, and from the soil through seepage, leaching and runoff. Calcium oxide (lime) is used extensively in mortar, stucco and plaster in the building industry. It is used in pulp and paper production, sugar refining, petroleum refining and tanning. Lime is also widely used as a wastewater treatment chemical. A major source of atmospheric calcium is the burning of fossil fuels (Ismail et al., 2013).

2.9 Model Development

The InfoWorks River simulation (IWRS) software simulates one dimensional (I-D) channel flow by solving the fully dynamic de Saint-Venant equations, which define the conservations of mass and momentum (Chiang, Willems, & Berlamont, 2010; Mah, Lai, Chan, & Putuhena, 2012; Othman et al., 2013; Toriman, Karim, Mokhtar, Gazim, & Abdullah, 2010). IWRS I-D model used for the prediction of discharge and water level for a wide range of rivers, reservoirs, complex floodplains and narrow estuaries under both steady and unsteady conditions (Mah et al., 2012). (Horritt & Bates, 2002) was discussed in the literature that a 1-D model performing equally as a 2-D model.

The reasons to use the river modelling because this method is easier than the mathematical formulas or site sampling which are include the high cost and also the safety. And, *Manual Saliran Mesra Alam* (MSMA) in vol.6 under the title Network System and Computation explains that a mathematical model is highly recommended for drainage or river analysis so that a complete system can be studied and analysed efficiently.

The IWRS software was widely used for flood analysis and modelling in Malaysia such as (Bustami, Bong, Mah, Hamzah, & Patrick, 2009; Chiang et al., 2010; Mah et al., 2012; Othman et al., 2013; Toriman et al., 2010) by using the different types of design to restructure of the river network. But, lack in development of water quality model. Thus, this study is more focussing to generate the water quality model simulation due to the highly polluted Penchala River impacting by the rapid urbanization occurred in Selangor state.

Water quality models are very useful in describing the ecological state of a river system and to predict the change in this state when certain boundary or initial conditions are altered. Such changes may be due to morphological modifications to the water body, such as straightening, and discharge regulations using control structures (Cowx & Welcomme, 1998), changes in the type (point or non-point), amount and location of pollutant loading into the system, and changes in meteorological inputs due to changing trends in climate.

The calibration and validation process is critical to determine confidence in model simulations and the overall reliability of the calibrated model. Calibration is the process of adjusting or "tuning" the parameter values to obtain an optimal agreement between the simulated observed data. During model calibration, numerical values for each of the parameters, state variable initial condition, boundary conditions etc. must be supplied for the model. Model validation is the process of assessing the degree of reliability of the calibrated model using one or more independent data sets data i.e. not the same data used for calibration. It is a process of testing whether the model meets the objectives stated. The calibrated model parameters are held constant (i.e. hydraulic conditions, climatic conditions etc.) and the independent initial and boundary conditions (stream water quality, headwater stream discharge) are entered into the model to simulate new conditions (McCutcheon, 1989)

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 (Whitehead, Williams, & Lewis, 1997). Water quality models can be used to predict the characteristics of water quality conditions in aquatic systems in order to ensure the water quality objectives will be maintained under a wide variety of conditions. Models provide the ability to develop a credible and defensible water quality management program. They are continually being developed and improved to optimize the demands of environmental regulations and protection.

CHAPTER 3 METHODOLOGY

3.1 Introduction

Chapter 3 presents the methodology and briefly describes the study area, data collection and preliminary data analysis. The testing includes in-situ and laboratory.

The development of river models includes hydraulic and water quality. The procedure consist many steps such as the selection of the event based data for hydraulic river model. The event based data consists are rainfall, water level and discharge. Once the hydraulic model was completed, and then the water quality model is conducted by inserting the water quality parameters as the initial and boundary pollutant condition. The main procedures of the research methodology are presented in detail through this chapter. Figure 3.1 below shows the methodology flows chart for this research study.

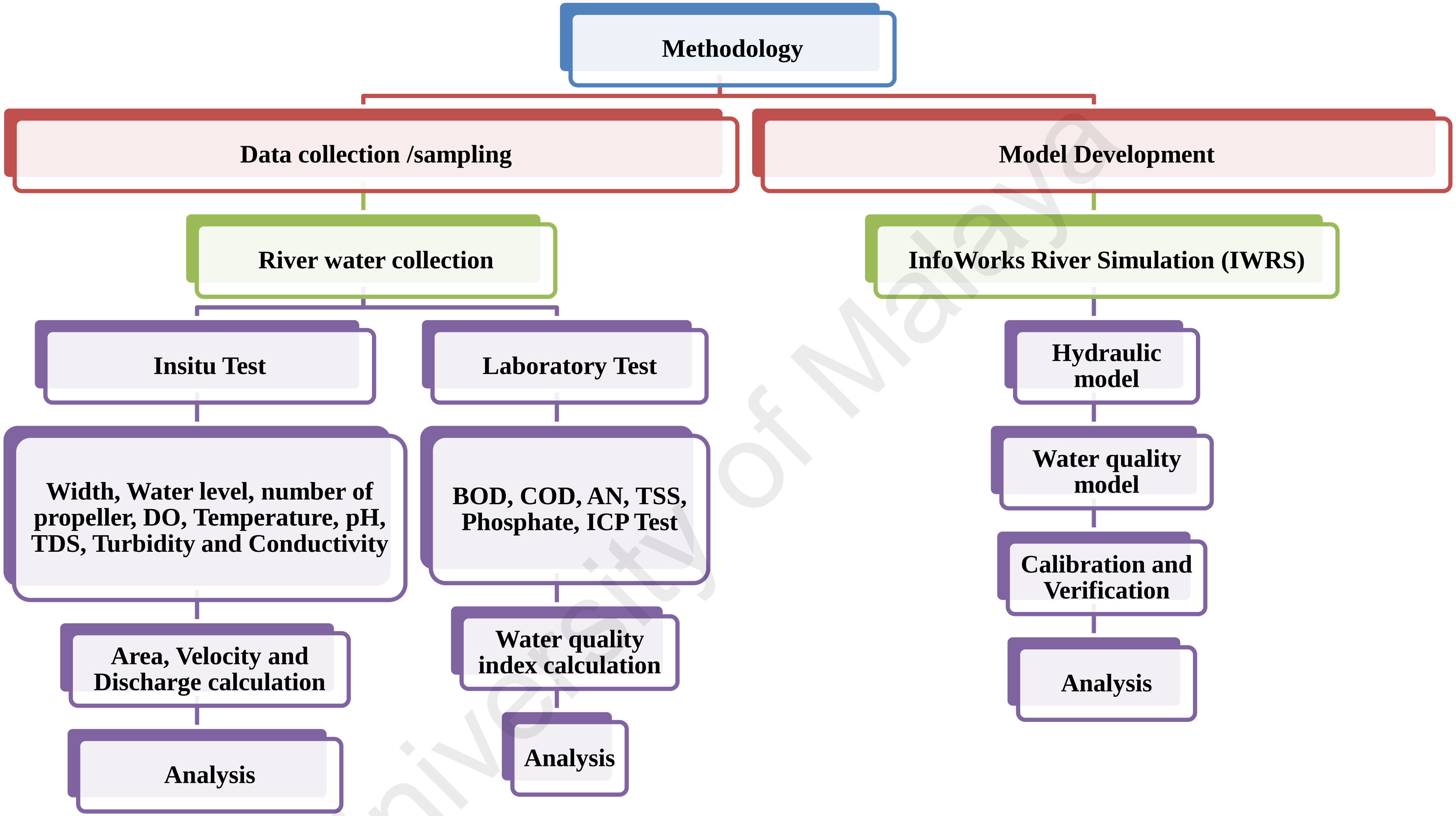


Figure 3. 1: Methodology flow chart

3.2 Study Area

Sungai Penchala (Penchala River) is a tributary of the Klang River and passes through several important townships. Penchala River is only 12 km long (4 km in Kuala Lumpur Federal Territory and 8 km in Selangor state) and is the shortest but most polluted tributary of the Klang River. Penchala River is a relatively short river but almost 80% of the original river has been channelized with concrete, as it flows through residential and commercial areas. Penchala River upstream is at Kiara Hill and downstream is at Kampung Ghandi (Kg. Ghandi). The width of the river is about 15 to 20 meters. The depth of the river is 4 meters. Penchala River catchment has an area of 14 square kilometres. Figure 3.2 shows the catchment of Penchala River.

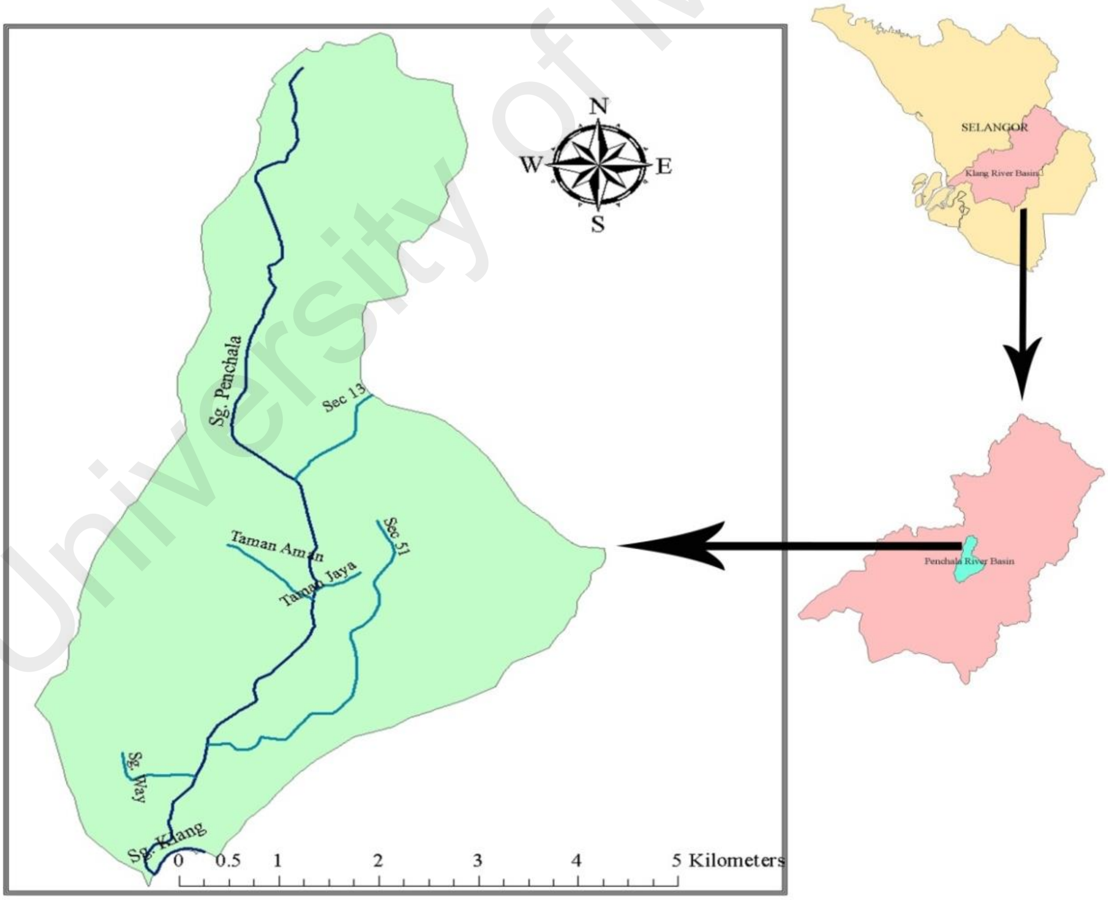


Figure 3. 2: The catchment of the Penchala River

Penchala River flows down from Kiara Hills into two main tributaries: one through Kuala Lumpur (KL) Golf and Country Club and the other through the Kiara Park in Taman Tun Dr Ismail. The tributary in Taman Tun Dr Ismail first flows through the Kiara Park where it is turned into a canal lined with terracotta bricks, with an exception at a short stretch to allow public access to the water. It is reunited with the other tributary near the Damansara Sewage Treatment Plant. By then, the river is further contaminated with animal waste and human sewage: the first is discharged from the Equestrian Park at the foothill of Kiara Hills, the second, from a malfunctioning sewage treatment plant operated by the KL Golf and Country Club. The river then enters the Petaling Jaya district at Section 17 (Damansara Intan) and flows through many residential and industrial areas. Here, islands of rubbish begin appearing in and along the banks of the river. The eyesore is worst in Section 19 where about 800 squatter houses are located. More pollution is pumped into the river from the industrial areas of Section 13 and 14 before it eventually winds up in Klang River near Kg. Ghandi. Figure 3.3 below shows a landuse map at Penchala River.

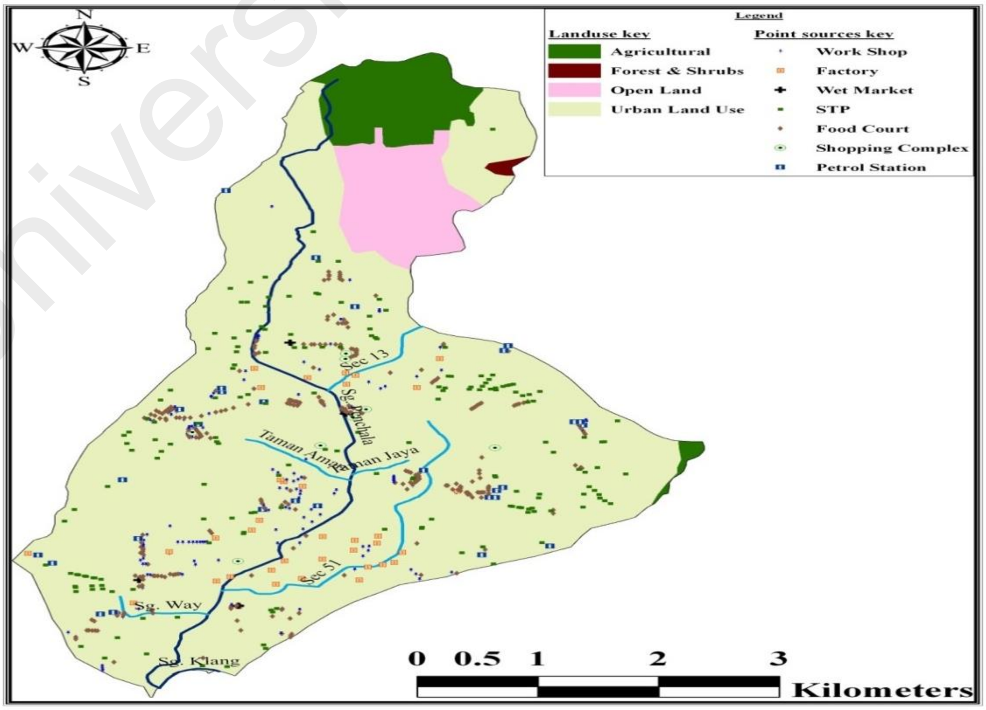


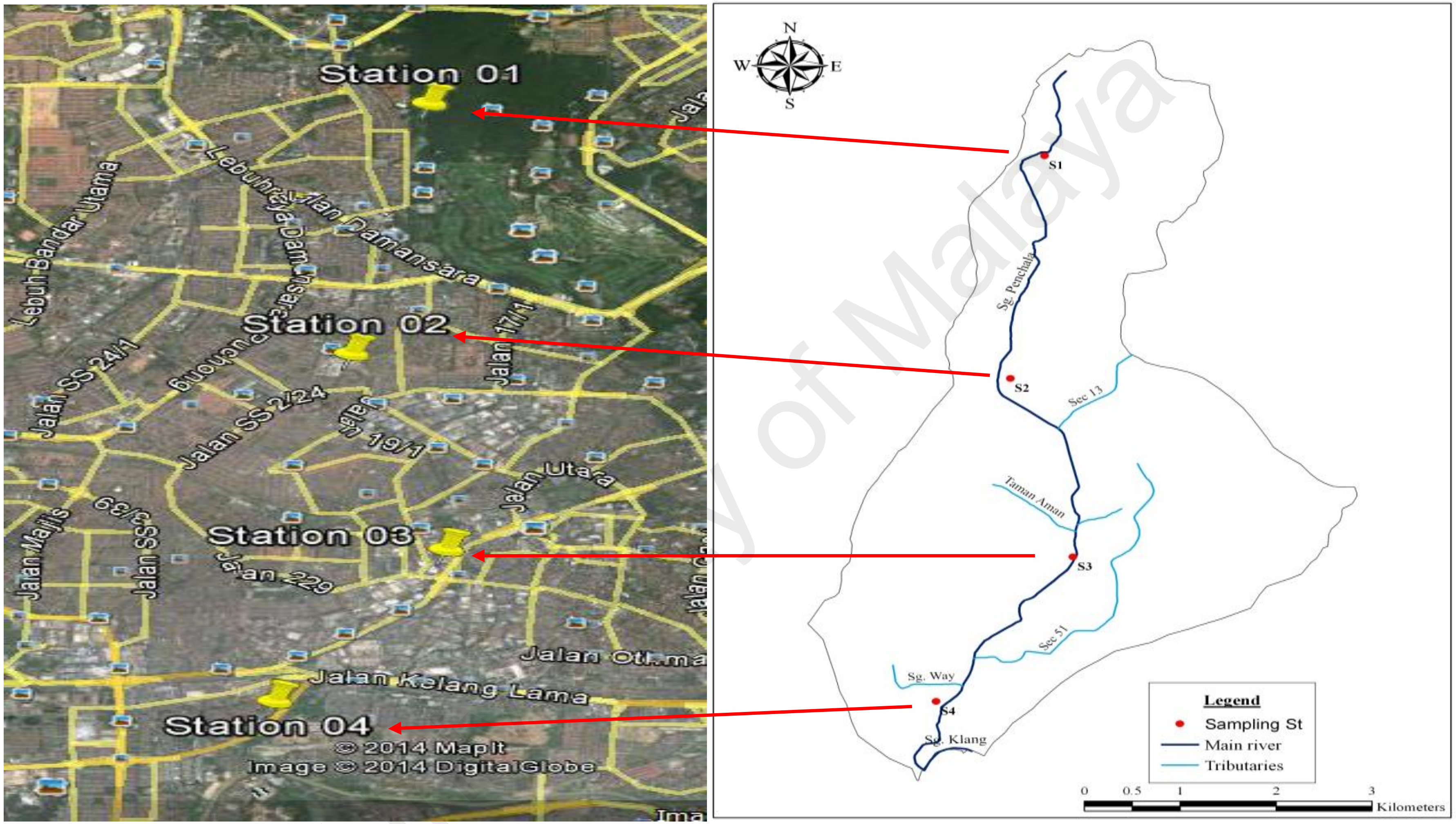
Figure 3. 3: Landuse map at Penchala River

3.2.1 Sampling stations

There are 4 sampling stations that are situated along the river, namely Station 1 (St1) at the upstream, Station 2 (St2) and Station 3 (St3) at the middle-stream and Station 4 (St4) at the downstream of the river. The distance from one station to another is about 4 km each. All sampling stations were chosen based on the accessibilities of the places. Safety is the first priority while conducting the sampling. Table 3.1 shows the geographical description of the sampling stations and Figure 3.4 shows the location of the sampling stations along Penchala River.

Table 3. 1: Geographical Description of Sampling stations.

Stations	Stations Name	State/District	GPS Coordinate	Area Type
St1	Taman Lembah Kiara	Kuala Lumpur Federal Territory	03^{O} 08’ 45.3” N	Recreational Area
			101^{O} 37’ 54.1” E	
St2	Jambatan ss2/19	Petaling, Selangor	03^{O} 07’ 7.4” N	Urban (residential and commercial area)
			101^{O} 37’ 42.7” E	
St3	Jalan 222	Petaling, Selangor	03^{O} 05’ 49’’ N	Urban (residential, commercial and factories area)
			101^{O} 38’ 4.1’’ E	
St4	Kg. Ghandi	Petaling, Selangor	03^{O} 04’ 45.4” N	Urban (residential, commercial and factories area)
			101^{O} 37’ 18.0” E	



a) Google Earth **b)** ArGIS

Figure 3. 4: The location of the sampling stations a) Google Earth b) ArGis

Station 1: Taman Lembah Kiara.

The first sampling station was located inside Lembah Kiara Recreational Park, Taman Tun Dr. Ismail (TTDI). It is an upstream and natural river. At first, the river was untouched, but later, a construction at the river bank on one side of the river along the sampling site was conducted.

a) The elevation view (Google Earth)

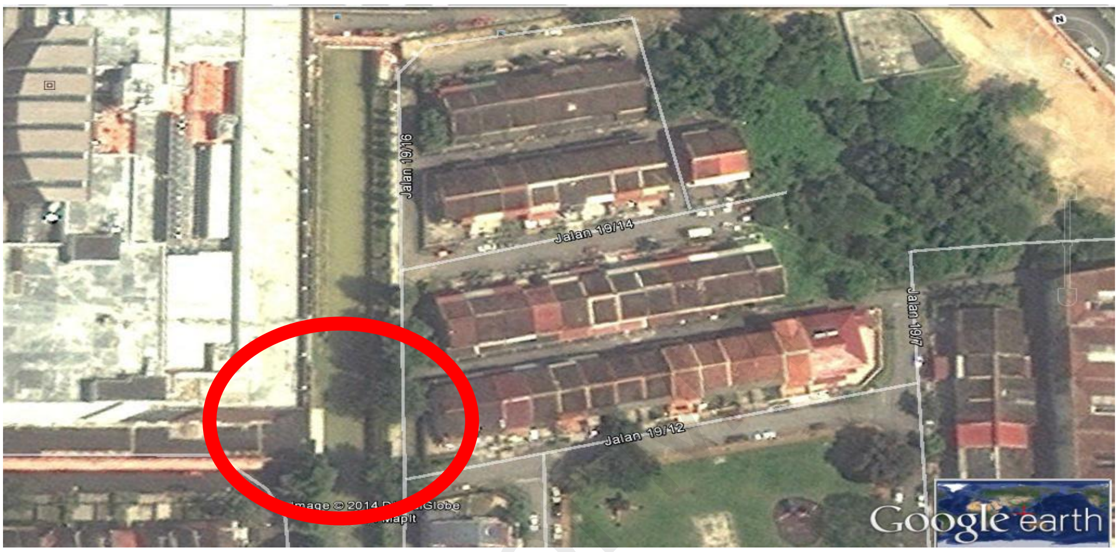
b) Site photo

Figure 3. 5: The pictures of the Penchala River at Station 1

a) The elevation view b) Site photo

Station 2: Jambatan SS2/19

The second sampling station was located behind SS2 Mall at Seksyen 19, Petaling Jaya and there is also a residential area nearby. It is a middle-stream and man-made drain which is made up of concrete. The drain is 14.3m in width and 6m in height on both sides. There is a construction work in progress on one side of the river bank.



a) The elevation view (Google Earth)

b) Site photo

Figure 3. 6: The pictures of the Penchala River at Station 2

a) The elevation view b) Site photo

Station 3: Jalan 222

The third sampling station was located at Jalan 222, Petaling Jaya. There are 4 main buildings near the river which is Harley Davidson Shop, SATO Malaysia Electronic Manufacturing Sdn Bhd, Nutrimetics Worldwide (M) Sdn Bhd and Renewal Lutheran Church. It is a middle-stream and man-made drain which is made up from concrete. The drain is 13m in width and 6m in height on both sides. The waste from the shops and factories located nearby, flows directly into the drain.

a) The elevation view (Google Earth)

***b)** Site photo*

Figure 3. 7: The pictures of the Penchala River at Station 3

a) The elevation view b) Site photo

Station 4: Kampung Ghandi (Kg. Ghandi)

The last sampling station was located at Kg. Ghandi, Petaling Jaya. It is located nearby an Info Centre of Department of Irrigation and Drainage (DID) and residential area. The station is a downstream and natural river. There had been a construction work at the river bank and the construction was already finished during the fourth sampling.

a) The elevation view (Google Earth)

b) *Site photo*

Figure 3. 8: The pictures of the Penchala River at Station 4

a) The elevation view b) Site photo

3.3 Data Collection

The data collection or sampling was conducted on monthly basis starting from November 2013 until October 2014.

Overall, there are 12 sets of data that have been successfully collected. The data collection is divided into 2 parts which are in-situ testing and laboratory testing. For in-situ testing, the parameters involved are pH, electrical conductivity (EC), turbidity, temperature, total dissolved solid (TDS) and Dissolved Oxygen (DO), water level, width and number of propeller (n). For the laboratory testing, the parameters involved are Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Ammonical Nitrogen (AN), Total Suspended Solids (TSS), phosphate, and heavy metals.

Meanwhile, areas, velocity, discharge, Water Quality Index (WQI) were calculated by using the formulas. Lastly, the hydraulic and water quality river model was developed using the InfoWorks River Simulation 14.0 (IWRS 14.0).

3.3.1 Sampling Procedure

The Biochemical Oxygen Demand (BOD) water samples were collected by filling up the BOD bottles in the water and also capped while they were still in water. This was to disallow any air space in the bottles. Water samples were collected in 2 bottles (500ml/bottle), for each sampling station. All the water samples were kept cool in a box with ice for transportation purposes from the sampling site to the laboratory. Figure 3.9 below shows the steps for river water collection and in-situ testing. During sampling, the in-situ testing was done for the width, water level, number of propeller (n), DO, Temperature, pH, TDS, Turbidity and EC by using the respective instruments as shown in Figure 3.10.

(a) (b) (c) (d)

Figure 3. 9: Procedure for sampling and insitu-testing (a) water collection (b) insitu test (c) water measurement (d) river water sample kept cool (transportation)

YSI 550A Dissolved Oxygen 50'
It was used to measure DO concentration

Multi Parameter
It was used to measure pH, Temperature, TDS, and EC.

HACH 21000P Portable Turbidity Meter
It was used to measure turbidity concentration.

Leica Distro Laser Distance
It was used to measure the river width.

Current Meter
It was used to measure the number of proppeller (n), velocity calculation.

Depth Sounder
It was used to measure the river water level.

Figure 3. 10: In-situ testing equipments

3.3.2 In-situ Procedure

The DO concentration was measured using the DO meter. The probe guard is attached and the sonde is deployed within a representative area of appreciable flow to provide adequate mixing around the probes. The meter is turned on and waited for 60 seconds before checking DO reading. From 60 seconds onwards, the DO reading is observed; when DO value is already stabilize (no change more than 0.05 mg/l within 10 seconds). The reading was then taken. The same method was used for the pH, TDS, EC and temperature by using YSI Multi parameter.

The turbidity concentration was measured using turbidity meter. The sample was filled into the small bottle provided with this instrument. The bottle was put into the turbidity meter and read icon was pressed. The value was taken in NTU units.

The water level was measured using the depth sounder. A suitable spot is selected (middle river) where the river water is flowing. The depth sounder is put on the spot and the readings were taken. Three different readings are taken from the same spot and the average is calculated.

A suitable location is selected at the river that represents the actual width of the river. The laser distance is used to measure from one end to the other of the river bank. The steps are repeated for 3 times and the average is calculated

The current meter is assembled and put into measuring point. The propeller revolutions (r) are counted during the pre-set measuring time (t) by means of counter set. The speed, $n = r/t$ is determined. The water velocity, v is calculated by means of equation $v=0.1025.n + 0.028$, where $n =< 19.24$, v = velocity in m/s, n = number of propeller revolutions in 1/s.

Discharge, Q is calculated using the equation Q=AV where A represents the area of the river and V represents the velocity of the water. Area, A is calculated by multiplying the water level by the width of the river.

3.3.3 Laboratory Procedure

Laboratory analysis was testing for 6 parameters as shown in Table 3.2 below by using standards method (APHA, 1998).

Table 3. 2: Laboratory testing

Water quality parameters	Test name
COD	APHA 5220B: Open Reflux method
BOD	APHA 5210B: 5Days BOD Test
AN	ASTM D3590-II: Standard Test Methods for Total Kjeldahl Nitrogen in Water
TSS	APHA 2540B: TSS dried 103^0 to 105^0
Heavy Metal	ICP – AES analysis
Phosphate	APHA 4500P

3.4 Water Quality Index

The WQI considers six parameters to evaluate the overall status of river water. The WQI consists of DO, BOD, COD, TSS, AN and pH. DO is defined as the amount of oxygen dissolved in water when oxygen gas and water are mixed together. DO is one of the most important parameters for calculating water quality index, since it is used to measure the amount of gaseous oxygen available in water for biochemical activity. BOD is another important water quality parameter, and BOD is the amount of oxygen required to oxidize a substance to carbon dioxide and water by the microorganisms. The index gives information about the total DO concentration required during the degradation and oxidation process of some organic compounds in water. COD is defined as the amount of organic matter that is prone to oxidation by a strong chemical oxidant. COD is an essential parameter for measuring water quality and is useful to determine the amount of organic pollutants found in surface water or waste water. Another essential parameter is TSS, which regularly consists of a large amount of suspended organic matter. These composites are discharged into the environment through different sources such as sewage treatment, agricultural activity and waste ignition. AN is defined as the amount of ammonia and ammonium compounds. These compounds are transferred into the environment out of the different sources such as waste incineration, sewage treatment, cattle excrement and car exhausts. Surface water requires a specified pH to protect aquatic life and control undesirable chemical reactions.

WQI calculation is based on six parameters, as shown in equation (3.1). The largest portion is carried by the DO index with 0.22 and pH is the smallest portion contributing 0.12 in the equation. The WQI equation eventually comprises the sub-indices calculated according to the best-fit relationships given in Table 3.3.

$$WQI = 0.22SI_{DO} + 0.19SI_{BOD} + 0.16SI_{COD} + 0.16SI_{SS} + 0.15SI_{AN} + 0.12SI_{pH} \qquad (3.1)$$

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.

Table 3. 3: Sub-index calculations (Sources: DOE, Malaysia).

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

Based on the WQI value, the water quality can be categorized into 5 classes in regard to its suitability of use (Table 3.4 and Table 3.5). Class I water quality is considered safe for direct drinking, Class II requires treatment for drinking purposes and is safe for swimming, Class III calls for intensive treatment for drinking, Class IV is only suitable for plant and domestic animal uses and Class V cannot be used for the purposes listed in Classes I–IV. Water quality categories are highly affected by varying characteristics in the surrounding areas.

Table 3. 4: DOE Water Quality Index Classification (Sources: DOE, Malaysia).

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

Table 3. 5: DOE Water Quality Classification Based On Water Quality Index (Sources: DOE, Malaysia).

WQI Class	WQI Value/Class	Category	Uses
V	<31	Very bad	Extensive treatment is required
IV	31.0-51.9	Bad	Irrigation
III	51.9-76.5	Moderate	Recreational use with body contact
II	76.5-92.7	Good	Water supply - conventional treatment required
I	>92.7	Excellent	Conservation of natural environment
			Water supply - practically no treatment necessary except disinfection or boiling

3.5 Statistical Analysis

3.5.1 One-way analysis of Variance (ANOVA)

The one-way analysis of variance (ANOVA) is used to determine whether there are any statistically significant differences of water quality between the sampling stations along the Penchala River. Statistical analysis ANOVA was analyzed by using Minitab software for physico-chemical parameters, water quality index and heavy metals. The input data was used is the raw data of each parameters (November 2013 to October 2014) for 4 stations along Penchala River.

Specifically, the one way ANOVA tests the null hypothesis:

$$Ho{:}\mu_1=\mu_2=\mu_3=\ldots\mu_k \tag{3.2}$$

Where μ= group mean and k=number of groups

The example of ANOVA results was shown in Table 3.6. The example of ANOVA results consists two parameters are pH parameter for no significant difference while COD parameter for significant difference.

Table 3. 6: Example of ANOVA results a) pH parameter b) COD parameter

a)

Stations	N	Mean	Grouping	P-value
S1	12	6.1079	A	0.957
S2	12	5.9946	A	
S3	12	6.1004	A	
S4	12	6.0208	A	

(b)

Stations	N	Mean	Grouping	P-value
S1	12	15.05	A	0.007
S2	12	40.81	A	
S3	12	62.73	B	
S4	12	67.89	B	

**If grouping letter are same then no significant difference between stations.*

P-value and statistically significant

P-value is to determine the appropriateness of rejecting the null hypothesis in a hypothesis test. P-values range from 0 to 1. The p-value is the probability of obtaining a test statistic that is at least as extreme as the calculated value if the null hypothesis is true. Before conducting the analyses, the alpha (α) level was determined as 0.05. If the p-value is below the alpha level, then the difference to be statistically significant and reject the test's null hypothesis.

3.6 Model Development

3.6.1 River Modelling

The used of modelling in study of the behaviour of the water quality parameters and also flow is the easy method if compared to the sampling along the river especially in safety aspects. The equation below is to determine the flow rate by assuming a steady flow.

$$Q = \frac{1}{\eta} A R^{2/3} S^{1/2} \tag{3.3}$$

Q = Flow rate

A = Area

R = Hydraulic radius

P = wetted parameter

S = channel gradient

η = Manning’s roughness

However, under real conditions the flow of a river is not steady due to the rainfall and also from the discharging water from the drain. Therefore, the Saint – Venant equation was applied in order to descrives flow in unsteady condition.

The Saint-Venant equation below describes unsteady flow behaviour by taking consideration continuity and momentum equilibrium. Conservative form of the Saint-Venant equation is shown below:

a) Continuity equation

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial x} = 0 \tag{3.4}$$

b) Momentum equation

$$\frac{1}{A}\frac{\partial Q}{\partial t} + \frac{1}{A}\frac{d}{dx}\left(\frac{Q^2}{A}\right) + g\frac{dy}{dx} - g\left(S_o - S_f\right) = 0 \tag{3.5}$$

$\frac{1}{A}\frac{\partial Q}{\partial t}$ = Local acceleration term

$\frac{1}{A}\frac{d}{dx}\left(\frac{Q^2}{A}\right)$ = Convective acceleration term

$g\frac{dy}{dx}$ = Pressure force term

$g\left(S_o - S_f\right)$ = Gravity and friction force term

3.6.2 Initial data preparation

At the early stage of the modelling, the following data were collected in order to build a river model. The primary data required are those as listed in Table 3.7.

Table 3. 7: The necessary information and data

NO.	Info Type	Format	Use	Source
1	River cross sections	Digital or hardcopy	Primary input to hydraulic model	DID
2	Rainfall/ Water level/Discharge	Digital or hardcopy	Hydrologic analysis	DID
3	Locations plan	Digital or hardcopy	Reference/hydrology	DID
4	River alignment plan	Digital	Primary input to hydraulic model	DID
5	Land use map	Digital or hardcopy	Hydrologic analysis	DOA

In order to demonstrate all the steps in the overall process of river modelling, a flow charts as in Figure 3.11 was prepared to serve as a practical guide.

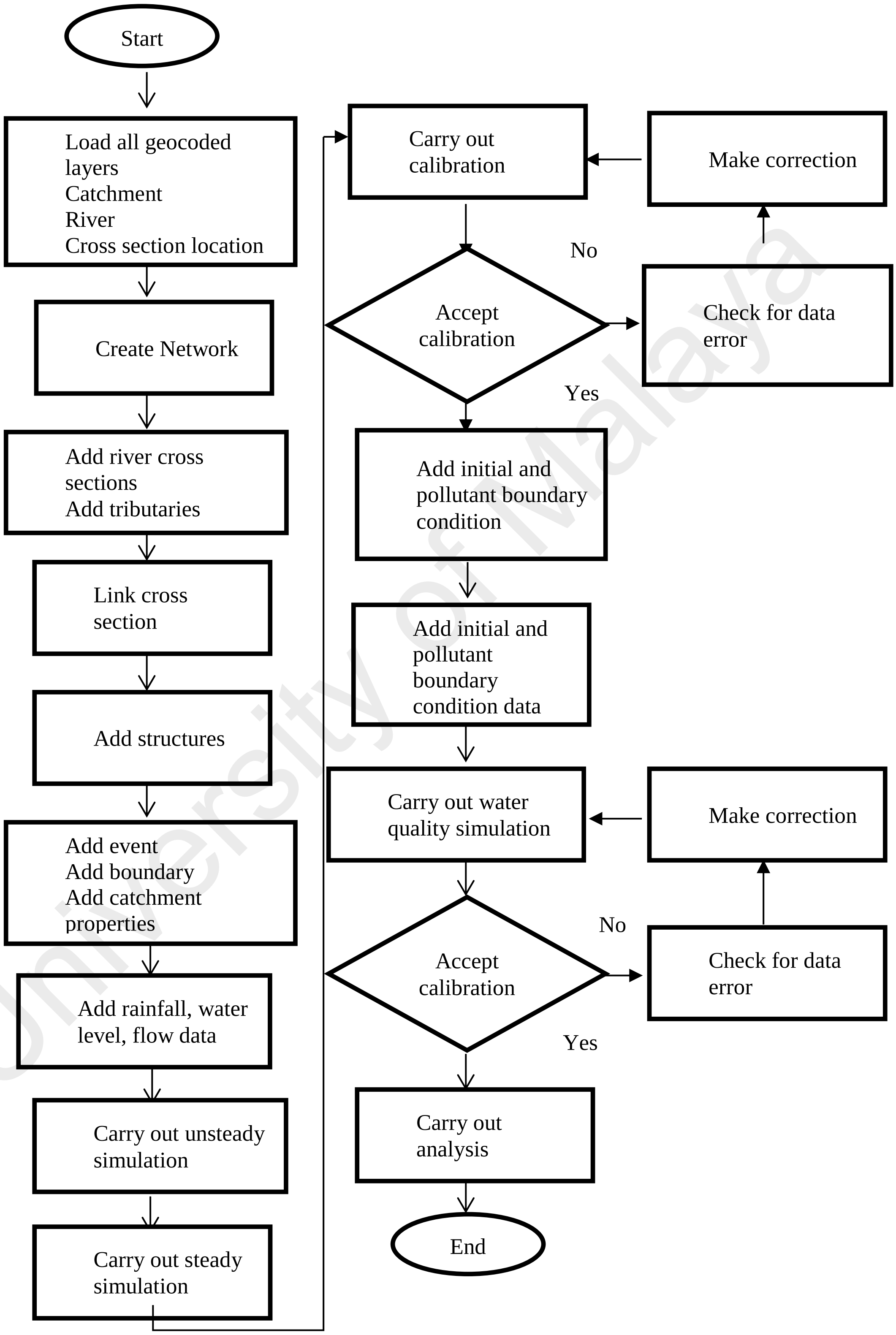


Figure 3. 11: River modelling flow chart

3.6.3 Building a river model

Presented below is the flow chart for model development and analysis.

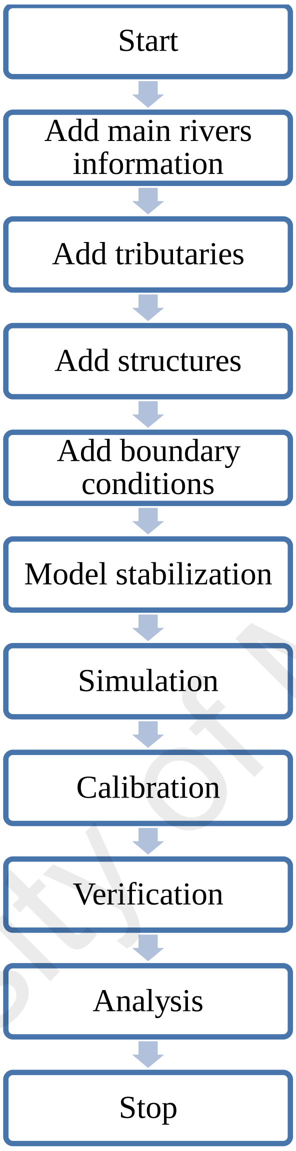


Figure 3. 12: Flow chart for building a river model

Cross sections

Table 3.8 show a details of each cross sections used in river model along the Penchala River. In modelling, the cross sections namely as CSO1 until CS08 started from upstream to the downstream of the river. Every cross sections was inserted the manning coefficient as shown in Table 3.8 accordance to Table B.1

Table 3. 8: Details of Cross sections and Manning coeffiecient values.

Cross Section Names	Cross Section ID/Nodes	Manning Coeffiecient (η)
Taman Tun Dr Ismail (TTDI)	CS01	0.030
Tropicana City Mall	CS02	0.015
SS2/19	CS03	0.015
IWK Section 14	CS04	0.015
Jalan 222	CS05	0.015
Avon Sg. Way	CS06	0.015
Jalan Klang Lama, Anchor factory	CS07	0.015
Kg. Ghandi	CS08	0.030

Hydrology input – Rainfall runoff model

Rainfall runoff model is when rain water fall on the ground, it will infiltrate into the soil and the excess water will travel as surface water. The formula below is to calculate the rainfall runoff model.

- T_c = time of concentration

$$T_c = \frac{(3.28L)^{0.8}(\frac{1000}{CN-9})^{0.7}}{1900(S_w)^{0.5}} \tag{3.6}$$

S_w = Weighted slope

$$S_w = [\frac{\sum_{i=1}^{n} L_i \sqrt{S_i}}{\sum_{i=1}^{n} L_i}]^2 \quad (3.7)$$

L = Length of river (m)

CN = Curve Number

S = Slope

- T_p = time to peak

$$T_p = 0.67T_c \quad (3.8)$$

- Δt = time duration

$$\Delta t = 0.133T_c \quad (3.9)$$

Table 3.9 shows the curve number (CN), area and time to peak used in the modelling for each subcatchment. The curve number is the empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess (Table A.5).

Table 3. 9: CN, Area, and Tp values for each subcatchment

Subcatchment	CN	Area (km^2)	T_p (hours)
1	85	1.82	0.150
2	85	0.50	0.380
3	85	5.70	0.330
4	85	8.09	0.380
5	85	2.22	0.210

3.6.4 Boundary conditions

In any hydrodynamic river simulations, the main input required are the shape of the river as represented by cross section and hydraulic structure. However at the end of a river model the control factor is either flow or water level. This input is called boundary conditions. Boundary conditions are data entered either upstream or downstream to make a model complete. The Table 3.10 shows the lists of boundary conditions in river modelling.

Table 3. 10: Lists of boundary conditions

Boundary conditions	**Types of data inserted**
Flow node	Discharges
Upstream node	Rainfall
Downstream node	Water level
Tributaries (Node1 to Node 5)	Rainfall

Flow-Time Boundary is applied on flow as the upstream inflow hydrographs. The Flow-Time Boundary specifies a set of pairs of data consisting of flows and times. Stage Time Boundary is used on downstream node located at the end of the network. A Stage Time Boundary specifies a set of pairs of data that comprises of water levels above datum and times. Boundary conditions also consists rainfall data as the boundary nodes in the middle of the river basin. The readings of rainfall and water level were shown in Table 3.11. All data of rainfall and water level used as the event based are from hydrological stations installed by this project (Table 3.11).

For water quality modelling, the initial condition values (Table 3.12) were inserted to the boundary conditions and cross sections nodes. Whilst, for boundary pollutant condition values (Table 3.13) was only inserted in boundary conditions nodes. The initial condition values are used as the based values and boundary pollutant condition is the actual values in the modelling. The data of the initial condition values are from average of DO, BOD, and pH of one year sampling result. The data of boundary pollutant condition values are from the average of DO, BOD and pH during wet season only.

Table 3. 11: Rainfall and water level distribution on 12th to 13th October 2014

No.	Date	Time	Rainfall data(mm)					Upstream: Rainfall (mm)	Downstream: Water level (m)
			SS2/24/ Node 1	Taman Jaya/ Node 2	Jalan 222/ Node 3	PJ oldtown/ Node 4	Kg. Ghandi/ Node 5	Jmbtn 19/21	Kg.Ghandi
1	10/12/2014	180000	5	9	3	8	27	1	10.39
2	10/12/2014	190000	212	693	548	573	452	82	11.13
3	10/12/2014	200000	83	130	200	256	733	86	11.89
4	10/12/2014	210000	26	24	13	19	31	61	11.82
5	10/12/2014	220000	28	28	15	21	14	19	11.52
6	10/12/2014	230000	39	26	27	24	28	45	11.22
7	10/12/2014	240000	41	34	36	29	24	47	11.05
8	10/13/2014	10000	39	32	37	31	30	35	11.06
9	10/13/2014	20000	12	11	13	12	11	17	11.03
10	10/13/2014	30000	2	2	1	2	0	3	11.05
11	10/13/2014	40000	0	0	2	0	0	0	11

Table 3. 12: Water quality initial condition data

Initial Condition Data (Based Value)		
WQ Parameters	**Range (mg/l)**	**Average (mg/l)**
DO	2 - 3	2.5
BOD	10 – 20	15
pH	5 -6	5.5

Table 3. 13: Water quality boundary pollutant condition data

Boundary Condition Nodes ID	Boundary Pollutant Condition Data		
	DO (mg/l)	**BOD (mg/l)**	**pH(mg/l)**
Upstream node	3.00	9.00	6.20
Flow node	2.80	9.50	6.15
Node01	2.60	10.00	6.10
Node02	2.40	12.00	6.00
Node03	2.00	14.00	6.40
Node04	1.80	16.00	6.20
Node05	1.60	18.00	5.90
Downstream node	1.40	20.00	5.80

3.6.5 Simulation

Simulation is the last process involving river modelling. This procedure is carried out to view the behaviour of the river network under particular conditions and the effects of the input or given boundary conditions on the modelled river over a period of time. Simulations are grouped into runs, with each run applying to a single network but utilizing one or more event data sets. The time span given for simulations depends on the model.

- Steady flow simulation

  The reason to run a steady flow simulation is to check the model had been built correctly and able to do simulation. It is also to create initial conditions data to be used for an unsteady flow simulation

- Unsteady flow simulation

  To look at flow behaviour during unsteady condition for full hydrograph

- Water quality simulation

  To predict the water quality conditions of the river using water quality parameters are DO, BOD, and pH. Others water quality parameters are not considered in this simulation due to incapability of IWRS function.

3.6.6 Calibration/Correction

Model calibration is the adjustment of the parameters of a mathematical model to represents the river system correctly. This is achieved by comparing the simulated values to the observed occurrence.

The data required for calibration was the Manning's roughness coefficient, *n* for river and floodplains. Manning's *n* roughness coefficient depends on channel material, surface irregularities, variation in shape and size of cross section, vegetation and flow condition, channel obstruction, and degree of meandering. The calibration session involves a trial and error method where different sets of model options and parameters were used until an acceptable match between the observed and modelled is achieved. The following description is a detail of calibration process of hydraulic and water quality model:

a) Hydraulic model

Table 3.14 shows the observation data for hydraulic calibration. The calibration point was choosing at Kg. Ghandi and verification point at Jalan 222 for flow and stage. The calibration and verification was made by comparing the maximum simulation values to the observation values from DID, Malaysia for stage, and flow from rating curve (Figure A.1 and A.2)

Table 3. 14: Observation data for hydraulic calibration

Time	Kg.Ghandi		Jalan 222	
	Flow(m^3/s)	Stage (m)	Flow(m^3/s)	Stage (m)
18:00:00	9.53	10.39	9.14	16.91
18:15:00	51.32	10.39	25.83	16.92
18:30:00	28.96	10.39	10.48	17.39
18:45:00	11.50	10.76	11.84	18.51
19:00:00	10.24	11.13	12.55	19.63
19:15:00	62.19	11.5	11.95	19.32
19:30:00	174.55	11.77	15.65	18.94
19:45:00	285.13	11.82	18.89	18.52
20:00:00	382.48	11.89	21.12	18.06
20:15:00	389.02	11.89	30.18	17.84
20:30:00	340.47	11.91	26.93	17.87
20:45:00	285.59	11.87	22.95	17.69
21:00:00	233.20	11.82	19.89	17.52
21:15:00	183.95	11.7	17.55	17.31
21:30:00	140.37	11.69	16.99	17.34
21:45:00	98.23	11.56	15.75	17.3
22:00:00	54.78	11.52	14.98	17.3
22:15:00	31.09	11.38	13.50	17.29
22:30:00	29.53	11.33	13.26	17.35
22:45:00	29.47	11.29	12.88	17.37
23:00:00	29.40	11.22	12.37	17.23
23:15:00	29.16	11.19	11.94	17.39
23:30:00	29.61	11.12	11.74	17.4
23:45:00	30.53	11.08	12.02	17.43
24:00:00	32.00	11.05	12.26	17.42
0:15:00	33.27	11.05	12.74	17.62
0:30:00	34.94	11.06	13.12	17.82
0:45:00	36.45	11.06	12.95	17.5
1:00:00	37.80	11.06	13.01	17.48
1:15:00	39.03	11.07	13.07	17.46

Continued

1:30:00	39.49	11.06	12.98	17.41
1:45:00	39.64	11.02	12.82	17.4
2:00:00	39.89	11.03	12.63	17.34
2:15:00	38.59	11.07	12.53	17.24
2:30:00	34.59	11.06	12.27	17.23
2:45:00	30.15	11.05	11.96	17.21
3:00:00	25.70	11.05	11.63	17.16
3:15:00	22.04	11.03	11.36	17.16
3:30:00	19.49	11.02	11.24	17.18
3:45:00	17.12	10.94	11.17	17.14
4:00:00	15.11	11	11.10	17.11

b) Water quality model

The calibration was made by comparing the maximum simulation values to the sampling data (October 2014). The calibration consist 3 parameters are DO, BOD and pH as shown in Table 3.15. The calibration was made start from station 2 to 4 accordance to cross sections starting point.

Table 3. 15: Observation data for water quality calibration

Stations	**DO**	**BOD**	**Ph**
2	2.27	8.22	5.78
3	2.1	12.63	5.72
4	1.65	15.8	5.77

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Introduction

Chapter 4 presents the results and discussion of the research. It contains detailed explanation on the water quality of Penchala River, including physico-chemical parameters, WQI and metal contamination. Water quality data is necessary in order to determine the condition of the water body of a river. It is important to monitor water quality over a period of time in order to detect the changes that happen in the water's ecosystem.

The water quality was assessed by the physico-chemical parameters which are BOD, COD, AN, DO, TSS, Temperature, TDS, Conductivity, Turbidity, Phosphate, pH, Discharge, Water level and velocity. Besides that, the WQI was calculated using the six parameters of BOD, COD, AN, DO, TSS and pH. Heavy metal was tested to measure for any metal contamination in river. All the parameters were analyzed based on average dry season (May 2014 to September 2014) and wet season (November 2013 to March 2014) represents in column chart and average of one year sampling data (November 2013 to October 2014) represents in line chart.

Then, a river model for hydraulic and water quality was set up uses the results from the sampling. The simulation results were compared with observation data to make a calibration.

4.2 Water Quality analysis

4.2.1 Physico – chemical parameters analysis

Laboratory Test

Biochemical oxygen demand (BOD) is a procedure for determining how fast the biological organisms use of oxygen in a water body. In the wet season, the highest BOD was recorded in the middlestream at station 3, whereas the lowest was recorded at station 1 in the upstream. Furthermore, the maximum value in the dry season and average were recorded at station 4, while the minimum were recorded at station 1 (Figure 4.1).

Moreover, the BOD variation between stations was significantly different (ANOVA, $P<0.05$) between the stations along the Penchala River. The BOD concentration continually increases from upstream to downstream especially during the dry season.

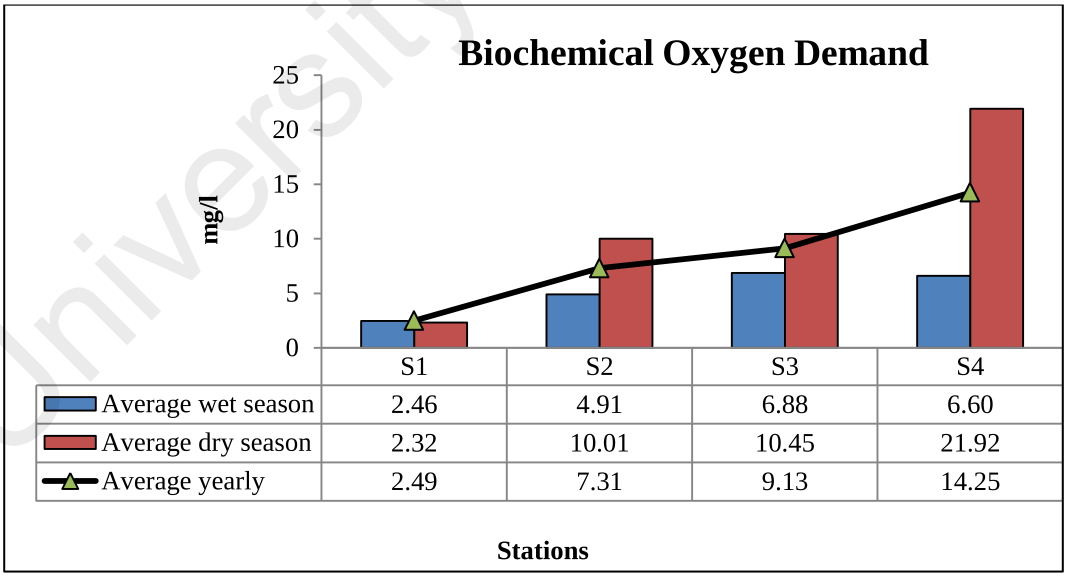


Figure 4. 1: Graph for BOD of average yearly, average of dry season and average of wet season, Penchala River, Stations 1-4

BOD level is much related to DO level. When BOD levels increase, the DO levels decrease. This scenario exists because the bacteria present in river will use up the

DO available to decompose the organic waste. In the figure above, the BOD levels at station 2 to 4 are high since the amount of organic waste, COD concentration (Figure 4.2) at those stations are also high since they are near to residential, commercial and industrial area as shown in the land-use map (Figure 3.3). Similarly, if there is none or less organic waste present in the water, there will not be as many bacteria present to decompose it and thus the BOD will tend to be lower and the DO level will tend to be higher as shown at station 1 (Figure 4.3). Generally, BOD concentration has positively correlated to the COD concentration while negatively correlated to DO concentration.

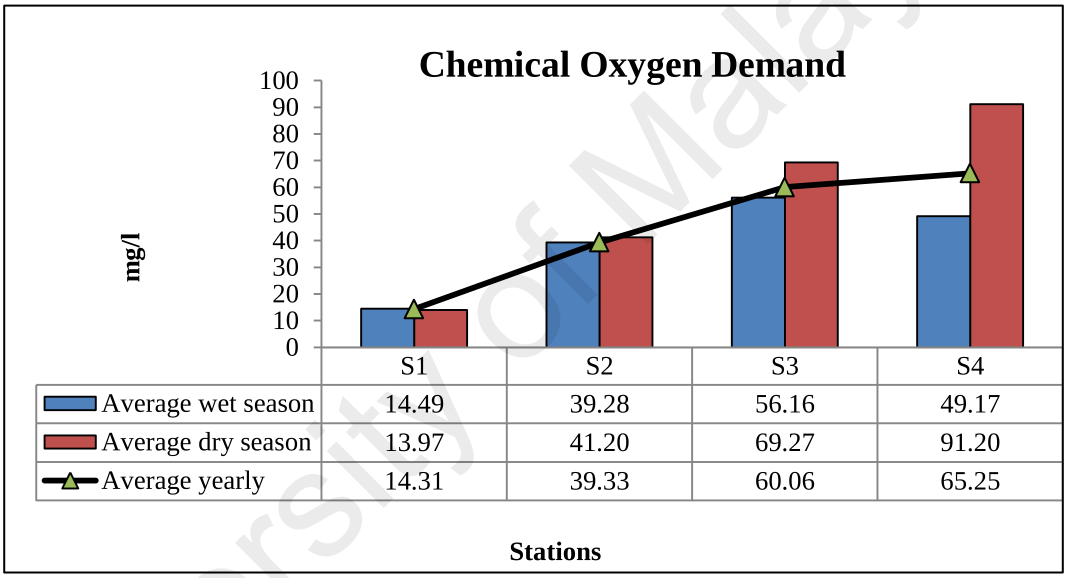


Figure 4. 2: Graph for COD of average yearly, average of dry season and average of wet season, Penchala River, Stations 1-4

Chemical oxygen demand (COD) is to indicate the amount of organic pollutants in water. The COD concentrations of water samples were ranging between minimum at station 1 and maximum at station 4 in the wet season, dry season and average. Moreover, statistically significant differences of COD were found between stations (ANOVA, $P<0.05$). Generally, the lower COD level indicates a low level of pollution, while the high level of COD points out the high level of pollution.

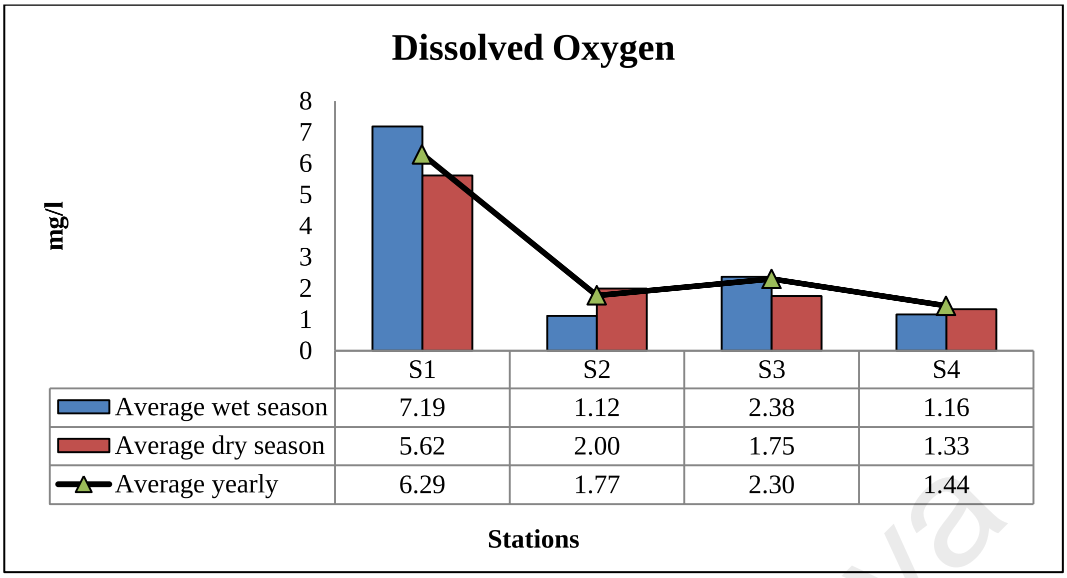


Figure 4. 3: Graph for DO of average yearly, average of dry season and average of wet season, Penchala River, Stations 1-4

The dissolved oxygen (DO) of the water samples analyzed ranged from 1.12 to 7.19 mg/L during wet season, from 1.33 to 5.62mg/L during dry season, and from 1.44 to 6.29 mg/L for average. The lowest DO was recorded at station 2, while the highest value was at station 1 in the wet season. In the dry season and average, the maximum value was at station 1, while the least value was at station 4 (Figure 4.3). Furthermore, statistically significant differences were found between stations (ANOVA, $P<0.05$).

The river water at station 1 has the highest value of DO since its location is surrounded by canopy vegetation compared to other stations which are exposed to sunlight because there is no vegetation surrounding the stream. The canopy vegetation helps to lower the temperature as cold water holds more DO compared to hot water. In terms of pollution, station 1 is almost free from organic waste since it is away from residential and industrial area so less organic waste is channelled to the stream.

However, station 2 to 4 shares a different fate since it is near to residential and industrial area hence the more organic waste. Bacteria that exist in the river use the DO available to breakdown the organic waste to simpler organic substance causing the drop in DO value at the respective station.

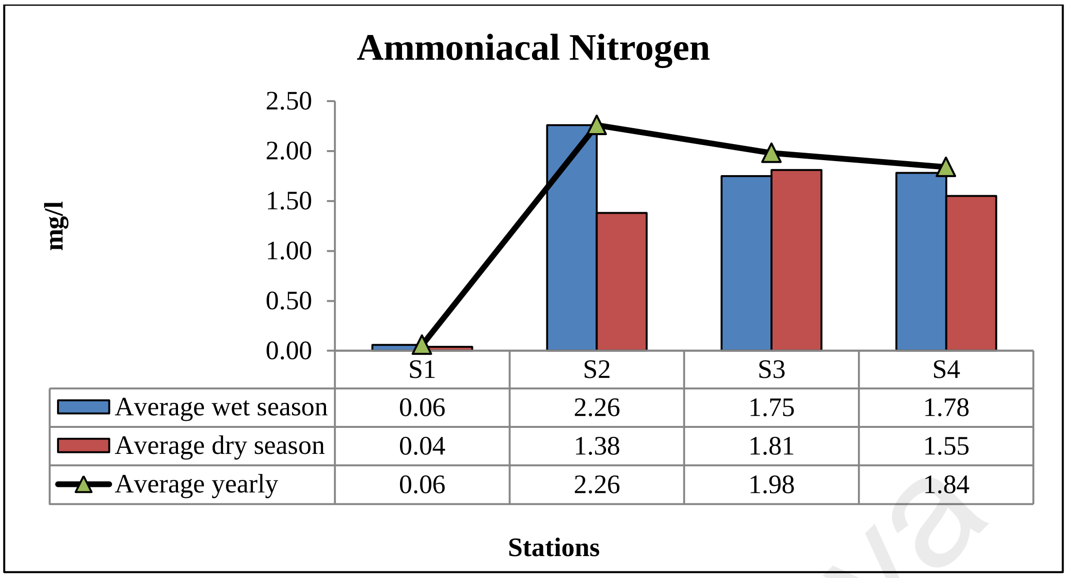


Figure 4. 4: Graph for AN of average yearly, average of dry season and average of wet season, Penchala River, Stations 1-4

Ammoniacal nitrogen (AN) is to indicate nutrient status, organic enrichment and health of the water body, higher AN value can be toxic to fish, but in small concentrations, it could serve as nutrients for growth of algae. The AN concentrations of water samples ranged between minimum at station 1 and maximum at station 2 during wet season and average, whereas in dry season, they ranged between minimum at station 1 and maximum at station 3 (Figure 4.4). In addition, there were significantly differences between stations (ANOVA, $P< 0.05$). The higher AN concentration recorded at station 2 is due to the faulty septic tank in public housing at Kiara Hills and also IWK sewage plant which discharge directly into Penchala River.

The higher AN values are due to the sewage of organic compounds containing nitrogen by municipal effluent discharges, decomposition of organic waste deposition, and other industrial applications nearby. At middle and downstream of Penchala River, the growth rate of algae bloom is higher and it can be seen at many parts of river. It is due to fact that the high concentration of AN promote the growth of algae and uses the DO available in the river. The water body has slightly turned into green in colour and become a turbid.

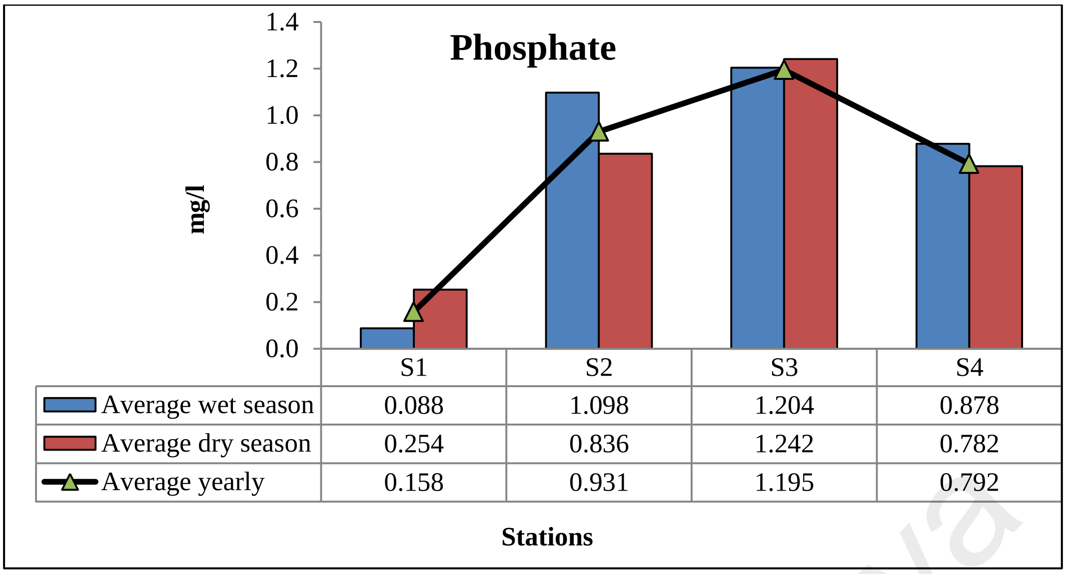


Figure 4. 5: Graph for PO_4 of average yearly, average of dry season and average of wet season, Penchala River, Stations 1-4

Phosphate (PO_4) is one of the parameter tested for the nutrients status in the river waters same as the AN. The highest value of PO_4 in the wet season, dry season and average were recorded in station 3, while the least one were recorded at station 1 (Figure 4.5). Besides, there was significance difference in PO_4 between stations (ANOVA, $P<0.05$).

High values of PO_4 were recorded at station 3 due to the fertilizer grass of gold field in KGPA and the sewage outlet from Kiara Hill public housing connecting directly into Penchala River. Another factor is due to the industrial area where a factory is situated nearby the sampling station on middle stream compared to downstream where there is only a residential area

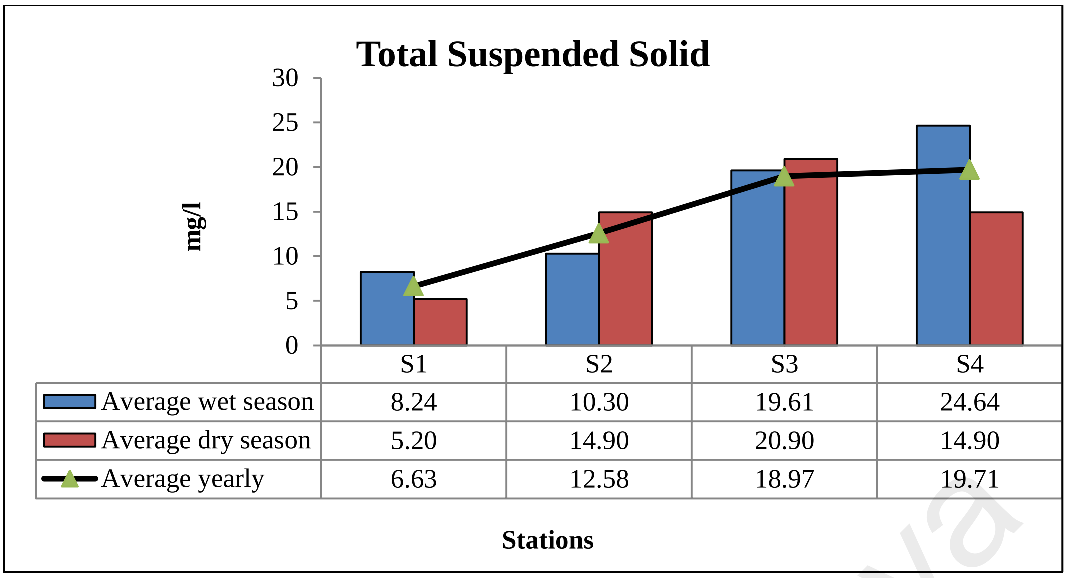
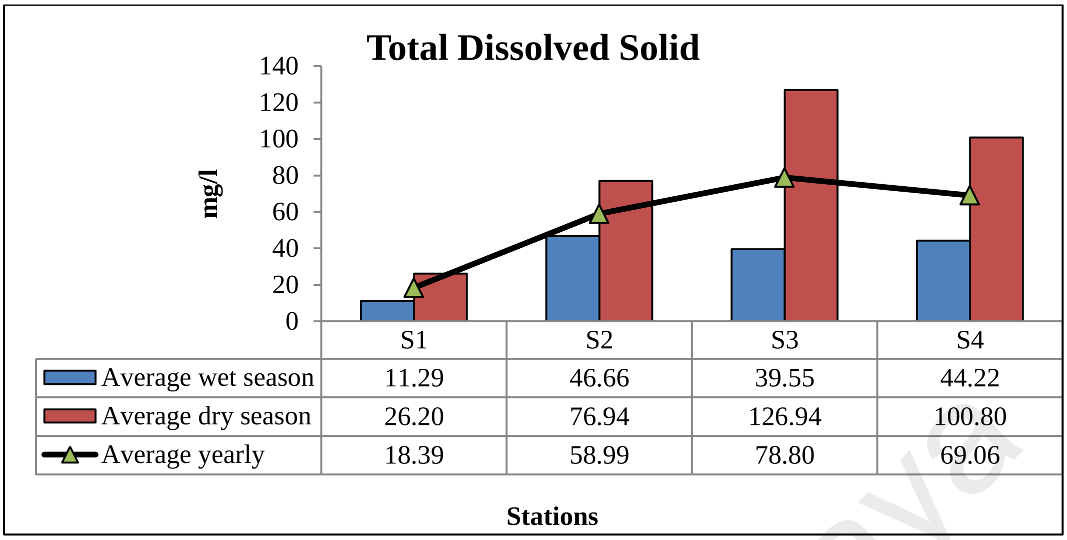


Figure 4. 6: Graph for TSS of average yearly, average of dry season and average of wet season, Penchala River, Stations 1-4

The total suspended solid (TSS) is to measure the amount of suspended solid in the river water. The TSS values of water samples ranged between minimum at station 1 and maximum at station 4 in the wet season and average, whereas in dry season, they ranged between minimum at station 1 and maximum at station 3 (Figure 4.6) . In addition, ANOVA result showed there is significant difference (P<0.05) in TSS between stations.

The highest value of TSS during wet season recorded at station 4 due to the rainy days which stimulated serious erosion on the two sides of the river banks along the river. In addition, the high TSS values are due to the particles carried by the flowing water from upstream to downstream which then cause high concentration of suspended solids. Thus, more particles are suspended at the river bed downstream. At station 2 and 4, soil erosion occurs because of the construction of the river banks. The eroded soil particles from those activities are carried by rainwater to surface water and consequently increase the suspended solids in the river.

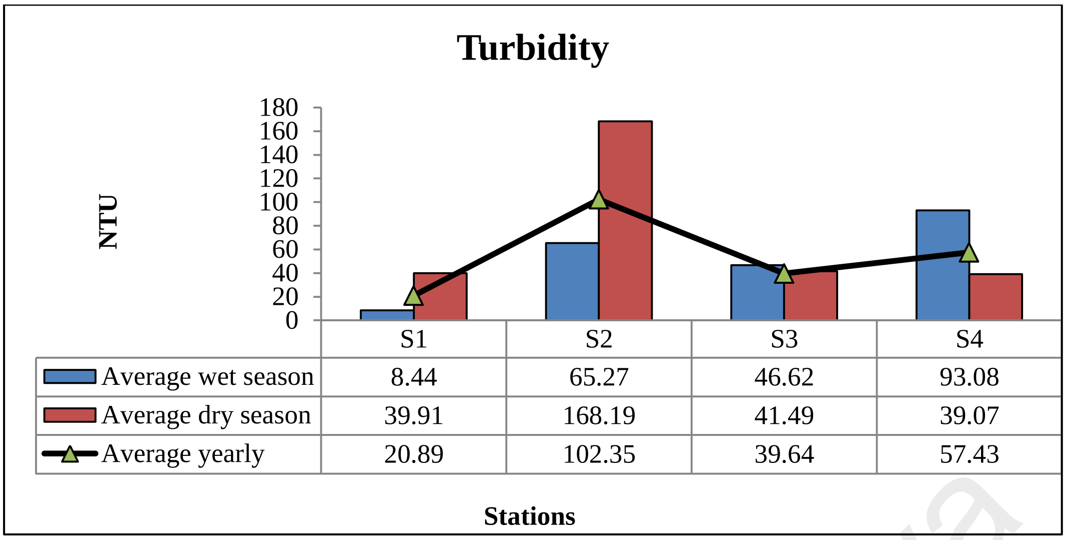
In-situ Test



	S1	S2	S3	S4
Average wet season	11.29	46.66	39.55	44.22
Average dry season	26.20	76.94	126.94	100.80
Average yearly	18.39	58.99	78.80	69.06

Figure 4. 7: Graph for TDS of average yearly, average of dry season and average of wet season, Penchala River, Stations 1-4

The total dissolved solids (TDS) is to measure the total amount of mobile charged ions including mineral, salts, or metal dissolved in the river water. The dissolve size is less than 2 microns. The highest TDS value obtained was recorded at station 2, and the lowest value obtained was at station 1 during wet season. And, the highest TDS concentration was recorded at station 3, and the lowest concentration at station 1 during dry season and average (Figure 4.7). Moreover, it was noticed that wet season have lower TDS values compared to the dry season. ANOVA result showed there is significant difference (P<0.05) in TDS between stations.



	S1	S2	S3	S4
Average wet season	8.44	65.27	46.62	93.08
Average dry season	39.91	168.19	41.49	39.07
Average yearly	20.89	102.35	39.64	57.43

Figure 4. 8: Graph for Turbidity of average yearly, average of dry season and average of wet season, Penchala River, Stations 1-4

Turbidity is a measure of the cloudiness of the river water. Cloudiness is caused by the suspended solids and plankton that are suspended in the water column. Turbidity values varied between the lowest value at station 1 and highest value at station 4 during wet season. While, turbidity value ranged from lowest turbidity was recorded station 1 while the highest value at station 2 during dry season and average (Figure 4.8). Moreover, turbidity showed no significantly different between stations (ANOVA, *P* >0.05). High values for NTU at Station 2 in dry season because drying up the river water due to hot weather. River water becomes more turbid.

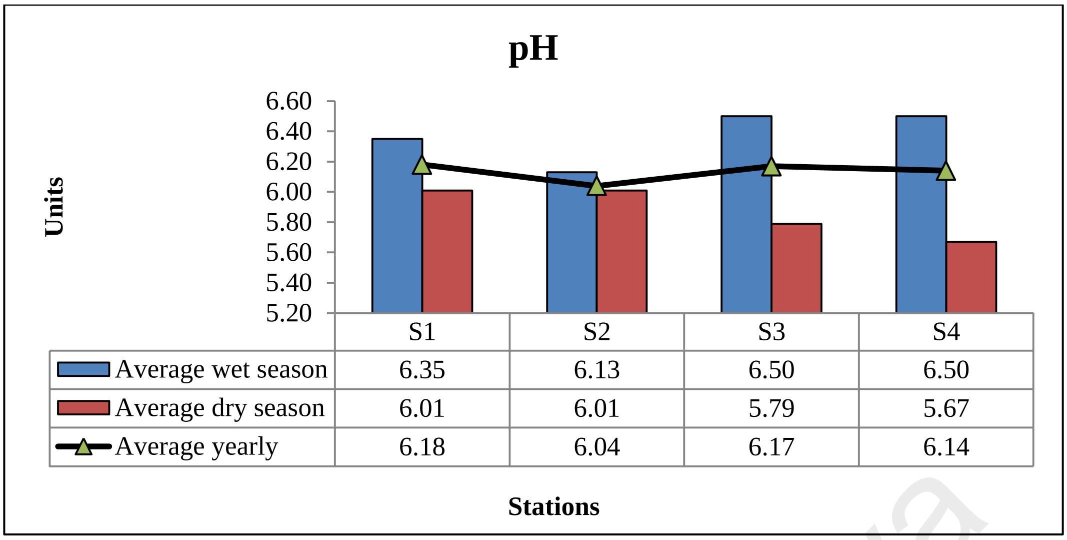
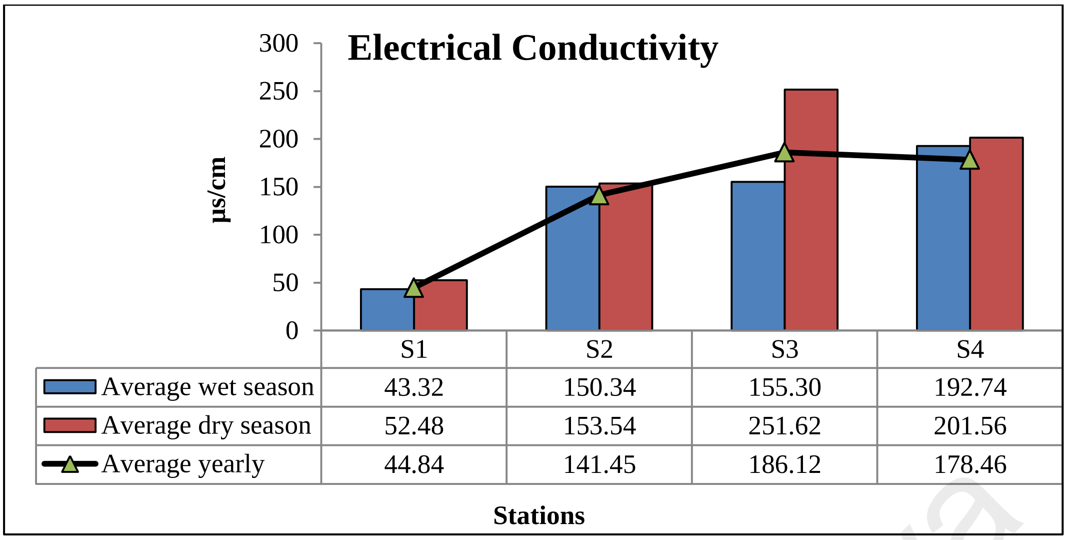


Figure 4. 9: Graph for pH of average yearly, average of dry season and average of wet season, Penchala River, Stations 1-4

The pH values showed different values between the wet season and dry season. The higher are obtained at station 3 and 4, whereas the lower is obtained at station 2 in the wet season. In the dry season, the highest pH was obtained at the station 1 and 2, whereas the lowest value was obtained at station 4. For average, the highest pH was obtained at the upstream at station 1, whereas the lowest value was obtained at the downstream at station 2 (Figure 4.9). Moreover, statistically significant differences were not found among sampling stations (ANOVA, $P>0.05$).

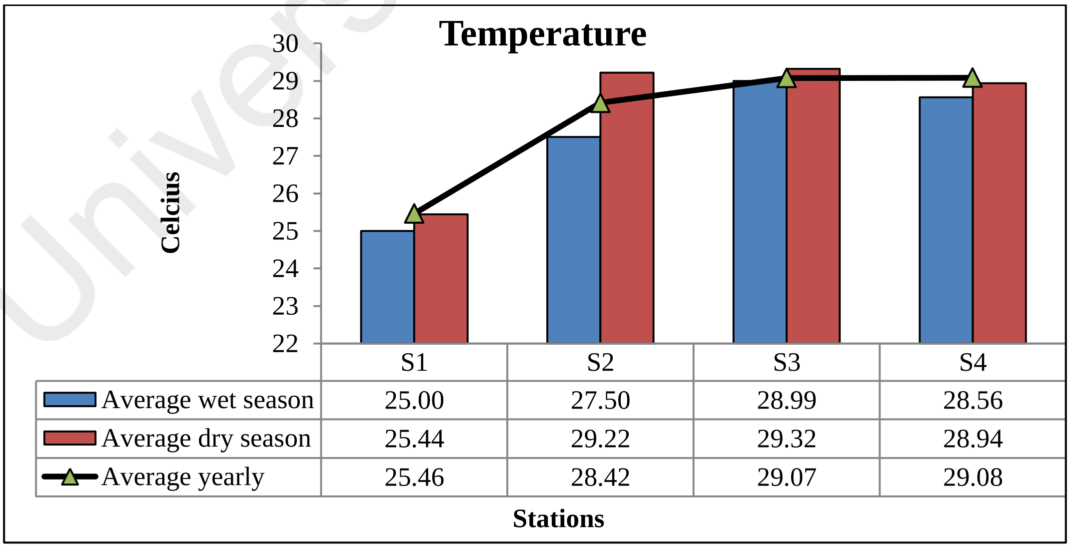
Overall, the range of pH from 6.5 to 9 is mainly appropriate for aquatic life. The pH values depend upon the presence of dissolved substances that come from bedrock, soils and other materials in the watershed. The value of pH also depends on temperature whereby high temperatures will heighten the values of pH, and on the contrary, low temperature will decrease the concentration of pH. The stability of the pH concentration is very important in order to maintain the water quality of the river.



	S1	S2	S3	S4
Average wet season	43.32	150.34	155.30	192.74
Average dry season	52.48	153.54	251.62	201.56
Average yearly	44.84	141.45	186.12	178.46

Figure 4. 10: Graph for EC of average yearly, average of dry season and average of wet season, Penchala River, Stations 1-4

Conductivity is a measure of how well water can pass an electrical current. In the wet season, the lowest value of conductivity was observed at station 1, while the highest was at station 4. While, the maximum value of conductivity was observed at station 3, whereas the minimum was at station 1 during dry season and average (Figure 4.10). The significant differences were found between stations (ANOVA, *P*<0.05).



	S1	S2	S3	S4
Average wet season	25.00	27.50	28.99	28.56
Average dry season	25.44	29.22	29.32	28.94
Average yearly	25.46	28.42	29.07	29.08

Figure 4. 11: Graph for Temperature of average yearly, average of dry season and average of wet season, Penchala River, Stations 1-4

Temperature values ranged from 25.00– 28.99°C in the wet season, 25.44–29.32°C in the dry season and 25.46-29.08°C for average as shown in Figure 4.11. Station 3 in the middlestream of both wet season and dry season recorded the highest value of 28.99°C and 29.32°C, respectively. And, station 4 in the downstream of average recorded the highest value of 29.08°C.

Furthermore, the temperature was increased progressively from upstream to downstream, and statistically significant differences were found between stations (ANOVA, $P<0.05$). Generally, many factors such as the weather condition, sampling time, and location impact on the increase or decrease of temperature by which its role effect on the percentage of dissolved oxygen, biological activities, and other parameters.

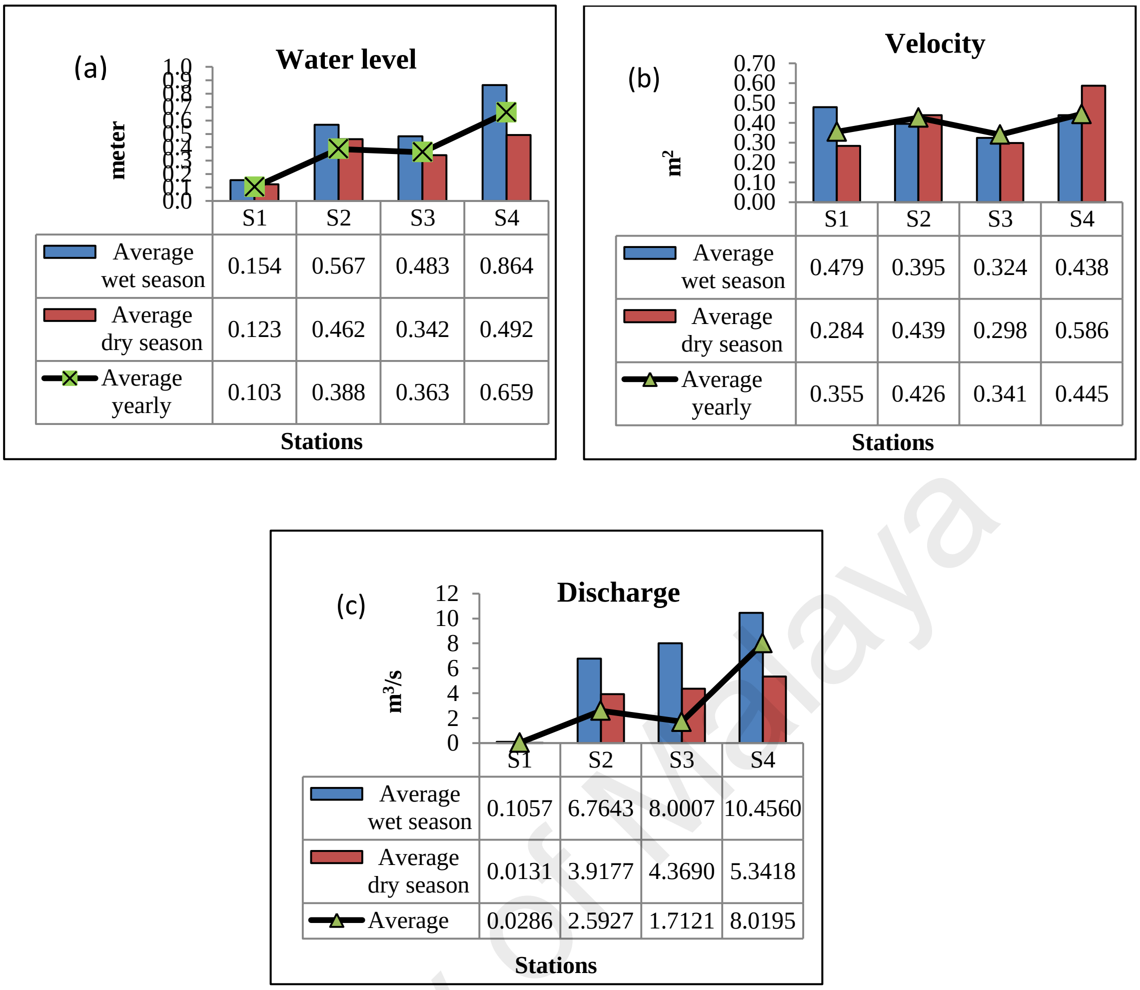


Figure 4. 12: Distribution values of average yearly, average of dry season and average of wet season, Penchala River, Station 1-4.

(a) water level (b) velocity and (c) discharge

Three parameters are analysed for physical data are water level, velocity and discharge. The water level was ranging between 0.15 and 0.86m in the wet season, from 0.12 and 0.49m in the dry season, and from 0.10 and 0.66m for average (Figure 4.12(a)). In the wet season, dry season and average, the highest water level was recorded in the dowsntream at station 4, whereas the lowest was recorded at station 1 in the upstream. Morever, the statistical analysis showed significant changes between stations (ANOVA, $P<0.05$). Station 1 is a natural sampling site with a small area with low water level has been recorded. Station 2 and 3 are concreted sampling sites. And, station 4 is a natural sampling site with a big area. Basically, the water level values depend on the condition and physical characteristics of sampling sites.

The velocity pattern (Figure 4.12 (b)) ranged from 0.32 to 0.48 m^2/s in the wet season, from 0.28 to 0.59m^2/s in the dry season, and from 0.34 to 0.44m^2/s for average. Statistical analysis found no significant changes between stations (ANOVA, $P>0.05$). A slight increased in velocity value is found at station 2 and 4 due to the construction of river bank. Most of the construction material has blocked the water pathway and causing the waterway to become narrow hence increasing the velocity at station 2 and 4.

Discharge is obtained by multiplying the area of the river with velocity. When one or both of them increase, the discharge value will also increase. The discharge of the river ranging between 0.11 and 10.46m3/s in the wet season, from 0.01 and 5.34m3/s in the dry season, and from 0.03 and 8.02m3/s for average (Figure 4.12 (c)). In the wet season, dry season and average, the highest discharge was recorded at the station 4, while the lowest was recorded at the station 1. Statistical analysis showed significant changes between stations (ANOVA, $P<0.05$). The higher discharge value recorded at the station 4 is due to high water level value compared to the other stations.

4.3 Water quality index analysis

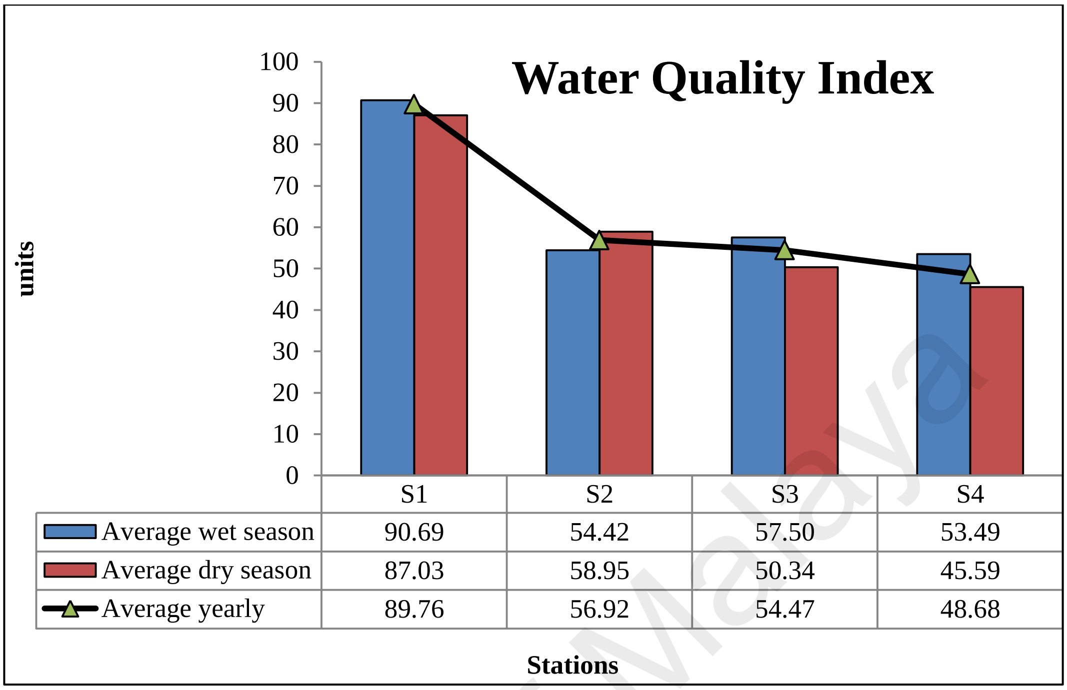


Figure 4. 13: Graph for WQI of average yearly, average of dry season and average of wet season, Penchala River, Stations 1-4

The water quality index (WQI) of the river was ranging between 53.49 and 90.69 in the wet season, from 45.59 and 87.03 in the dry season, and from 48.68 and 89.76 for average (Figure 4.13). In the wet season, dry season and average, the highest WQI was recorded at the station 1 in the upstream, whereas the lowest was recorded at station 4 in the dowstream. Statistical analysis using the one way ANOVA showed significant difference between stations ($P<0.05$).

Additionally, the WQI class in the wet season, dry season and average was classified as Class II at the station 1, and Class III at the station 2 (Table 4.1), according to DOE standard classification (Table 3.4). Furthermore, the WQI class was classified in Class III at the station 3 in the wet season and average, whereas; fall in Class IV during the dry season. Morever, the WQI class at the station 4 was catogorized in Class III in the wet season, and fall in Class IV in the dry season and average.

The seasonal impact on WQI can be clearly seen at station 3 and 4, where the WQI class was drop from Class III during wet season to Class IV during dry season (Table 4.1). It is because the river water drying during the dry season. At station 2, WQI value during wet season is low compared to dry season is due to the construction of river bank, which is the rainfall, will drag the construction material surrounding the river bank into the river. In overall, the heavy water flow during wet season in this study helps to improve the water quality which indicates that the rainfall did not carry any pollutants load into the river.

The upstream section is consider as clean river water as located at the recreational area with the presence of canopy as natural environmental filter in preventing direct air pollution to the upper stream and almost free from the pollution. The middlestream was considered as slightly polluted. The drastic changes of WQI class from upstream to middle stream are influenced by land-use, which are upstream and downstream respectively, whereas, the downstream section had the worst WQI class.

Table 4. 1: Penchala River water quality classes for average yearly, average of wet season and average of dry season.

PENCHALA RIVER WATER QUALITY CLASSES								
Stations	**Data Analysis**	**BOD**	**COD**	**AN**	**DO**	**pH**	**TSS**	**WQI**
1	**Wet season**	II	II	I	I	II	I	II
	Dry season	II	II	I	II	II	I	II
	Average	II	II	I	II	II	I	II
2	**Wet season**	III	III	IV	IV	II	I	III
	Dry season	IV	III	IV	IV	II	I	III
	Average	IV	III	IV	IV	II	I	III
3	**Wet season**	IV	IV	IV	IV	II	I	III
	Dry season	IV	IV	IV	IV	III	I	IV
	Average	IV	IV	IV	IV	II	I	III
4	**Wet season**	IV	III	IV	IV	II	I	III
	Dry season	V	IV	IV	IV	III	I	IV
	Average	V	IV	IV	IV	II	I	IV

The summary of Penchala River water quality classes was shown in Table 4.1 accordance to DOE Standard Classification (Table 3.4). From the table above, it can be seen that the classes of WQI degrades along the Penchala River as the river water flows from upstream to downstream. The TSS and pH parameters had less effect on WQI changes, however BOD, COD, AN, and DO parameters highly influence the WQI classes.

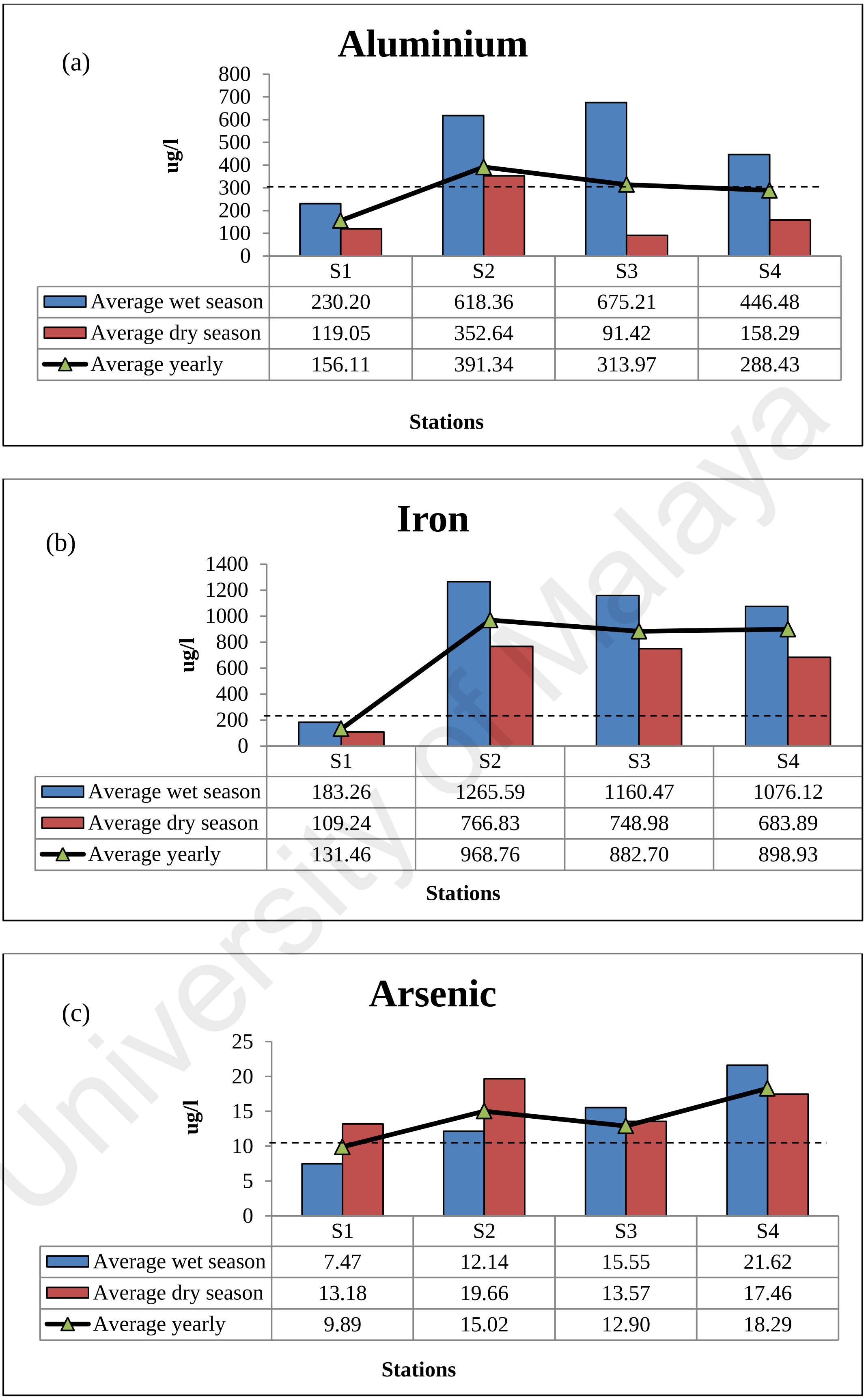
The WQI classes at station 1 and 2 remains constant during wet season, dry season, and average eventhough DO change from Class I during wet season to Class II during dry season and average at station 1, and BOD change from Class III during wet season to Class IV during dry season and average at station 2. However, the WQI classes at station 3 have change from Class III during wet season and average to Class IV during dry season caused pH fall from Class II during wet season and average to Class III dry season. Same goes at station 4, the WQI classes have change from Class III during wet season to Class IV during dry season and average caused by BOD fall from Class IV during wet season to Class V during wet season and average and COD fall from Class III during wet season to Class IV during wet season and average (Table 4.1)

4.4 Heavy metal analysis

In this research, heavy metal was tested for 13 elements namely Zinc, Silver, Cadmium, Cobalt, Chromium, Copper, Nickel, Lead, Aluminium, Iron, Magnesium, Manganese and Arsenic. However, only 6 metals were dominant which are Zinc, Aluminium, Iron, Arsenic, Manganese and Magnesium. Only 3 elements exceeded the limits set by the Malaysian Drinking water quality standard namely Aluminium, Iron and Arsenic. Other elements' values were near to zero. The silver metal was not considered in this study due to the unstable concentration level during sampling duration.

Average of dry season and average of wet season represent in column chart and average yearly represent in line chart for each parameters. According to the results, the concentrations of all metals varied widely from upstream to downstream of the Penchala River.

The unit used for heavy metal elements is in ug/l which equals to 0.001 mg/l.



	S1	S2	S3	S4
Average wet season	230.20	618.36	675.21	446.48
Average dry season	119.05	352.64	91.42	158.29
Average yearly	156.11	391.34	313.97	288.43

	S1	S2	S3	S4
Average wet season	183.26	1265.59	1160.47	1076.12
Average dry season	109.24	766.83	748.98	683.89
Average yearly	131.46	968.76	882.70	898.93

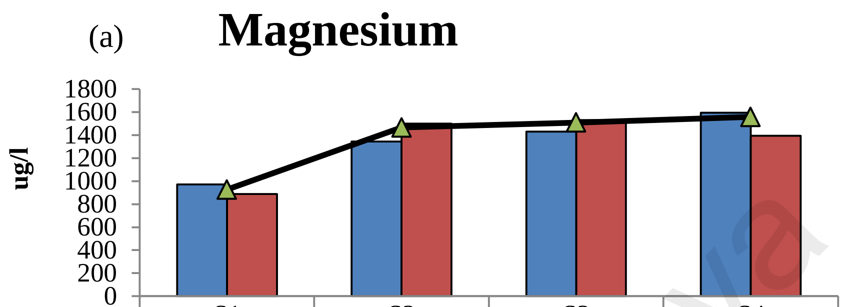
	S1	S2	S3	S4
Average wet season	7.47	12.14	15.55	21.62
Average dry season	13.18	19.66	13.57	17.46
Average yearly	9.89	15.02	12.90	18.29

Figure 4. 14: Graph of (a) Aluminium, (b) Iron and (c) Arsenic at the Penchala River

The Aluminium (Al) concentrations of water samples were fluctuating between minimum at station 1 and maximum at station 2 in the wet season and average, whereas in dry season, they were fluctuating between minimum at station 3 and maximum at station 2 (Figure 4.14(a)). Statistical analysis showed no significant difference of Al level between stations (ANOVA, *P>0.05*). Based on the Malaysian Drinking water quality standard, the Al values exceeded the limits (Al>200ug/l) in wet season (station 2 to 4), in dry season (station 2) and average (station 2 and 3). High Al values at middle and downstream especially station 2 is probably due to low values of pH (Figure 4.9), by leaching from minerals and also by the waste water, as the middle and downstream are surrounded by residential, commercial and factories area (Figure 3.3).

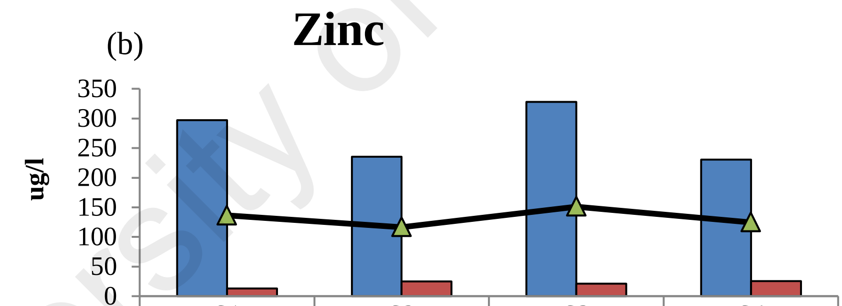
The highest Iron (Fe) was recorded at station 2 and the lowest was recorded at station 1 in the wet season, dry season, and average (Figure 4.14(b)). Statistical analysis showed significant difference found between the stations (ANOVA, P<0.05). Based on the Malaysian Drinking water quality standard, the Fe values exceeded the limits (Fe>300ug/l) in the wet season, dry season, and average at station 2 to 4. High Fe values at middle and downstream of Penchala River were due to release from natural deposits, industrial wastes, refining of iron ores, and corrosion of iron containing metals into the river water. The Fe metal is an important nutrient for algae and other organisms and it exists naturally especially in rocks.

The Arsenic (As) of the river was fluctuating between minimum at station 1 and maximum at station 4 in the wet season and average, whereas in dry season, they were fluctuating between minimum at station 1 and maximum at station 2 (Figure 4.14(c)). The statistical analysis showed no significant difference of As level between stations (ANOVA, P>0.05). Based on the Malaysian Drinking water quality standard, the As values exceeded the limits (As>10ug/l) in wet season and average (station 2 to 4), dry season (station 1 to 4). Significant increases in arsenic concentrations of river waters may also occur as a result of pollution from industrial or sewage effluents (Conrad, Andreae, & Schimel, 1989) as IWK sewage plant is located nearby station 2. It is also due to the bedrock lithology or contribution from base flow.



	S1	S2	S3	S4
Average wet season	971.40	1343.15	1429.98	1593.90
Average dry season	889.09	1499.25	1531.65	1395.47
Average yearly	926.63	1466.29	1509.35	1557.75

Stations



	S1	S2	S3	S4
Average wet season	297.31	235.26	327.93	230.59
Average dry season	13.04	24.91	21.35	25.57
Average yearly	136.39	116.47	151.30	124.82

Stations

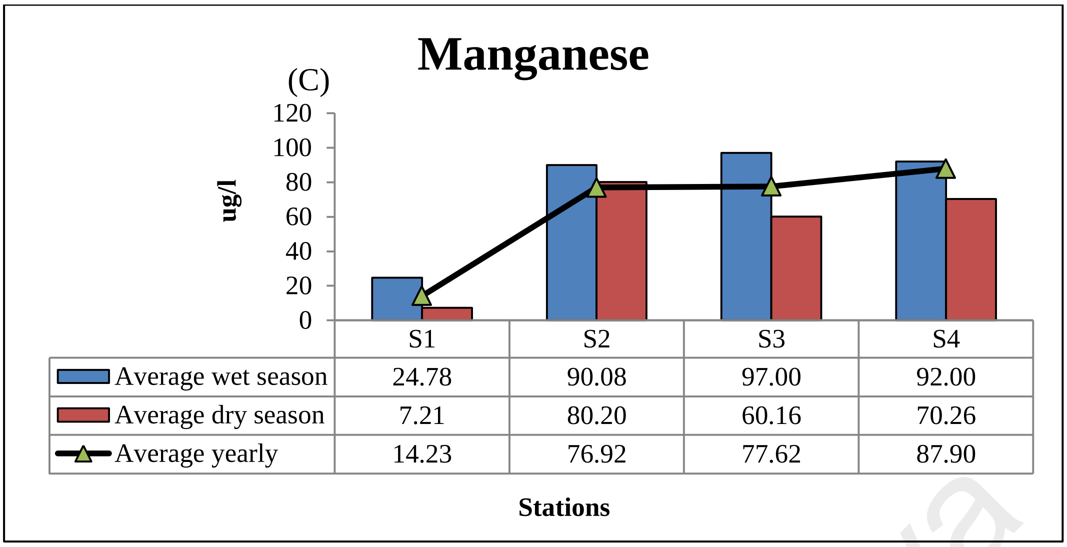


Figure 4. 15: Graph of (a) Magnesium (b) Zinc (c) Manganese at the Penchala River

The highest Magnesium (Mg) was recorded at station 4 in wet season and average, while station 3 in dry season, and the lowest was recorded at station 1 in wet season, dry season, and average (Figure 4.15(a)). The statistical analysis showed significant differences of Mg level between stations (ANOVA, $P<0.05$). Based on the Malaysian Drinking water quality standard, the Mg concentrations values was under the limits (Mg<150000ug/l). Mg is present in river water because it is washed from rocks and subsequently ends up in water. Mg has many different purposes and can get into the water in different ways.

The Zinc (Zn) concentrations of water samples were fluctuating between minimum at station 4 and maximum at station 3 in the wet season, whereas in dry season, they were fluctuating between minimum at station 1 and maximum at station 4. In addition, the Zn concentrations were ranging between minimum at station 2 and maximum at station 3 for average (Figure 4.15(b)). Statistical analysis found no significant changes between stations (ANOVA $P>0.05$). Based on the Malaysian Drinking water quality standard, the Zn mean values were under the limit (Zn<3000ug/l). The sources of Zn in river water are from industrial wastewater especially from galvanic industries and battery productions. And, leaks from Zn pipes and rain pipes would become one of the causes Zn metal is present in Penchala River.

The Mangenese (Mn) of the river ranging between minimum at station 1 in the wet season, dry season and average, while the maximum at station 3 during wet season, station 2 during dry seasin and at station 4 for average (Figure 4.15(c)). The statistical analysis showed no significant difference of Mn level between stations (ANOVA, $P<0.05$). Based on the Malaysian Drinking water quality standard, the Mn mean values were under the limit (Mn<100ug/l). The main sources of contaminated raw water by Mn were due to the sewage discharged, and latex effluent into the river (Hasan, Abdullah, Kamarudin, & Kofli, 2011).

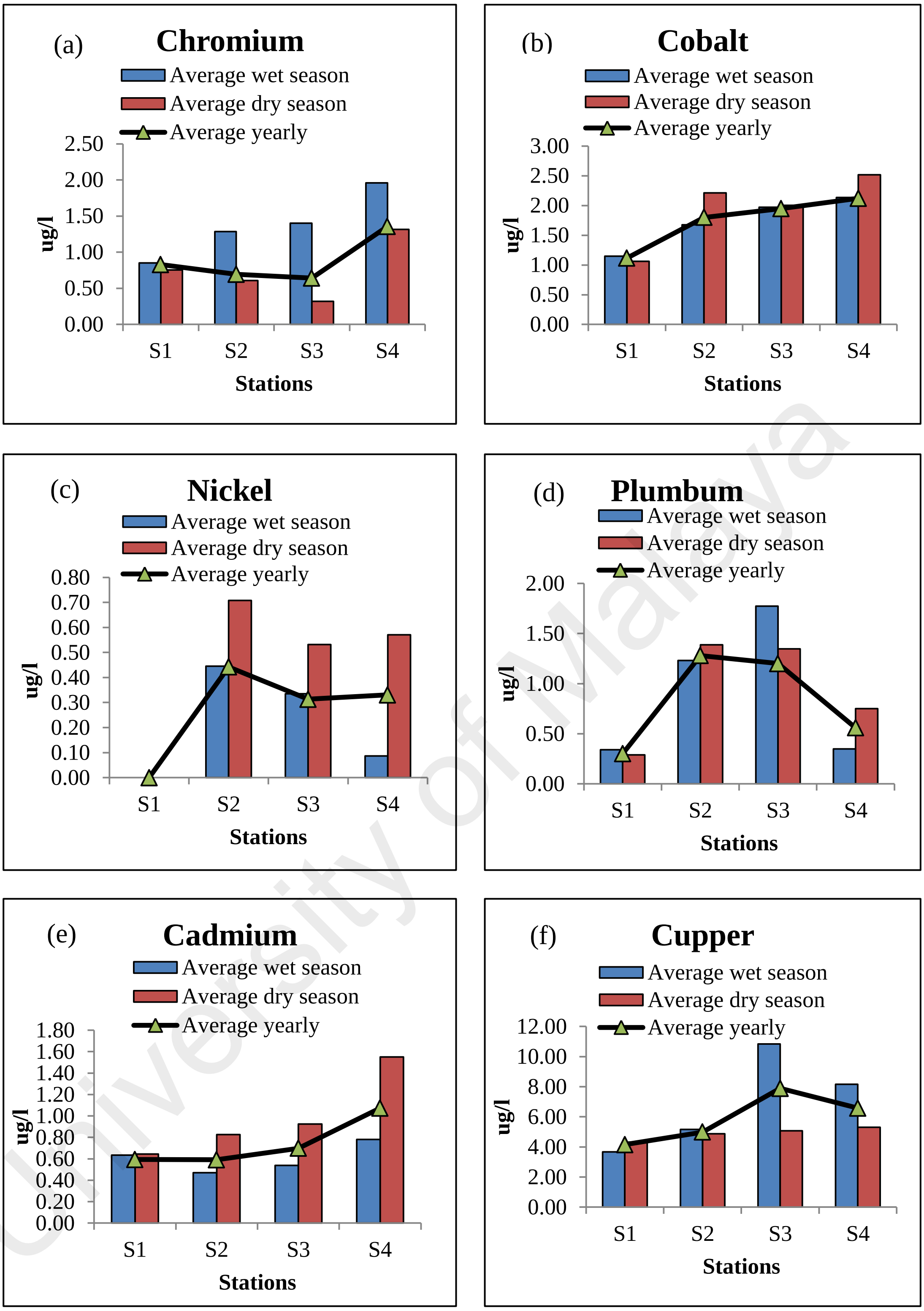


Figure 4. 16: Graph of (a) Chromium (b) Cobalt (c) Nickel (d) Plumbum (e) Cadmium and (f) Cupper at the Penchala River

.

The Chromium (Cr) concentrations was under 2.0 ug/L (Figure 4.16 (a)), the Cobalt (Co) concentrations was under 2.5 ug/L (Figure 4.16 (b)), the Nickel (Ni) concentrations was under 0.60 ug/L (Figure 4.16 (c)), the Plumbum (Pb) concentrations was under 2.0 ug/L (Figure 4.16 (d)), the Cadmium (Cd) concentrations was under 1.40 ug/L (Figure 4.16 (e)), and the Cupper (Cu) concentrations was under 10 ug/L (Figure 4.16 (f)) in the wet season, dry season and average analysis. Statistical analysis found have no significant changes of Cr, Cu, Cd, Co, Ni and Pb level between stations (ANOVA, P>0.05) along the Penchala River. Based on the Malaysian Drinking water quality standard, the Cr, Cu, Cd, Ni and Pb were under the limit (Cr<50ug/l), (Cu<1000ug/l), (Cd<3ug/l), (Ni<20ug/l), and (Pb<10ug/l). No limit for Co level is reported in Malaysian Drinking water quality standard. The Cr, Cu, Cd, Ni and Pb elements showed less effect on metal contamination in Penchala River water. Table 4.2 shows the summary of heavy metals comparison between averages of one year and seasonal variations data analysis for Penchala River.

Table 4. 2: Heavy metals comparison between average yearly and seasonal variations data analysis

No.	Heavy Metals	Data Range (ug/l)	Malaysian Drinking Water Quality Standard Limit						Exceed the limit
			One year data (ug/l)	Stations	Wet season (ug/l)	Stations	Dry season (ug/l)	Stations	
1	Zinc	100-200	<3000		<3000		<3000		
2	Aluminium	0-1500	>300	St2, and 3	>300	St2, 3 and 4	>300	St2	√
3	Iron	0-500	>200	St2, 3 and 4	>200	St2, 3 and 4	>200	St2, 3 and 4	√
4	Arsenic	10-20	>10	St2, 3 and 4	>10	St2, 3 and 4	>10	1 river	√
5	Manganese	<100	<100		<100		<100		
6	Magnesium	800-1600	<15000		<15000		<15000		
7	Cadmium	<2	<3						
8	Cobalt	<3	-						
9	Plumbun	<2	<10						
10	Nickel	<1	<20						
11	Cupper	<10	<1000						
12	Chromium	<2	<50						

Table 4. 3: Summary of ANOVA results

No.	Parameters	P-value	Significant difference	No significant difference
1	Biological Oxygen Demand	0.001	√	
2	Chemical Oxygen Demand	0.007	√	
3	Dissolved Oxygen	0.001	√	
4	Ammoniacal Nitrogen	0.002	√	
5	pH	0.957		√
6	Total Suspended Solid	0.019	√	
7	Temperature	0.001	√	
8	Total Dissiolved Solid	0.001	√	
9	Electrical conductivity	0.001	√	
10	Phosphate	0.001	√	
11	Turbidity	0.063		√
12	Water level	0.001	√	
13	Velocity	0.900		√
14	Discharge	0.001	√	
15	Zinc	0.973		√
16	Aluminium	0.533		√
17	Iron	0.001	√	
18	Arsenic	0.324		√
19	Manganese	0.001	√	
20	Magnesium	0.001	√	
21	Cadmium	0.489		√
22	Cobalt	0.268		√
23	Plumbun	0.890		√
24	Nickel	0.915		√
25	Cupper	0.568		√
26	Chromium	0.524		√

Table 4.3 shows summary of ANOVA results of each parameter included physico-chemical and heavy metals. The ANOVA was analyzed by using Minitab software to determine whether there are any statistical siginificant differences of water quality between the sampling stations along the Penchala River which are located at upstream towards downstream. The statistical significant difference was identified based on p-value as shown in Table 4.3. If the p-value of each parameter is less than alpha level (0.05), there is significant difference between the sampling stations. If the p-value of each parameter is greater than alpha level (0.05), there is no significant difference between the sampling stations.

Based on the ANOVA results in Table 4.3, physico-chemical parameters have significant difference between the stations except for the pH, velocity and turbidity. Meanwhile, for the heavy metals concentration between sampling stations along the Penchala River, only three metals (Fe, Mg and Mn) have significant difference and other metals have no significant difference.

Statistically, water quality parameters with significant difference between the sampling stations along the Penchala River brought to water quality definition of Penchala River varies from upstream to downstream, whereas for nonsignificant difference of water quality parameters between the sampling stations shows same quality from upstream to downstream.

4.5 Model Development

4.5.1 Introduction

A one-dimensional hydrodynamic model called InfoWorks RS which deployed the full St. Venant equation was used to study the behaviour of the pollution process in this river system. The modelling process involves two phases, namely the flow model (hydraulic) and the water quality model. The hydraulic model is capable of analysing steady and unsteady river. The hydraulic data inputs are river cross sections, details of hydraulic structure along the river, rainfall from all tributaries, discharge and water level data. The model later proceeds with water quality model, the data inputs are initial conditions and boundary pollutants condition. And, the output data of water quality model are DO, BOD, and pH.

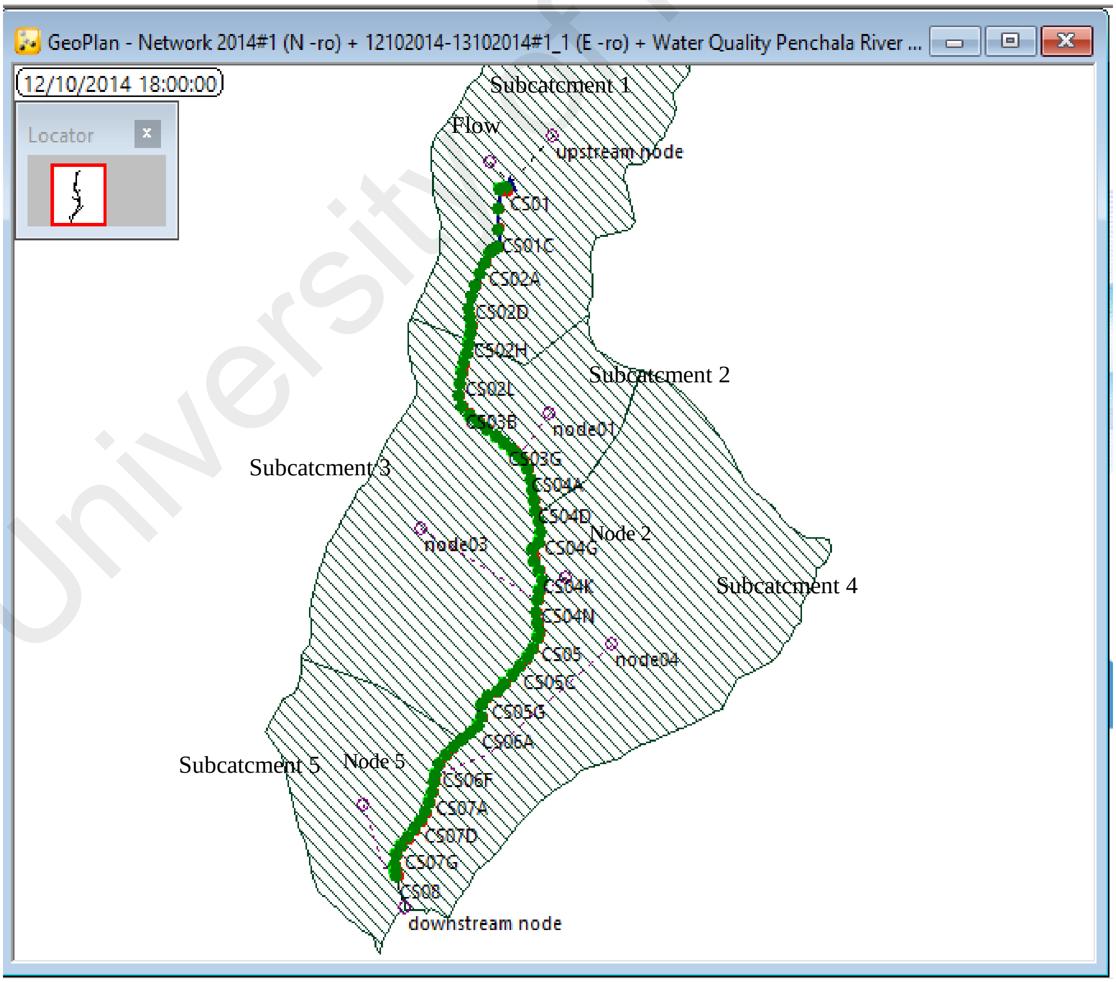


Figure 4. 17: The layout of the Penchala River

Figure 4.17 is the layout of the Penchala River using InfoWorks River Simulation version 14.0 (IWRS 14.0). The layout is significantly to know the cross section starting point and end point. Penchala River layouts have eight cross sections named as CS01 to CS08 (Table 3.7). The types of data inserted into cross sections are distance (x-axis), elevation and initial condition. The distance between each cross section is estimated 1km interval then it was interpolated into 0.25km interval. For interpolated cross sections named as CS01A, CS01B until it met CS02, then it start again with CS02A. This will repeated until CS08. The upstream and downstream of Penchala River named as upstream node and downstream node. The tributaries are represented as Node01, Node02, Node03, Node04 and Node05 throughout Penchala River. Table 4.4 shows the detail of the boundary nodes used in the modelling.

Table 4. 4: Details of the boundary nodes

Stations Name	**Boundary condition Nodes ID**	**Types of Data**	**Types of Boundary condition Nodes**
Jambatan 19/21 (Rainfall)	Upstream Node	Rainfall, Boundary Pollutant and Initial Condition	Start Node
Jambatan 19/21 (Streamflow)	Flow	Discharge, Boundary Pollutant and Initial Condition	Start Node
Jalan SS2/24 (Sec 13)	Node01	Rainfall, Boundary Pollutant and Initial Condition	Tributaries
Taman Jaya	Node02	Rainfall, Boundary Pollutant and Initial Condition	Tributaries
Jalan 222 (Taman Aman)	Node03	Rainfall, Boundary Pollutant and Initial Condition	Tributaries
Pj Old Town (Sec 51)	Node04	Rainfall, Boundary Pollutant and Initial Condition	Tributaries
Kg.Ghandi (Rainfall)	Node05	Rainfall, Boundary Pollutant and Initial Condition	Tributaries
Kg.Ghandi (Water level)	Downstream Node	Water level, Boundary Pollutant and Initial Condition	End Node

In order to record rainfall and water level data along Penchala River, this project was installed 9 hydrological stations. However, there is no direct measurement of stream flow data. Therefore, the initial condition was used in this modelling as the flow which is located at the upstream. The initial condition for the flow node was set as $10m^3/s$ following the try and error method. The schematic diagram of the Penchala River is illustrated in Figure 4.18.

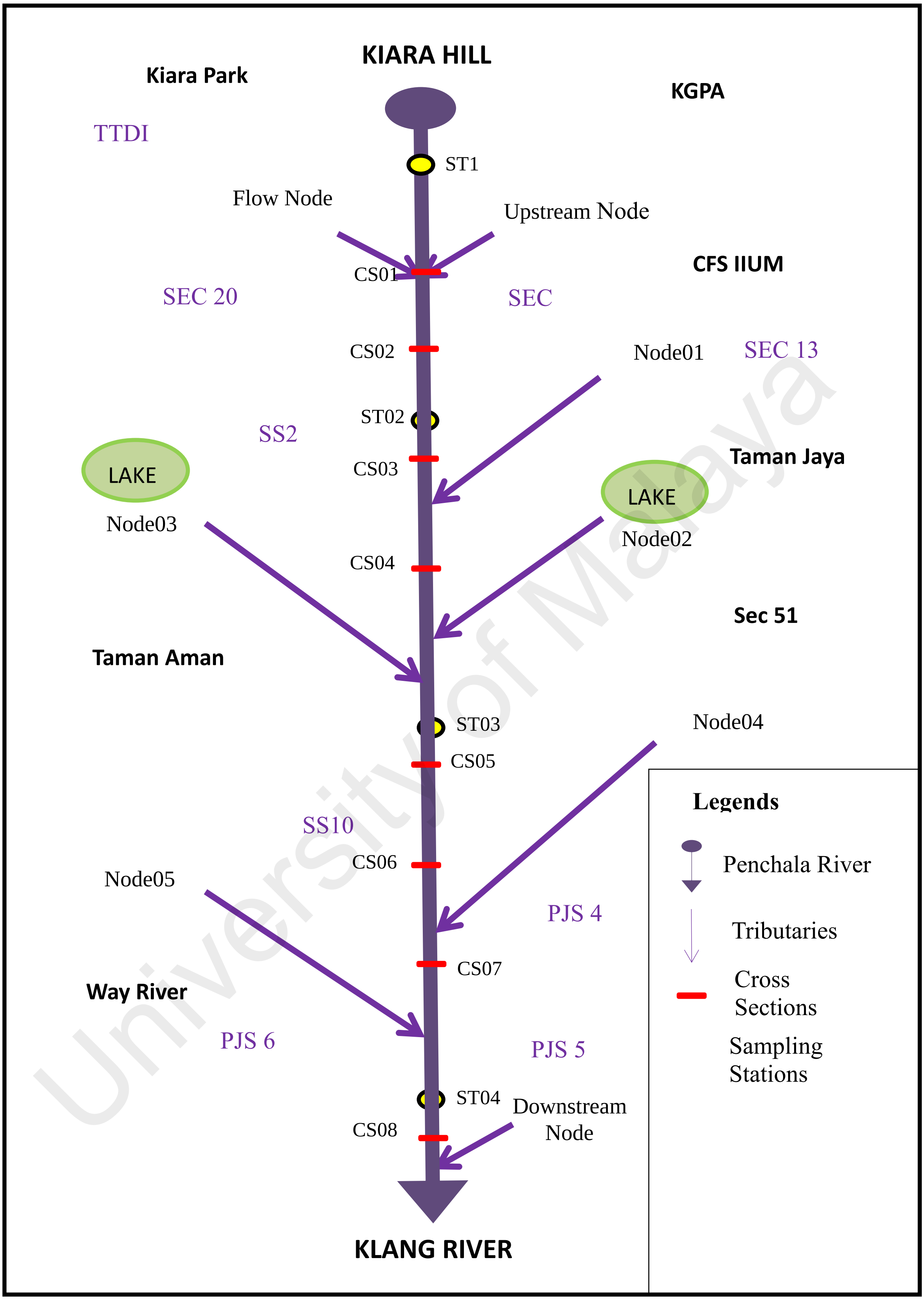


Figure 4. 18: The schematic map of Penchala River

4.5.2 Calibration and Verification

Hydraulic calibration and verification

Calibration and verification was carried out based on observed event on 12th to 13th October 2014 from 18:00:00 to 04:00:00. Hydraulic model result consist the stream flow and stage at Kg Ghandi for calibration point and Jalan 222 for verification point. A comparison of the observed and simulated hydraulic model is represented in following figures.

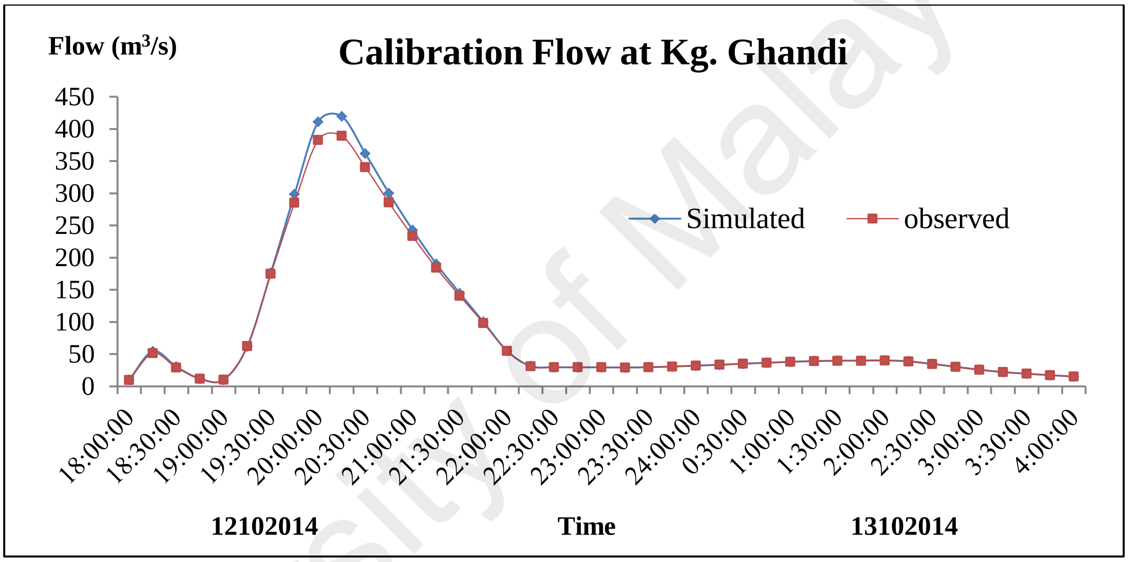


Figure 4. 19: Graph of Calibration Flow at Kg. Ghandi

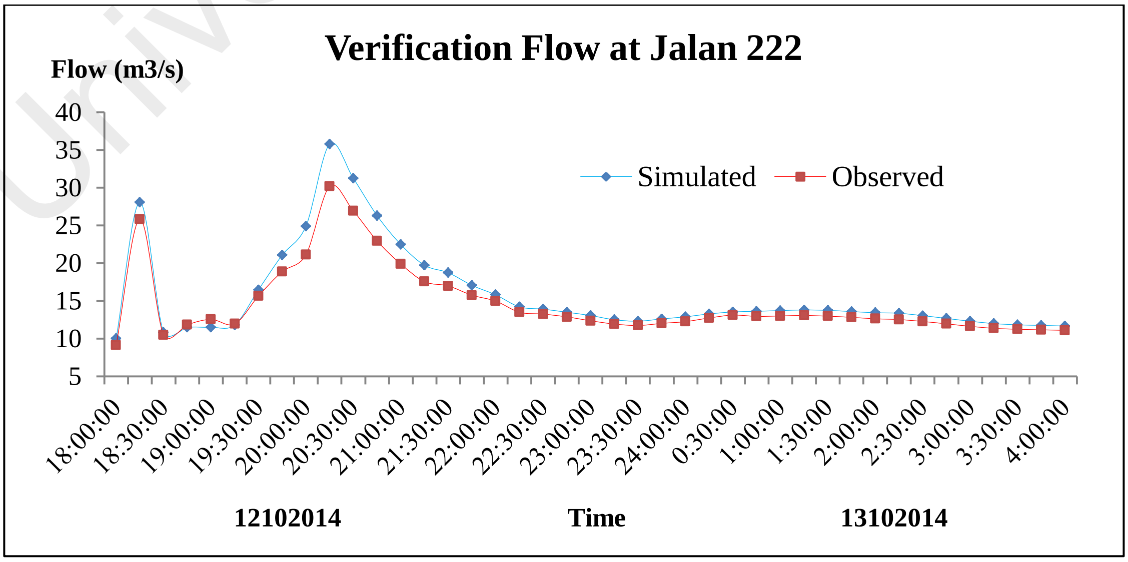


Figure 4. 20: Graph of Verification Flow at Jalan 222

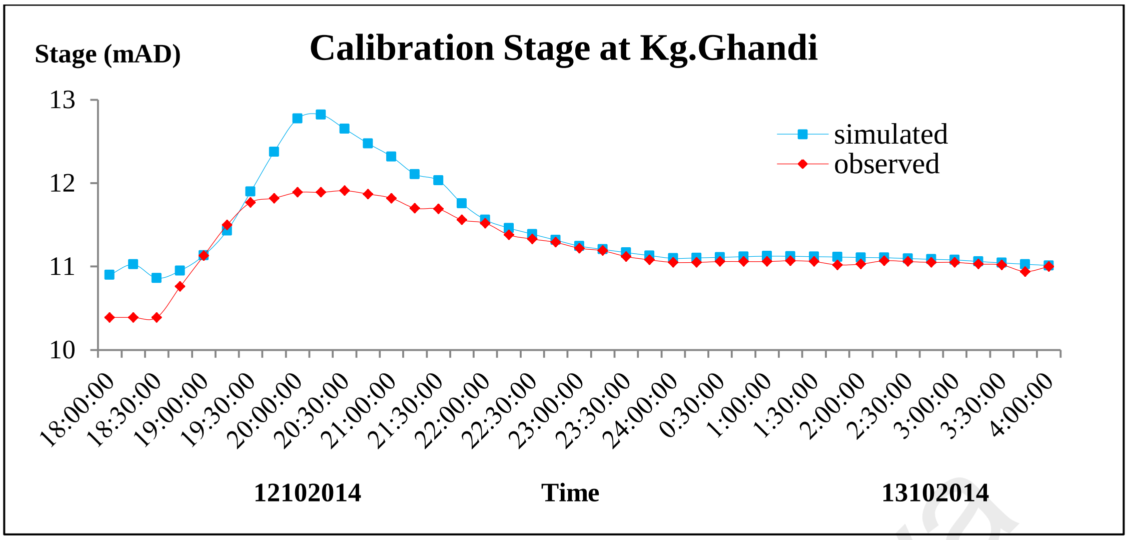


Figure 4. 21: Graph of Calibration Stage at Kg. Ghandi

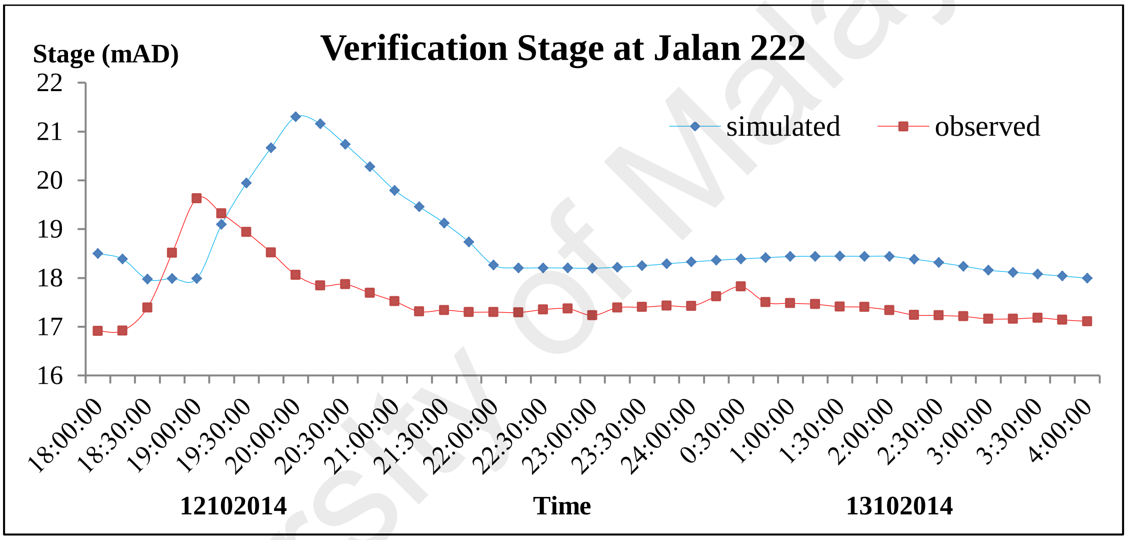


Figure 4. 22: Graph of Verification Stage at Jalan 222

Figures 4.19 to 4.22 show the recorded and modelled stream flow and stage at Kg. Ghandi and Jalan 222. And, Table 4.5 shows the comparison of observed and simulated flow and stage. The percentage errors for calibration and verification of stream flow are 7.83% and 18.59% for maximum and 4.91% and 9.40% for the minimum. And, the percentage errors for calibration and verification of stage are 7.65% and 8.50% for the maximum, and 4.9% and 6.37% for minimum (Table 4.5). Many factors influenced the difference and lagging time of stage illustrated in Figures 4.21 and 4.22 such as the values of Tc and T_p (Eq 3.5 and 3.7), the catchment properties, modelling coeffiecient rate and others.

Table 4. 5: Comparison of observed and simulated flow and stage

Parameters	Flow (m^3/s)				Stage (mAD)			
	Kg. Ghandi		Jalan 222		Kg. Ghandi		Jalan 222	
	Max	Min	Max	Min	Max	Min	Max	Min
Observed	389.02	9.53	30.18	9.14	11.91	10.39	19.63	16.91
Simulated	419.48	10	35.79	10	12.82	10.9	21.3	17.99
% Error	**7.83**	**4.91**	**18.59**	**9.4**	**7.65**	**4.91**	**8.5**	**6.37**

Figure 4.23 shows the R^2 values for modelling classification of flow and stage at Kg.Ghandi and Jalan 222. The flow calibration at Kg.Ghandi and flow verification at Jalan 222 shows an excellent aggrement. While stage calibration at Kg, Ghandi shows a very good aggrement (R^2, 0.65-0.85) but stage verification at Jalan 222 shows very poor aggrement (R^2, 0.2-0.5).

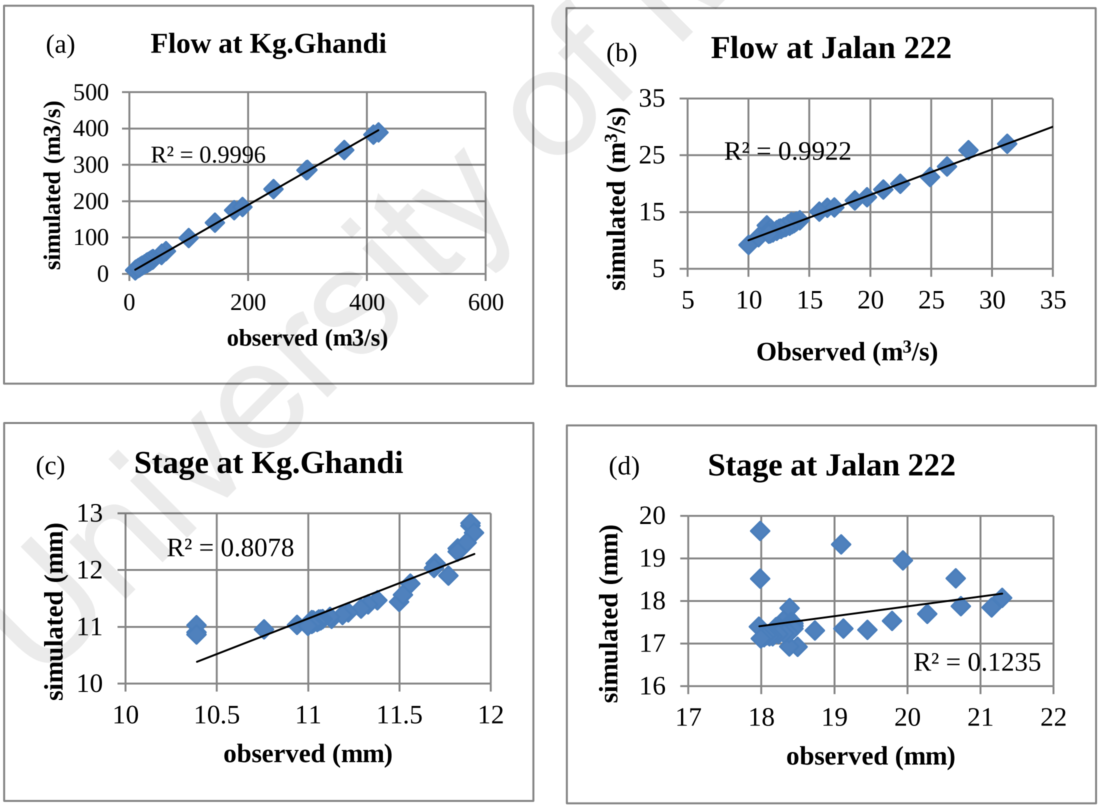


Figure 4. 23: R^2 values for modelling classification

(a) Flow at Kg.Ghandi, (b) Flow at Jalan 222 (c) Stage at Kg.Ghandi (d) Stage at Jalan 222

Water Quality calibration and verification

In order to run a water quality model, we must first have a hydraulic model which has been calibrated and verified. Once the model has been successfully verified, the water quality model can be run at the same time as the hydraulic model. The result below showed the water quality calibration. The simulated date was run from 12 to 13 October at 1800 to 0400 for 3 parameters are DO, BOD, and pH. The calibration results are represented in the following graphs.

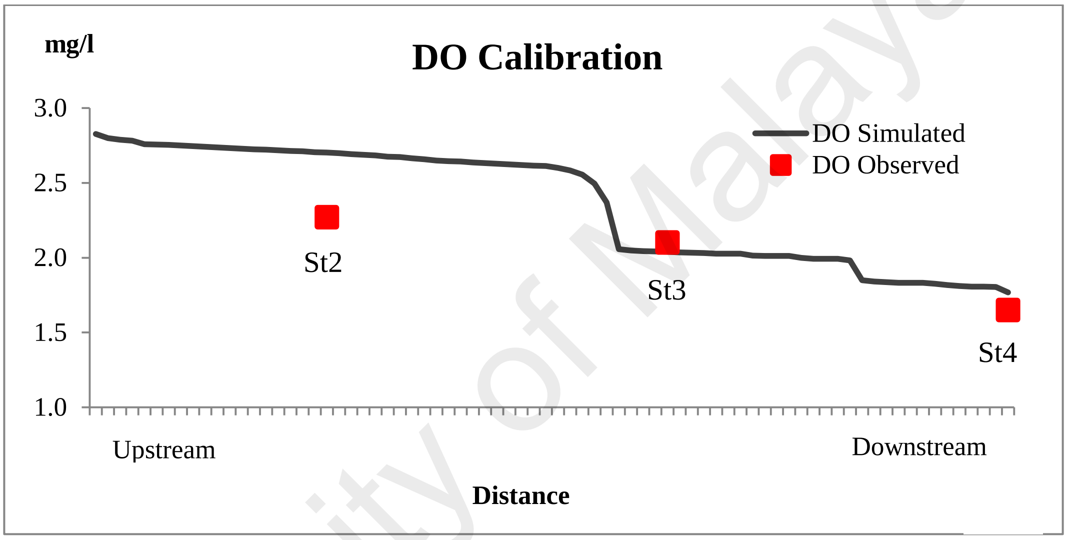


Figure 4. 24: Graph of DO Calibration at Penchala River

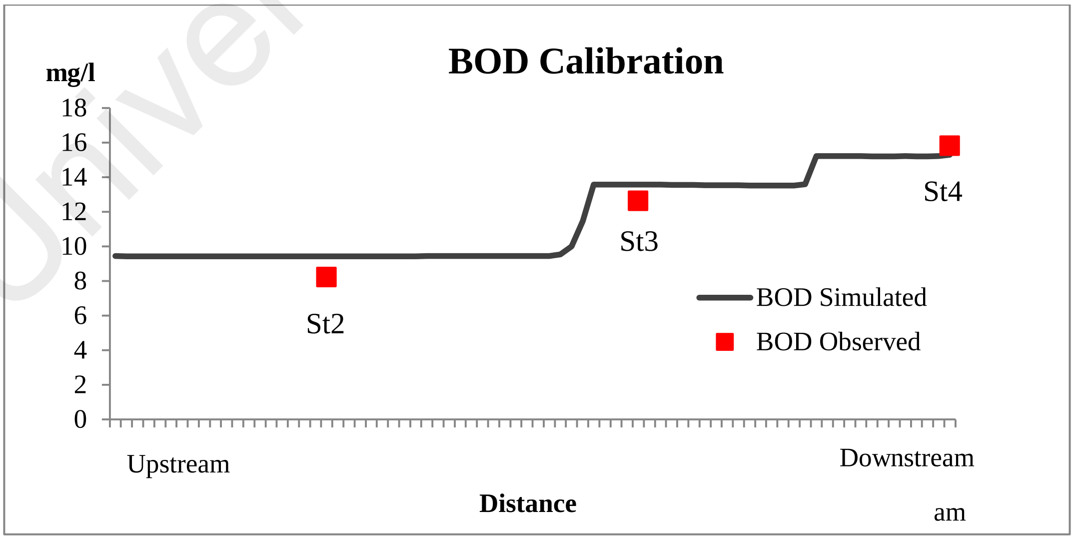


Figure 4. 25: Graph of BOD Calibration at Penchala River

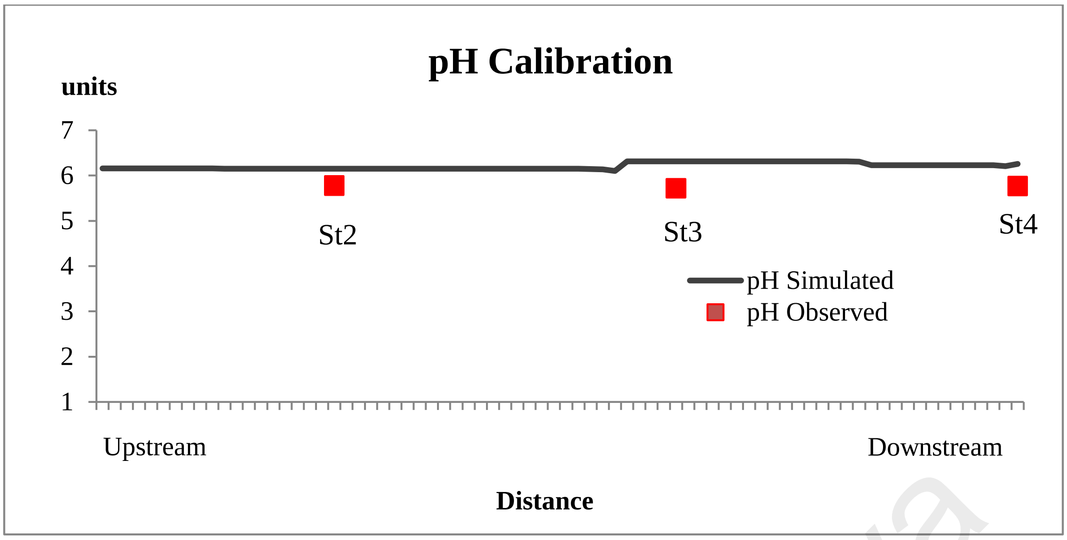


Figure 4. 26: Graph of pH calibration at Penchala River

Figure 4.24 shows the DO calibration graph at middle and downstream of Penchala River. The simulated values are high compared to the observed values. The percentages error between observed and simulated data is shown in Table 4.6 with an error are 19%, 2.9% and 7.15% for station 2, 3 and 4 respectively. The big difference in value at station 2 is maybe due to the heavy rainfall used as the hydrological event based. In simulation, it detected that the heavy rainfall would make self-purification/dilution of pollution in river water. Therefore, during that time, the pollutant inside the river water was decreased and less oxygen was used, hence dissolved oxygen would be higher. As well as the BOD calibration represented in Figure 4.25, the high values of DO recorded in the river water will degrade the BOD values. The calibration recorded the percentages error are 14.6% at station 2, 7.47% at station 3 and 3.22% at station 4. The calibration of pH shown in Figure 4.26 recorded errors are 6.47% and 10.37% at middle-stream and 8.47% at downstream (Table 4.6).

Many factors influenced the reliability of model predictions. One of that is the accuracy of input data which are initial condition and boundary pollutant condition values. The initial condition values are used as the base values and boundary pollutant condition is the actual values in the modelling. Because the hydraulic river model was run during the heavy rainfall, the input data of water quality model are the average of wet season sampling data and the observed values was taken during wet season (October 2014).

Figure 4.27 shows the R^2 values for modelling classification of BOD, DO and pH. The water quality calibration of DO and pH shows a very good agreement and BOD is excellent agreement accordance to Table B.4.

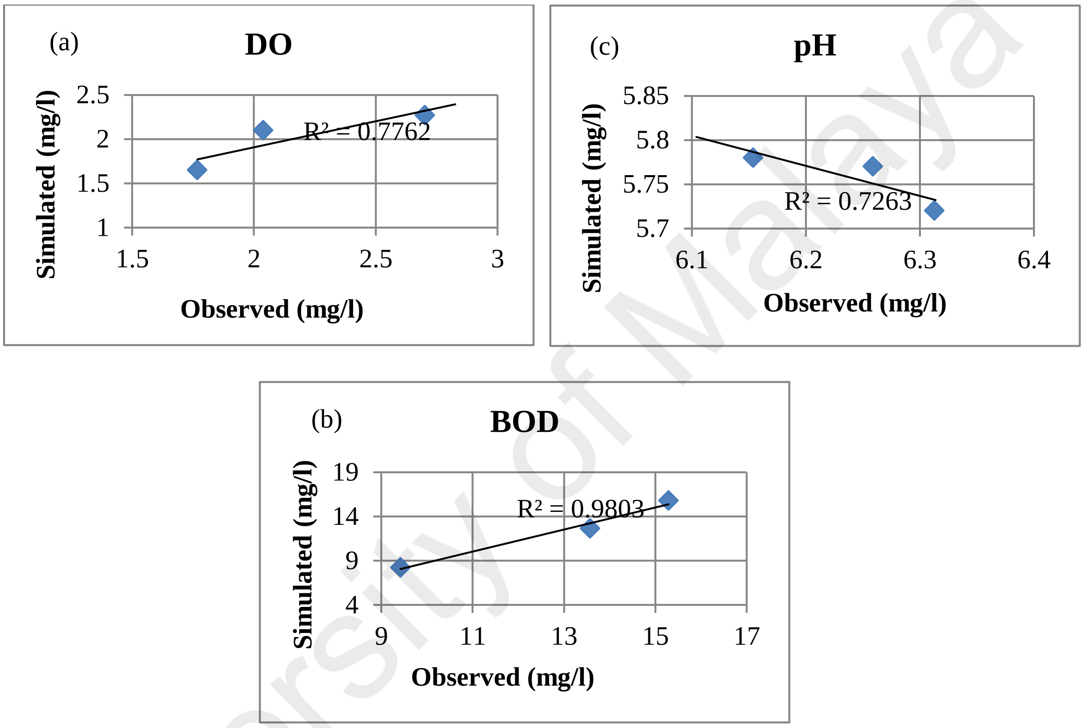


Figure 4. 27: R^2 value for modelling classification
(a) DO (b) BOD (c) pH

Table 4. 6: Comparison of observed and simulated water quality parameters

Water Quality model parameter at the Penchala River									
Parameters	**DO**			**BOD**			**pH**		
	St2	**St3**	**St4**	**St2**	**St3**	**St4**	**St2**	**St3**	**St4**
Observed	2.27	2.10	1.65	8.22	12.63	15.80	5.78	5.72	5.77
Simulated	2.70	2.04	1.77	9.42	13.57	15.29	6.15	6.31	6.26
% Error	**19.0**	**2.9**	**7.2**	**14.6**	**7.5**	**3.2**	**6.5**	**10.4**	**8.5**

4.5.3 Results of Simulation

Hydraulic Simulation

Figures 4.28 and 4.29 show the simulated stream flow and stage at CS05 (Jalan 222) and CS07 (Kg. Ghandi) obtained from the model. CS05 and CS07 located at middle and downstream of the river.

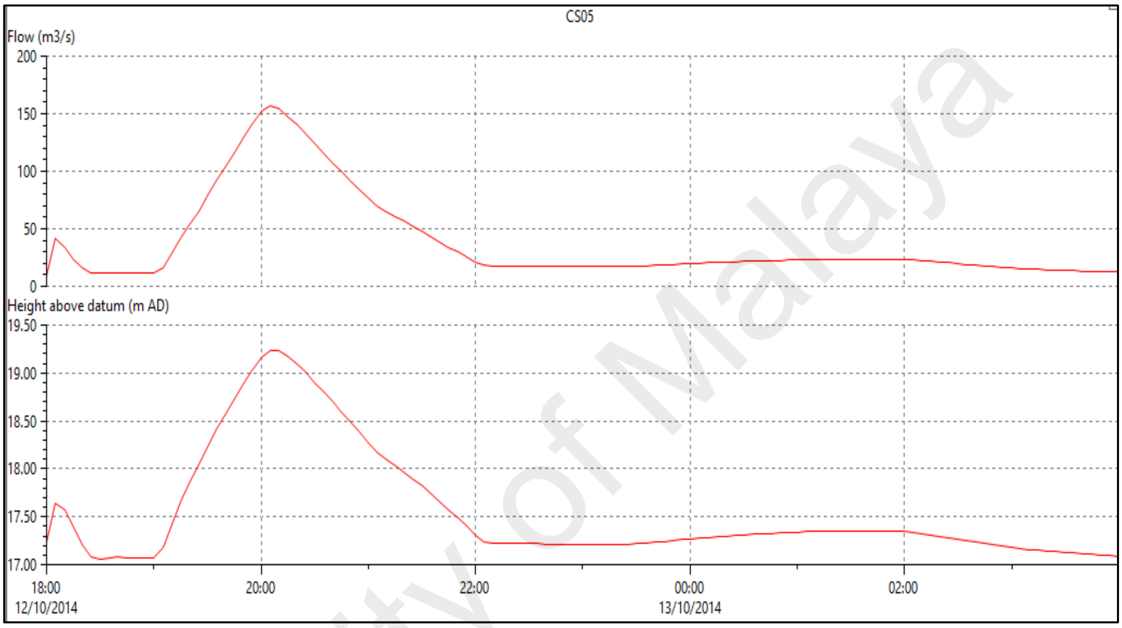


Figure 4. 28: Stream flow and stage at CS05

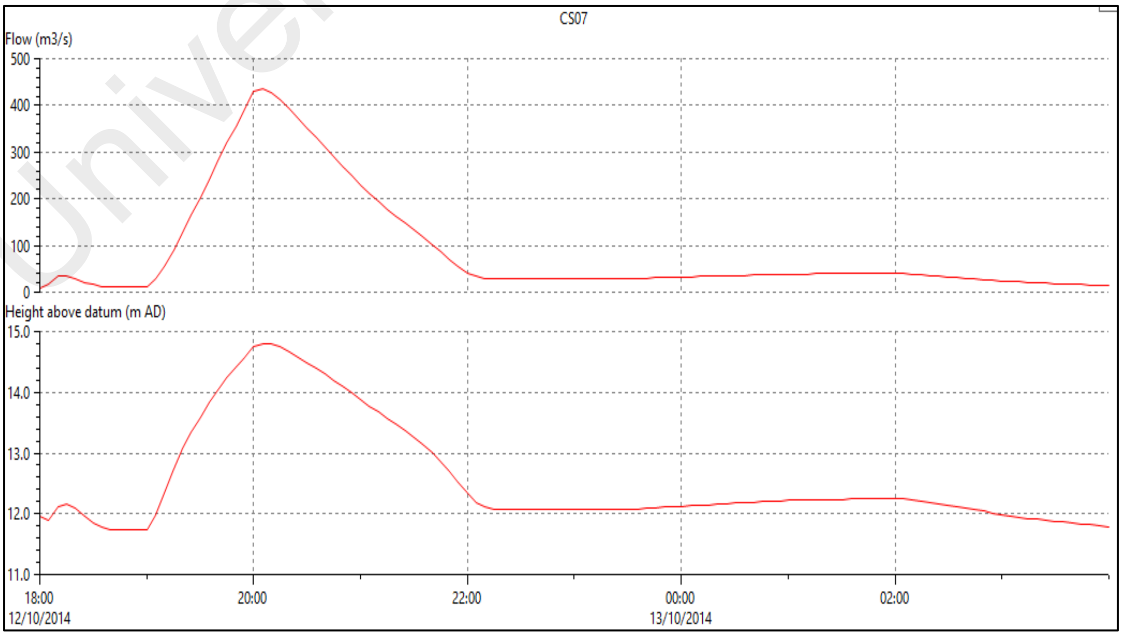


Figure 4. 29: Stream flow and stage at CS07

Water Quality Simulation

Figures 4.30 and 4.31 are simulated DO, BOD and pH at CS05 (Jalan 222) and CS07 (Kg. Ghandi) obtained from the model. The graph shows the concentration of DO, BOD and pH versus time. The Figure 4.32 shows the maximum water level result throughout Penchala River.

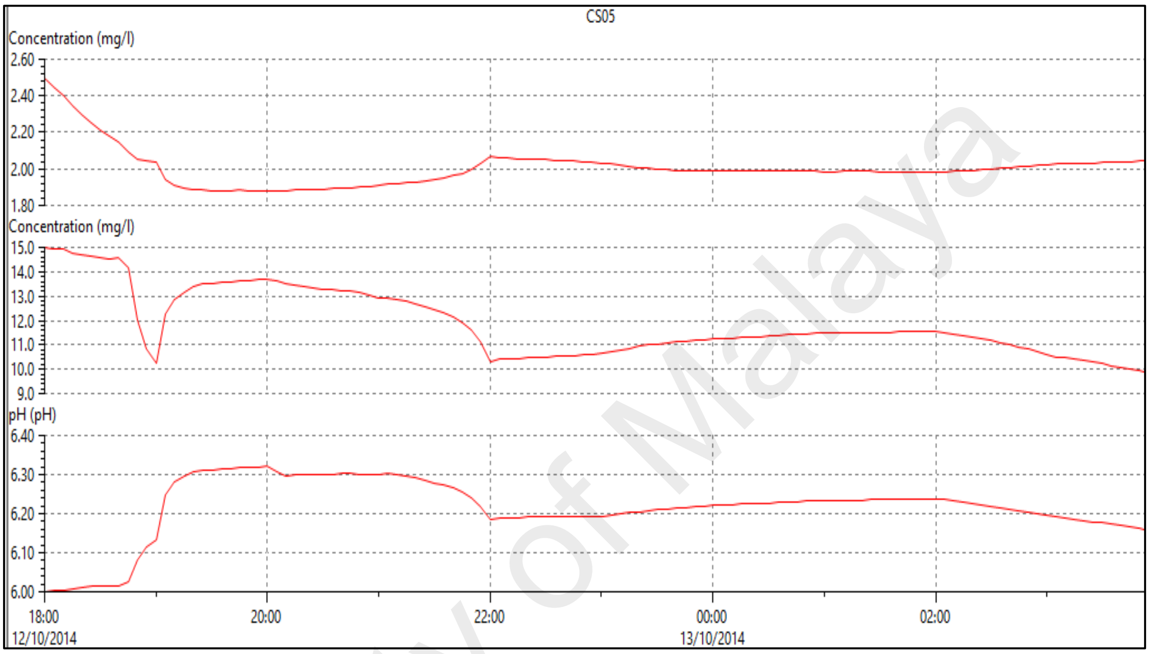


Figure 4. 30: DO, BOD and pH at CS05

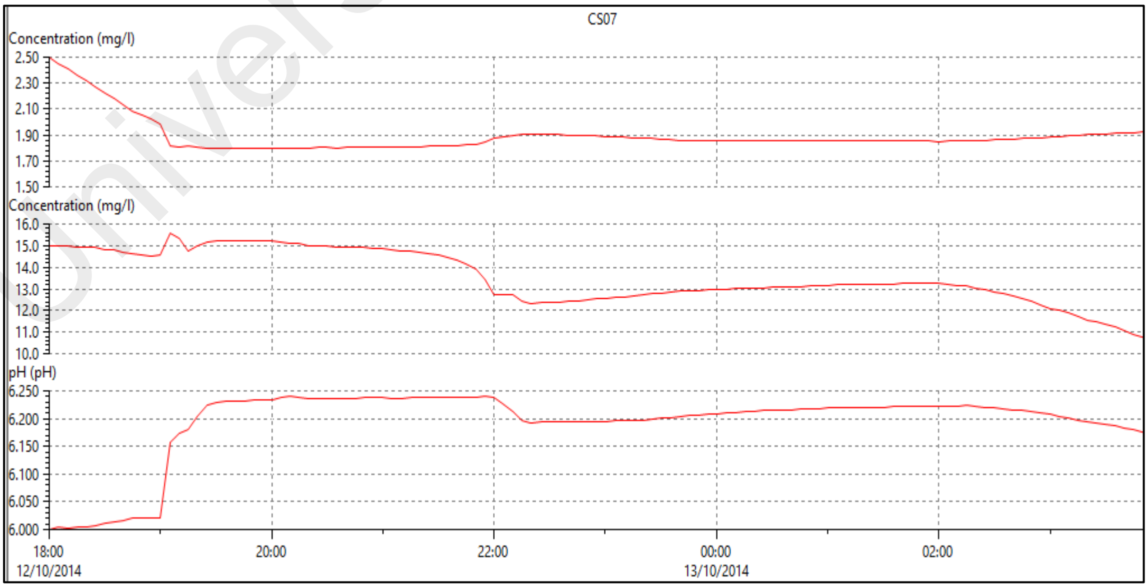


Figure 4. 31: DO, BOD and pH at CS07

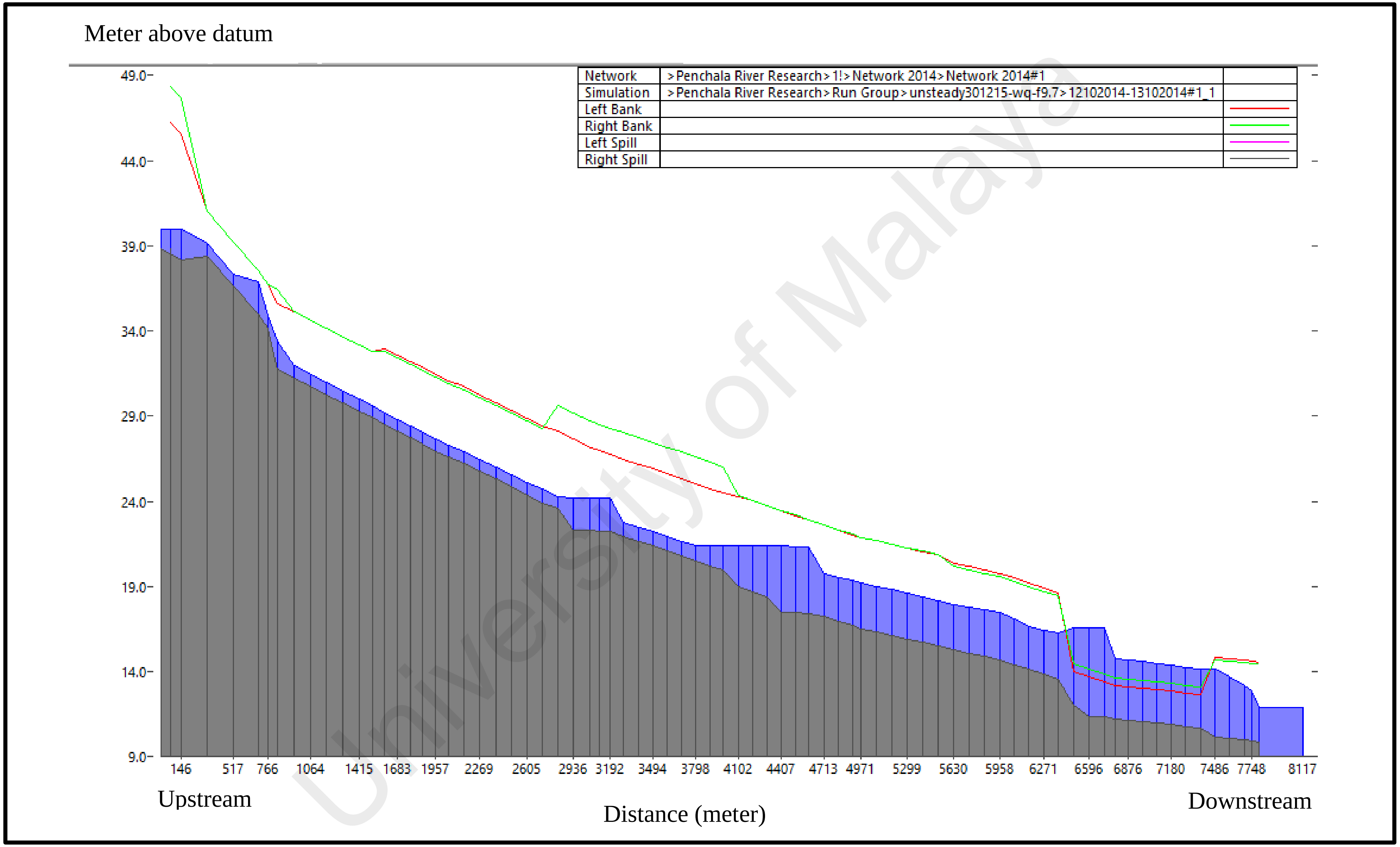


Figure 4. 32: Maximum water level result throughout Penchala River.

CHAPTER 5 CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter summarizes the conclusions, and also included recommendations for future work relating to the results of this study.

5.2 Conclusion

Water pollution of the Penchala River varies based on the locations of the sampling stations. The upstream (St1) of the Penchala River was categorized as clean water, the middle stream (St2 and St3) as slightly polluted water and downstream (St4) as polluted water. This conclusion is supported by WQI classification according to the DOE standard classification, St1 was classified as Class II, whereas St2 and 3 were classified as Class III, and St4 was classified as Class IV. In addition to that, the physico-chemical parameters and WQI results have a significant change between stations *(*ANOVA, $P<0.05$) except for pH, velocity and turbidity. But, only 3 elements (Mn, Mg and Fe) have a significant change between stations *(*ANOVA, $P<0.05$) in heavy metals. From the results, it is interesting to note that, Penchala River varies from upstream to downstream in water quality pollution but not in metal contamination.

The seasonal impact of the Penchala River during wet season showed the better water quality compared during dry season. During the dry season, the water becomes more polluted than usually because the drying up of the water river. The physico-chemical parameters, WQI and heavy metals values during wet season were slightly better than dry season especially at middle (St3) and downstream (St4) of the river which indicates that the rainfall runoff did not carry any pollutants load into the river but helped to recover water contamination. Therefore, it was found through this study the water quality and metal contamination of the Penchala River is significantly affected by seasonal variations as the river flows towards downstream.

The last conclusion is regarding the hydraulic and water quality river model development. It is observed the calibration and verification results of stream flow and stage of the hydraulic model have indicated a good agreement and performance by the model is capable of simulating unsteady flow events with a reasonable degree of accuracy. In case of water quality modelling, it can be clearly seen BOD and pH calibration along Penchala River showed a good agreement at middle and downstream whereas DO calibration showed a slight disagreement at middle-stream of Penchala River. In future, this water quality modelling result can further test another observation data to get more appropriate simulation result. This simulation of hydraulic and water quality can be useful in order to design or make the scenarios for reduction of pollution in Penchala River. Lastly, hydraulic and water quality river models are indispensable tools for easy monitoring.

5.3 Recommendations

As Penchala River is located at an urban area in Kuala Lumpur federal territory and Selangor state, the treated water for every drain or any point and non-point sources discharging into Penchala River are highly recommended especially at middle and downstream, which are surrounded by factories, residential and commercial areas. Especially, the case of faulty septic tanks at public housing in Kiara Hills which the flow of wastewater is directly into Penchala River. Every residential and industrial area should be provided with their own sewerage system to prevent waste from being thrown or channelled directly into the river. Additionally, continuous monitoring and bio-monitoring approach could potentially be developed and implemented for better water management in Malaysia. River monitoring should be conducted every month to assess river condition and eco-system.

Laws regarding river pollution should be implemented and strictly enforced to prevent future pollution from disturbing the river ecosystem. If any pollution is noted during the time of river monitoring, the residential or industrial building should be immediately fined. Furthermore, water cleaning programs should be organized to clean and improve the condition of existing rivers. Throughout this program, a polluted river can be improved and cleaned from visible rubbish. It can also bring awareness to the public, especially those living close to Penchala River so that the river can be protected, cared and recovered. Results from this study are also to warn the society to be more cautious and aware not to play around in this river water because Penchala River has been proven to be contaminated. Further specific recommendations in this research study are discussed below.

The following recommendations are made based on the results of this study:

1) This research study only did heavy metal test analysis for river water. It is highly recommended for heavy metal test analysis for river sediment in future.
2) For river model development, some scenarios are needed to design the reduction of water pollution along Penchala River in future.

REFERENCES

Abdullah, M. Z., Louis, V. C., and Abas, M. T. (2015). Metal Pollution and Ecological Risk Assessment of Balok River Sediment, Pahang Malaysia. *American Journal of Environmental Engineering, 5*(3A), 1-7.

Al-Badaii, F., and Shuhaimi-Othman, M. (2014). Heavy Metals and Water Quality Assessment Using Multivariate Statistical Techniques and Water Quality Index of the Semenyih River, Peninsular Malaysia. *Iranica Journal of Energy & Environment, 5*(2), 132-145.

Al-Badaii, F., Shuhaimi-Othman, M., and Gasim, M. B. (2013). Water Quality Assessment of the Semenyih River, Selangor, Malaysia. *Journal of Chemistry, 2013*.

Al-Mamun, A., and Zainuddin, Z. (2013). Sustainable River Water Quality Management in Malaysia. *IIUM Engineering Journal, 14*(1).

Al-Shujairi, S. (2013). Develop and apply water quality index to evaluate water quality of Tigris and Euphrates Rivers in Iraq. *Int J Mod Eng Res (IJMER), 3*(4), 2119.

Amadi, A., Olasehinde, P., Okosun, E., and Yisa, J. (2010). Assessment of the water quality index of otamiri and oramiriukwa rivers. *Physics International, 1*(2), 102.

APHA, A. (1998). WEF (1998) Standard methods for the examination of water and wastewater: American Public Health Association, Washington, DC.

Baharuddin, M. F. T., Ismail, Z., Othman, S. Z., Taib, S., and Hashim, R. (2013). Use of time-lapse resistivity tomography to determine freshwater lens morphology. *Measurement, 46*(2), 964-975.

Bhargava, D. S. (1983). Use of water quality index for river classification and zoning of Ganga river. *Environmental Pollution Series B, Chemical and Physical, 6*(1), 51-67.

Bidhendi, G. N., Karbassi, A., Nasrabadi, T., and Hoveidi, H. (2007). Influence of copper mine on surface water quality. *International Journal of Environmental Science & Technology, 4*(1), 85-91.

Bordalo, A., Nilsumranchit, W., and Chalermwat, K. (2001). Water quality and uses of the Bangpakong River (Eastern Thailand). *Water research, 35*(15), 3635-3642.

Bordalo, A. A., Teixeira, R., and Wiebe, W. J. (2006). A water quality index applied to an international shared river basin: the case of the Douro River. *Environmental management, 38*(6), 910-920.

Boyacioglu, H. (2007). Surface water quality assessment using factor analysis. *Water SA, 32*(3), 389-393.

Brown, R. M., McClelland, N. I., Deininger, R. A., and Tozer, R. G. (1970). A Water Quality Index- Do We Dare.

Bustami, R., Bong, C., Mah, D., Hamzah, A., and Patrick, M. (2009). Modeling of Flood Mitigation Structures for Sarawak River Sub-basin Using InfoWorks River Simulation (RS). *World Academy of Science Engineering and Technology*, 14-18.

Chiang, P., Willems, P., and Berlamont, J. (2010). *A conceptual river model to support real-time flood control (Demer River, Belgium).* Paper presented at the River Flow 2010 International Conference on Fluvial Hydraulics, TU Braunschweig, Germany.

Colter, A., and Mahler, R. L. (2006). *Iron in drinking water*: University of Idaho Moscow.

Conrad, R., Andreae, M., and Schimel, D. (1989). Control of methane production in terrestrial ecosystems. *Exchange of trace gases between terrestrial ecosystems and the atmosphere.*, 39-58.

Cowx, I. G., and Welcomme, R. L. (1998). *Rehabilitation of rivers for fish*: Food & Agriculture Org.

Cude, C. G. (2001). Oregon Water Quality Index A Tool For Evaluating Water Quality Management Effectiveness1: Wiley Online Library.

Czarra F. (2003). Fresh Water: Enough for You and Me? *Occasional paper from The American Forum for Global Education*(174), 2-10.

Davis, M. L., and Cornwell, D. (1991). Introduction to Environmental Engineering (McGraw Hill). *Inc., New York.*

DID. (Malaysia). Department of Irrigation and Drainage Malaysia, Ministry of Natural Resources and Environment.

DOE. (2008). Malaysia Environmental Quality Report 2008. Kuala Lumpur, Malaysia: Department of Environment (DOE), Ministry of Natural Resources and Environment.

DOE. (2003). *Water quality management in Malaysia*. Kuala Lumpur:DOE Documents.

EPU. (2000). *Economic Planning Unit, National Water Reources Study 2000-2050*. Government of Malaysia Department of Prime Minister's Officer.

Fulazzaky, M. A., Seong, T. W., and Masirin, M. I. M. (2010). Assessment of water quality status for the Selangor River in Malaysia. *Water, Air, and Soil Pollution, 205*(1-4), 63.

Gholikandi, G. B., Haddadi, S., Dehghanifard, E., and Tashayouie, H. R. (2012). Assessment of surface water resources quality in Tehran province, Iran. *Desalination and Water Treatment, 37*(1-3), 8-20.

Gloag, D. (1981). Sources of lead pollution. *BMJ, 282*(6257), 41-44.

Gorashi, F., and Abdullah, A. (2012). Prediction Of Water Quality Index Using Back Propagation Network Algorithm. Case Study: Gombak River. *Journal of Engineering Science and Technology, 7*(4), 447-461.

Harrison, R. (2012). *Lead pollution: causes and control*: Springer Science & Business Media.

Harun¹, S., Abdullah, M. H., Mohamed¹, M., Fikri¹, A. H., and Jimmy, E. O. (2010). Water quality study of four streams within Maliau Basin Conservation area, Sabah, Malaysia.

Hasan, H. A., Abdullah, S. R. S., Kamarudin, S. K., and Kofli, N. T. (2011). Problems of ammonia and manganese in Malaysian drinking water treatments. *World Appl Sci J, 12*(10), 1890-1896.

Hassan, A. (2009). River and Floodplain Modelling: A Practical Approach. *National Hydraulic Research Institute of Malaysia*.

Health, U. D. o., and Services, H. (1993). Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Chromium*.

Henriksen, H. J., Troldborg, L., Nyegaard, P., Sonnenborg, T. O., Refsgaard, J. C., and Madsen, B. (2003). Methodology for construction, calibration and validation of a national hydrological model for Denmark. *Journal of Hydrology, 280*(1), 52-71.

Horritt, M., and Bates, P. (2002). Evaluation of 1D and 2D numerical models for predicting river flood inundation. *Journal of Hydrology, 268*(1), 87-99.

Horton, R. K. (1965). An index number system for rating water quality. *Journal of Water Pollution Control Federation, 37*(3), 300-306.

Hossain M.A., Sujaul I.M., and Nasly M.A. (2013). Water Quality Index: an Indicator of Surface Water Pollution in Eastern part of Peninsular Malaysia. *Research Journal of Recent Sciences, 2*(10), 10-17.

Ismail, Z., Primasari, B., and Shirazi, S. M. (2011). Monitoring and management issues of heavy metal pollution of Gombak River, Kuala Lumpur. *International Journal of the Physical Sciences, 6*(35), 7961-7968.

Ismail, Z., Salim, K., Othman, S. Z., Ramli, A. H., Shirazi, S. M., Karim, R., and Khoo, S. Y. (2013). Determining and comparing the levels of heavy metal concentrations in two selected urban river water. *Measurement, 46*(10), 4135-4144.

Kane, S., Lazo, P., and Vlora, A. (2012). *Assessment of heavy metals in some dumps of copper mining and plants in Mirdita Area, Albania*. Paper presented at the Procceding of the 5th International Scientific Conference on Water, Climate and Environment.

Karanth, K. (1987). *Ground water assessment: development and management*: Tata McGraw-Hill Education.

Kazi, T., Arain, M., Jamali, M., Jalbani, N., Afridi, H., Sarfraz, R., and Shah, A. Q. (2009). Assessment of water quality of polluted lake using multivariate statistical techniques: A case study. *Ecotoxicology and Environmental Safety, 72*(2), 301-309.

Krenkel, P. (2012). *Water quality management*: Elsevier.

Loukas, A. (2010). Surface water quantity and quality assessment in Pinios River, Thessaly, Greece. *Desalination, 250*(1), 266-273. doi:http://dx.doi.org/10.1016/j.desal.2009.09.043

Lumb, A., Sharma, T., and Bibeault, J.-F. (2011). A review of genesis and evolution of water quality index (WQI) and some future directions. *Water Quality, Exposure and Health, 3*(1), 11-24.

MacDonald, L. H., Smart, A. W., and Wissmar, R. C. (1991). Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska.

Mah, Y. S., Lai, S. H., Chan, R., and Putuhena, F. J. (2012). Investigative modelling of the flood bypass channel in Kuching, Sarawak, by assessing its impact on the inundations of Kuching-Batu Kawa-Bau Expressway. *Structure and Infrastructure Engineering, 8*(7), 705-714.

Massoud, M. A. (2012). Assessment of water quality along a recreational section of the Damour River in Lebanon using the water quality index. *Environmental Monitoring and Assessment*, *184*(7), 4151-4160.

McCutcheon, S. C. (1989). *Water quality modeling*: Wiley Online Library.

Mehrdadi, N., Bidhendi, G., Nasrabadi, T., Hoveidi, H., Amjadi, M., and Shojaee, M. (2009). Monitoring the arsenic concentration in groundwater resources, case study: Ghezel ozan water basin, Kurdistan, Iran. *Asian journal of chemistry, 21*(1), 446-450.

Mehrdadi, N., Ghobadi, M., Nasrabadi, T., and Hoveidi, H. (2006). Evaluation of the quality and self purification potential of Tajan river using QUAL2E model. *Iranian Journal of Environmental Health Science & Engineering, 3*(3), 199-204.

Mei, K., Zhu, Y., Liao, L., Dahlgren, R., Shang, X., and Zhang, M. (2011). Optimizing water quality monitoring networks using continuous longitudinal monitoring data: a case study of Wen-Rui Tang River, Wenzhou, China. *Journal of Environmental Monitoring, 13*(10), 2755-2762.

Morillo, J., Usero, J., and Gracia, I. (2002). Partitioning of metals in sediments from the Odiel River (Spain). *Environment International, 28*(4), 263-271.

Nasrabadi, T. (2015). An IndexApproach toMetallic Pollution in RiverWaters. *International Journal of Environmental Research, 9*(1), 385-394.

Nasrabadi, T., Bidhendi, G. N., Karbassi, A., and Mehrdadi, N. (2010). Partitioning of metals in sediments of the Haraz River (Southern Caspian Sea basin). *Environmental Earth Sciences, 59*(5), 1111-1117.

Ngai Weng Chan. (2012). Managing Urban Rivers and Water Quality in Malaysia for Sustainable Water Resources. *Water Resources Development, 28*(2), 343-354.

Othman, F., Amin, M., Farahain, N., Mi Fung, L., Elamin, M., and Eldin, A. (2013). *Utilizing GIS and Infoworks RS in modelling the flooding events for a tropical river basin.* Paper presented at the Applied Mechanics and Materials.

Othman, F., M. E, A. E., and Mohamed, I. (2012). Trend analysis of a tropical urban river water quality in Malaysia. *Journal of Environmental Monitoring, 14*(12), 3164-3173.

Peavy, H. S. (1985). *Environmental engineering*: McGraw-Hill Science, Engineering & Mathematics.

Pejman, A., Bidhendi, G. N., Karbassi, A., Mehrdadi, N., and Bidhendi, M. E. (2009). Evaluation of spatial and seasonal variations in surface water quality using multivariate statistical techniques. *International Journal of Environmental Science & Technology, 6*(3), 467-476.

Prasad, B., and Bose, J. (2001). Evaluation of the heavy metal pollution index for surface and spring water near a limestone mining area of the lower Himalayas. *Environmental Geology, 41*(1-2), 183-188.

Ramakrishnaiah, C., Sadashivaiah, C., and Ranganna, G. (2009). Assessment of water quality index for the groundwater in Tumkur Taluk, Karnataka State, India. *Journal of Chemistry, 6*(2), 523-530.

Reduction, (2001). *Assessing the TMDL Approach to Water Quality Management*: National Academy Press.

Sanchez, E., Colmenarejo, M. F., Vicente, J., Rubio, A., García, M. G., Travieso, L., and Borja, R. (2007). Use of the water quality index and dissolved oxygen deficit as simple indicators of watersheds pollution. *Ecological Indicators, 7*(2), 315-328.

Sarala Thambavani, D., and Uma Mageswari, T. (2013). Water quality indices as indicators for potable water. *Desalination and Water Treatment*(ahead-of-print), 1-11.

Shanbehzadeh, S., Vahid Dastjerdi, M., Hassanzadeh, A., and Kiyanizadeh, T. (2014). Heavy Metals in Water and Sediment: A Case Study of Tembi River. *Journal of environmental and public health, 2014*.

Shirazi, S., Imran, H., and Akib, S. (2012). GIS-based DRASTIC method for groundwater vulnerability assessment: a review. *Journal of Risk Research, 15*(8), 991-1011.

Shirazi, S., Islam, M., Ismail, Z., Jameel, M., Alengaram, U. J., and Mahrez, A. (2011). Arsenic contamination of aquifers: A detailed investigation on irrigation and portability. *Sci. Res. Essays*, *6*(5), 1089-1100.

Shuhaimi-Othman, M., Lim, E. C., and Mushrifah, I. (2007). Water quality changes in Chini Lake, Pahang, West Malaysia. *Environmental Monitoring and assessment, 131*(1-3), 279-292.

Stambuk-Giljanovic, N. (1999). Water quality evaluation by index in Dalmatia. *Water research, 33*(16), 3423-3440.

Toriman, M. E., Karim, O. A., Mokhtar, M., Gazim, M. B., and Abdullah, M. P. (2010). Use of InfoWork RS in modeling the impact of urbanisation on sediment yield in Cameron Highlands Malaysia. *Nat Sci, 201*(8).

Viessman, W., Hammer, M. J., and Perez, E. M. (2009). *Water supply and pollution control*: Pearson Prentice Hall.

Wang, X.-L., Lu, Y.-L., Han, J.-Y., He, G.-Z., And Wang, T.-Y. (2007). Identification of anthropogenic influences on water quality of rivers in Taihu watershed. *Journal of Environmental Sciences, 19*(4), 475-481.

Whitehead, P., Williams, R., and Lewis, D. (1997). Quality simulation along river systems (QUASAR): model theory and development. *Science of the Total Environment, 194*, 447-456.

Yisa, J., and Jimoh, T. (2010). Analytical studies on water quality index of river Landzu. *American Journal of Applied Sciences, 7*(4), 453.

Zhang, Y., Guo, F., Meng, W., and Wang, X.-Q. (2009). Water quality assessment and source identification of Daliao river basin using multivariate statistical methods. *Environmental Monitoring and assessment, 152*(1-4), 105-121.

http://www.met.gov.my/, Malaysian Meteorological Department, 5 May 2014

http://publicinfobanjir.water.gov.my/, The official web of public Infobanjir, Department of Irrigation and Drainage Malaysia, 23 February 2014.

https://www.doe.gov.my/portalv1/en/, Official portal of Department of Environment, 7 May 2015

http://www.innovyze.com/products/infoworks_cs/, 8 January 2015

http://kmam.moh.gov.my/, Drinking water quality surveillance programme, Engineering Services programme, Ministry of Health, Malaysia, 9 February 2016

https://statistics.laerd.com/spss-tutorials/one-way-anova-using-spss-statistics.php,19 September 2017.

LIST OF PUBLICATIONS AND PAPER PRESENTED

Journal Paper

Othman, F., Muhammad, S.A., Azahar, S.A.H., Alaa Eldin, M.E., Mahazar, A., and Othman, M.S. (2015). Impairment of the water quality status in a tropical urban river. *Desalination and Water Treatment*, 1-7.

Conference Paper

Othman, F., Muhammad, S.A., Seasonal Comparison of an Urban River using the Water Quality Index, 8^{th} International Conference on Environment and Natural Sciences (2015). Kuala Lumpur, Malaysia.

Ongoing Paper

The impact of tropical Seasonal Variation on Water Quality Index and Benthic Macroinvertebrate as the Biological Indicator.