APPLICATION OF MODIFIED RIVER HEALTH INDEX FOR SUNGAI PENCHALA

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APPLICATION OF MODIFIED RIVER HEALTH INDEX FOR SUNGAI PENCHALA

ABSTRACT

The aim of this study is to have a tool of management of an urban river. A simple tool in terms of index aimed to be developed to manage urban river to meet its intended usage. River Health Index (RHI) developed by combining both physico-chemical parameters and biological measures through scores and weightages. Sungai Penchala is the small urban river chosen for this study. Water quality study, which include physico-chemical parameters, benthic macroinvertebrates and surrounding land use activities have been carried out since May 2016 to September 2016. Ten sampling points have been selected to represent the condition of the river from upstream to downstream. WQI used to represent physico-chemical status of river while Average Species per Taxon (ASPT) value reported for biological water quality condition. Residential, commercial, industrial and mixed type of anthropogenic activities recorded at Sungai Penchala. Average WQI value of Sungai Penchala reported at 58. ASPT score of Sungai Penchala ranges from 2.2 to 5.1. Study findings showed that the Water Quality Index (WQI) and ASPT of Sungai Penchala has a significant positive Spearman rank correlation (0.857, $p<0.05$). This suggests biological monitoring can be carried out together with physico-chemical monitoring to study river health. RHI in this study required some modification during its development by adapting and simplifying an established framework. Station 1 reported ‘Good’ RHI while Station 4 reported ‘Poor’ RHI. RHI developed can be used to serve as one among earliest integrative indicators in monitoring and reporting the river health in our country.

Keywords: river health, water quality, benthic macroinvertebrates, index

PENGAPLIKASIAN INDEKS KESIHATAN SUNGAI YANG DIUBAHSUAI UNTUK SUNGAI PENCHALA

ABSTRAK

Tujuan kajian ini adalah untuk mempunyai suatu alat pengurusan sungai bandar. Alat mudah dari segi indeks dibangunkan untuk menguruskan sungai bandar untuk memenuhi penggunaannya mengikut keperluan. Indeks Kesihatan Sungai (RHI) telah dibangunkan dengan menggabungkan kedua-dua parameter fiziko-kimia dan biologi melalui skor dan berat. Sungai Penchala iaitu sungai bandar yang kecil dipilih untuk kajian ini. Kajian kualiti air yang merangkumi parameter fiziko-kimia, makroinvertebrata benthik dan aktiviti kegunaan tanah sekitar telah dijalankan dari Mei 2016 hingga September 2016. Sepuluh titik pensampelan telah dipilih untuk mewakili keadaan sungai dari hulu ke hilir. Indeks Kualiti Air (WQI) digunakan untuk mewakili status fiziko-kimia sungai manakala Nilai Purata Spesies per Taxon (ASPT) dilaporkan bagi keadaan kualiti air biologi. Aktiviti perumahan, komersial, perindustrian dan aktiviti campuran telah dicatatkan di Sungai Penchala. Purata nilai WQI Sungai Penchala dilaporkan 58. Skor ASPT Sungai Penchala dalam lingkungan antara 2.2 hingga 5.1. Dapatan kajian ini menunjukkan bahawa WQI dan ASPT Sungai Penchala mempunyai hubungan yang kuat dengan korelasi Spearman positif (0.857, $p < 0.05$). Ini meyakinkan pemantauan biologi perlu dijalankan dengan pemantauan fiziko-kimia untuk mengkaji kesihatan sungai. RHI dalam kajian ini telah melibatkan beberapa pengubahsuaian semasa pembangunannya dengan menyesuaikan dan memudahkan rangka kerja yang telah diterbitkan. Stesen 1 melaporkan RHI 'Baik' manakala Stesen 4 melaporkan RHI 'Tercemar'. RHI yang dibangunkan boleh digunakan sebagai salah satu daripada petunjuk integrasi terawal dalam pemantauan dan pelaporan kesihatan sungai di negara kita.

Kata kunci: kesihatan sungai, kualiti air, makroinvertebrata benthik, indeks

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LIST OF SYMBOLS AND ABBREVATIONS

°*C*	:	Degree Celcius
NH_3-N	:	Ammoniacal Nitrogen
ASPT	:	Average Species Per Taxon
BOD	:	Biochemical Oxygen Demand
COD	:	Chemical Oxygen Demand
DO	:	Dissolved Oxygen
DID	:	Department of Irrigation and Drainage
DOE	:	Department of Environment
RHS	:	River Health Score
RHI	:	River Health Index
TSS	:	Total Suspended Solids
WQI	:	Water Quality Index

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CHAPTER 1: INTRODUCTION

1.1 Background of Study

This chapter provides insight on urban rivers and typical river health monitoring types. The chapter also highlights problem statement that leads to the study. Aim, objectives as well as scope and limitations of proposed study spelled out in this chapter.

1.1.1 Urban Rivers

Urban rivers are rivers that flow through cities in descriptive sense while it can be expressed deeply as rivers that been involved in the phases of urbanization, whether it is flowing through urban centers or not (Castonguay, 2012). 68% of world's population expected to live in urban areas by 2050 with Asia and Africa will have 90% increase of urban settlements (United Nations, 2018). Altered ecosystems with decrease in services provision by urban stream that widespread throughout the world, brings into a lot of researches in recent years (Walsh et al., 2005; Wenger et al., 2009; Castonguay, 2012; Szczepocka, 2018). Being vulnerable to pollution, urban rivers or stream usually express depraved physical, chemical and biological conditions, which termed as 'urban stream syndrome' (Meyer et al. 2005; Walsh et al. 2005; Walsh et al., 2009). Elevated hydrograph, increased uptake of nutrients with pollutants, channelization, and reduced biotic life are symptoms of the urban stream syndrome (Meyer et al. 2005). They are highly susceptible to impacts associated with land use changes due to growing urbanization (Feminella, 2005). Different stretches of rivers in a city might poses different levels of symptoms. The factors for these changes need to be identified to plan and construct mitigate actions.

Urban rivers often neglected for management due to lack of key beneficial usage such as drinking and irrigation. Urban rivers often seen as pollutant carrier and water flow regulator especially in cities (Wang et al., 2004). In cities, urban rivers provide social benefits (Darjosanjoto & Nugroho, 2015). Among the social benefits, opportunities of urban population getting into contact with the natural environment, accessibility that leads into social life and open space helps promoting movement and interchange between different type of users (Silva & Jacobi, 2014). Besides social benefits, urban rivers still provide valuable usages such as enhancement of urban environment quality, promoting aesthetic, recreational and cultural values (Chou, 2016). Despite valuable offerings by urban rives, they are still not managed properly and often sacrificed due to lack of planning and real estate pressure (Benages et al., 2015).

1.1.2 River Health Monitoring

One of the important urban river management aspect is monitoring the quality of water resources (Arief, 2017). Traditionally, physical, chemical and biological aspects of water quality monitored when it comes to river monitoring (Asadollahfardi, 2014). However, ecological values of rivers especially urban rivers need to be considered and included in monitoring for better management. Globally, this concept known as river health which incorporates both ecological principles and human values (Bond et al., 2012). It was suggested that efforts to protect ecological health must consider the human uses and amenities derived from river basin (Rapport, 1991). Since rivers provide 97 percent of Malaysian potable water, it is vital to maintain the river health to progress further in parallel to national development by achieving sustainability of better ecosystem health (Mokhtar & Yoneda, 2018). A river is considered healthy when ecological integrity of it can be sustained (Bond et al., 2012). River health usually represented by specific indicators such as Water Quality Index (WQI), biological indicators or cumulative index such as River Health Index (RHI). Water Quality Index (WQI) which solely using physico- chemical components used in Malaysia to assess river health. In Malaysia, river is classified into clean, slightly polluted and polluted based on WQI (DOE, 2017). On contrary, National Water Quality Standards (NWQS) classifies rivers into 6 classes based on beneficial usage, which WQI becomes the base for determination. Hence, it is always confusing for river conservationists and managers to refer two different systems besides weakness in existing WQI which don't have biological components as unit of measure.

1.2 Problem Statement

In Malaysia, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Ammoniacal Nitrogen (NH_3-N) and pH are six physico-chemical parameters employed by DOE to evaluate river water quality (DOE, 2017). Their values grouped together to form Water Quality Index (WQI) to state a river's quality. Lack of biological aspects in Malaysian Water Quality Index poses doubt on complete status of river or better known as river health. As noted in many researches, focus has shifted from mainly physical and chemical measures to more biological aspects to assess river condition (Singh & Saxena, 2018). There are no existing integrative indices which collectively involve physical, chemical and biological aspects to measure river health in Malaysia. Urban rivers particularly do need complete assessment in terms of integrative indices as usually biological life will be affected due to concretization process. Having biological components in integrative indices will ensure future management to plan and implement mitigation measures to suit incorporation of biological life into river.

Sungai Penchala is one of the eleven tributaries of the heavily urbanized Sungai Klang. This urban river by nature starts in Federal Territory of Kuala Lumpur and flows through Selangor. Both these states are very well known for their heavy human densities as well as urbanization factors respectively. Sungai Penchala mainly used for flood control, pollutant movements and for recreational purposes. Sungai Penchala which is 14km long has the mix of different types of human activities such as residential, industrial, as well as commercial activities that possibly contribute to river pollution. The river water quality starts to deteriorate from Kiara Hill until it joins Sungai Klang at Desaria, Petaling Jaya (DID, 2015). Besides being the urban river that faces pollution issues, the river is also subject of interest for number of river rehabilitation programs as well as studies. For instance, Selangor Department of Drainage and Irrigation (DID) started the Sungai Penchala rehabilitation program since 2000 and continues it until different names of activities. DID KL too focus Sungai Penchala particularly at its upstream for activities. Besides this, Global Environment Centre as NGO together with SPARK Foundation too started Penchala rehabilitation project in 2002 and expanded in a bigger scale in 2015 focusing more on soft approach which is by educating targeted groups on love towards Sungai Penchala. Although various parties are taking measures to protect this small urban river, the river is still struggling to meet its intended target to become clean river or to meet its intended usage. Currently, WQI is being used to monitor the Sungai Penchala health and pollution mitigation measures are planned based on this, similar to other rivers in Malaysia. Since recreational benefits is one among the key beneficial usage of Sungai Penchala, there is need for holistic river health index beyond WQI.

1.3 Aim and Objectives

The aim of this study is to develop a simple tool in terms a holistic index that can give complete status of river health. River Health Index (RHI) will act as alternative approach to determine river health which can be used for other similar rivers in country or neighboring countries. RHI intended to be modified from published framework and tested with small urban river that has different types of anthropogenic activities to represent pollution sources in the country. Sungai Penchala is used as case study. At the end of the study, relationship between RHI with different stretches of urban river which subjected to variable anthropogenic activities also can be explored to know their interrelationship. Development of river health index is first in kind for an urban river in Malaysia, which the outcome can be replicated for other rivers. To achieve this aim, this research was supported by four objectives which are:

1. To define different types of anthropogenic activities in Sungai Penchala
2. To characterize the water quality of Sungai Penchala to anthropogenic activities
3. To characterize benthic macroinvertebrates resulting from anthropogenic behavior in Sungai Penchala
4. To apply modified river health index for Sungai Penchala

1.4 Scope and limitations

The study selected Sungai Penchala as small urban river to be tested with modified RHI due to its land use that affected by different type of anthropogenic activities. Sungai Penchala also provide beneficial usage such as recreation and aesthetic values. Appropriate integrative indices studied, and literature review done to select the suitable published framework. The selected framework studied in detail for its adaptation and modified index in terms of RHI develop to suit local context.

Sampling stations to represent different types of anthropogenic activities set in Sungai Penchala and data collected. Satellite image of sampling stations through desktop study identified and verified during field sampling. The study involved analysis of water quality based on only six key parameters which are DO, COD, BOD, TSS, NH_3-N, and pH to derive Malaysian WQI. The study also determined distribution and diversity of benthic macroinvertebrates to calculate Average Species per Taxon (ASPT) value to represent biological health of river. Both physico-chemical parameters and ASPT were combined to develop River Health Index (RHI), proposed measurement unit for urban river health. RHI developed is modification from existing published framework. Modified RHI tested and validated with Sungai Penchala. The validated RHI can be used in other rivers to plan mitigation based on identified problems. Overall study involved ten stations but RHI only applied for eight stations as two stations were inaccessible for benthic' sampling.

CHAPTER 2: LITERATURE REVIEW

2.1 Urban river pollution

This section spells out pollution within urban rivers. Concept of urban stream syndrome introduced in this section. Urban river pollution in Malaysia also discussed in this section.

2.1.1 Urban stream syndrome

Land use changes in an urban setting always give detrimental effects to stream within that area (Kominkova et al., 2005). Streams in urban areas will have multiple functions. They carry pollutants and suspended solids, provide habitats for living things especially aquatic biota and the area also becomes platform for social as well as cultural activities for human (Walsh et al., 2005). With these key functions, urban streams affected by pollution in recent years attracted number of researchers investigating the impacts of anthropogenic activities on streams.

The degradation and type of changes urban streams going through was better described through 'urban stream syndrome' (Walsh et al., 2005). This term summarizes the impacts into flashier hydrograph, changes in urban channel's morphology. Water quality deterioration leads into changes in ecological health of these rivers. There are number of factors that leading to this syndrome in an urban area.

Sewer overflows (CSO), partially treated or untreated discharge of wastewater, effluents from wastewater treatment plant and sediments from development works are some of the stressors leading to urban river pollution (Kominkava, 2012). Hydro morphological change is one among the alterations described in urban stream syndrome. The changes due to urbanization also have effects on urban river ecosystem. Rain events elevate hydrographs, which there will be plenty of rainwater entering the drains. The rainwater will be quickly drained which the increased flow often needs better flood mitigation. Increased flow with high run-off will give impact to ecological value of river (Pollert, 2004).

Besides this, physico-chemical change is also one important element of urban river syndrome. In an urban setting, there will be continuous inflow of wastewater into the drainage or rivers. For instance, rainwater consisting wastewater from different types of industrial as well as commercial areas will have insoluble substances, organic particles, and toxic materials that can modify existing river water constituents (Gasperi et al., 2010). Organic matter pollution will lead to oxygen deprivation and alterations of redox scenarios of aquatic ecosystem. There will be changes in relocation of pollutants as well as heavy metals that can lead to their bioavailability increase (Burns et al., 2005). Increasing temperature of water due to hotter surfaces of impervious areas, riverbanks without vegetation and heavy buildings are among the factors that lead to urban river syndrome. The altered condition will give impact to solubility of dissolved oxygen in water as well as shorten the periods of natural cold of water (Pollert et al., 2004).

Deterioration of biological components of urban rivers is also one of the urban river syndromes. There are different organisms of aquatic biota in a river. Aquatic biota consists of phytoplankton and macrophytes acting as producers, consumers which are zooplanktons, invertebrates and fish, and decomposers which are bacteria and fungi (Kominkava, 2012). Although they are different levels of aquatic biota in the river, they are interrelated which collapse of one group will affect the others. These fauna are vulnerable to both quantity and quality of water in urban rivers. This makes aquatic organisms used as bio-indicator whereby diatoms and macroinvertebrates commonly used to indicate health of urban rivers (Booth, 2005; Walsh et al., 2005).

With the physico-chemical parameters and biological components addressed, urban stream syndrome should considered into planning by relevant authorities. Any restoration or rehabilitation measures will be made effective, if mitigate actions planned based on symptoms of this syndrome.

2.1.2 Urban river pollution in Malaysia

Malaysia being developing country, has developed very rapidly for last three or four decades with heavy urbanization (Chan, 2005). Only 46% rivers in Malaysia found to be clean while 51 rivers (11%) found to be polluted (DOE, 2017) d. 58% of rivers found to be clean in year 2008. This shows Malaysia lost 12% of clean rivers within just 10 years.

Most (53%) of the polluted rivers located in Johor state (DOE, 2017). Sebulung River, Sengkuang River, Tampoi River and Tukang Batu River are among the most polluted rivers in Malaysia, located in Johor Bahru, urbanized town. Tukang Batu River is only river in Malaysia that recorded Class V river which indicates the river is in dead state.

In Malaysia, river pollution caused by both point sources and non-point sources. Point source pollution in Malaysia monitored under Environmental Quality Act 1974 (DOE, 2017). Non-point source pollution on the other hand is due to run-off and not monitored through any legislations (Zaki, 2016). Under the Environmental Quality Act 1974, changes in chemical nature of the waterbodies against limited condition are considered as water pollution. Hence, pollution load in waterbody due to the discharge of waste or pollutants that caused impaired beneficial use of water, hazardous to health, safety or welfare, animals, fish or aquatic life or violation of any condition, limitations or restrictions prescribed under the Environmental Quality Act 1974 are important to be determined. Pollution load calculated by Department of Environment Malaysia (DOE) to investigate the type of pollution in rivers (DOE, 2017).

The calculation of pollution loads focused to five (5) types of pollution (DOE, 2017). The accounted pollution sources are manufacturing industries, sewage treatment including individual septic tank (IST), centralized septic tank (CST), piggery, agricultural industries and wet market. Biochemical Oxygen Demand (BOD), Suspended Solid (SS) and Ammoniacal Nitrogen (NH_3-N) are the three (3) main parameters that give the significant effects to water quality and commonly discussed (DOE, 2017).

A total of 545 tonnes/day pollution load for Biochemical Oxygen Demand (BOD) were generated in year 2017 (DOE, 2017). Sewage remained the largest BOD loads generator with a total load of 268 tonnes/ day (49%) and followed by piggery which precipitating 210 tonnes / day (39%). Suspended Solids (SS) loads gave in a total of 909 tonnes/day in which piggery remained the largest contributor with a total load of 437 tonnes/ day (48%) and followed by sewage 355 tonnes/ day (39%). Assessment on Ammoniacal Nitrogen (NH_3-N) loads resulted in a total of 229.3 tonnes/day. Analysis showed that sewage is the largest NH_3-N load with 190 tonnes/ day (82.9%) and followed by piggery generating 26 tonnes/ day (11.3%).

Urban areas are more polluted than rural places due to industrialization, sewage discharge and other domestic activities (Chan, 2005). Anthropogenic activities such as industrial discharge, domestic effluents, the use of agricultural chemicals, land use and cover changes are the major factors that influence surface water quality (Zhang et al., 2010). Nutrient and organic pollution caused by anthropogenic activities poses threat to urban river condition as well. Nutrient and organic pollution includes point source and nonpoint source pollution, such as domestic wastewater, effluent from wastewater treatment plants and agricultural run-off. Heavy metal pollution considered as point source pollution and primarily discharged from smelting and heavy industrial enterprises (Zhang et al. 2010). Besides this, solid waste also can be one of the big sources of pollution. For instance, DOE identified garbage thrown by the public is the main cause of river pollution in Penang state (Chan, 2005).

May (2006) found that urban catchments were highly correlated with nutrients such as ammonium ions, reactive phosphates and suspended solids. Stream channelization is a common practice in urban area. Stream channelization is done to move, widen, narrow, straighten, shorten, cut off, divert, line or fill a natural or altered stream channel. Stream channelization can lead to changes in the amount and speed of the water flowing through the channel. Channelization normally done by lining the channels with concrete, excavating sand and gravel from the stream bed and sloping it back along the banks, or constructing culverts. Channelization may affect the water quality in the following ways (Meyer et al., 2005):

- Drinking water quantity: an increase in the velocity of water may bring into less recharge of groundwater. The impact would be more visible in areas where groundwater is an important source of drinking water and its replenishment is slow.

- Increased nutrients: Increased accumulation of nutrients in streams would lead to algal blooms which can affect human health as well as animals such as livestock.

- Pollution in streams: Streams channelization cause floods, where huge water run-off will pick up pollutants such as phosphorous, nitrogen, pesticides, sediments and heavy metals (Taylor & Owens, 2009). This affects the stream water quality; eventually increase the cost of drinking water treatment. Removal of trees and vegetation along the stream bank may increase the pollutants in streams, including nitrogen, phosphorous, *Escherichia coli*, pesticides and sediment. There also possibility for an increase in water temperature and consequently the dissolved oxygen in water may decrease.

2.2 River monitoring

River monitoring plays crucial role in management of rivers especially urban rivers. There are different types of parameters concerned when comes to river monitoring. Following section gives insights on Malaysian Water Quality Index, unit of measurement of rivers in Malaysia. Besides this, biological monitoring and its importance highlighted in this section.

2.2.1 Malaysian Water Quality Index

DOE Water Quality Index (WQI) is the common value used to represent the status of rivers in Malaysia (DOE, 2017). WQI is computed based on six physico-chemical parameters which are pH, dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), and Ammoniacal Nitrogen (NH_3-N). The WQI calculations are performed not on the parameters themselves but on their sub-indices. The sub-indices are named SIPH, SIDO, SICOD, SIBOD, SISS and SIAN respectively. Table 2.1 shows the DOE's six key parameters according to classes (Table 2.1).

Table 2.1: National Water Quality Standard (NWQS) for Malaysia (Source: DOE, 2017)

Parameter	Unit	Classes					
		I	IIA	IIB	III	IV	V
pH		6.5 – 8.5	6 - 9	6 - 9	5 - 9	5-9	-
DO	mg/L	7	5-7	5-7	3-5	<3	<1
BOD	mg/L	1	3	3	6	12	>12
COD	mg/L	10	25	25	50	100	>100
SS	mg/L	25	50	50	150	300	300
NH_3-N	mg/L	0.1	0.3	0.3	0.9	2.7	>2.7

WQI argued to have limitation in representing the actual health of river. This is because biological characteristics such as Total Coliform, Faecal Coliform, diversity of benthic macroinvertebrates and important heavy metals are not included in the summation for WQI although their limits specified in National Water Quality Standards.

In addition, WQI and classes for beneficial usages of river are always confusing. Malaysian river classified into beneficial usages based on DOE's six classes (Table 2.2). Class II has two sub-classes (Class IIA and Class IIB) each having different beneficial uses. On other hand, DOE only have Class II, which has single range of WQI limit from 76.5 to 92.7. It is always confusing whether Class II standard limit applicable for beneficial usages of both Class IIA and Class IIB respectively. Moreover, the key parameter for body contact, Feacal Coliform's concentration is not considered in WQI computation which gives a scenario even though particular river is within Class II limit, microbiological sampling is still needed beyond WQI to ensure beneficial usage (body contact in this case) to be met.

Table 2.2: Classification of rivers (Source: DOE, 2017)

Class	Uses
I	• Conservation of natural environment • Water supply I – practically no treatment necessary (except by disinfection or boiling only) • Fishery I – very sensitive aquatic species
II A	• Water supply II-conventional treatment required • Fishery II – sensitive aquatic species
II B	• Recreational with body contact
III	• Water Supply III – advanced treatment required, • Fishery III – common (economic value) and moderately tolerant species • Livestock drinking
IV	• Irrigation
V	• None of the above

Thirdly, summarized data will only represent short-term water quality at that place or time. WQI based on these parameters needed continuous monitoring as well as at different places to represent overall health of river. WQI can be a reporting tool to convey the river status to general population, but rehabilitation or restoration of impaired river cannot depend on WQI alone but need further data especially biological or microbiological components.

Each of six parameters carry respective weightages in Water Quality Index (WQI) calculation. Among those, DO carries maximum weightage of 22% and pH carries the minimum of 12% in the WQI equation (DOE, 2017). Each of the parameters have sub-indices incorporated to calculate overall Water Quality Index. It is understood that except Ammoniacal Nitrogen, values for other parameters exceed the limits stated in the effluent standard A and B of the EQA. It is suggested that the lower and upper limits of the parameters should be revised with respect to the effluent standards and the requirements for raw water quality criteria set by the Malaysian Water Association (Mamun & Zainuddin, 2013). The revision is necessary, especially for the rehabilitation of urban rivers, which does not have adequate base flow due to high impervious surfaces in the river basin.

WQI index always confused by river management authorities when comes to reporting. DOE report the WQI based on three main classifications (Table 2.3) while WQI also can be classified based on NWQS' 6 beneficial classes (Table 2.2). It is always confusing when river conservationists report other way around. Although Water Quality Index (WQI) is the current measurement unit to assess the river water quality in Malaysia, its limitation show that it needs to be considered for revision as well as improvement.

Table 2.3: DOE Water Quality Classification Based on Water Quality Index (Source: DOE, 2017)

Parameter	Index Range		
	Clean	**Slightly Polluted**	**Polluted**
Ammoniacal Nitrogen	91-100	80-90	0-79
Biochemical Oxygen Demand	92-100	71-91	0-70
Total Suspended Solid	76-100	70-75	0-69
Water Quality Index (WQI)	81-100	60-80	0-59

2.2.2 Biological monitoring

Biological monitoring can be done with any living organisms which they are known as biological indicators but benthic macroinvertebrates, fish, and periphyton (algal) assemblages are used more often, in this order (Norris, 2000). Benthic macroinvertebrates, or more simply "benthos", are animals without backbones that are larger than ½ millimeter in size (Yule & Yong, 2004). Benthic organisms that live on or within sediments, rocks, logs, debris and aquatic plants during some period in their life span includes immature forms of aquatic insects, mollusks, aquatic worms and crustaceans (Minshall & Minshall, 1977).

Benthic macroinvertebrates used most often based on several reasons. First, macroinvertebrates do not migrate in a short -term period, thereby ensuring exposure to a pollutant or stress reliably conveys local conditions. This reliable presentation of ecological condition allows for comparison of sites that having close proximity. Secondly, macroinvertebrates life stages are short enough that sensitive life stages will be affected by stress, but long enough that any impairment is measurable in the assemblage. Macroinvertebrates are found in even the smallest streams and have a wide range of sensitivity to all types of pollution and stress, allowing for monitoring in most conditions. Finally, sampling macroinvertebrates is easier, cost effective, and does not permanently harm the local assemblage (Norris, 2000).

Different from higher invertebrates, the lower invertebrates are lacking in detailed taxonomy classification and this includes all the invertebrates except molluscs and arthropods (Lewis, 2008). Since these animals live in the water for all or part of their lives, they are highly dependent on water quality for survival (Water and Rivers Commission, 2000). Most of the benthic macroinvertebrates start their lives in the water and have different life cycles. The most common type of macroinvertebrates are aquatic insects (Water & Rivers Commission, 2000).

Macroinvertebrates are important in the aquatic food chain and they can be categorized on the roles as functional feeding groups which generally determine their abundance in the river (Water & Rivers Commission, 2001). The shredders feed on organic material, such as leaves and woody materials and convert this matter into finer particles. They comprised of amphipods, isopods, freshwater crayfish and some Trichoptera (caddisfly) larvae (Water & Rivers Commission, 2001). Collectors or filter feeders feed on fine organic particles produced by shredders, microorganisms and by physical processes. Collectors include Ephemeroptera (mayflies) nymph, mussels, water fleas and worms (Water & Rivers Commission, 2001).

The scrapers graze on algae and other organic matter attached to rocks and plants. Examples of scrapers include snails, limpets and Ephemeroptera larvae. Lastly, the highest level of Predators feed on live prey and this includes dragonfly and damselfly larvae, adult beetles and beetles larvae, some midge larvae and some stonefly larvae (Water & Rivers Commission, 2001).

Biological indicators are becoming useful in assessing the overall effect of environmental contaminations by their role in aquatic ecosystems (Azrina et al., 2006; Durran, 2007). Those biological indicators describing the condition and threats to freshwater ecosystems are required to measure progress in halting the rapid decline in freshwater species. Tolerance of bio-indicator organism usually have its limit; therefore the presence or absence and its health state can determine some of the chemical and physical components in the environment without the complex measurement and laboratory work. Changes in benthic macroinvertebrates community with water pollution have many been documented and measured using different aspects including biomass, species density and species composition (Cranston, 2004).

Many studies have used benthic macroinvertebrates as bioindicators specially to assess the anthropogenic activities (Akmal et al., 2013; Kok, 2016; Mustow, 2002). There are several reasons, which explain the popularity of macroinvertebrates as an indicator of water quality. Firstly, they are present everywhere, which makes them vulnerable to different types of changes in the aquatic systems. There are many species, and this provides various responses to environmental stresses (Yule & Yong, 2004) and their sensitivity to organic pollution. Secondly, the sedentary nature of benthic macroinvertebrate allows effective analyses of disturbance effects and lastly, having a long life cycles compared to other groups allows illumination of temporal changes in environment (Yule & Yong, 2004). Macroinvertebrates as biological indicator has certain range of physical and chemical conditions in which they can survive, where some organisms are tolerable to a wide range of conditions, while others are very sensitive and cannot tolerate changes. They indicate excellent, good, fair or poor water quality. The EPT (Ephemeroptera, Plecoptera and Trichoptera) orders are observed as pollution sensitive and thus makes them important indicators with excellent water quality. Pollution tolerant organisms that can adapt to poor water quality include leeches, aquatic worms and some Diptera larvae (Yule & Yong, 2004).

In many parts of the world, various measurements on biological indices had been invented and improved using stream macroinvertebrate to detect and monitor water pollution, species abundance and other form of human impacts. The rivers in Thailand once used Biological Monitoring Water Party (BMWP) score in classifying water quality in Thailand (Mustow, 2002). However, due to the incapability of distinguishing between sites of highly impacted by pollution and relatively unpolluted sites, the

BMWP score was later being modified (Mustow, 2002). The working party has developed a standardized score system derived from the degree of intolerance to pollution. A standard list is used based on National Water Council 1981 with scores from 1 to 10, categorizing from the most to the least pollution tolerant, respectively (Mustow, 2002). The Average Score per Taxon (ASPT) is the sum of the score of all the families collected, and divided by the number of taxa used in the calculation (Mustow, 2002).

The average sensitivity of the families of the organisms present is known as the Average Score Per Taxon (ASPT) and can be determined by dividing the BMWP score by the number of taxa present. A high ASPT score is considered indicative of a clean site containing large numbers of high scoring taxa (Armitage et al., 1983).

The highest score of ASPT is 10. Similar to BMWP, water quality also can be categorized to clean, moderately clean and polluted water quality based on ASPT score. Table 2.4 shows the water quality class based on ASPT index score.

Table 2.4: ASPT Index score based on water quality class (Source: Mandaville, 2002)

Score	Water quality class	Category
7.6-10	Very clean	A
5.1-7.5	Clean	B
2.6-5.0	Moderate clean	C
1.0-2.5	Polluted	D
0-0.9	Very polluted	E

2.3 River health

River health is global concept and key component for monitoring when effective management is a concern. Concept of river health and related monitoring initiated in Europe as well as other countries in 19th century and spread to worldwide due to its importance (Norris, 2000). Importance of river health also leads into development of index incorporating parameters related to it and widely used in many countries. Following section gives limelight on river health and its related indices.

2.3.1 Concept of river health

The River Health Programme was initiated in South Africa in order to determine the ecological status of river systems, as a basis towards supporting the rational management of river ecosystems (Norris, 2000). According to Norris (2000), River Health Programme (RHP) is a management information system that produces information for a specific objective. The primary focus of the RHP is to determine the health of aquatic ecosystems. River health is assessed by studying the fauna and flora that exists in the river. Macroinvertebrates are good short to medium term indicators of ecosystem health, while fish and riparian vegetation are good long-term indicators of river health. By using these biological indicators, the status of the rivers' health can be monitored and if necessary, corrective action taken. The integration of biological indicators with chemical and physical indicators can be used to assess the river health of a river. The aim is to ensure public health protection and to protect the desirable water quality.

Anthropogenic activities can alter water flow and degrade river habitats and biotic conditions (Aazami et al., 2015), which have great impacts on river ecosystem health. Land use types are closely related to the characteristics of anthropogenic activities, which in turn determine the anthropogenic substances carried into hydrological systems through run-off processes (Lee et al., 2014). Land use intensity is also an important factor that controls the structure of aquatic communities and can be used as a proxy of the composition and structure of macroinvertebrate assemblages (Tornblom et al., 2011). Landscape characteristics are widely accepted as factors that strongly influence stream water quality (Kandler et al., 2009). Economic development level also has a strong effect on nutrient pollution (Duan et al., 2009). Population density and industrial development have been important drivers of water quality deterioration in inland waters (Duan et al., 2009, Zhou et al., 2017). Because administrative units do not encompass the entire watershed in most cases, the number of studies linking socio-economic metrics to water quality are limited (Zhou et al., 2017). Munyika et al. (2015) reported a study on Orange River in Namibia by applying the South African Scoring System 5 (SASS5) to assess the current water quality and overall health status of the river using physical, chemical and biological parameters and their link with the land use pattern.

2.3.2 Development of river health index

There are number of indices used to represent the health of a river. Globally, biotic indices and multi-metric approaches frequently used to measure river health (Singh & Sonali, 2018). Multi-metric approach is widely practiced in US and it is seen as an approach that presents data in an easier way that can be understood by anyone. However, multi-metric approach lacks its credibility in accessing the river health in terms of deficiency in its matching with reference sites with test sites, metrics selection which been compromised and sub-indices that lacks independence (Norris, 2000).

Moreover, predictive models also quite popular in accessing the river health. For instance, RIVPACS is one type of predictive model approach that commonly used in United Kingdom (Wright, 1995). It is a mode of statistical model that predict aquatic macroinvertebrates that would be found in a site if environmental stress is absent. This in turn will be compared with existing taxa in a place and this can be done effectively in a site-specific basis (Simpson et al., 1996). The river health assessment till date can be divided into three main approaches which are (Singh & Sonali, 2018):

1) Single metric studies (e.g. flora, fauna, biological etc.)
2) Ecological related studies (e.g. plant photosynthesis rate, plant respiration rate etc.)
3) Composite indices (e.g. based on physico-chemical and biological parameters)

South African Scoring System version 4 (SASS4) is one example index developed to assess the health of aquatic ecosystems in Africa (Vos et al., 2002). Overall Index of Pollution (OIP) is an index proposed to classify surface water quality for India (Sargaonkar & Deshpande, 2003). OIP uses only physico-chemical parameters and does not include biological parameters.

River health assessment is also getting popular in China as many studies are focusing on this. River health (RH) score was used to assess the Lia River (China) health condition (Meng et al., 2009).

The formula used was:

$$RH = \sum_{l=1}^{n}(EHi \times Wi) \tag{2.1}$$

Where *EHi* represents the value of the ith assessing index; *Wi* is the weight value of the i^{th} assessing index. The study found biological properties through algae biomass and benthic index directly proportional to physico-chemical characteristics of the river.

Besides this, biotic index using macroinvertebrates developed and used to measure health of lotic ecosystems of Singapore (Blakely et al., 2014). The index has tolerance value ranging from 1 to 10. This tolerance value calculated by summation of scores of all taxa present at one site and divided by number of taxa present to calculate the index which is better known as SingScore. It can be calculated based on following formula:

$$SingScore = \left(\sum_{i=1}^{i=S} ai \,/ S\right) \times 20 \tag{2.2}$$

where *S*= total number of taxa in the sample; *ai*=tolerance value for the i^th^ taxon.

In addition, health of Chambal River in India assessed through three indices which are River Pollution Index (RPI), Ecological Quality Index (EQI), and Overall Index of Pollution (OIP) (Yadav et al, 2014). River Pollution Index (RPI) used four parameters namely DO, BOD, SS and NH_3-N to compute the index (Liou et al., 2004).

Ecological Quality Index (EQI) calculated as follows:

$$EQI = \{\text{Status no. for } EQI \text{ of } CTSI + \text{Status no. for } EQI \text{ of } WQI + 1/\ SID\} \tag{2.3}$$

Where *CTSI* stands for Carlson's Trophic State Index; *SID* is Simpson's Index of Diversity. The third index used for this river health measurement was Overall Index of Pollution (OIP) and this can be computed as follows:

$$OIP = \sum_i Pi/n \tag{2.4}$$

River health (RH) index was developed for Ylang-Ylang River in Philippines using participatory approach among experts which determined the scoring scheme of each identified indicators (Kristine, 2018). The index had equal weightages for both physico-chemical indicators and biological indicators, determined based on experts' opinion. Table 2.5 shows the classification of rivers based on developed RHI for Ylang-Ylang river.

Table 2.5: Classification of rivers based on RHI

River Health Score	RHI indicator
5	Very good
4	Good
3	Moderate
2	Poor
1	Critical

The RHI developed taking Ylang-Ylang river can be good basis to be replicated especially in Malaysia as all three indicators including physical, chemical and biological can be measured for rivers here as well.

2.4 Urban river management

River management is important to ensure river meets its intended usage as it benefits both mankind as well as environment. Many frameworks were established to be the foundation for effective river management. Unfortunately, the management frameworks including Integrated River Basin Management (IRBM) is not localized neither specifically tailored for urban rivers but applies for all types of rivers. Following section gives insight on current river management frameworks that can be related to urban river management or at least can be considered as a foundation to be modified on to suit urban river management.

2.4.1 Integrated river basin management

Integrated River Basin Management (IRBM) better understood as mean of coordinating the process of planning, development, management and use of land, water and related natural resources within hydrologic boundaries. The development of regional and national strategies for IRBM gained momentum during World Summit on

Sustainable Development (WSSD) in 2002 (Salman, 2004). It was reported during this period that new organizations such as Global Water Partnership (GWP) and World Water Council (WWC) urged governments to pursue a more integrated approach for land, water and other resources management.

Practical application of IRBM has remained problematic although there has been extensive support for the concept (Margerum & Hooper, 2001). This is because IRBM involves many and different stakeholders to manage a river basin. In Malaysia, river management is carried out by all three levels of government which are federal, state and local government. Particularly, urban river management are mostly managed by local governments such as city halls and municipalities (Chan, 2005). State government mostly have power over water and rivers which Selangor is one among the good exemplary by having own enactment to manage its own water resources. At federal level, there are policies and initiatives taken to protect rivers. Public sewer systems upgraded and there has been additional construction of sewage treatment plants to improve river water quality that subjects to sewage pollution (Mokhtar, 2010).

However, IRBM as management tool for urban rivers is facing issue mainly due to overlapping powers between federal and state. There is no single comprehensive law that gives platform for IRBM to really succeed for a river, particularly urban river management.

2.4.2 Environmental flow management

Many urban rivers mainly channelized for flood control purpose (Yin, 2018). With flood control in place, the water usually focused more for human uses than river themselves, water needed to sustain ecological value of river. Water shortages is the major reason for ecological degradation (Petts, 2009). Thus, environmental flows (e-flows) or assessing rivers' water requirements, has become important scope of research on this field.

Habitat provision for species and consideration to meet that requirement is also one of the key components of environmental flow assessment. The methods developed currently more suitable for natural rivers, that having high species diversity which makes easier to identify the species that needs protection (Yin, 2018). This is opposite to urban rivers that are channelized, which the current methods are not suitable. This is because river channelization results in the sediment removal from riverbed and lead to increased flow velocity (Goeller & Wolter, 2015). This makes habitat provision element unsuitable for e-flow assessment in urban rivers as the riverbed is altered. Thus, pollutant dilution and aesthetics are usually considered in environmental flow assessment, followed by management according the findings (Wang & Wang, 2004).

Hydrological connectivity is another element to be considered for environmental flow management for urban rivers it linked to river health. It is basically comprising three types of connectivity which are lateral, longitudinal and vertical connectivity. Role of plants and animals in the basin included in lateral connectivity (Besacier et al., 2014; Leigh & Sheldon, 2009). On other hand, issues of species migration and transportation of organic and inorganic materials from upstream and downstream of river included in longitudinal connectivity (Obolewski, 2011). Exchanges between the river and groundwater which includes differentiation between sub-surface habitats such as benthic macroinvertebrates) are covered in vertical connectivity (Casas et al., 2015; May, 2006).

Hence, it can be observed hydrological connectivity with other factors such as pollutant dilution and aesthetics are some of the elements that needed to be included in environmental flow assessment. All these elements are vital to be included in study of river health assessment of urban river. Data on these scopes will help authorities to better manage urban river considering knowledge on environmental flow is still lacking in Malaysia.

2.5 River care initiatives in Malaysia

In Malaysia, there are number of stakeholders such as government agencies, private agencies and NGOs undertaking significant initiatives for better management of rivers.

Government launched 'Love Our Rivers' campaign in 1993 with 10 years of Sungai Klang Cleaning Programme initiated. In 2006, government launched One State One River program (1S1R). Each state chose one river to rehabilitate and Sungai Penchala was chosen river for Department of Irrigation and Drainage, Selangor (Fathoni et al., 2011). In 2011, 'River of Life' was launched focusing on revitalization of Sungai Klang and Gombak River. River of Life (ROL) distinct from other projects undertaken by government as it had Class IIB (suitable for body contact) as rehabilitation target for river. In 2012, 1S1R programme was rebranded as 'living river' mainly to emphasize the livingness of river. Similarly, National Water Resources Policy also adapted. Currently, National Water Resources bill is being promoted for tabling in parliament, mainly aim to have holistic management of river (Ahmad, 2019).

Besides government agencies, river care initiatives also actively promoted through other stakeholders such as private partners and NGOs. For instance, Working Actively Through Rehabilitation and Education (W.A.T.E.R.) is one notable project that initiated in 2007 by SPARK Foundation and Global Environment Centre (GEC), a local Malaysian NGO focusing mainly on urban river rehabilitation. Sungei Way was an urban river which rehabilitated through 'River within River' concept. Class IV-V of that river was managed to improve to Class III through infusion of biological components such as wetland plants, community participation and smart partnership with relevant agencies (Global Environment Centre, 2011). Sungai Penchala is also urban river focused under this initiative which aimed to involve various stakeholders such as government agencies, local community, business partners and youths. Besides private partners and NGOs, higher education institutions such as University of Malaya (UM) and National University of Malaysia (UKM) are also actively involved in river care initiatives in Malaysia.

University Malaysia through its Water Warriors group actively monitor Pantai River that flows through its campus as well as actively involved students and public to care for the river (Utusan Online, 2017). Besides this, National University of Malaysia (UKM) actively involved their students for Alur Ilmu River clean up and rejuvenation that join Langat River, another main source of raw water for seven water treatment plants in Selangor (Kurniawati, 2018).

This shows there are different stakeholders involved in river care initiatives in Malaysia. Urban rivers especially focused in most of their initiatives, evidently showing there are increasing concern for rehabilitation of this type of rivers. Although initiatives such as river restoration and river rehabilitation focused by these stakeholders, it is still unsure on monitoring of impacts through these initiatives. DOE's Water Quality Index (WQI) is still being the standard monitoring means, which lacks holistic view.

2.6 Need of holistic index for urban river

Urban river pollution is well discussed in literatures and it is one among the key concerns of sustainable development. Literatures indicates that there is lack of holistic measurement of river health, hence leading to improper management. There are various types of river health indices already in place but not used extensively. Most of the river health indices used to measure river health are still focusing on physico-chemical properties which leads to incomplete assessment when comes to holistic river health measurement. Urban river health particularly needs holistic measurement as continuous development needed proper monitoring of urban rivers (Benages et al., 2015).

River health index particularly for urban river need to be developed. Research is needed to test and apply developed river health index on an urban river which the successful output can be replicated for other urban rivers in Malaysia. Research results are important especially for planners and river rehabilitation managers in the country. Successful river rehabilitation depends on holistic measurement of baseline data. River health index developed can serve as one of the key aspects of baseline data before initiation of any urban river rehabilitation projects. Successful river rehabilitation will ensure services of urban rivers to society to be met. Besides river rehabilitation managers and planners, society will have access to proper as well as adequate information on urban river health. With adequate information, the monitoring process will be more reliable. Besides this, the index also can be used to set targets of improvement for the river that undergoes rehabilitation process. In other words, river health index is not only used to measure baseline data but also can be included in project management context which the index can be used as yardstick for success of rehabilitation project.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter covers site selection, sampling procedure and statistical analysis used in this study. The study used Sungai Penchala as chosen small urban river to establish river health index. Physico-chemical monitoring and benthic macroinvertebrates study conducted to develop river health index. A total of ten stations selected in the river to achieve the aim of study. Sampling carried out twice a month from May 2016 to September 2016.

3.2 Study Area

Urban river chosen as sampling site for this study. Urban river chosen proposed to be small as current study is one among the pilot initiatives in Malaysia. Currently, there are no available standards to classify the rivers to small and big rivers. However, there are classification of main river basins and small river basins in Malaysia (DID, 2015). Main river basins are defined as basins that has the area more than $80km^2$. Hence, small urban river for this study represented by any river that has catchment area lesser than $80km^2$. Small urban river chosen also must have presence of anthropogenic activities as then only, changes in water characteristics can be observed and tested with developed river health index. Hence, Sungai Penchala in Petaling Jaya chosen as small urban river studied for this research.

Sungai Penchala is the tenth tributary of Sungai Klang which flows in an urbanized area. It has $50km^2$ of the catchment area (DID, 2015). The length of Sungai Penchala is 14km. 12km flows through Petaling District while another 2 km is in the Damansara District. The river source is up on the Kiara Hill, which makes the boundary between Kuala Lumpur and Petaling Jaya. The river being an urban river, flows through a highly developed area, which has increasing human population densities from the upstream to downstream. The river modified for the drainage system and were facing serious pollution in terms of domestic wastewater, industrial wastewater, runoff and solid waste (Fazleena, 2010). There have been previous researches done investigating the WQI trend of Sungai Penchala, focusing its physico-chemical parameters and benthic macroinvertebrates (Akmal et al., 2013; Fathoni et al., 2014). Sungai Penchala Basin also observed to be having different type of anthropogenic activities. Besides this, Sungai Penchala also has Sungai Way River (2km) as key tributary.

3.3 Definition of different types of anthropogenic activities

Ten sampling stations were chosen along Sungai Penchala. Sampling stations named by their places or building nearby. Table 3.1 shows the list of sampling stations.

Table 3.1: Details of sampling stations

Sampling station	Name	GPS Coordinates
1	Kiara Hill	3° 9' 14.3388" N, 101° 38' 7.26" E
2	Lembah Kiara park	3° 8' 52.5804" N, 101° 37' 55.9632" E
3	Rimba Kiara Park	3° 8' 23.0604" N, 101° 37' 36.8112" E
4	Ken Damansara Condominium	3° 7' 43.3164" N, 101° 37' 40.8792" E
5	SS2 Mall	3° 7' 12.5184" N, 101° 37' 39.1152" E
6	BAT	3° 6' 55.9476" N, 101° 37' 43.7016" E
7	Piccadilly	3° 6' 18.1332" N, 101° 38' 4.344" E
8	Avon	3° 5' 25.7964" N, 101° 37' 45.1308" E
9	Sg. Way	3° 4' 44.4216" N, 101° 37' 5.5884" E
10	Desa Mentari Flats	3° 4' 33.7152" N, 101° 37' 18.0444" E

Criteria used to select sampling stations are:

- Nearby to any observable and significant point sources
- The whole river segments (upstream, midstream and downstream) are covered
- Observable types of human activities such as residential, industrial and squatter area taken in account

Figure 3.1 shows the location of sampling stations in Sungai Penchala. Figure 3.2 shows snapshots of the sampling stations. Sungai Way River which is the tributary of Sungai Penchala was also chosen as one of the sampling stations. The type of anthropogenic activities in each station observed and recorded to relate its impact on both water quality and diversity of benthic macroinvertebrates. Anthropogenic activities at 1 km radius of sampling stations studied. Residential areas, commercial, industrial and mixed forms are terms used to define type of anthropogenic activities in Sungai Penchala basin. Google Earth Pro version 6.2 used to identify type of anthropogenic activities and field verification done during sampling.

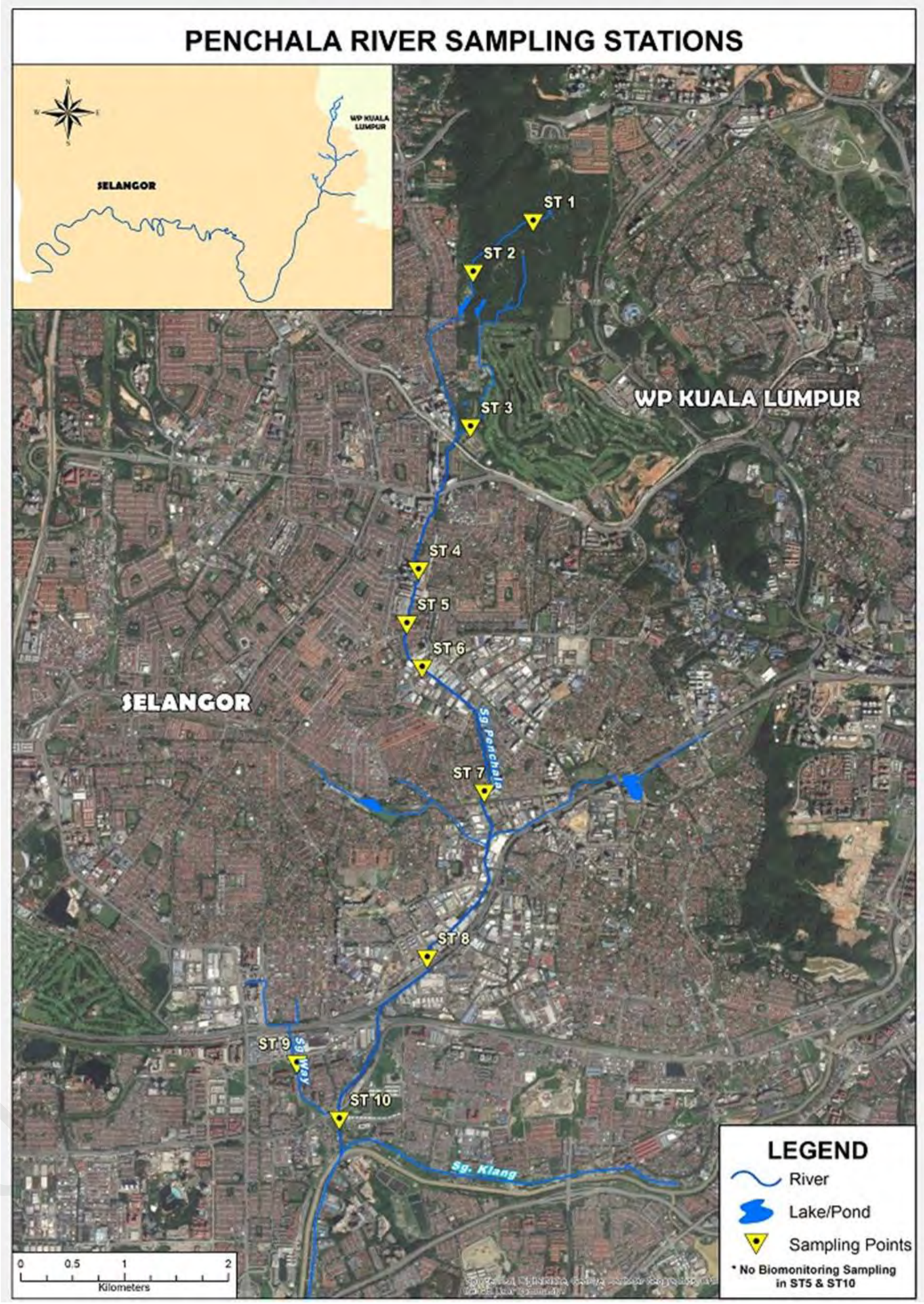

Figure 3.1: Location of ten sampling stations in Sungai Penchala (Source: Google Earth Pro 7.1)

Figure 3.2: Snapshots of sampling station

3.4 Characterization of water quality of Sungai Penchala to anthropogenic activities

Physico-chemical characteristics of river studied to relate impacts of anthropogenic impacts. River water samples collected and analyzed for its physico-chemical characteristics based on APHA methods. Following section gives insights on sampling as well as analysis of physico-chemical characteristics of river water.

River water samples were collected manually using grab sampling method from each ten assigned stations. The samples were collected at a depth of 30 cm below water surface. Water samples were collected at middle of the river. Minimum of 3L of water samples were collected for each station for detailed laboratory analysis. Parameters such as pH, temperature, Ammoniacal Nitrogen and dissolved oxygen were measured in-situ using YSI Quatro Pro Plus water quality multi parameter probe as these are the sensitive parameters. Then, the river water samples were collected in acid washed Polyethylene sampling containers and kept in containers at 4°C for further analysis. The sampling technique and preservation followed the standard methods recommended by American Public Health Association (APHA 2006).

Samplings were done for five months starting from Mei to September 2016. Two sampling per month was done which is on first week and third week of each month respectively. Table 3.2 shows the sampling dates. Water quality sampling carried out at all the ten stations.

Table 3.2: Sampling dates for data collection

No	Month	Sampling date
1	May	2 May 2016
2	May	17 May 2016
3	June	3 June 2016
4	June	15 June 2016
5	July	3 July 2016
6	July	14 July 2016
7	August	3 August 2016
8	August	18 August 2016
9	September	3 September 2016
10	September	17 September 2016

Physico-chemical parameters of river water determined through analysis of river water samples. Analysis of some of the parameters were done on site and other parameters analyzed in laboratory. Temperature, conductivity, pH and Dissolved Oxygen (DO) were measured *in-situ*. These parameters measured using YSI Pro Plus meter (Multi Sensor). Biological Oxygen Demand (BOD) and Total Suspended Solids (TSS) were analyzed in laboratory based on APHA standard methods (APHA, 2006). Chemical Oxygen Demand (COD) was analyzed using HANNA Instruments COD Reagent and DRB200 Reactor. Ammoniacal nitrogen (NH_3-N) were analysed using Ammonium test kits. DOE's Water Quality Index (WQI) were calculated using DO, pH, TSS, COD, BOD and NH_3-N.

The WQI was calculated by DOE (DOE, 2017) equation:

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

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 SS; SI_{pH} = sub-index of pH.

3.5 Characterization of benthic macroinvertebrates resulting from anthropogenic behavior in Sungai Penchala

Benthic macroinvertebrates used as biological unit of measurement to characterize anthropogenic impacts in Sungai Penchala. Benthic macroinvertebrates sampling carried out together with water quality sampling with similar frequency (Table 3.2). Benthic macroinvertebrates study carried out at eight sampling stations except Station 5 and Station 10 as the sites were not accessible for benthic sample collection during this period of study. This is due to the method employed for this study using kick-net sampling method used and one needs to physically get down into the stream or river to collect the benthic macroinvertebrate samples. In this method, the net was placed facing the water flow. Then, area in front of sampler disturbed by kick for about three minutes. The act repeated to collect triplicates at each study site. The sediment samples collected were transferred into plastic buckets, sieved, and transferred into vial and preserved using 70% ethanol. The vials were pre-labelled for each study site before storage (Bwalya, 2015; Hauer & Lamberti, 2011).

Then, the vials were transported to laboratory and the samples were identified till family level using technique referred in Freshwater Invertebrates in Malaysia by Yule and Yong (2004). The macro invertebrate organisms were classified and taxonomically grouped according to their pollution tolerance level. For instance, the organisms were grouped into very sensitive, sensitive, moderately tolerant, tolerant and most tolerant to pollution which refers to organic based pollution. The pollution tolerance index of macroinvertebrates ranged from very high with the maximum score of 10 to the lowest with score of 0. Average Score Per Taxon (ASPT) index was calculated to indicate the biological richness of benthic macroinvertebrates at sampling stations in Sungai Penchala. It can be determined by dividing the Biological Monitoring Water Party (BMWP) score by the number of taxa present (Mandaville, 2002). ASPT index calculation is based on the average value of each taxa (families) sampled which is done by summing up the indicator values and divided by numbers of taxa (families) sampled. A high ASPT index values indicates high biological richness while low values indicate bad/degraded lower biological richness (Armitage et al., 1983).

ASPT was calculated by (Mandaville, 2002):

$$ASPT = \frac{BMWP_S}{Taxa_n} \tag{3.2}$$

where, s = site and n = total number.

Besides this, other ecological diversity indices such as Shannon-Weiner Diversity Index, Margalef Richness Index and Pielou Evenness Index value were calculated to indicate biological diversity for benthic macroinvertebrates.

Shannon-Weiner Diversity Index helps to identify major changes in a community and was calculated in the following way (Shannon, 1948):

$$H' = -\sum \rho_i \ln \rho_i \tag{3.3}$$

where ρ_i is the ratio of individual benthic macroinvertebrates in order *i*.

Margalef Richness Index gives simplified count of number of different species in a study area and was calculated as per follows (Magurran, 1988).:

$$D_{Mg}=\frac{(s-1)}{\ln N} \tag{3.4}$$

Where, s is the total number of species of benthic macroinvertebrates recorded and N is the total number of individuals found in sample.

Pielou's Evenness index shows how close in numbers each species presents in an area (Pielou, 1966) and calculated as per follows:

$$J=\frac{H'}{\ln(S)} \tag{3.5}$$

Which H' is the Shannon -Weiner diversity index and S refers to total number of observed species in a community. The index will have higher values if there are more variations in the benthic community

3.6 Modification of river health index for Sungai Penchala

River Health Index (RHI) proposed for Sungai Penchala. RHI for Sungai Penchala developed using some modification made in published framework which a study developed RHI for Ylang-Ylang River in Philipines (Kristine, 2018). This framework was chosen because it had physico-chemical parameters as well as biological components. In addition, the framework used in Philipines share same region of Southeast Asia where Malaysia located as well.

Firstly, Physico-chemical indicator score was assigned utilizing main six WQI parameters. Class IIB target set (suitable for body contact) to be in line with target set by Malaysian government for River of Life project, Sungai Klang rehabilitation effort. Sungai Penchala is also tributary of Sungai Klang, which similar targets will complement each other. First, total number of physico-chemical parameters complied with Class IIB targets (Table 2.1) calculated. Then, physico-chemical score based on number of complied parameters assigned as per Table 3.3 Based on physico-chemical score, physico-chemical indicator sub-index developed.

Table 3.3: Physico-chemical indicator score for RHI

Number of parameters complied	Physico-chemical indicator score	Physico-chemical indicator sub-index
6	5	Very good
5	4	Good
4	3	Moderate
2 to 3	2	Poor
0 to 1	1	Critical

Biological indicator score was created in line with ASPT range as it is only one value compared to six parameters in WQI. Table 3.4 shows biological indicator score as well as respective sub-index of proposed RHI.

Table 3.4: Biological indicator score for RHI

ASPT Score Range	Biological indicator score	Biological Indicator Sub-Index
7.6-10	5	Very good
5.1-7.5	4	Good
2.6-5	3	Moderate
1.0-2.5	2	Poor
0-0.9	1	Critical

The weightages for each indicator scores followed as per published framework where 33 experts ranging from engineers, environmental scientists, geologists, environmental planners, and NGOs gave their inputs (Kristine, 2018). It had equal percentage (50% and 50%) for both indicator scores which was maintained for proposed RHI for Sungai Penchala, small urban river.

Therefore, 50 percent of physico-chemical indicator score and 50 percent of biological indicator score will be added together to derive River Health Score (RHS) for Sungai Penchala.

Modified RHS can be calculated as per:

$$Modified\ RHS = 50\%_{PC} + 50\%_{B} \quad (3.6)$$

Where, *PC* = Physico-chemical indicator score and *B* = biological indicator score.

RHS calculated lead to modified River Health Index (RHI) for Sungai Penchala as per Table 3.5.

Table 3.5: Modified River Health Index (RHI) for Sungai Penchala

River Health Score Range	River Health Index
4.1- 5	Very good
3.1- 4	Good
2.1- 3	Moderate
1.1 - 2	Poor
0- 1	Critical

3.7 Statistical analysis

Spearman rank correlation (ρ) used to find significant relationship between parameters and it is done through IBM SPSS Statistics Version 22. Correlation between WQI parameters and ecological indices also performed. The Canonical Correspondence Analysis (CCA) was used to investigate the influence of environmental variables on the distribution of benthic macroinvertebrates (CANOCO 4.5).

CHAPTER 4: RESULTS & DISCUSSION

4.1 Inventory of anthropogenic activities

Inventory of anthropogenic activities and its categorization by types of human activities is vital to understand the pollution sources at respective sampling stations. The study had 10 sampling stations. Table 4.1 shows the type of anthropogenic activities at each respective station.

Table 4.1: Type of anthropogenic activities at sampling stations

Sampling station	Name	Type of anthropogenic activities
1	Kiara Hill	• Natural environment • Public park with minimum human intervention
2	Lembah Kiara park	• Public park with more visitors
3	Rimba Kiara Park	• Public park with lesser visitors compared to TLK.
4	Ken Damansara Condominium	• Residential area
5	SS2 Mall	• Mixed commercial area with residential
6	BAT	• Mixed commercial with industry area
7	Piccadilly	• Commercial area mixed with residential
8	Avon	• Highway • Industrial area
9	Sg. Way	• Mix of residential, commercial and industrial area
10	Desa Mentari Flats	• Confluence of Sg.Way, Sungai Penchala and Sungai Klang • Residential

Based on the Table 4.1, sampling station 1 located in secondary forest which has very minimal human activity though the area functions as federal public park. The Sungai Penchala originates at this station, hence, the station considered control for other sampling stations. Second sampling station is also a public park but with more visitors and situated within residential area. Third sampling station which is in also public park has minimal human activities as well. However, this park too situated within heavy residential area. Rimba Kiara park is less popular compared to Lembah Kiara parks, thus have minimal human activity.

The fourth sampling station situated adjacent to high cost condominium which the discharge into the river from residential areas. Fifth sampling station located in mixed commercial area with houses which makes river receives discharge from shops, hawkers, restaurants and residential. Sixth sampling station has mixed commercial area with industrial premises. The sampling station is adjacent to an industry which receiving waters will be filled up with chemical contents though the discharge being treated before it is released into the river. The seventh sampling station has high commercial activities mixed with single story housings. Station 4-7 are located at midstream of Sungai Penchala. Although the whole Sungai Penchala basin is urbanized, mixed types of anthropogenic activities such as industrial, residential, and commercial observed here. The eight-sampling station has highway running across it and have industries surrounding the sampling stations. The ninth sampling station has mix of three types of human activities, namely residential, commercial and industrial.

The last station is also point before Sungai Penchala merges into Sungai Klang. Station 8-10 represent downstream of Sungai Penchala. Overall, the ten stations have different type of human activities at each station, which makes the pollution sources also to be vary.

4.2 Relationship between water quality and anthropogenic activities in Sungai Penchala

Relationship between water quality and anthropogenic activities in Sungai Penchala discussed in two sub-sections. First sub-section covered physico-chemical properties pf Sungai Penchala according to three types of river segments. Second sub-section details the relationship between anthropogenic activities and its impact on water quality index (WQI).

4.2.1 Sungai Penchala Physico-Chemical Analysis

Physico-chemical changes of river water quality within 10 sampling stations analyzed and discussed in this section. Sampling stations divided into three segments which are upstream, midstream and downstream. DO, BOD, COD, TSS and NH_3-N are the five physico-chemical parameters were discussed according to three segments of river. pH discussed overall for ten sampling stations instead of river segments as this parameter didn't show significant variation. Table 4.2 shows the sampling stations according to three types of segments. Possible anthropogenic impacts towards physico-chemical changes also highlighted in each sampling stations.

Table 4.2: List of sampling stations with river segments

Sampling Station	River Segment
1 to 3	Upstream
4 to 7	Midstream
8 to 10	Downstream

4.2.1.1 Upstream

Station 1 (Kiara Hill) reported average DO of 5.39 mg/L which is within range of Class IIB standard (5-7mg/L). Good average DO levels in headwaters indicates the source of Sungai Penchala is still clean and suitable for other aquatic life. Class IIB standard set as benchmark for all the parameters studied as it is possible and practical target that can be achieved for urban river such as Sungai Penchala. BOD reported to be in average of 4.4 mg/L. Although it is higher than Class IIB standard of 3 mg/L, the spike is maybe due to natural degradation of organic matter such as dry leaves and twigs that happening within this source (Wen et al., 2007). Figure 4.1 shows the average DO, BOD and COD levels at Station 1.

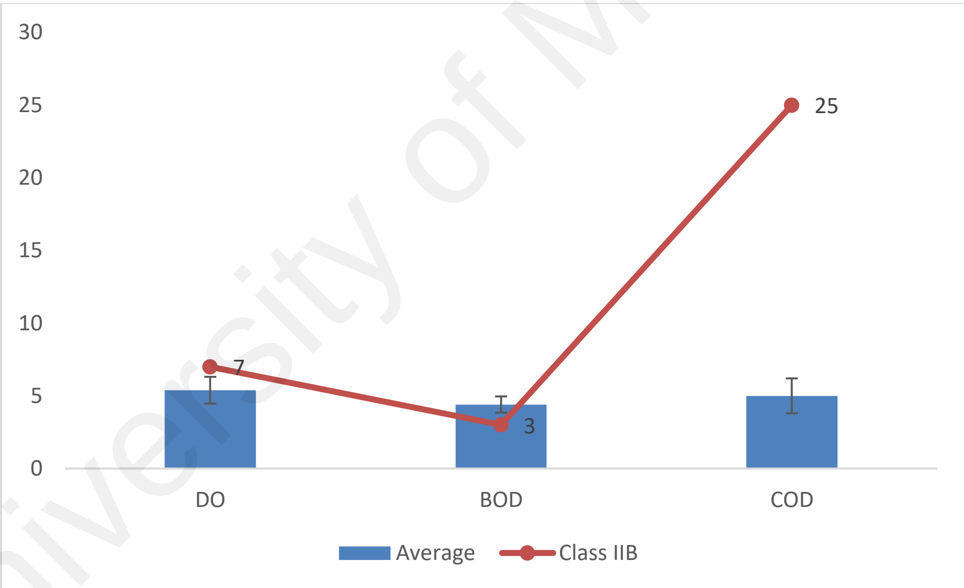

Figure 4.1: Average DO, BOD & COD at Station 1 (Kiara Hill)

Average COD at station 1 (5 mg/L) is also far below Class IIB standard mainly due to absence of industries within this station. Average TSS is also observed to be 3.25 mg/L far below Class IIB standard. The results indicate this site is free from sedimentation impacts and average ammoniacal nitrogen reading shows almost none (0.06 mg/L) mainly due to absence of wastewater treatment plants here. Figure 4.2 shows the average TSS and NH3-N at station 1. Overall, good levels of physico-chemical parameters in Station 1 shows evidence of lesser/almost absence of anthropogenic activities can lead to better river water quality as lesser pollution ending up into river.

Figure 4.2: Average TSS & NH3-N at Station 1

Station 2 (Lembah Kiara Park) is almost similar to Station 1 in terms of anthropogenic activities. However, the river passing through man-made public park which is better known as Lembah Kiara Park. Average DO reported to be 4.53 mg/L which is below Class IIB standard. Average BOD is also reported to be 5 mg/L higher than Class IIB standard, slightly higher compared to Station 1. Average COD reported to be 9 mg/L which is still below Class IIB standard, this reading mainly due to its location within a public park. Figure 4.3 shows the average levels of DO, BOD and COD at Station 2.

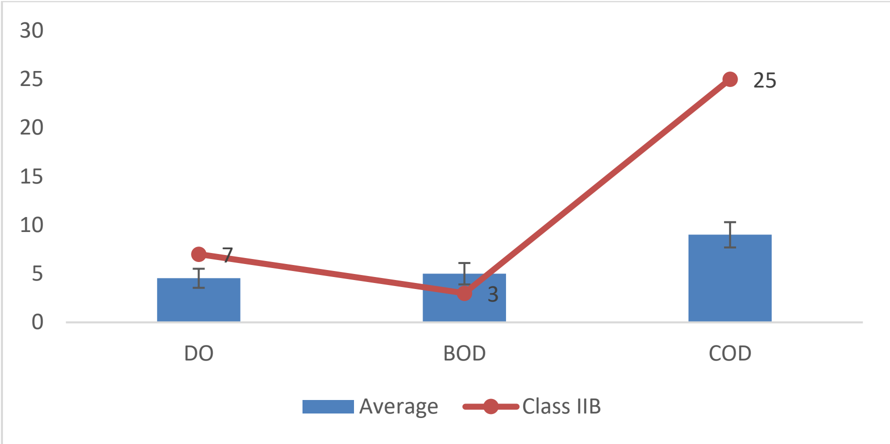

Figure 4.3: Average DO, BOD & COD at Station 2 (Lembah Kiara Park)

Average TSS reported to be 23.5 mg/L (below Class IIB standard) and NH3-N reported to be 1.16 mg /L higher than Class IIB standard. The reading reported in Station 2 is 19 times higher than in Station 1. Spike of NH3-N within 2km distance is maybe due to animal excreta especially from monkeys, which were found abundant in both stations. Either by human or animal excreta can cause total nitrogen loading into river (Gumbo, 2005). Although open defecation by humans don't have evidence for this Station 2 but conversation with public during sampling period confirmed there were cases reported previously. Figure 4.4 shows the average TSS and NH_3-N at Station 2. Overall, water quality reported to be similar to Station 1 maybe due to similar kind of anthropogenic activities except high levels of NH_3-N in Station 2.

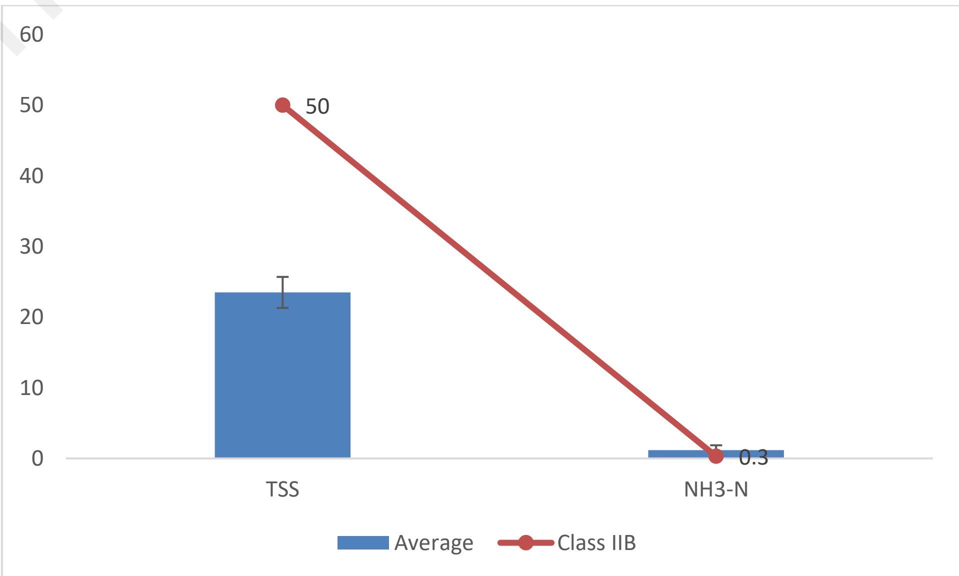

Figure 4.4: Average TSS & NH3-N at Station 2

Station 3 (Rimba Kiara Park) is almost similar to Station 2 in terms of visitors and public park nature. River width is bigger compared to Station 2 (4 times larger). Average DO of 3.87 mg/L observed to be declining from upstream and this condition mainly due to increasing pollution loads such as organic matter, sediments and other non-point sources that can reduce DO levels (Wen et al., 2007). Average BOD, COD and NH_3-N is also reported to be higher maybe due to location of long house settlement known as Bukit Kiara Long House before this sampling station. There is no centralized wastewater treatment plant and the residents are still depending on individual septic tanks (IST) that can possibly contribute to high BOD, COD and NH_3-N due to failure in treating high amount of incoming sewage (DOE, 2017). Figure 4.5 and Figure 4.6 shows the average DO, BOD, COD, TSS and NH_3-N at Station 3 respectively.

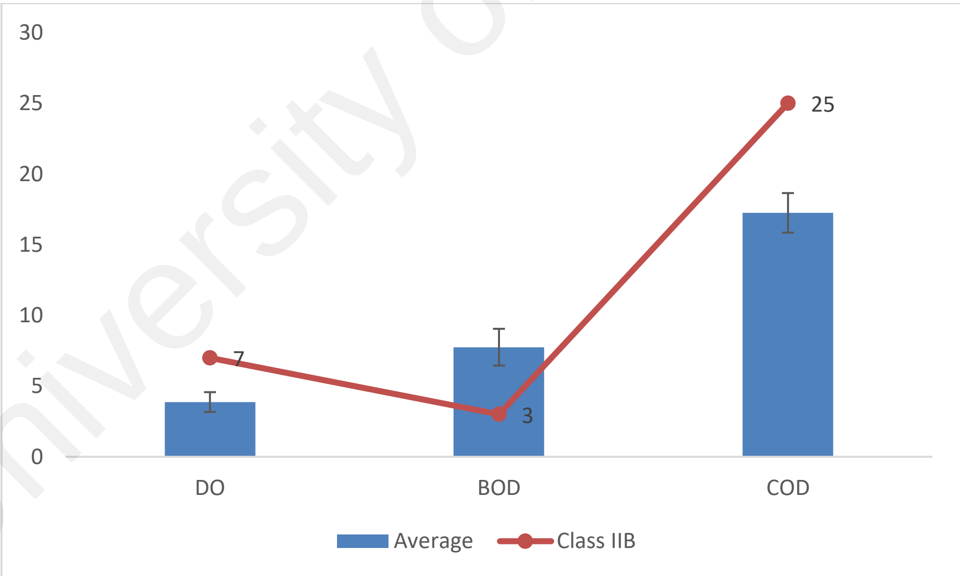

Figure 4.5: Average DO, BOD & COD at Station 3 (Rimba Kiara park)

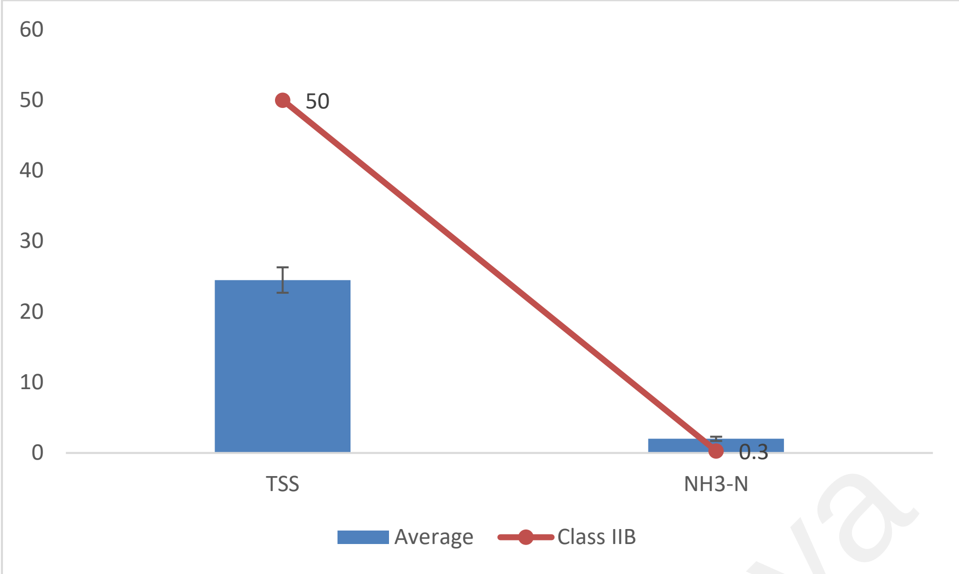

Figure 4.6: Average TSS & NH3-N at Station 3

4.2.1.2 Midstream

Station 4 (Ken Damansara Condominium) is located nearby to Kent's condominium. Station 4 located downstream 1km from TTDI IWK sewage treatment plant (Figure 4.7). Low level of DO and higher BOD as well as COD is maybe due to effluents from sewage treatment plant added with surface run-off (Kominkava, 2012). Figure 4.8 shows the levels of average DO, BOD and COD at Station 4. Besides being located nearby to sewage treatment plant, the water flow in this station also observed to be stagnant during most of the field sampling which also maybe contribute to accumulation of pollutants overtime, leading to poor chemical water quality parameters reading.

Figure 4.7: TTDI IWK Wastewater treatment plant

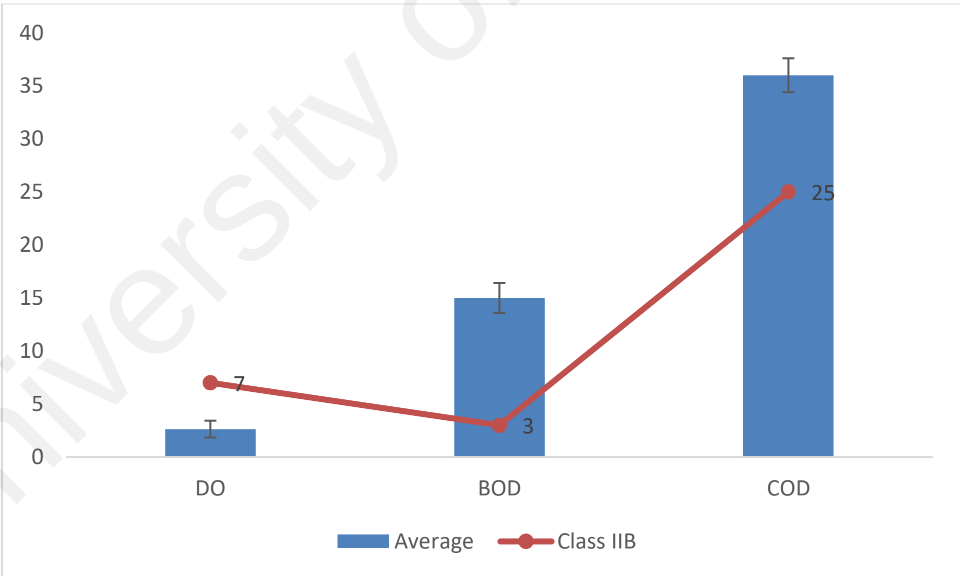

Figure 4.8: Average DO, BOD & COD at Station 4 (Ken Damansara Condominium)

Average TSS is observed to be lower than Class IIB standard and average NH_3-N level reported to be 2.1 mg/L is 7 times higher than Class IIB standard. Higher level of NH_3-N is maybe due to partially treated effluent from IWK wastewater treatment plant. Besides this, greywater from surrounding residential areas also maybe contribute to high level of NH_3-N at this station (Azni et al., 2004; Mohamed et al., 2017). Figure 4.9 shows the average TSS and NH_3-N at station 4.

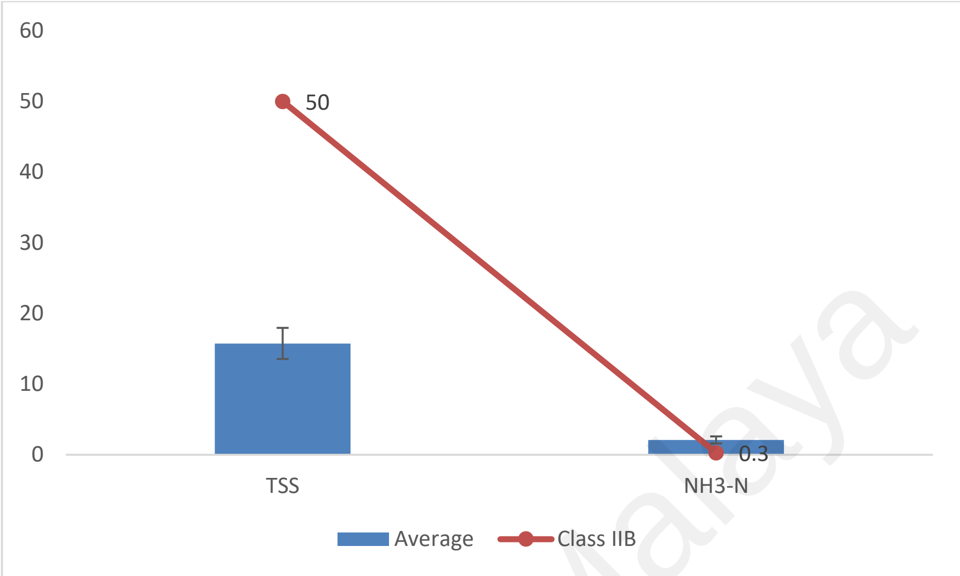

Figure 4.9: Average TSS & NH_3-N at Station 4

Station 5 (SS2 Mall) located within mix of commercial and residential area. Higher levels of average BOD and COD levels indicates the impact of commercial and residential areas which organic loading can be sourced from them. However, average DO level reported to be 3.34 mg/L higher than (27%) compared to Station 2. Although there is not much significant change in type of anthropogenic activities in both Station 4 and Station 5, the river flow observed to be higher in Station 5 compared to stagnant/still water in Station 4. High velocity can increase assimilative capacity of river and dilution of pollutants (Floehr et al., 2013). Average NH_3-N is also reported to be higher than Class IIB standard and is also may be due to effluents from small IWK sewage treatment plant (Figure 4.10) located 800m from sampling station. Figure 4.11 and Figure 4.12 shows the average DO, BOD, COD, TSS and NH_3-N at station 5 respectively.

Figure 4.10: IWK wastewater treatment plant in Section 19, PJ

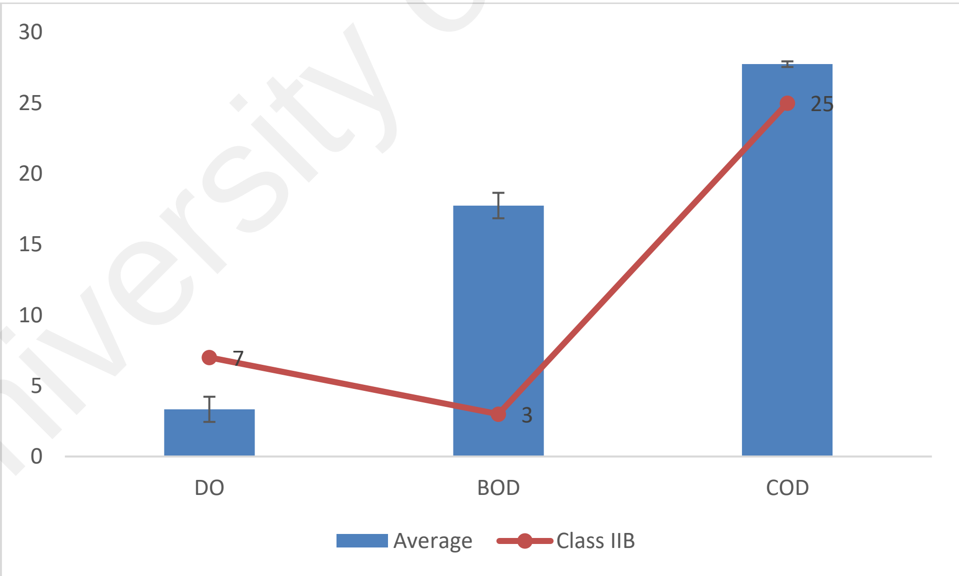

Figure 4.11: Average DO, BOD & COD at Station 5 (SS2 Mall)

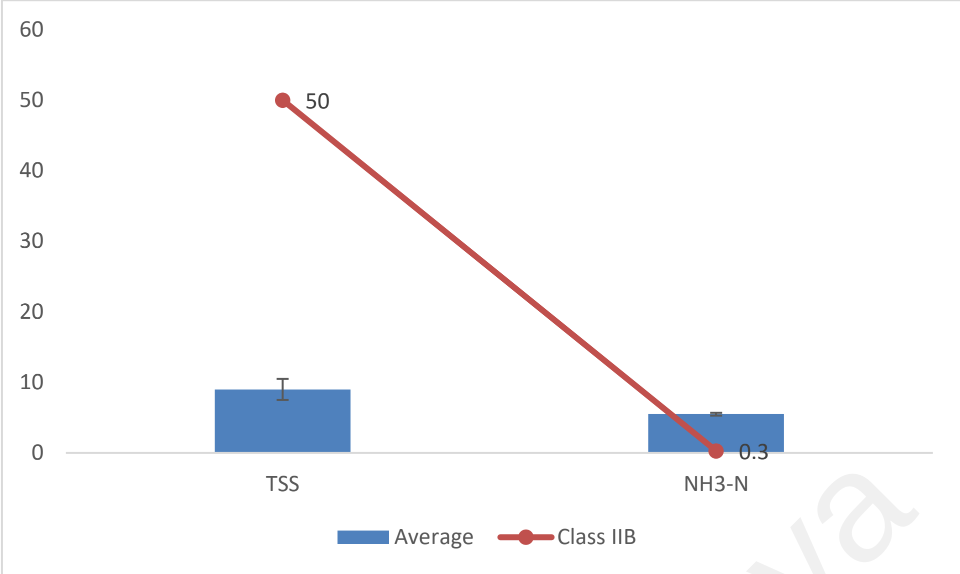

Figure 4.12: Average TSS & NH_3-N at Station 5

Station 6 located adjacent to British Tobacco Factory (BAT) in Petaling Jaya. However, the factory was almost ceasing its operation during the sampling period. Station 6 also have mix of commercial areas with restaurants, roadside stalls, Toyota car workshop, Perodua workshop with other activities. The trend is almost similar to Station 5 maybe due to similar kind of anthropogenic activities taking place in both stations. The pollution level in terms of BOD, COD and TSS can be observed increasing from each sampling stations moving downstream. This situation is best explained by pollutant transport through river network which impact of upstream pollution can be felt downstream as pollutants can be accumulated (Zhang et al., 2010). Figure 4.13 and Figure 4.14 shows the average DO, BOD, COD, TSS and NH_3-N at Station 6.

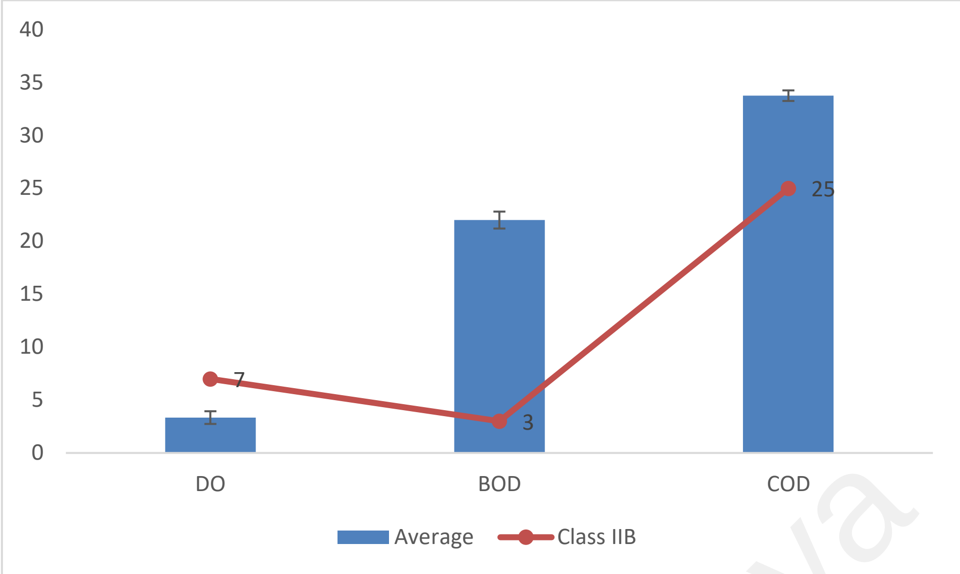

Figure 4.13: Average DO, BOD & COD at Station 6 (BAT)

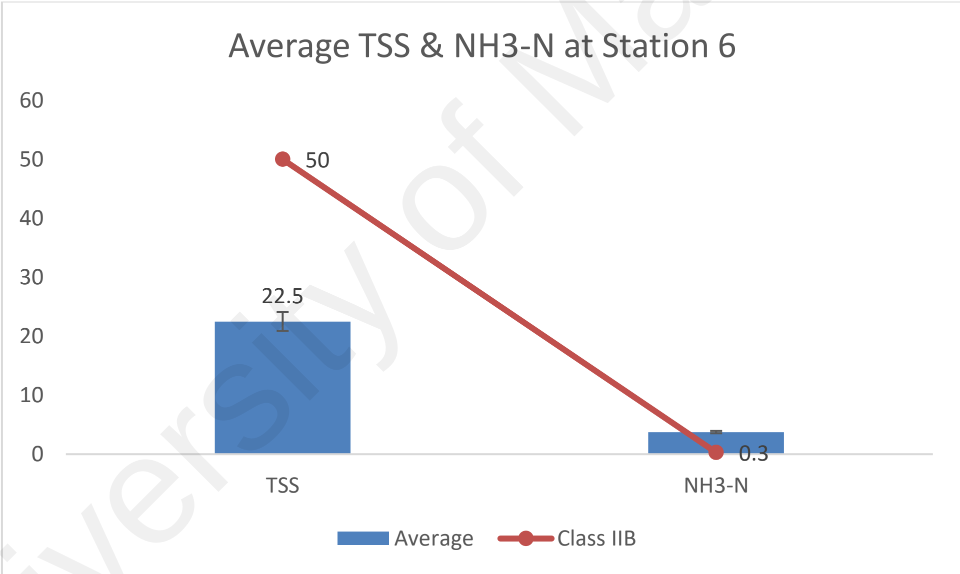

Figure 4.14: Average TSS & NH_3-N at Station 6

Station 7 (Piccadilly) is located within mix of anthropogenic activities as well. The sampling point is just immediately after discharge outlet (Figure 4.15) from Piccadilly Restaurant and Millenium Square in Petaling Jaya.

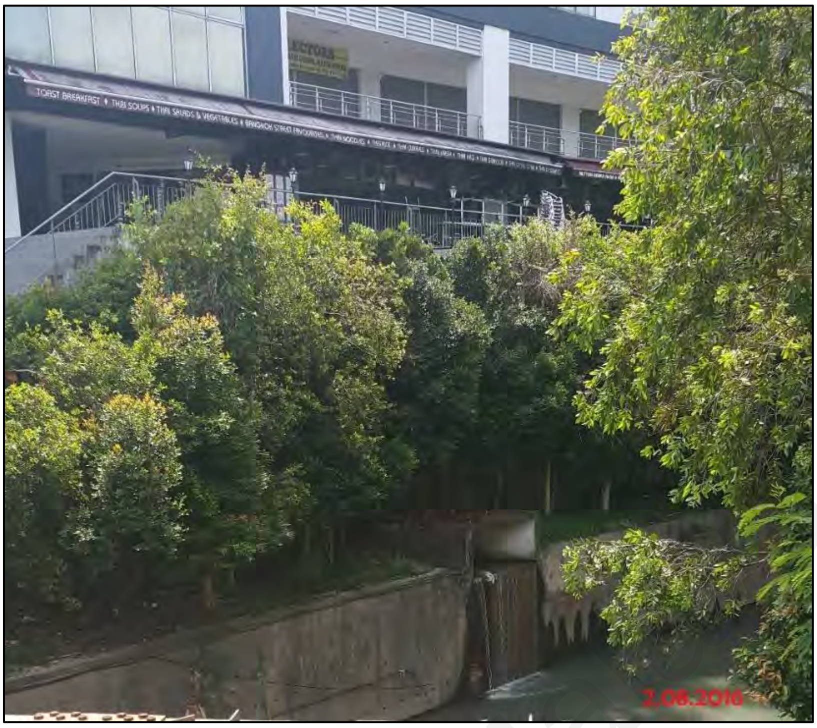

Figure 4.15: Discharge outlet to Station 7

Hence, the higher BOD and COD level reported in this Station maybe due to effluent from commercial areas as well as run-off from nearby residential areas which greywater may constitute major percentage. Figure 4.16 and Figure 4.17 shows the average DO, BOD, COD, TSS and NH_3-N levels in Station 7 respectively.

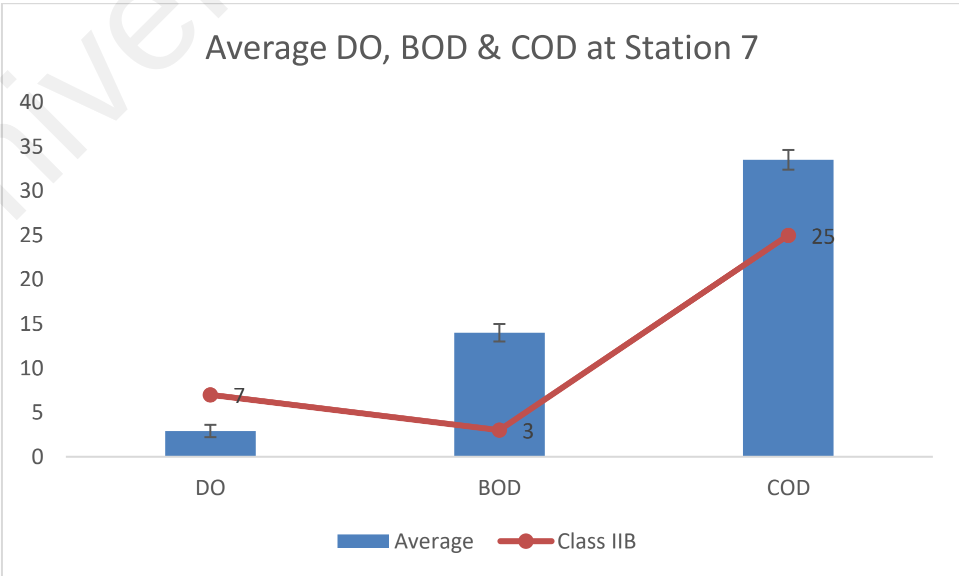

Figure 4.16: Average DO, BOD & COD at Station 7 (Piccadilly)

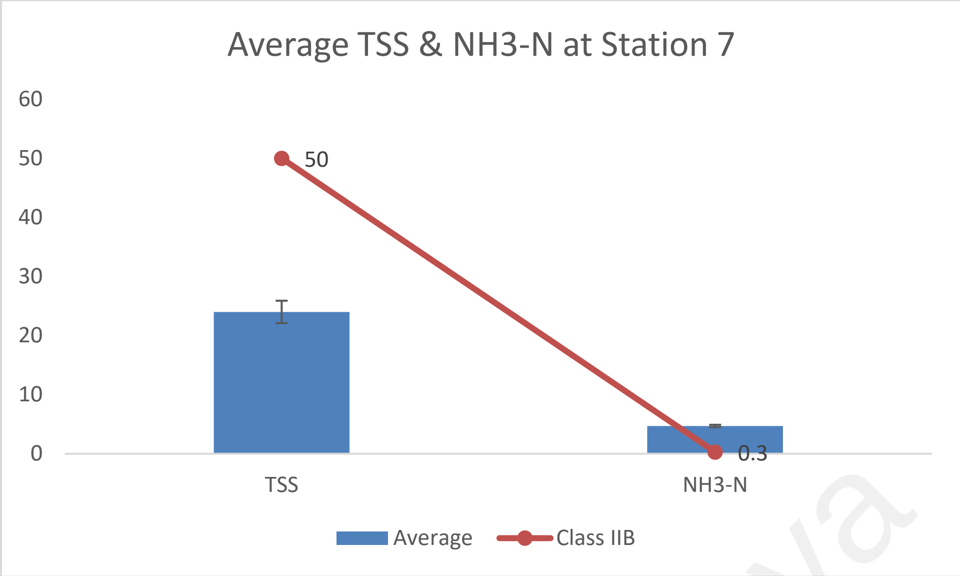

Figure 4.17: Average TSS & NH_3-N at Station 7

4.2.1.3 Downstream

Station 8, 9 and 10 represent downstream of Sungai Penchala. Station 8 located nearby to Federal Highway and besides Avon company. Higher BOD level reported in this station maybe due to similar reasons as per previous stations. However, lower COD reported in this Station compared to previous stations maybe due to lesser industries located within this station's catchment compared to previous stations. Higher level of TSS compared to other stations reported in Station 8, which is mainly maybe due to surface run-off from adjacent highway. Besides Avon, there are sales galleries also located adjacent to this station. Figure 4.18 and Figure 4.19 shows the average DO, BOD, COD, TSS and NH_3-N at Station 8.

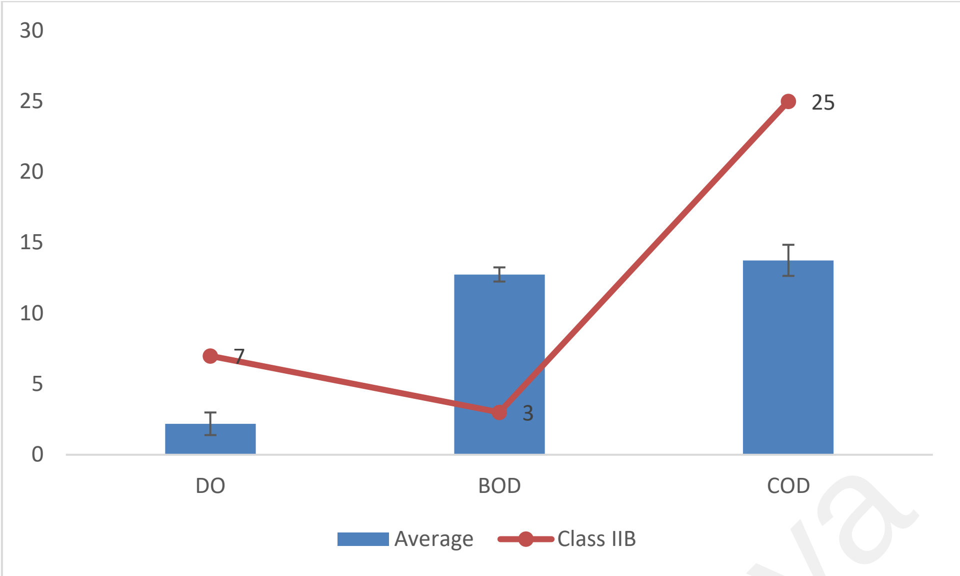

Figure 4.18: Average DO, BOD & COD at Station 8 (Avon)

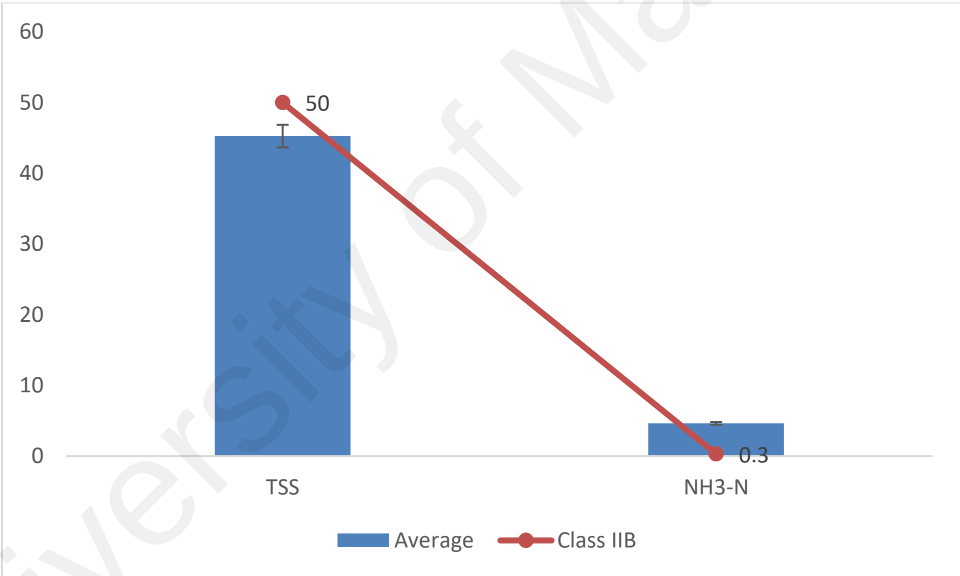

Figure 4.19: Average TSS & NH_3-N at Station 8

Station 9 is located within Sungei Way river, 2km tributary of Sungai Penchala. Sungei Way is one among the key tributaries of Sungai Penchala that suspected to carry high pollutant loadings into the river due to mix type of anthropogenic activities carried out in Sg.Way river basin. Station 9 reported almost lower average DO level compared to other stations and also reported very high BOD and COD. This is mainly maybe due to effluents from workshops, adjacent factories, restaurants and greywater from low cost apartments surrounding Sungei Way River. Figure 4.20 shows the surrounding low cost flats within catchment of Sungei Way River. Figure 4.21 and Figure 4.22 shows the average DO, COD, BOD, TSS and NH_3-N at Station 9.

Figure 4.20: Surrounding low cost flats at Station 9

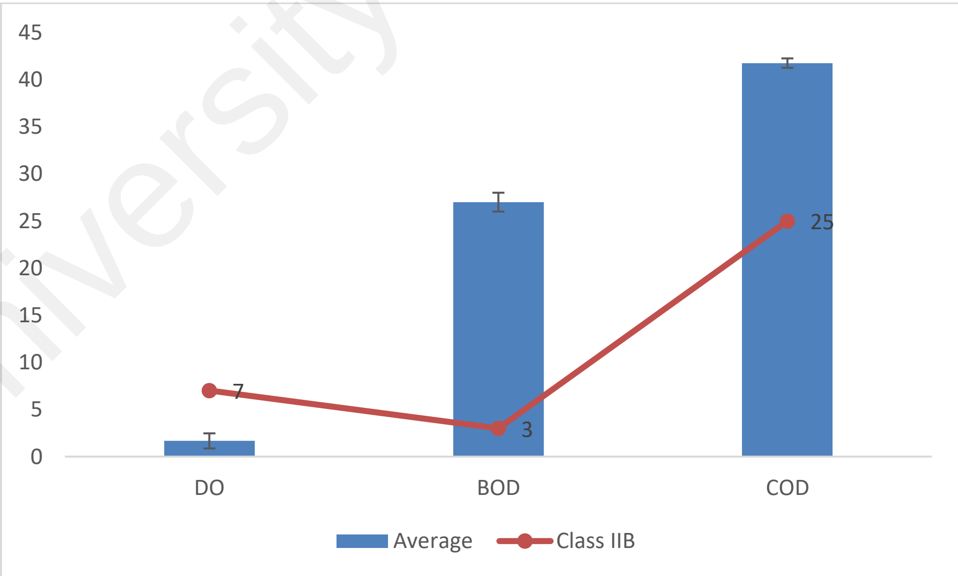

Figure 4.21: Average DO, BOD & COD at Station 9 (Sg.Way)

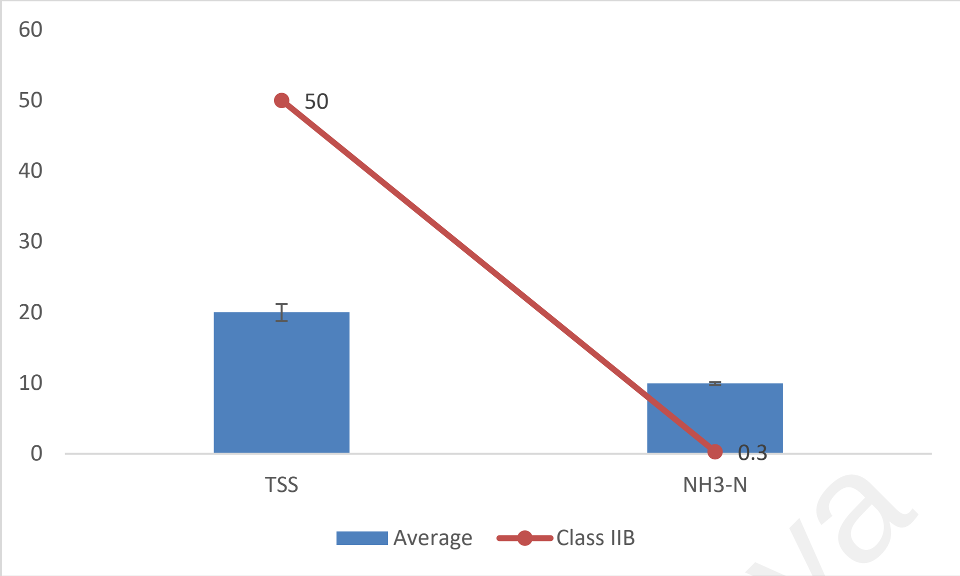

Figure 4.22: Average TSS & NH_3-N at Station 9

Station 10 (Desa Mentari Flats) is the last sampling station and have residential as well as New Pantai Express (NPE) highway as major anthropogenic activities reported within this station. BOD and COD reported to be higher mainly maybe due to pollutants carried downstream besides inlets that contributes to higher spike. Besides this, average DO of 1.18 mg/L reported indicating this station is can almost go dead chemically anytime soon. The wider river is still unable to dilute the pollutants indicating incoming pollutants loadings higher than natural capacity of river to neutralize it. Average NH_3-N is also reported to be higher maybe due to sewage ending up in this station either partially or not treated. Station 10 is vital to be managed as it merges into Sungai Klang which the pollutants can be carried away to it. Figure 4.23 shows the average DO, BOD and COD at station 10. Figure 4.24 shows the average TSS & NH_3-N at Station 10.

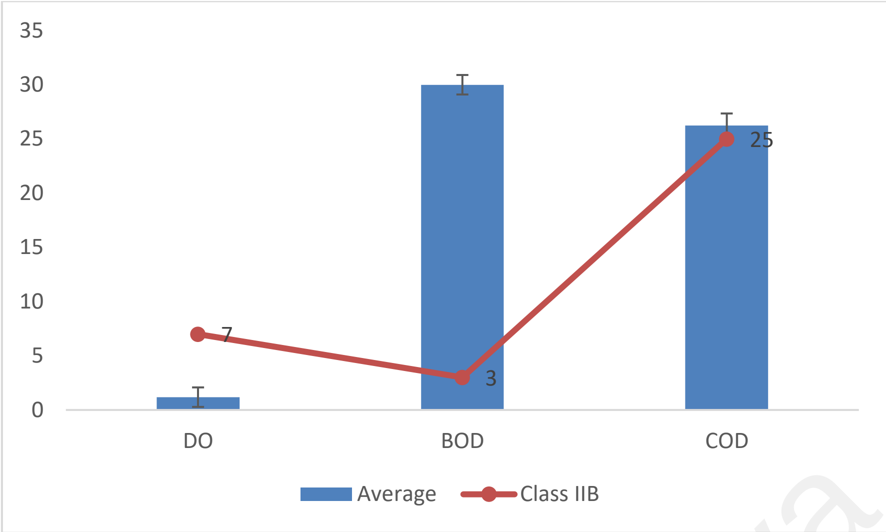

Figure 4.23: Average DO, BOD & COD at Station 10 (Desa Mentari flats)

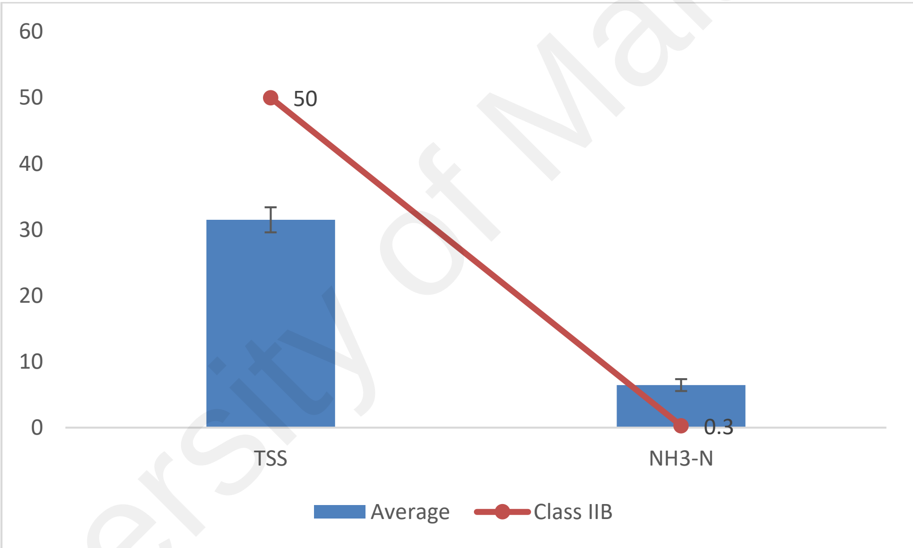

Figure 4.24: Average TSS & NH_3-N at Station 10

4.2.1.4 Average pH

The pH of river water is the measure of how acidic or basic the water is on a scale of 0-14. It is a measure of hydrogen ion concentration. Water's acidity can be increased by acid rain but is kept in check by the buffer limestone. Extremes in pH can make a river inhospitable to life. Low pH is especially harmful to immature fish and insects. Acidic water also speeds the leaching of heavy metals harmful to fish. Rapid pH fluctuations are due to pollutant discharge for both freshwater and estuarine (DOE, 1986). The study reported average of pH level starting from 6.93 to 7.25 (Figure 4.25).

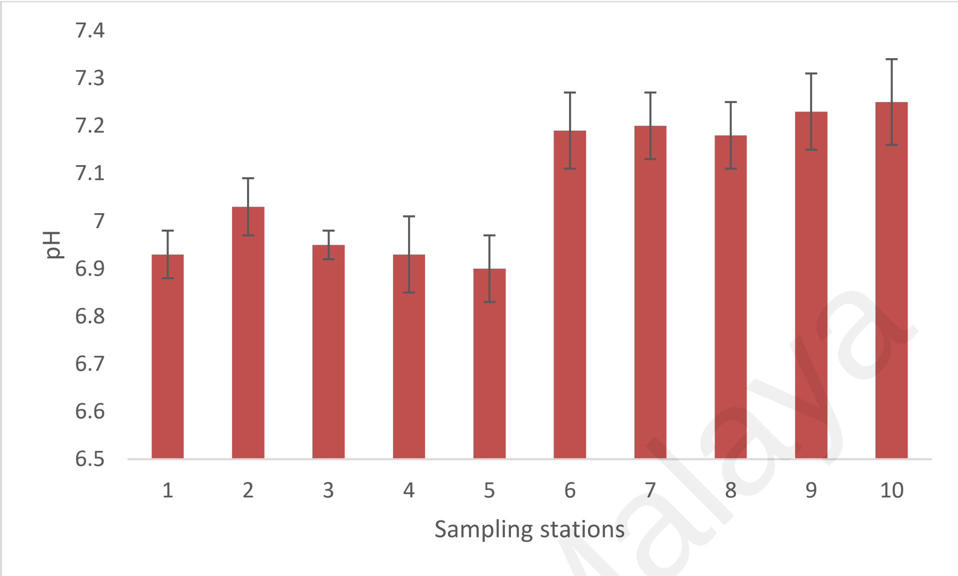

Figure 4.25: Average pH values recorded for 10 sampling stations in Sungai Penchala

All the stations are within Class I NWQS pH level which is in the range of 6.5 to 8.5. This indicates the Sungai Penchala in overall is not too acidic or alkaline. pH is very vital for survival of aquatic life.

4.2.2 Impacts of anthropogenic activities on water quality of Sungai Penchala

Malaysian National Water Quality Index used to study the relationship between river water quality and anthropogenic activities. The six parameters for each of the sampling stations combined to indicate Water Quality Index (WQI) of each sampling stations. Figure 4.26 shows the average WQI values recorded for 10 sampling stations in Sungai Penchala. None of the sampling stations achieved Class I DOE level. Even Station 1 which is the head water source of Sungai Penchala only managed to achieve the upper limit of Class II WQI which is 89, slightly lesser than 92.7 (Class I). Current WQI at this station is slightly higher than WQI of 86.06 reported by past study (Nis Hansini, 2009). Station 1 also functions have lesser anthropogenic pressure compared to other stations. Kiara Hill due to its location and beneficial usage also protected by number of key stakeholders such as National Landscape Department, Department of Irrigation and Drainage Kuala Lumpur, KL, Global Environment Centre (GEC) and active community groups such as Friends of Bukit Kiara (FoBK).

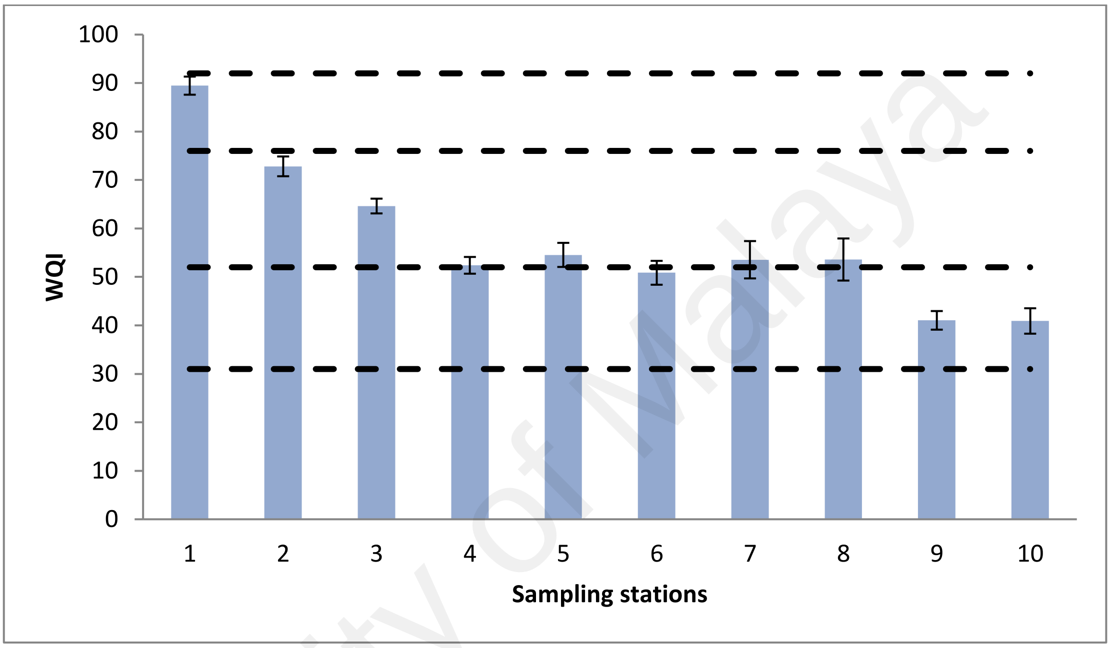

Figure 4.26: Average WQI values for 10 sampling stations in Sungai Penchala

The river restoration efforts at Station 1 also might lead to the WQI source improvement over the years (Global Environment Centre, 2015). Station 2 and Station 3 respectively reported Class III. This is mainly due to higher anthropogenic activities carried out in both these stations compared to Station 1. Deterioration of water quality noticed as WQI changed immediately from upper limit of Class II (89) to mid-Class III (65) within 1 km distance. The significant difference between both these stations and Station 1 is presence of human activities ranging from residential settlements, commercial outlets and public parks. Within natural setting, even one or two types of of anthropogenic activities can lead to deterioration of river water quality (Kominkava, 2012; Meng et al., 2009).

Station 4, Station 5, Station 6, Station 7, and Station 8 reported lower limits of Class III. This shows worrying and serious issue as anytime these stations can convert to Class IV. Class IV river water quality is only suitable for irrigation purposes and not suitable at all for body contact (DOE, 2017). All the above mentioned stations located in midstream of Sungai Penchala which also home for heavy commercial and industrial activities besides crowded with human settlements. Station 9 and Station 10 reported to having Class IV WQI level, indicating downstream of Sungai Penchala is extremely polluted. Both the stations reported same WQI of 41. Station 10 is also located nearby to the confluence of Sungai Penchala and Sungai Klang, which the pollutants from Sungai Penchala possible transported to Sungai Klang, eventually to Straits of Malacca. Both these stations located in Desa Mentari, Petaling Jaya which is heavily populated with low cost flats, houses, old commercial settlements, car workshops and industries. Overall, Sungai Penchala reported average WQI of 58 which represented by Class III DOE WQI standard. The study shows different types of anthropogenic activities do contribute to different level of pollutants being released into the river, thus establishing relationship between river water quality deterioration. Besides direct discharge of anthropogenic effluents, runoff due to their activities also can lead to the water pollution. Anthropogenic activities such as washing, vegetation clearing and industries often lead to more intensive land use which in turn increases runoff (Kibena et al., 2013).

WQI variation and differences among the sampling stationa is also can be explored with Station 1 as control site. This is because Station 1 for Sungai Penchala should be cleaner compared to other stations as its located at upstream as well as with very minimal anthropogenic activities. Even the minimal anthropogenic activities in terms of jogging and walking carried out in the mindset with water source protection considered as top priority by users. The mean differences of each sampling stations compared to Station 1 is shown in Table 4.3.

Table 4.3: Tukey post hoc test for sampling stations

Sampling Stations		**Mean Difference**	**Std. Error**
1	2	13.00000*	2.35202
	3	22.60000*	2.35202
	4	34.80000*	2.35202
	5	34.60000*	2.35202
	6	37.20000*	2.35202
	7	35.60000*	2.35202
	8	35.40000*	2.35202
	9	48.20000*	2.35202
	10	48.20000*	2.35202

Table 4.3 shows the differences in terms of WQI of each station with Station 1 which considered as cleaner site and having lesser as well as controlled human activities. Station 9 and Station 10 have similar higher mean difference compared to Station 1. They located in downstream and their high variation is due to heavy human activities at both locations. Station 6 reported to have second higher mean difference compared to Station 1, which means this station need to be given priority and attention for rehabilitation purpose by river managers as it is easier to improve river condition in midstream compared to downstream (Station 9 and Station 10). Station 6 having mix of

both commercial and industrial area which contributes to significant pollution load to Sungai Penchala. This is evident which Station 6 reported third highest BOD and COD value respectively after Station 9 and 10 during sampling. Station 2 reported lowest mean difference compared to Station 1.This is mainly due to similar type of human activities at Station 1 but human density is higher in Station 2. While Station 2 almost have lowest mean difference compared to Station 1, this site can be improved further with nature-based solution such as constructed wetland and alternately limit pollution caused by public through enforcement. With these low-cost approaches, Station 2 too can be improved further into cleaner site. Since it is urban river with concrete channel, it is difficult to improve or expect Station 9 & Station 10 to be similar to Station 1 which will be having higher discharge of cleaner river water compared to previous stations. However, pollution load as well as anthropogenic activities need to be controlled at downstream (Station 9 and Station 10) to prevent further deterioration of water quality here.

Average WQI based on river segments also explored to observe whether there is any spatial trend of pollution. Spatial over temporal variation considered for this study as the sampling carried out from May to September which there were no significant temporal variations in context of Malaysian weather and rainfall. Spatial trend also will help to establish the linkage of urbanization trend towards water quality. Sungai Penchala can be seen affected by increasing urbanization trend when moving from upstream to downstream by having different types of anthropogenic activities Figure 4.27 shows the trend of WQI based on Sungai Penchala segments.

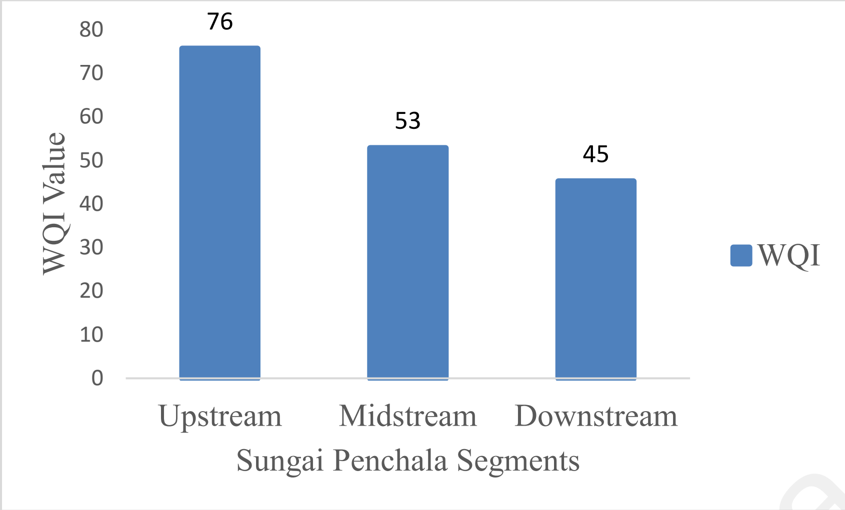

Figure 4.27: Average WQI values according to Sungai Penchala segments

The trend shows river water quality deterioration moving downstream. Different types of human activities with mixed manner shows evidently it affects the river water quality particularly starting from midstream to downstream. Besides this, pollutants transport from upstream to downstream also can be the cause for this declining trend as river is moving waterbody. Globally, pollutant transport in rivers being given wide attention as their effects are significant. Water quality models and monitoring programs are also analyzing the pollutant transport in rivers (Ali, 2007; Gazzaz et al., 2015; Tiwari et al., 2015).

4.3 Relationship between benthic macroinvertebrates and anthropogenic activities in Sungai Penchala

Relationship between benthic macroinvertebrates and anthropogenic activities in Sungai Penchala analysed and discussed in three sub-sections. First sub-section discusses on distribution as well as diversity of benthic macroinvertebrates in Sungai Penchala. Second sub-section discusses the impacts of anthropogenic activities on benthic macroinvertebrates in Sungai Penchala. Third sub-section discussed the relationship between water quality parameters and benthic macroinvertebrates in Sungai Penchala.

4.3.1 Distribution and diversity of benthic macroinvertebrates

Benthic macroinvertebrates sampled at eight stations in Sungai Penchala. Another two stations left out as it is being not feasible to carry out benthic macroinvertebrates' sampling at those sites. Different types of benthic macroinvertebrates found during sampling. Figure 4.28 to 4.33 shows some of the families of benthic macroinvertebrates found in Sungai Penchala.

Figure 4.28: Crane Fly Larvae (Family: Tipulidae)

Figure 4.29: Shrimp (Family: Palaemonidae)

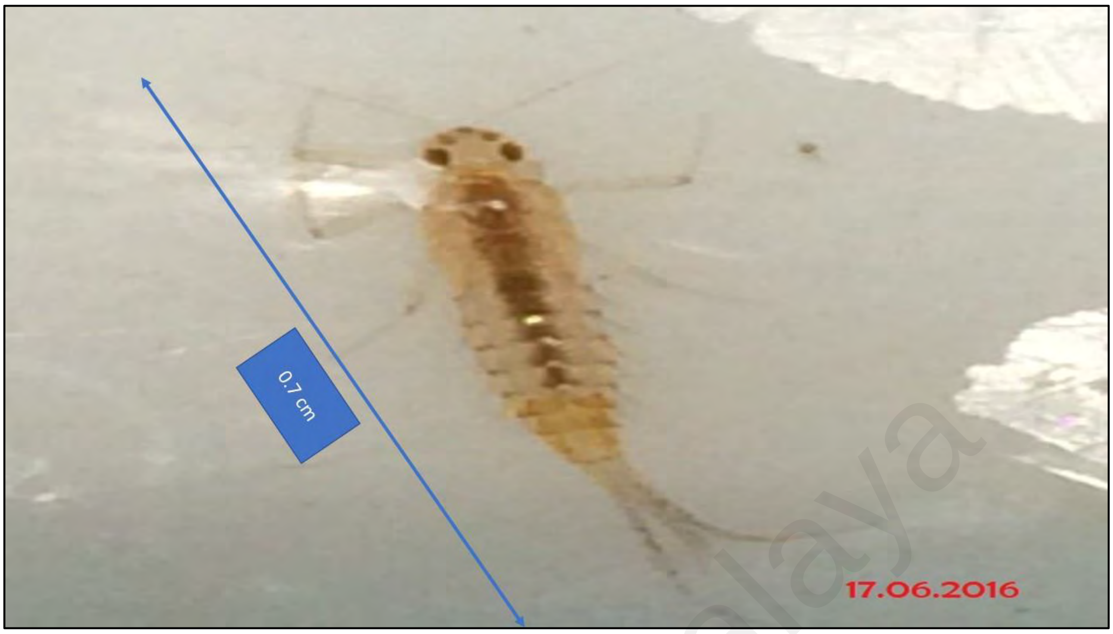

Figure 4.30: Mayfly nymph (Family: Baetidae)

Figure 4.31: Clubtail dragonfly larvae (Family: Gomphidae)

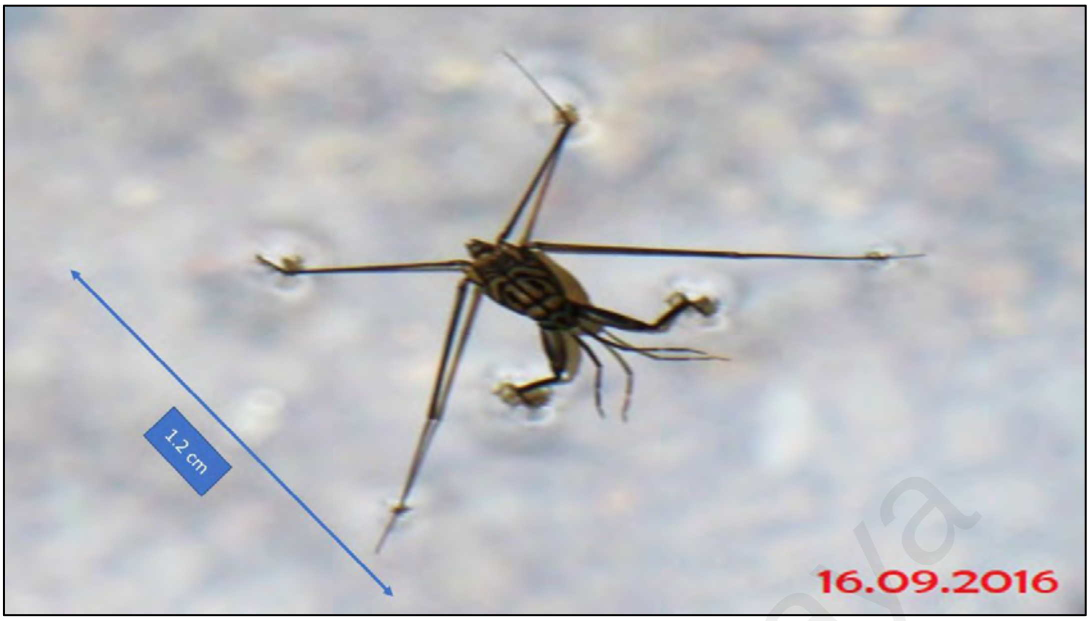

Figure 4.32: Pond skater (Family: Gerridae)

Figure 4.33: Bloodworm (Family: Chironomidae)

A total of 981 individuals with 28 families of benthic macroinvertebrates sampled within five months of sampling started from May 2016 to September 2016. Figure 4.34 shows number of individual benthic macroinvertebrates found at eight sampling stations. Highest number of benthic macroinvertebrates found in Station 2 which is in Lembah Kiara Public Park with the total of 177 individuals sampled. The least number of benthic macroinvertebrates which 57 individuals was found in Station 3 which is Rimba Kiara Park.

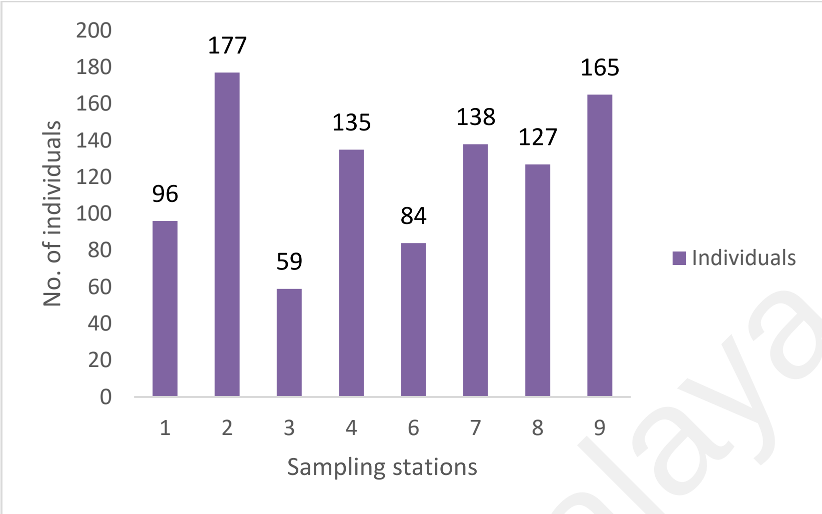

Figure 4.34: Number of benthic macroinvertebrates found in 8 sampling stations in Sungai Penchala

Abundance of benthic macroinvertebrates also analyzed for its distribution at each of the sampling stations. Table 4.4 shows the distribution and diversity of families present in each of the sampling stations.

Table 4.4: Distribution and diversity of benthic macroinvertebrates in Sungai Penchala

Sampling Station	Number of Families	Families	Individuals	Total Number of Individuals
1	11	Palaemonidae	23	96
		Potamidae	3	
		Corydalidae	1	
		Baetidae	4	
		Heptageniidae	1	
		Tipulidae	2	
		Chironomidae	9	
		Hydrometridae	14	
		Gerridae	22	
		Hydrophilidae	8	
		Thiaridae	9	

Table 4.4, continued

Sampling Station	Number of Families	Families	Individuals	Total Number of Individuals
2	12	Palaemonidae	11	177
		Caenidae	1	
		Gomphidae	15	
		Libellulidae	12	
		Coenagrionidae	6	
		Chironomidae	78	
		Gerridae	16	
		Naucoridae	6	
		Hydrometridae	3	
		Hydrophilidae	8	
		Thiaridae	14	
		Bithyniidae	7	
3	11	Palaemonidae	11	59
		Libellulidae	2	
		Coenagrionidae	5	
		Tabanidae	1	
		Ephydridae	1	
		Hydrophilidae	1	
		Bithyniidae	20	
		Viviparidae	1	
		Gerridae	5	
		Haplotaxidae	8	
		Turbificidae	4	
4	7	Chironomidae	83	135
		Bithyniidae	10	
		Viviparidae	3	
		Planorbidae	4	
		Haplotaxidae	17	
		Turbificidae	8	
		Hirudinea	10	
6	9	Chironomidae	47	84
		Tabanidae	2	
		Ephydridae	1	
		Culicidae	5	
		Thiaridae	4	
		Bithyniidae	6	
		Planorbidae	5	
		Turbificidae	3	
		Hirudinea	11	

Table 4.4, continued

Sampling Station	Number of Families	Families	Individuals	Total Number of Individuals
7	8	Pyralidae	1	138
		Chironomidae	91	
		Culicidae	3	
		Muscidae	7	
		Syrphidae	5	
		Bithyniidae	19	
		Planorbidae	2	
		Hirudinea	10	
8	6	Ephydridae	3	127
		Chironomidae	59	
		Syrphidae	4	
		Bithyniidae	27	
		Planorbidae	11	
		Hirudinea	23	
9	6	Chironomidae	104	165
		Syrphidae	13	
		Culicidae	10	
		Bithyniidae	20	
		Turbificidae	11	
		Hirudinea	7	
TOTAL	28			981

Figure 4.35 shows families of benthic macroinvertebrates with highest percentage distribution in eight sampling stations. Station 1 reported Palaemoniadae as its highest (24%) number of individuals belonging to this family. Corydalidae and Heptagenidae are two families reported lowest abundance with 1 individual reported for each of the families in Station 1. Station 2 reported Chironomidae as highest (44.1%) number of individuals. Caenidae family reported to be the lowest with 1 individual reported in Station 2. 20 individuals (33.9%) reported to be belonging for Bithynidae family at Station 3 and make it highest compared to others. Hydrophilidae, Tabanidae, Viviparidae and Ephydridae are four families reported lowest abundance with each family reported 1 individual at Station 3.

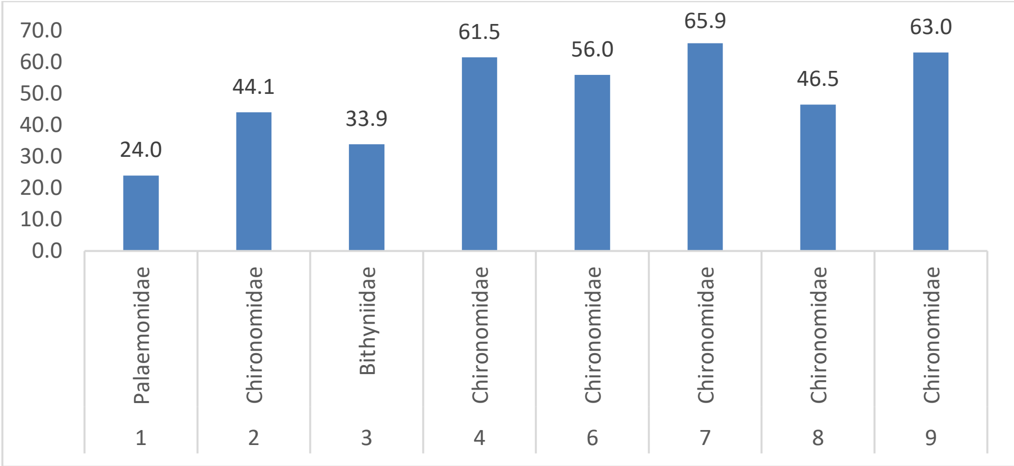

Figure 4.35: Family of benthic macroinvertebrates with highest percentage at each station

Chironomidae was reported with highest number of individuals found in Station 4 with 83 (61.5%). Viviparidae reported to be the family found in lowest abundance with 3 individuals reported at Station 4. Station 6 to 9 reported Chironimidae as highest family reported at respective stations ranging from 46.5% to 65.9%. Ephydridae reported to be the lowest (1 individual) distributed family in Station 6 while Pyralidae was the lowest with 1 individual reported in Station 7. Ephydridae with 3 individuals found to be the lowest family reported in Station 8 while Hirudinea with 7 individuals reported to be the lowest family in Station 9.

Figure 4.36 shows the percentage of overall benthic macroinvertebrates collected at 8 sampling stations. It was found that Chironomidae holds the highest distribution with 471 (48%) individuals found during sampling period. Bithynidae is second highest with 11% (109 individuals) found during sampling. Syrphidae and Planorbidae are two families that recorded 22 individuals respectively during sampling. Hydrometridae and Hydrophilidae are also two families also reported same number of individuals respectively which was 17. Pyralidae, Caenidae, Corydalidae and Heptagenidae are four families recorded 1 individual respectively during sampling period.

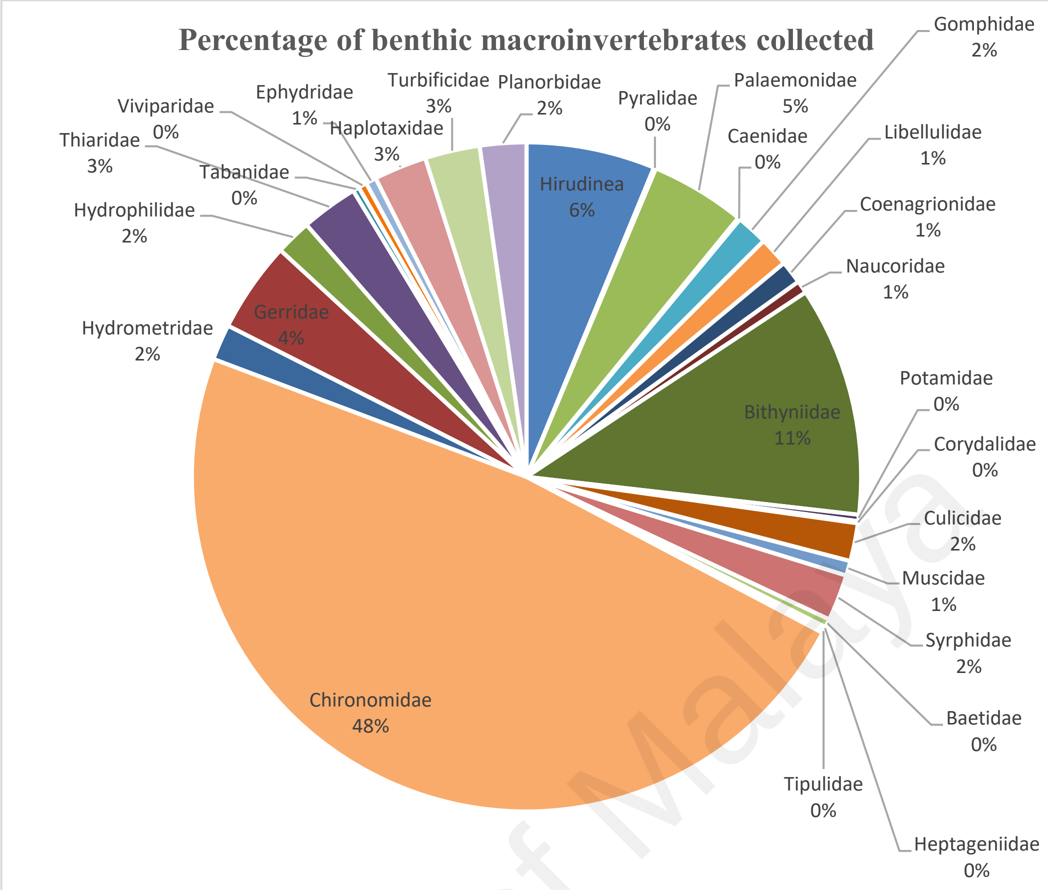

Figure 4.36: Percentage of benthic macroinvertebrates collected at 8 stations

Ecological indices used to study the diversity of benthic macroinvertebrates in Sungai Penchala. Table 4.5 shows the ecological indices used to evaluate the diversity of benthic macroinvertebrates in Sungai Penchala. Macroinvertebrate community structure has commonly been used as an indicator of the condition of an aquatic system (Norris, 2000).

Table 4.5: Ecological Indices for Sungai Penchala

Sampling Stations	Name	Ecological Indices		
		Shannon Wiener Diversity Index	Margalef Richness Index	Pielou J Evenness index
1	Bukit Kiara	2.121	2.41	0.8535
2	Taman Lembah Kiara	1.939	2.125	0.7803
3	Taman Rimba Kiara	1.943	2.452	0.8102
4	Kents Condominium	1.302	1.223	0.669
6	BAT	1.19	1.421	0.572
7	Piccadilly	1.521	1.806	0.6923
8	Avon	1.404	1.032	0.7836
9	Sg.Way	1.231	0.9793	0.6873

Diversity indices are efficient in indicating physical and toxic pollution which stress most species in a community without encouraging replacement species. Diversity and anthropogenic disturbances are inversely related. Station 1 recorded highest Shannon-Wiener diversity index which is 2.121 compared to other sampling stations. Station 6 which is near to industrial area recorded lowest Shannon Winer Diversity Index which is 1.19. Margalef Richness Index also calculated to investigate diverse station. Station 3 which is the Rimba Kiara Park recorded highest index of 2.452 while Station 10 which is the Sg. Way reported lowest Margalef Diversity Index (0.9793). Pielou J Evenness index also calculated to know the species' evenness in Sungai Penchala. Almost all the stations achieved more than medium evenness species in each respective station. Station

1 has the highest Pielou J Evenness evenness index of 0.8535 while Station 6 reported the lowest index (0.572).

4.3.2 Characterization of benthic macroinvertebrates resulted by anthropogenic activities in Sungai Penchala

Chironimidae found to be the family with highest distribution in Sungai Penchala (Figure 4.36). Chironimidae is highly tolerant family which indicates Sungai Penchala is biologically polluted. In lentic and lotic environments, the analysis of benthic fauna, particularly Chironomidae, has played a dominant role (Saether, 1979). In industrial and urbanized areas, streams are subject to physical (canalization, modification of banks, cleansing, regulation, etc.) and chemical (industrial or municipal sewage, etc) stress, which strongly modifies the water quality (Grumiaux et al., 1998). This stress is reflected in the composition of benthic macroinvertebrate communities that respond quantitatively, not only to the availability of trophic resources, but also to variations in their physical habitat as well as chemical variations in water and sediments (Grumiaux et al., 1998; Wang et al., 2007). Among macroinvertebrate taxa, Chironomidae is one of the richest groups having a lot of species inhabiting lotic and lentic habitats (Cranston, 2004).

Chironimidae found to be the family with highest distribution at 6 out of 8 stations where benthic macroinvertebrates collected. Station 6 to 9 especially are the stations that reported different type of heavy anthropogenic activities. Maybe these activities with concretized nature of river here makes condition unfavorable for good indicators to present. Due to their ubiquity and different species habitat preference, Chironomids are well known as indicators of organic and inorganic pollution including heavy metal contamination (Marziali et al., 2010). The Chironomids are widely reported from many moderately to highly polluted Malaysian rivers including Juru River (Al-Shami et al., 2010; Azrina et al., 2006; Siregar et al., 1999).

Average Species per taxon (ASPT) score used to study the relationship between anthropogenic activities and benthic macroinvertebrates (Mustow, 2002). ASPT consist of scores assigned for each taxon based on their tolerance to pollution. For instance, score '0' assigned to Chironomidae which is highly tolerant to pollution and can be seen in polluted river or waterbodies. Hence, ASPT score is easier to assess the anthropogenic sites' impacts on benthic macroinvertebrates.

Figure 4.37 shows the average ASPT score for eight sampling stations in Sungai Penchala. Station 2 which is in Lembah Kiara park reported highest average ASPT score with 5.1 which marks biological water quality in this station is clean. This shows this station is still clean to support aquatic life especially benthic macroinvertebrates. The lowest average ASPT score reported is Station 4 with score of 2.2 Station 4 is located adjacent to condominium and flow is very slow compared to other stations. Pollution associated with slow moving water possible causes Station 4 to be poor habitat for benthic macroinvertebrates. ASPT score ranging from '1' to '2.5' indicates the river water to be polluted. ASPT score ranging from '2.6' to '5' indicates moderately clean water. Four stations indicate moderately clean water status based on APST score. There are Station 6, Station 7, Station 8 and Station 9 respectively. All these stations share the similarity of location of anthropogenic activities, which they are heavily populated with various types of human activities taking places such as residential, commercial, industrial and mixed activities as well. Lowest average ASPT score reported in these stations indicates anthropogenic activities also do affect the biological water quality of river, thus directly affect the life of benthic macroinvertebrates (Kok & Weng, 2015; Wang et al., 2007; Water & Rivers Commission, 2000).

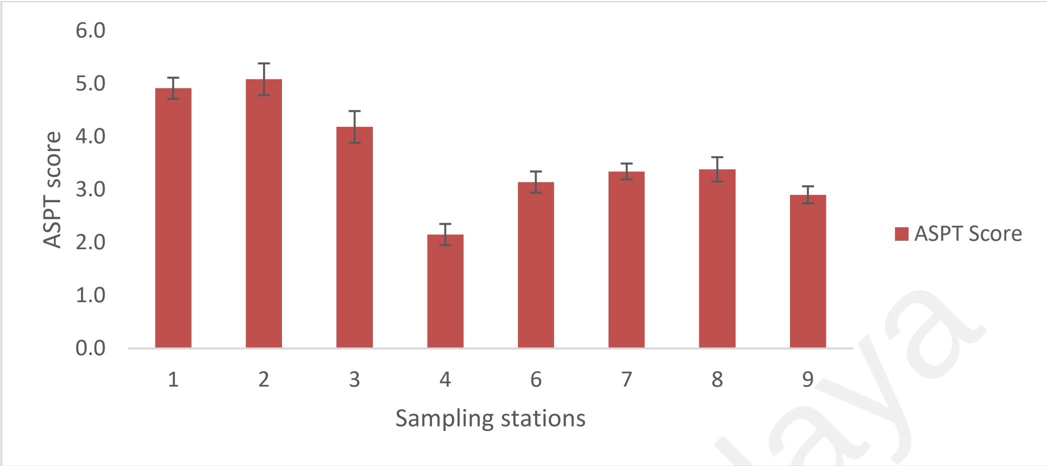

Figure 4.37: Average ASPT score for 8 sampling stations in Sungai Penchala

4.3.3 Relationship between water quality and benthic macroinvertebrates of Sungai Penchala

Water quality and benthic macroinvertebrates distribution were used to reflect river health of Sungai Penchala. Physico-chemical water quality best represented through water quality index (WQI) while macroinvertebrates distribution reflected through ASPT score, in respect to their relationship to anthropogenic impacts. Water quality parameters also interrelated with distribution of macroinvertebrates. Figure 4.38 shows ordination diagram of distribution of benthic macroinvertebrates particular to water quality parameters analyzed in this study. Study found majority of families (55.6%) showed positive correlation with dissolved oxygen. Dissolved oxygen carries highest sub-index value in DOE's WQI calculation making it is most valuable parameter compared to other five parameters (DOE, 2017). Hence, high diversity of benthic macroinvertebrates towards DO suggest rehabilitation efforts including aeration, water flow regulation, water level raise and wetland planting in impaired river stretch possibly can lead to improvement of benthic invertebrates.

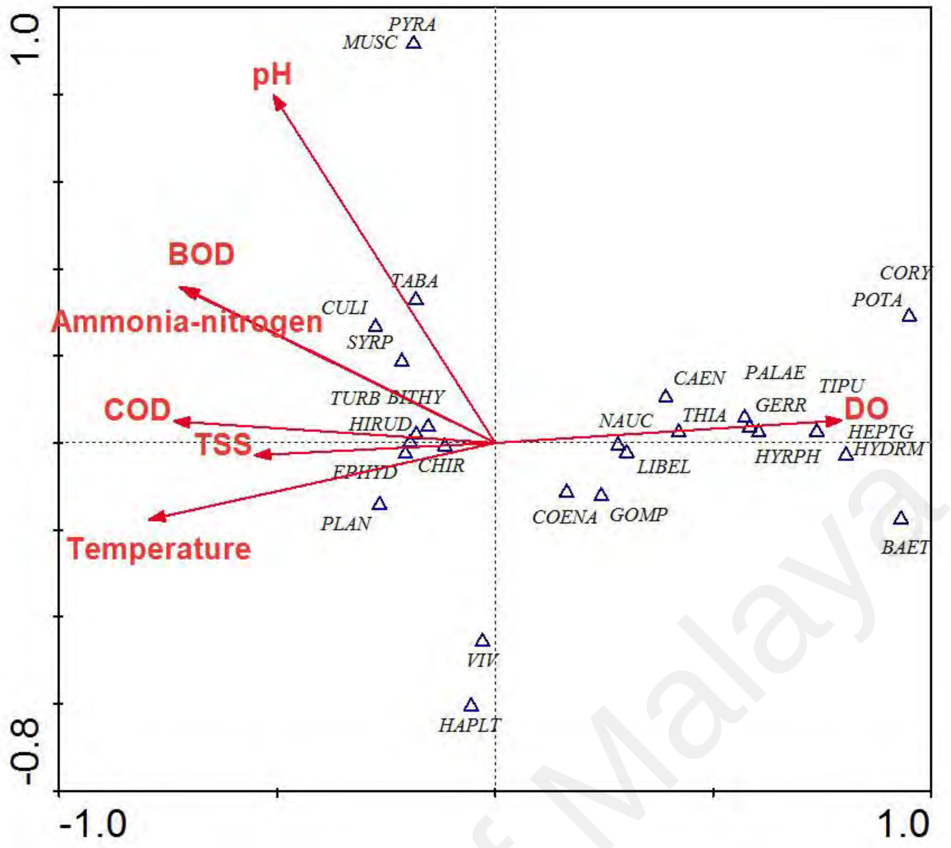

Figure 4.38: **Ordination diagram (CCA) of benthic macroinvertebrates**

Most of freshwater ecologists accepted that dissolved oxygen plays important roles in benthic distribution in aquatic environment (Singh & Sharma, 2014). The oxygen concentration is higher in cooler water due to high solubility (Bispo et al., 2006). Lewis (2008) observed that rivers at higher altitude usually low in temperature and high oxygen in water favored the assemblages of insects compared to lowland rivers. Several sensitive case insects especially mayflies showed high sensitivity to low oxygen. Dissolved oxygen is also one key water quality parameter that affected by anthropogenic impacts. Majule (2010) reported that human, wildlife and livestock activities had significant impacts on water quality of the Mara River through organic matter deposition into the channel, thus resulting in the low dissolved oxygen levels observed. Table 4.6 shows the correlation between WQI parameters and ecological indices.

Table 4.6: Correlation between parameters and ecological indices

Ecological Indices	Spearman rank correlation coefficient					
	DO	**BOD**	**COD**	**TSS**	**pH**	**NH_3 - N**
Shannon Wiener Diversity Index	.442**	-.415**	-.361*	-.187	-.198	-.315*
Margalef Richness Index	.563**	-.510**	-.388*	-.159	-.170	-.412**
Pielou J Evenness Index	.095	-.105	-.122	-.083	.006	.001
ASPT	.690**	-.629**	-.641**	.057	-.324*	-.480**

**Significant correlation ($p<0.05$)

Study found Shannon Weiner Diversity Index (0.442) and Margalef Richness Index (0.563) showed significant positive correlation with Dissolved Oxygen , lower than ASPT (0.690). ASPT value showed significant negative correlation with COD and BOD, indicating organic pollution will affect diversity of benthic macroinvertebrates (Bond et al., 2012). Besides this, WQI and ASPT was shown positive Spearman rank correlation significant correlation (0.857, $p<0.05$).

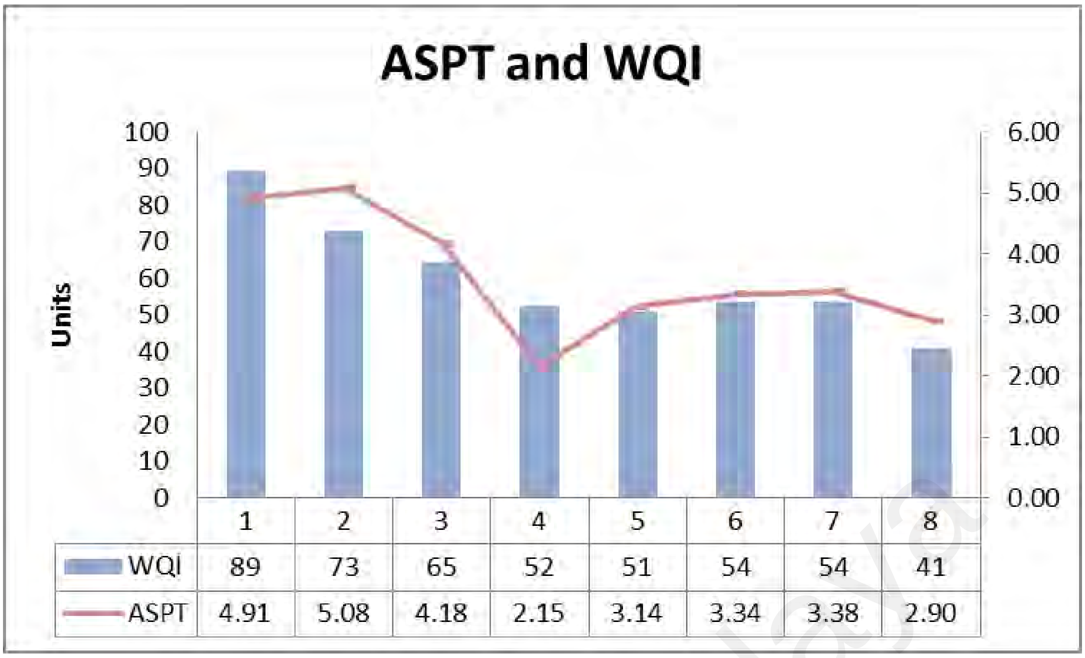

Figure 4.39: **Correlation between ASPT and WQI**

Figure 4.39 shows the correlation of ASPT and WQI score for sampling stations. High positive correlation with significant value showing both WQI and ASPT can be used together to relate Sungai Penchala health to study anthropogenic impacts. The study finding also makes benthic macroinvertebrates as suitable biological indicator that can be used to study the anthropogenic impacts together with existing water quality parameters. They both can be used together to assess river health for a river, proven for this small urban river. Water quality index and biological water quality index also proven to be used together to assess river health in other studies (Duran & Suicmaz, 2007; Kalyonchu & Zeybeck, 2011; Kok & Weng, 2015; Singh & Saxena 2018).

4.4 Application of modified RHI for Sungai Penchala

Only eight sampling stations except Station 5 and Station 10 were involved as unable to generate bioindicator score for those two stations as biomonitoring was not carried out there. Table 4.7 shows the physico-chemical indicator scores for each stations involved with taking account number of parameters complied with Class IIB limits.

Table 4.7: Physico-chemical indicator score for Sungai Penchala

Sampling Station	Average pH	Class IIB pH range	Average DO (mg/L)	Class IIB DO range	Average COD (mg/L)	Class IIB COD limit	Average TSS (mg/L)	Class IIB TSS limit	Average NH3-N (mg/L)	Class IIB limit	Average BOD (mg/L)	Class IIB BOD limit	Parameters complied	Physico-chemical (PC) indicator score
1	6.93	6 to 9	5.4	5 to 7	5	25	3.2	50	0.06	0.3	2.8	3	6	5
2	7.03	6 to 9	4.5	5 to 7	8.6	25	23.6	50	1.16	0.3	4.9	3	3	2
3	6.98	6 to 9	3.8	5 to 7	16.2	25	25.6	50	2	0.3	7.4	3	3	2
4	6.9	6 to 9	2.6	5 to 7	36.4	25	15.6	50	2.22	0.3	13.8	3	2	2
6	7.15	6 to 9	3.4	5 to 7	33.4	25	21.4	50	5.7	0.3	20.3	3	2	2
7	7.19	6 to 9	3.2	5 to 7	33.4	25	24	50	4.9	0.3	13.2	3	2	2
8	7.16	6 to 9	2.4	5 to 7	13.2	25	45.4	50	4.86	0.3	12.2	3	2	2
9	7.26	6 to 9	1.5	5 to 7	41.6	25	19.6	50	9.98	0.3	26	3	2	2

Table 4.8 shows the biological indicator score for Sungai Penchala while Table 4.9 shows the modified RHI for Sungai Penchala derived through RHS.

Table 4.8: Biological indicator score for Sungai Penchala

Sampling Station	ASPT	ASPT Range	Biological indicator (B) score
1	4.9	2.6-5	3
2	5.1	5.1-7.5	4
3	4.2	2.6-5	3
4	2.2	1.0-2.5	2
6	3.1	2.6-5	3
7	3.3	2.6-5	3
8	3.4	2.6-5	3
9	2.9	2.6-5	3

Table 4.9: Modified RHI for Sungai Penchala

Sampling Station	Physico-chemical (PC) indicator score	A=50% of PC score	Biological (B) indicator score	C=50% of B score	Modified RHS (A +C)	RHS Range	Modified RHI
1	5	2.5	3	1.5	4	3.1- 4	Good
2	2	1	4	2	3	2.1- 3	Moderate
3	2	1	3	1.5	2.5	2.1- 3	Moderate
4	2	1	2	1	2	1.1 - 2	Poor
6	2	1	3	1.5	2.5	2.1- 3	Moderate
7	2	1	3	1.5	2.5	2.1- 3	Moderate
8	2	1	3	1.5	2.5	2.1- 3	Moderate
9	2	1	3	1.5	2.5	2.1- 3	Moderate

Significant high positive correlation between WQI and APST found this study also justifies the need of equal percentage for biological component. Computation of RHI for Station 1 with minimal human activity showed higher RHI in parallel to individual WQI and ASPT value reported earlier. Station 4 showed the lowest RHI. In average, Sungai Penchala reported River Health Score of 2.7 based on eight sampling stations set in this study. It gives moderate status as RHI for Sungai Penchala. Hence, it is possible to develop RHI for other urban rivers based on this modified framework.

National Water Quality Standard (NWQS) by DOE Malaysia is currently used to indicate river water quality and as per reviewed in this study. DOE's water quality index (WQI) lacks function as holistic tool for river management mainly due to its failure incorporating biological elements. Hence, RHI developed through this study proposed to be applied as management tool for urban river.

RHI proposed in this study can be a holistic management tool in terms of setting targets for particular stretch within a river. River needs targets for holistic management which not available currently in Malaysia (Zaki, 2016). Table 4.10 shows targeted RHI for Sungai Penchala as case study. For instance, in next 10 years, Station 1 should attain RHI of very good (RHS=5) which indicates the site must be preserved and improved further from now onwards. Targets also can help to prevent any additional pollution loading such as development to come in near future as target is already set. Targets will be more achievable if it can be translated into KPIs of agencies, Department of Irrigation and Drainage or local authority. Targets need to be practical and achievable as well. For instance, Station 9 at downstream can target to achieve 'Moderate' RHI instead of 'Very Good' RHI as earlier is more practical and achievable within 10 years time.

Table 4.10: **Targeted RHI**

Sampling Station	Current RHI (year 2016)	Targeted RHI for next 10 year (year 2026)
1	Good	Very Good
2	Moderate	Good
3	Moderate	Good
4	Poor	Moderate
6	Moderate	Moderate
7	Moderate	Moderate
8	Moderate	Moderate
9	Poor	Moderate

In nutshell, RHI can be a good management tool as it helps to set targets as well as incorporate biological monitoring in assessment. Composite indices such as RHI can give more insight on river health and lead to better management of the river (Blakely et al., 2014; Meng et al., 2009; Sargaonkar & Deshpande, 2003; Singh & Sonali, 2018; Vos et al., 2002;).

CHAPTER 5: CONLUSION

Urban river pollution is often overlooked in the context of river management. Lack of key beneficial usage of urban rivers and concretized nature of river put them on last priority for an effective management. Lack of an effective management especially with growing anthropogenic activities in cities do contribute to deterioration of urban river water quality. The study agreed that deterioration of urban river water quality is affected by anthropogenic activities. This study also understood that biological characteristics of river too altered due to anthropogenic activities, besides deterioration of physico-chemical parameters.

Sungai Penchala reported WQI of 58 which represented by Class III DOE WQI standard. The study found anthropogenic activities affect the physico-chemical parameters as well as overall WQI. Ten sampling stations selected along Sungai Penchala recorded at four different types of anthropogenic activities. Residential, commercial, industrial or mixed activities reported at sampling stations. Location of sewage treatment plant nearby to stations especially Station 4 and Station 5 possible contribute to high levels of COD, BOD and NH3-N. Highest TSS level reported in Station 8 possible due to road run-off as the station is closer to Federal Highway. Station 9 and Station 10 reported Class IV (41) WQI l which marks the downstream of Sungai Penchala is extremely polluted due to mixed type of anthropogenic activities.

Benthic macroinvertebrates found in Sungai Penchala and represented biological health of Sungai Penchala. A total of 981 individuals with 28 families of benthic macroinvertebrates found in Sungai Penchala, showing the river is still rich with aquatic life. Similar to deterioration of physico-chemical characteristics due to anthropogenic activities, the study found benthic macroinvertebrates affected too. Chironomidae which is highly tolerant family as well as poor biological indicator holds the highest distribution with 471 individuals (48%) found during sampling period. Chironimidae found to be the family with highest distribution at 6 out of 8 stations where benthic macroinvertebrates collected. Palaemoniadae and Bithynidae were the other two families indicating moderate to good biological indicators found in remaining 2 stations respectively. Two stations recorded moderate to good biological indicators found to be having lesser anthropogenic activities compared to other stations. Lowest ASPT score recorded especially in Station 4, Station 6, Station 7, Station 8 and Station 9 indicates different types of anthropogenic activities do impact presence of benthic macroinvertebrates especially poor biological indicators.

Physico-chemical monitoring through WQI is the usual representation for river health in Malaysia. Biological monitoring widely incorporated in river health assessment at other countries but not in Malaysia. The study found both physico-chemical and biological monitoring can be used to evaluate river health especially for urban river. Through this study, WQI and ASPT found to be associated with significant positive Spearman rank correlation (0.857, $p<0.05$). Significant positive correlation found through this study provides opportunities for future studies to incorporate both physico-chemical and biological components in river health assessment.

In addition, the study developed River Health Index (RHI) based on a published framework. RHI developed with equal weightages given to both physico-chemical monitoring and biological monitoring. Presence of benthic macroinvertebrates in urban river through this study as well as significant positive correlation found between physic-chemical monitoring and biological monitoring supports equal weightage for biological component. RHI serves as alternative to WQI in terms of holistic tool for effective river management. Station 1 reported ‘Good’ RHI while Station 4 reported ‘Poor’ RHI. It supports RHI can be used as tool for managing urban river as ‘Good’ status is indicating mitigation efforts should focus either preservation or improvement if needed. On the other hand, ‘Poor’ stretch of river needs immediate attention which any mitigation efforts can focus there first. Moreover, the study managed to propose RHI as part of management tool which targets of river stretches in terms of ‘Good’ and ‘Moderate’ can be set based on baseline data. Target setting, which eventually can be translated into KPI’s of agencies or even public, can lead to effective management of urban rivers. Practical target setting at whole will ensure the river to meet its intended usage, which RHI developed through this study offer to function as yardstick.

Besides this, future studies also can be looked at parameters beyond water quality and diversity of benthic macroinvertebrates to be included in RHI. Similar study also can be replicated at other types of river as this study was carried out in a small urban river. It is further suggested that any newly developed measurement unit, RHI in this case, need to be informed to beneficiaries and active involvement of local communities, NGOs, CBOs, private players as well as scientists are needed in order to meet intended usage of river.

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