PHYSICO-CHEMICAL PARAMETERS AND MACROBENTHOS OF PENCHALA RIVER

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ABSTRACT

The aim of this study is to determine the relationship between physico-chemical parameters with existence and diversity of macrobenthos at four selected stations at Penchala River. WQI was determined by analysing water samples through water sampling routine for 12 months starting November 2013 until October 2014. *In situ* measurements involved were temperature, pH, dissolved oxygen (DO), total dissolved solid (TDS), and conductivity. Laboratory analysis was undertaken for total suspended solid (TSS), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Ammoniacal Nitrogen (NH_3-N). Measurements for physical parameters were done for water level, river width, and river water velocity. The WQI value Penchala River were in the range of 58.1 – 71.0. Station 2, 3, 4 received pollutant from difference sources such as residential, commercial and industrial area which discharged high concentration of nutrients and organic pollutant. The natural physical characteristics at Station 1 encourage the existence and support high diversity of macrobenthos. The deterioration of water quality, velocity and water level thus affected the existence of macrobenthos at Station 2, 3 and 4. The Pearson's correlation of coefficients shows high correlation between WQI and Margalef richness index (r= -0.735, P=0.007), Simpsons diversity index (r= -0.618, P=0.032), Shannon-Weiner diversity index (r= -0.642, P=0.024) and Pielou evenness index (r= -0.589, P=0.044) indicate that biological monitoring at Penchala River by using macrobenthos is suitable as an alternative way to determine the river health.

ABSTRAK

Tujuan kajian ini adalah untuk menentukan hubungan antara parameter fizikal-kimia dengan kewujudan dan kepelbagaian makrobentik di empat stesen terpilih di Penchala River. Indeks kualiti air ditentukan bermula November 2013 sehingga Oktober 2014. Dalam ukuran in-situ, parameter yang terlibat adalah suhu, pH, oksigen terlarut (DO), jumlah pepejal terlarut (TDS), dan kekonduksian. Analisis makmal telah dijalankan bagi jumlah pepejal terampai (TSS), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), dan Ammoniakal Nitrogen (NH_3- N). Pengukuran parameter fizikal dilakukan untuk paras air, lebar sungai dan halaju air sungai. Indeks kualiti air di Sungai Penchala adalah dalam lingkungan 58.1 – 71.0. Stesen 2, 3, 4 menerima pencemaran daripada kawasan kediaman, perdagangan dan perindustrian dengan jumlah kepekatan nutrien dan bahan organik yang tinggi. Daripada pemerhatian, ciri-ciri fizikal semulajadi di Stesen 1 sangat menggalakkan kewujudan makrobentik. Berbanding dengan Stesen 2, 3 dan 4, gangguan yang berlaku tertahap kualiti air, halaju dan aras air telah memberikan kesan negatif kepada kewujudan makrobentik. Analisis korelasi Pearson menunjukkan hubungan yang kuat antara indeks kualiti air dengan indeks kekayaan Margalef (r= -0.735, P=0.007), indeks kepelbagaian Simpson (r= -0.618, P=0.032), indeks kepelbagaian Shannon-Weiner (r= -0.642, P=0.024) dan indeks kesamarataan Pielou (r= -0.589, P=0.044) membuktikan bahawa pemantauan biologi di Penchala River sesuai dijadikan cara alternatif untuk mendapatkan status kesihatan sungai.

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LIST OF SYMBOLS AND ABBREVIATIONS

1S1R	:	One State One River
APHA	:	American Public Health Association
BMWP	:	Biological Monitoring Working Party
BOD	:	Biological oxygen demand
COD	:	Chemical oxygen demand
CST	:	Communal septic tank
DID	:	Department of Irrigation and Drainage, Malaysia
DO	:	Dissolved oxygen
DOE	:	Department of Environmental, Malaysia
EPT	:	Ephemeroptera, Plecoptera and Tricoptera
INWQs	:	Interim National Water Quality Standards
IST	:	Individual septic tank
NGO	:	Non-government organisation
NH_3-N	:	Ammonical nitrogen
NTU	:	Nephelometric Turbidity Units
PDC	:	Penang Development Corporation
TDS	:	Total dissolved solids
TSS	:	Total suspended solids
WQI	:	Water Quality Index

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CHAPTER 1: INTRODUCTION

1.1 Background of study

1.1.1 Overview of urban river

'Urban river' is originally a natural river that flows through a heavily populated area. The urban river expose to a wide range of anthropogenic pressures including pollution, flow regime alterations, overfishing, habitat destruction and biological invasions. In particular, many lowland regions concentrate agricultural and/or industrial activities which adversely affect biological diversity in rivers (Compin, 2007). The impairment of water quality at urban tropical river is mostly derived from the inflow of nutrients, pesticides and heavy metals (Krueger, 1998; Beasley and Kneale, 2003; Schipper et al., 2008).

Nowadays, urban tropical rivers are highly polluted due to impacts from tremendous development and affected by human activities as well as urbanization. Urbanization of the watershed increases impervious area thereby increases the intensity of runoff and peak flow discharge rate. Other than that, it also increases the concentration of sediments and nutrient loading and consequently alters the river morphology and flow patterns (Bernhardt and Palmer, 2007).

Determination of the current water quality status of the urban tropical river is essential to identify the pollutant which contaminate the rivers so that recovery action can be made by the authority. Hence, preventive measures can be taken to avoid recurrence of the same pollutant. All the preventive measures are necessary to preserve the river as it is a vital resource in sustaining life, development and to the environment. In addition to that, the river is very important as the main habitat for macrobenthos, fishes, amphibians and others.

1.1.2 Application of macrobenthos as bioindicator

The terms of bioindicator refer to an organism that accumulates substances in their tissue. This organism has the ability by giving response to the environmental level of those substances or the extent (Hellawell, 1986). The biological indicator study involves the identification of macrobenthos is a scientific analysis to determine the interactions between macrobenthos with their surrounding environment. Aschengrau and Seage (2007) defines ecological study as the examination of the relationship between exposure and outcome by observing population level data rather than individual-level data. The study had been focused on the comprehensive data for a population to review trends and make interpretations of the river health condition or problem on a large scale. The ecological study also involved study on diversity, distribution and calculation of biomass. In addition, the study also takes into account the determination of the number of organisms and competition between them as well as among ecosystem.

History of running water quality assessment based on biological indicators had been developed in the 1980's which about 60% is based on macroinvertebrate analysis (De Pauw and Jawkes, 1994). Macrobenthos assemblages or guilds generally integrate environmental changes in physical, chemicals and ecological characteristics of their habitat over time space (Cook, 1976; Milbrink, 1983). In addition, macrobenthos have thus been attractive targets of biological monitoring of environmental quality in aquatic ecosystems in Europe and North America (Rosenberg and Resh, 1993). This new development denotes that the natural structure and variability of invertebrate communities. It derives biotic indices within a homogeneous physiographic ecoregion could be surrounded by ordination, direct gradient analysis and canonical correspondence analysis (Gauch, 1982; Ter Braak, 1986) and thereafter macroinvertebrate assemblages or indices in suspected altered sites could be compared against those in reference sites.

1.2 Statement of problem

Malaysia has the highest dependency on the inland river system as a sources of clean water for daily uses. Heavy industrialisation, rapid urbanisation and urban-expansion make an increasement of pressure in finding the appropriate preservation and conservation activities to sustain the river health. This situation give challenge to researchers in order to discover alternative courses of action to improve water quality (Muyibi et al., 2008).

In this study, the selected urban river is unique as the upstream is very clean which is located at Kiara Park, Taman Tun Dr. Ismail. The river is use as a favourite recreational spot for the local community of Taman Tun Dr. Ismail. Besides, it also supports a wide range of biodiversity in and around its water. Moving to the downstream, 70 % of the river has been channelized. The river is highly polluted with rubbish and sewage since it was discharged by the residential area located along the river. In addition to that, the river faces some continuous construction activities. The construction activities are being done to maintain the stability of the riverbank while constructing a new structure across the river. Thus, as a comparison between upstream to downstream, the water quality status at the downstream deteriorates from Class I to Class IV.

The river also polluted with solid waste which were thrown from restaurants, wet market and industrial discharge. As time goes by, the condition of the river worsens as it becomes shallower and the flow of the water slower. The situation become more worsen when it’s come to raining season. The natural flow of the river is now being stuck to let river flushing off for its self-purification. This situation also gives negative impacts to the aquatic ecosystem in the river. A clean river is known as an ideal place for aquatic species, especially aquatic insects such as Odonata, Trichoptera, Coleoptera and Ephemeroptera to breed. Now, it has been destroyed by the urbanization project along the river. Other than that, the conversion flow of water from natural river into a concrete river prevents its natural self-purification (Wang et al., 2012).

1.3 Aim and objectives

The aim of this study is to find an alternative way to determine water quality which is cheap, rapid and economically cost effective. The determination of water quality by using macrobenthos is expected to be one of the alternative way of assessing the current water quality status. These alternative ways are important to manage urban river health. In an urban city, a healthy river provides a panoramic scenery and further illustrates our country, Malaysia as a beautiful country with beautiful rivers.

Government launched One State One River (1S1R) programme in 2005 to help the Department of Irrigation and Drainage Malaysia (DID). The aim of this program is to create awareness for the public about river restoration. River restoration is a process where the degraded river being brought back to its normal condition. One State One River promotes the involvement of local communities to participate in river management, in order to create awareness for the citizens to keep our rivers clean and healthy (1S1R, 2016). Other than that, good management of urban river will able to control the discharge of pollutants into the urban river. In Malaysia, the government has made a significant effort to control the discharge of pollutants into a river by introducing Environmental Quality Act 1974 (EQA, 1974). The act has listed various type of pollutants with its permission limits which the offender will be convicted under one of its clause and/or be fined as prescribed.

The development of squatters also can be controlled by using effective management of the urban river. Suffian and Mohamad (2009) studied that the main factor that causes a high number of squatters in Kuala Lumpur is economic status. The squatters affect the water quality through their poor sewage system. Other than that a healthy urban river can be used as a recreational spot. As mentioned earlier, the upstream of the selected river is very clean. The local authorities can take this opportunity to build up the surrounding area to a recreational area for a picnic, jogging and cycling.

Moving towards sustaining healthy urban river, this study was done to determine the current water quality status and to study the effect of the deterioration of water quality parameters to diversity and existence of macrobenthos at the selected urban river. At the end of this study, multi-relationship among the parameters was established to see the significant factor that affects the diversity and the existence of the macrobenthos. This establishment serves as an alternative method to access the current water quality status and river health instead of by relying solely on massive laboratory analysis. In addition, this study could be the benchmark to evaluate future water quality changes.

To achieve the aim, this research was supported by three objectives and research questions which are;

1. To determine physico-chemical parameter of Penchala River

2. To determine the distribution and abundance of macrobenthos of Penchala River

3. To determine the relationships between physico-chemical parameters and biological indices of Penchala river

This study introduced a rapid determination of the current water quality status by looking at the distribution and abundance of the macrobenthos. To validate the results, the water quality derived from biological indicators were compared to the results obtained from calculation of Water Quality Index (WQI).

1.4 Scope and limitation

This study covered the determination of water quality analysis that involves in the calculation of WQI such as pH, dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solid (TSS), and ammoniacal nitrogen (NH_3-N) as well as *in-situ* parameters such as temperature, conductivity and total dissolved solids (TDS). This study also compared the basic physical parameters which were water level, velocity and discharge. The sampling sites were limited to only four stations since most of the river bank were inaccessible. The determination of macrobenthos was limited to family level and it is a minimum requirement for calculation of biotic index used in this study.

1.5 Implication by the limitation

The identification of macrobenthos was up to family level provide sufficient information as the organic pollutant that can be detected clearly on family- based score rather than species-score (Sandin and Hering, 2004). Lenat et al. (1994) recommend that family level can be used since less taxonomy training is required to identify macrobenthos. In addition, the time taken for sample identification can be shortened at most of the macrobenthos can be identified to family level. Other than that, it is a minimum requirement for calculation of biotic index used in this study. In addition, the identification and classification at a family level also can prevent mistakes and identification which leads to further data misinterpretation at the end of this study.

CHAPTER 2: LITERATURE REVIEW

2.1 River health for urban river

'River health' is define as highly depending on its usage. Every sector has their own definition towards river health. For example, the river is considered healthy for recreationist if they found the river can be swim, water skiing or boating. Rivers are also considered healthy for drinking water utility as there is enough pure or purifiable water throughout the year (Karr, 1999). Issues on maintaining the river health has become an arisement important topic. Human activities that are involve changes in land use and water resource development can alter physical, chemical and biological processes of river ecosystem (Karr, 1991). Thus, the restoration and maintenance of healthy river ecosystem have become important aim of river management (Gore, 1985; Karr, 1991; Rapport, 1991) as the river is believed can be restored (Gore, 1985; Brookes and Shields, 1996) and also enhanced (Rapport, 1989).

Bunn and Arthington (2002) reported that river health in ecological concept is the ability of the aquatic system to support and maintain key ecological processes and a community or organisms with a species composition, diversity, and functional organisation as comparable as possible to that undisturbed habitats within the region. They also stressed that the ecologically healthy river will have flow regimes, water quality and channel characteristics such that in the riparian zone, the majority of plant and animal species are native and the presence of exotic species is not a significant threat to the ecological integrity of the system. The native riparian vegetation communities are existed to ensure the sustainability for the majority of the river's length and native fish and other fauna can freely move and migrate up and down the river. The most important characteristic of the healthy river is major of the natural habitat features that are represented and maintained over time (Postel and Richter, 2012)

‘Urban river’ is a river where a significant part of the contributing catchment consists of development where the combined area of roofs, roads and paved surfaces results in an impervious surface area characterising greater than 10% of the catchment (Beach, 2003; Ladson, 2004).

Rivers are important as it provides the sources of clean water to Malaysian. Major cities in Malaysia have been established and flourished along rivers. For example, the city of Kuala Lumpur itself was started at the confluence of Klang and Gombak river (Keizrul, 2011 March 9). Moreover, the river also acts as an urban entity that has been played many roles and contributes in many ways to urban development such as for transportation, water supply, flood control, agriculture and power generation. Nowadays, urban river in Malaysia has been polluted with rubbish, silt, sullage and domestic waste as it flew across the highly urbanized area. As the time goes by, the river is now getting worse as it loses their ability to make a self-purification (Wang et al., 2012).

Moving towards to the Vision 2020, Malaysia is facing a high demand of water and it’s become a great pressure in preserving the current water resources as well as finding alternative ways of action in order to improve water quality (Othman et. al., 2012). The impairment of water quality is due to increasement of water demand from agriculture, industry, hydroelectric generation and continued pollution. The consequences are further exacerbated by population growth, rapid urbanization and climate changes (Birol et al., 2006). Thus, rapid industrialization has been putting pressure on urban areas especially in the Klang River Basin which is the densest populated area in the country.

In recent years, Malaysia has experienced water crisis at severe stage. For example, the area of Klang Valley often had to deal with the water crisis due to decreasing of water quality at Semenyih Dam perhaps polluted by a high concentration of ammonia. As a consequence, the dam had to be closed for the water quality recovery process. The awareness about importance of maintaining the water quality of river is being ignored by most of the Malaysians. Rivers that formerly clean without any pollution is now at the stage of growing concern (DOE, 2015).

Water pollution is generally generated from the point and non-point sources. The point sources are discharges from industrial and sewage treatment plant and example of pollution that generated from non-point are surface water runoff from agricultural land use, housing area, commercialized area and industrial area. The development of squatters along the river bank resulted in the river channel. This make the river bank to be used as a convenient dump sites, waste from households, such as food scraps, plastics and sullage whether in liquid or solid form has been thrown into the river without any sense of guilty. Apart from that, the discharge waste with or without partial treatment from factories also has been released indiscriminately into the river; thus reducing their drainage capacities and, in the long run, creating an unsustainable environment (DOE, 2017 February 10).

2.1.1 Relationship between river health and urban river

The health level of the urban river is mostly affected by alteration of land use and anthropogenic activities. The changes in the natural water flow caused by drought or human intervention had created difficulty in living conditions for fish and other wildlife. The level of health was disturbed as the water was overtaken for agricultural activities, industry and conventional usage. In addition to that, the extreme agricultural activities also cause fewer rainfall filters into the ground since it runs directly into the rivers instead of flowing into drains and rivers. This situation will reduce the amount of water that is recharged to groundwater system and further causing additional impacts to river ecological health via decrease in the base flow of a system (Paul and Meyer, 2001).

Other than that, changes to the shape or structure of the river also can affect the river health. This situation happened when there are barriers that prevents fish and other creatures migrating naturally. The changes also remove all the plants from the riverbank that further make it more likely to erode, reduces habitats for other wildlife, affects the river's natural temperature and reduces the soil's ability to filter polluted water entering the rivers (Tabacchi, 1998).

2.2 Threats to urban river

There are many factors that affected the urban river health, as listed below:

2.2.1 Channelisation

The rapid urbanisation forces all the engineers, scientist and environmentalist struggle find the best tools to ensure the sustainability of the biodiversity and ecosystem. One of the problems that faced by the urban river is channelisation. Channelisation is a practice of dredging and straightening stream where finally it turned into artificial channels. This practice is done to increase the flow rates and carrying capacities. Initially, this idea is to make the river to flow straightly in order to prevent a flash flood, especially in the city. The channel has now been extra-large and straight to allow it to take bigger flows that would occur during severe rainfalls and could move away as much water as possible and in a short period of time (McBride and Booth, 2005).

From the other side, channelisation affects the hydrology that gives significantly influences to the water quality, temperature, nutrient cycling, oxygen availability and the geomorphic processes that shape river channels and floodplains (Paul and Meyer, 2001).

Mahazar et al. (2013) reported that the urban river also can cause problems as it becomes a mechanism for transporting plagues and diseases in certain countries as the consequences of water blocked during flood event. Other than that, the alteration is a natural regime that caused reducing or increasing of flows, altering seasonality of flows, changing the frequency, duration, magnitude, timing, predictability and variability of current events, altering surface and subsurface water levels and changing the pace of rising or drop of water points. Even worse, the same report had recognised that the alteration of natural flow regimes as a major factor contributing to the loss of biological biodiversity and ecological function in an aquatic ecosystem. Because of that, a large number of species, populations or ecological communities that rely on river flow for their survival become threatened as extraction of water, which reduce the flowing of water that, lead to a lower distribution of organic matter on invertebrate and vertebrates depend on as well as this will kill vegetation depending on intermittent flooding, decreasing habitat for invertebrate as a result. In addition, simplification of channel structure will result in a dramatic decrease in the habitat value of the stream (Brooks et al. 2001). Other than that, changes in physical, chemical and biological conditions of rivers as well as the degradation of riparian zone increase the erosion thus leading to sedimentation impacts upon aquatic communities (Bennett and Simon, 2004).

The above statement gives an idea that the chanellisation, alteration of natural flow regimes and changes in physical, chemical and biological will affect the aquatic organisms such as diatoms (Lowe and Pan, 1996; Hill et al., 2001) and macrobenthos (Rosenberg and Resh, 1993; Metcalfe, 1989). Therefore, the aquatic organism has been identified by many studies that they are suitable as a biological indicator to integrate their total environment and their responses to complex sets of environmental conditions. Other than that, biological indicator also offer the possibility to obtain an overview of the current status of streams or rivers (Worf, 1980). In addition, many studies have proved that macrobenthos can serve as biological indicators as can they can integrate their total environment and their responses to complex sets of environmental conditions. Other than that, they also can offer the possibility to obtain an ecological overview of the current status of rivers (Rosenberg and Resh, 1993; Metcalfe, 1989; Soininen and Koinonen, 2004; Li and Liu, 2010; Lenat and Barbour, 1994; Statzner et al, 2001).

2.2.2 Extreme increasing and decreasing of water volume

Increasing and decreasing of water volume is depending on the quality of rain and the ability of soil to store water (Berndtsson, 2010). Theoretically, when rain hits the surface of soil which covered with grass, forested or other unpaved surfaces, the water soaks will directly flow into the ground. As the water reach the ground, most of the water is absorbed by roots and is stored in the soil. The water which is not absorbed or stored, will gradually flows into streams and creeks. This make the stream to flow slowly and increases to a peak flow, and later slowly decreases to a stable flow maintained by water stored in soils. Consequence to the situation, when rain hits concrete, paved or other impervious surfaces such as rooftops, sidewalks and driveways, the water immediately become runoff and rapidly flows into the streams and rivers. This is because the water does not get a chance to filter through the soil. As the water rises rapidly and this make a decrease of the size of peak flow. Later, this situation also flushes fishes and insects. The worst situation that can happen is when a large quantities of water flowing quickly through the stream channels will cause the banks of the stream to erode, adding sediment to the stream and further causing habitat loss. This situation will also drastically change the structure of the stream bottom by washing out rocks, logs, and vegetation which all these structures provide shelter and food for living animals in the stream (Finkenbine et al., 2000).

2.2.3 Shallow stream bottom

A healthy stream bottom generally made off from sediment, loose clay, gravels, logs, loose sand and boulders. In addition, the natural streams have less erosion and sediment deposition. Other than that, natural streams normally create flow patterns containing numerous bends and usually inside the bends it contains finer substrate deposited, while the outside of a bend tends to undercut the bank. This situation provides shallows in the depositional area and pools in the erosional area. The urban river which undergoes channelisation eliminates all of these processes and the habitat that they created. Excessively increased flow and channelisation results in degradation or elimination of natural substrate and thus decreased habitat diversity (Rapport and Whitford, 1999).

2.2.4 Loss of riparian vegetation

Another problem that the urban river faced is a loss of riparian vegetation. The riparian vegetation is defined as an area of trees, shrubs and other plants located next to, and upslope from, a body of water (Polyakov et al., 2005). The riparian vegetation plays an important role specially to regulate water temperatures by shading off the stream. Losses of these riparian vegetation had come to a results which is increasing of temperature This phenomenon thus decrease the stream’s ability to hold oxygen. Moreover, riparian vegetation also helps to filter pollutants and debris as well as stabilises stream banks by reducing erosion and sediment transportation. In conjunction to that, riparian vegetation also provide habitat for wildlife especially macrobenthos that live between their roots

2.2.5 Degradation of ecosystem services

The urban river also has to deal with degradation of ecosystem services. The degradation of ecosystem services is happening directly or indirectly relates to severe degradation of water cycle catchments and their reduced ability in managing water resources based on environmental mechanisms such as physical and green water retention, infiltration, interception and self-purification. The disruption has been recognised by Wagner and Zalewski et al. (2009) that can be classified into four main categories which are degradation of the hydrological process, disruption of the biogeochemical cycles and physical degradation of aquatic habitats. The degradation of the hydrological process is due to land use changes, water withdrawal from surface ecosystem and groundwater, improper river channelization for flood control and land drainage and soil erosion whereas the disruption of the biochemical cycles is affected by increasing of diffuse nutrient export from degraded landscapes and condensed matter outflow from urbanised areas.

Adaptation of hydro technical management or engineering is a potential to overcome all of this disruption. The effectiveness of this method is highly depends on the climatic conditions, the degree of natural processes degradation, cultural and social attitudes and policy as well as financial mechanisms (Batrich et al., 2004).

2.3 Managing urban river

A healthy urban river should have a diverse and complex ecosystem for many communities of plants and animals that exist together in balance. Chan (2012) stated that the urbanization increased dramatically in all major cities and towns as the country undergo rapid development for the last three or four decades. The expansion of agriculture and industrialization activities greatly affected the water supply in terms of quantity and quality (Chan, 2002).

The government has launched 1S1R program in 2005 to support the DID in order to get full participation from stakeholders in organizing a river restoration and water quality for the improvement program for one river in their state. One of the objectives is to ensure cleanliness, living and valuable rivers with the minimum water quality of Class II (WQI – 76.5 – 92.7) by 2015. As of 2013, Department of Environment Malaysia monitored 473 rivers all over Malaysia. In the percentages of, 58% (275) were asserted to be clean, 36.6% (173) were slightly polluted and another 5.3% (25) were found to be polluted (DOE, 2013).

The urban river that was heavily been polluted is Klang River which located in the Klang River basin, which is one of the densest populated areas of the country housing that is consisting 3.6 million people (Chop et al., 2002). Due to the serious pollution, DID has come out with a proposal to clean up the river and the objectives are; 1) to clean up the Klang River and its major tributaries from rubbish and silt, 2) to improve the water quality of the Klang River and its major tributaries to a standards minimum of Class III standards and, 3) to beautify the riverine areas with a sceneric view to provide and upgrade recreational facilities within the city. Other than that, the Federal Territory and Klang Valley Development Division of the Prime Minister’s Department also take some initiative to relocate about 2,650 squatters’ family which has been colonised along the river bank. Unfortunately, the relocation process was unsuccessful due to the inability of local authorities to provide alternative low-cost housing to the squatters (Chan, 1997).

Other than that, Sungai Penang also was listed as a polluted urban river by the Penang State Local Government. The Sungai Penang used to be very clean but after sometimes later the river has degraded too much and finally become one of the most polluted rivers in Peninsular Malaysia. The pollution occurred because of lack in public participation. The government also need to be well cooperate with non-government organization (NGOs) in the country’s development and involving with NGOs in water conservation and management since the role of NGOs is to link the industries and consumers (Chan, 2002).

Sungai Kluang is another polluted river. The river water of Sungai Kluang passes through the residential areas of Bayan Baru, Bukit Gedong and Bayan Lepas Industrial Zone before it drains into the Western Channel of Pulau Jerjak. Sungai Kluang is being polluted while it is passing through the industrial zone. The pollution is caused by the organic waste, suspended solids and heavy metals such as lead, nickel and zinc (Ibrahim, 2002). The NGOs, DID, Penang Development Corporation (PDC) united together with the local residents to develop a riverside park that will cater for the recreation needs of the Bayan Baru population. The programme provides a minimum landscaping, basic recreational amenities and a cycle track of 4 km stretch that also provides a mechanism for community participation in river management (Chan, 2002).

2.4 Water quality control for urban river

The water quality status of rivers in Malaysia has always been discussed by government agencies, local authorities, NGOs, researchers and public at large. To access the current status an extensive degree of quantification, the government is responsible to make sure that all the rehabilitation measures and engineering control that involve with a large cost to follow the appropriate plan and a very well decision making (Harding, 1998).

In Malaysia, the monitoring of river water quality has been started since 1978 by Department of Environment Malaysia as the authority. Their primary role is to establish a baseline and to detect water quality changes of a river and has been extended to identifying of pollution sources as well. Recently, their efforts are considerable and had been made in the past two decades to analyse pollution, either from point sources or non-point source in several rivers. Point sources can be listed such as sullage discharge from the residential area and partially treated effluent discharge from the industrial area. In contrast, non-point sources are derived from diffused sources that do not have specific discharge points such as from agricultural activities and surface run-off (DOE, 2017 February 10).

Referring to the report that was published by the Department of Environment Malaysia (DOE) 2013, the major pollution comes from manufacturing industries, sewage treatment plants, individual septic tank (IST), communal septic tank (CST), animal farm (pig farming), agro-based industries, wet markets and food service establishments.

Evaluation of water quality status is being done by using Water Quality Index (WQI). The WQI is a method that combines a group of water quality parameters in one concise for a specific use (Davis and McCuen, 2005). WQI has been developed to assess the suitability of water for a variety of uses and most of the WQI development in many countries requires selection of water quality parameters and assigning optional weights of the selected parameters.

The implementation of this method involves sampling of the river water at regular intervals from designated stations for in-situ and laboratory analysis to determine its water quality and biological characteristics. In the year of 2006, which is the latest, there are 891 manuals and 13 automatic monitoring stations (DOE, 2015) operated by Malaysia which include Sabah and Sarawak. The automatic stations were installed at a sensitive location, including upstream of water abstraction points. There are three types of monitoring stations which are baseline, ambient and impact stations. The baseline station was located at the upstream of the catchments or basin, which are located in the undevelopment area or with minimum activities. The ambient station was located at the downstream away from the either point or non-point sources to get the actual status of the water quality. Different from others, the impact station was operated for the purpose of enforcement. All the automatic stations have the ability to detect pollution influx at an early stage.

DOE Malaysia (1994) had set up a guideline as a benchmark for river water to monitor in Malaysia so that the quality of water is under control and not exceeding the limit that could stress out the ecological inside. The guidelines were focused on water for domestic water supply, fisheries and aquatic propagation, livestock drinking, recreation and agricultural use which involves over 120 physio-chemical and biological parameters. The WQI was used as a basis for assessment of a water body in relation to pollution load categorization and comprises weighted linear aggregation of sub-indices of DO, BOD, COD, NH_3-N, TSS and pH.

After several studies were done, the department published an Interim National Water Quality Standards (INWQs). The INWQs defined six classes, namely Class I, IIA, IIB, III, IV and V which Class I indicate the 'best' while Class V indicate the 'worst'.

The DOE had set up regulations to control pollutant loading from point and non-point sources is the Environment Quality (Sewage and Industrial Effluent) Regulations 1979 which include two standards of effluent quality, Standard A and B. Standard A refers to guidelines that need to meet by effluent discharged upstream of a water supply intake and Standard B is for effluent that is discharged downstream. The aim of this regulation is to support the development of water quality management approach for the long-term water quality of the nation's water resources.

2.4.1 Biological indicator for water quality monitoring

There are many ways to assess water quality in flowing water (lotic) and still water such as lakes (lentic). The most common method is by assessing on water quality which involves the determination of physical and chemical properties of the water. This method is widely used around the world but they have generally failed to provide a consistent and comprehensive condition of the water body. Other than that, physical measurement and chemical analysis which are dependent to one another and ecological state is poorly understood or too complex to understand. In addition, these methods are also do not take into account important changes to river habitat and are frequently instantaneous (Rosenberg and Resh, 1993).

The determination of water quality through physico-chemical characteristics only help to identify sources of water contamination. Further analysis is needed to get information on the health of the aquatic ecosystem. Hellawel (2012) concluded that the analysis of physico-chemical characteristics only serves as a transient picture of ecosystem health since concentration for each parameter will vary day to day and highly depending on the time, discharges, precipitation and water flow patterns.

Matthews et al (1982), Rosenberg and Resh (1993) and Gibson et al. (1996) defined monitoring water quality by using biological indicator is defined as an evaluation of the condition of a water body using biological surveys and other direct measurements of the resident biota in surface waters.

Compared to the biological indicator, the biological communities integrate all of the environmental stresses whether caused by human or natural activities within unlimited time. The success of this indicator can be qualified by the presence of sensitive species of macrobenthos at a healthy river and the absence of them at a poor river. Beside determination river health through physico-chemical method, biological communities in rivers and streams are important components in the evaluation of water quality. Biological communities provide an integrated and comprehensive assessment of the health over time. It also gives an integrative measure of the overall health of the stream and inadequately identifies impaired water (Karr, 1999).

The right selection of bioindicator is important since different types of bioindicators have different tolerance towards certain concentration of pollutants. Hellawell (1986) provide guidelines to select the best organism as indicators which were 1) readily identified, 2) sampled easily and quantitatively, 3) wide distribution, 4) abundance existence, 5) have economic importance, 6) readily accumulate pollutants and 7) have low variability.

Macrobenthos consist of crustaceans, mollusks, insects and other visible invertebrates. Plafkin et al (1989) mentioned that the macrobenthos are important bioindicator since they inhabit the degraded or contaminated resources Other than that, the macrobenthos is exposed directly to degradation throughout its life history. Resh (2008) studied that macroinvertebrates provided the highest return for research fund spent. This statement was supported by Bonada et al. (2006) who agreed that macrobenthos is accepted around the world as biological monitoring of streams and rivers.

2.5 Introduction of macrobenthos as biological indicator to determine water quality

Basically, macrobenthos are small animals without backbones that survive on and under submerged rocks and gravel, logs, in the sediment, in between debris and aquatic plants during their life cycle. Macrobenthos have special characteristics. Different species have different tolerances to a variety of pollutants such as organic pollutants, sediments and toxicants (William, 2005). Other than that, their variations also related to human activity in water basins, such as urbanisation and agriculture (Fore and Grafe, 2002).

Macrobenthos is recognised to serve as good indicators for overall stream health as they commonly inhabitants of streams. Rosenberg and Resh (1993), reported that the term ‘benthic’ means ‘bottom living’ and it is approved as these organisms usually inhabit at the bottom of substrates for at least part of their life cycle. They play an important role in the food webs, energy flow and in the circulation of nutrients as they serve as food for other higher organisms such as fish (Rosenberg and Resh, 1993). The existence and diversity of their population are highly dependent on the integration of the stream conditions that occurred during their life cycles. Diversity such as water quality, habitat characteristics, and changes in the flow, temperature and velocity. In addition, macrobenthos also reacts to physical factors of ecological significance that include streamflow, current velocity, channel shape, water depth, substrate and temperature and water quality indicators such as the concentration of dissolved oxygen, salinity and pH.

Several publications have appeared in recent years documenting the potential of macrobenthos as a biological indicator. Rosenberg and Resh (1993) stressed that the data on physico-chemicals is very limited for determination of river health. The study was supported by Oertal and Salanki (2003) who also agreed that the monitoring by using the chemical approach alone is not realistic and not enough data can obtain as it is very limited. In addition, they also argued that the approach would not take into account for the additive, synergic or antagonistic effect that might occur and also lack important data such trace metabolite and reaction products.

Turkmen and Kazanci (2010) have listed the advantages using macrobenthos as a biological approach to monitoring water quality. From his study, macrobenthos served as a better candidate compared to fish as they are high abundance and ubiquitous in nature. In addition, macrobenthos also rich with families that responses to environmental changes both natural and man-induced during their life cycle. Other than that, macrobenthos has a sedentary lifestyle and long lifespan also give them advantages as pollutant indicator. Furthermore, they are readily collected and identified and finally classified as sensitive.

Each of its families have a varied sensitivity of various types of pollutants. Their presence and absence will reflect the health conditions of the river either healthy (clean) or not healthy (polluted) (Karr, 1999). For example, the healthy river is favourable for Trichoptera, Ephemeroptera and Plecoptera larvae whereas Diptera larvae are found abundance in the not healthy river (Ab Hamid and Rawi, 2014). This characteristic might useful in order to study and identify the synergistic effect of different type of pollutants on a living organism (Cao et al., 1997). His study was parallel to Hellawell (1986) who found that aquatic invertebrates respond to their variations in physical habitats.

2.5.1 Use of macrobenthos as water quality indicator

In Malaysia, various type of considerable effort has been made to achieve a successfully analyse physical, chemical and biological pollution in several rivers. However, there were only a few efforts that include the study on diversity and abundance of macrobenthos for purposes of environmental bioassessment are available (Azrina, 2006). The study also mentioned that there is no comprehensive investigation on the effect of the different pollution on the diversity of macroinvertebrate inhabiting Malaysian's river has been carried out.

A study on macrobenthos community structure and distribution in Sungai Pichong, Gunung Chamah, Kelantan has been carried out by Aweng et al. (2012) to assess the species and distribution of macrobenthos at the highland river and also determining the physical and water quality factor that influence macrobenthos composition and distribution. They stated that the distribution of macrobenthos is highly depended on physical nature at the sub-stratum, nutritive content, degree of stability, oxygen content and level of hydrogen sulphide which supported by Anbuchezhian et al. (2009).

Azrina et al. (2006) studied on the anthropogenic impacts on the distribution and biodiversity of macrobenthos and water quality of the Langat River. They agreed that anthropogenic activities affect the water quality, biodiversity and distribution of macrobenthos. The macrobenthos with high in tolerance were present at all level of pollution while macrobenthos which low level of tolerance will disappear at "poor" Biological Monitoring Working Party (BMWP) score.

Other than that, biological monitoring was suggested to be used in recovery and conservation effort. Chironomidae and Simuliidae have a high potential for detection of organic pollutant while Hirudinea and Oligochaeta can be used for other polluted water as experimentally measured by Weng and Chee (2015).

Wahizatul et al. (2011) studied that the diversity and abundance of aquatic insects and values of biological indices in accessing water quality of Sungai Peres and Sungai Bubu in Terengganu. The ratio of Ephemeroptera, Plecoptera and Tricoptera (EPT) to Chironomidae is higher at the downstream stations in Sungai Peres and Sungai Bubu shows the impacts of anthropogenic activities on the water quality, diversity and distribution of aquatic insects were clear. This study agreed that biomonitoring approach by using aquatic insect communities as bioindicator provide useful information for appropriate management of freshwater streams in Malaysia.

2.5.2 Levels of tolerance of macrobenthos to water pollution

The tolerance value describes the resistance of organisms towards pollution. Numbers are given to represent their tolerance or intolerance towards pollution. The tolerance values for each family were developed by weighting species according to their relative abundance. According to a study by Carter and Resh (2013), the tolerance value is different based on their response to stressors such as an organic pollutant, toxic chemical and heavy metals. The general pollution tolerance for common aquatic organism towards the various level of dissolved oxygen is presented in Table 2.1.

Table 2.1: General pollution tolerance for common macrobenthos (Carter and Resh, 2013)

Level of dissolved oxygen	Level of tolerance value	Groups of macrobenthos
High	Low	Caddisfly Mayfly Stonefly Water Penny Riffles beetle Hellgrammite
Moderate	Intermediate	Damselfly Horsefly Crayfish Cranefly Dragonfly Blackfly
Low	High	Mosquito Aquatic earthworms Moth fly Rat-tailed maggot Midget Leech

2.5.3 Diversity indices

Diversity indices are a numerical expression that can provide a combination of quantitative values of species diversity and qualitative information on the ecological sensitivity of each taxon (Arslan et al. 2016). Graca (1998) defined biological indices as numerical expressions coded according to the presence of biological indicators differing in their sensitivity to environmental conditions. Gallardo et al., (2011) defined biotic indices as numerical expressions that combine a qualitative measure of species diversity with qualitative information on the ecological sensitivity of individual taxa. His definition is based on two principles that are (1) macroinvertebrate Plecoptera, Ephemeroptera, tricoptera, Gammarus, Asellus, red midges Chironomidae and Tubificidae disappear in the order mentioned as the organic pollution level rises, and (2) the number of taxonomic groups is reduced as pollution increases.

Accessing water quality by using biotic indices has been recognized as suitable criteria for understanding the quality of the aquatic environment. Biotic indices for several decades by many European researchers for routine rapid assessment of water quality in rivers (Hering et al., 2010).

Biotic indices developed for a particular zone have been applied in other geographical areas. For example, Belgian Biotic Index (De Pauw and Vanhooren, 1983) has been developed for Belgium, applied in Portugal (Fontura and Moura, 1984), Indonesia (Krystiano and Kusjantono, 1991) and Canada (Barton and Metcalfe Smith, 1992). Biological Monitoring Working Party (BMWP) score system was initially developed for river pollution surveys in the UK (Armitage, Moss, Wright and Furse, 1983) have been successfully applied in Malaysia (Yap et al., 2003; Mahazar, 2013).

In 2005, water quality monitoring programmes in Poland were mainly based on the determination of physical and chemical parameters. They intermittently used the saprobic index which was based on the analysis of microorganisms that belong to plankton community. By using plankton community, they were facing difficulties as many limitations occur in the biological water-quality assessment such as the difficulties in the taxonomic identification of microorganism and the lack of possibilities of the presentation of local conditions. Therefore, interest has been shown in the application of biological water quality monitoring techniques using macroinvertebrates which are advantageous, cost effective and simple and later Poland had led to the adaptation of the BMWP score system.

Mason (1980) stated that biotic indices have been developed to measure responses to organic pollution and may be unsuitable for detecting other forms of pollution. Diversity indices are used to measure stress in the environment. It has been seen large number species are found in unpolluted environment, with no single species making up the majority of the community and a maximum diversity is obtained when a large number of species occur in relatively low number in a community. When an environment becomes stressed, species sensitive to that particular stress tend to disappear. As result, species richness will be reduced and the density of the surviving species will increase. Species diversity indices usually take account of both the species richness and their evenness. There are numbers of diversity indices but the most widely used is Shannon diversity index, which is based on information theory (Sharma et al., 2010).

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter present the sampling procedure that was used in this study. The aim of the procedure is to get the adequate sample of the river water in Penchala River. The samples should be small enough in volume to be transported conveniently and large enough for analytical purpose. River water samples were collected from all four stations to assess their current water quality by measuring their chemical and physical properties. To achieve the research aim, a series of data sampling has been conducted from November 2013 to October 2014. For each sampling date, the river water was sampled in three replicates to ensure the accuracy.

3.2 Determination of location to represent urban river

Urban river refers to the river that flows through a well-developed area that covers with dense population or industrial area (Walsh et al., 2005). The urban river is contaminated by urban runoff which comes neither from a residential area, restaurants nor industrial area. Historically, monitoring of physico-chemical studies at urban river have been done by researchers in Klang Valley (Azrina et al., 2006; Chop et al., 2002, Mahazar et al., 2014; Norhayati et al., 1997; Yap et al., 2003). The Penchala River was chosen as an example to represent urban tropical river was because it can cover both pristine and polluted river health conditions along its 14 km river body. The upper stream was clean and natural with almost no disturbance from anthropogenic activities while the lower part was in contrast. Other than that, Penchala River also received various sources of pollutant neither from point sources nor non-point sources. In addition, Penchala River can also provide a suitable context to examine on how the macrobenthos response to deterioration of chemical and physical in space and time. As it flows through a highly urbanized area of Kuala Lumpur and Petaling Jaya, it receives discharges from the industrial, residential and squatter's area make it become the best example of the urban tropical river in Malaysia and perhaps it will be suitable to apply to other rivers for future studies.

3.2.1 Background of Penchala River

Penchala River has 50 km^2 of the catchment area. It is originally short, a clean river which rich with aquatic biodiversity. Nowadays, the river body at Station 2, 3 and 4 has been channelised for the drainage system and polluted by the domestic wastewater, industrial wastewater, agricultural area and housing development along the river bank

The research was done along 14 km of Penchala River, starting from its upper stream at Lembah Kiara Park and straight away to the downstream at Kampung Ghandi, right before it meets Sungai Klang. Penchala River has 50km^2 of the catchment area. It is originally a short, clean river which is rich with aquatic biodiversity. The clean river has been known as an ideal place for breeding for many aquatic species, especially aquatic insects such as Odonata, Trichoptera, Coleoptera and Ephemeroptera (Voshell, 2005). Nowadays, the river has been modified for the drainage system and polluted by the domestic wastewater, industrial wastewater, agricultural area and housing development along the river bank. From the same report, Department of Environment, Malaysia (DOE, 2013) also mentioned that the Penchala River has been polluted with rubbish, silt and domestic waste as it flew across the highly urbanized area of Kuala Lumpur and Petaling Jaya. Fathoni Usman et al. (2014) showed the trend of WQI from 1997 – 2007. The WQI were decreased and slightly improved started from 2002 onwards ranging from Class V – Class IV to Class IV – Class III as the 1 State 1 River programme was introduced by the Selangor State's Department of Irrigation and Drainage in 2002. Basically, the programme was aimed to organise a river restoration and water quality improvement programme with full stakeholder participation. However, a continuous monitoring and activities to further improve the water quality is still needed.

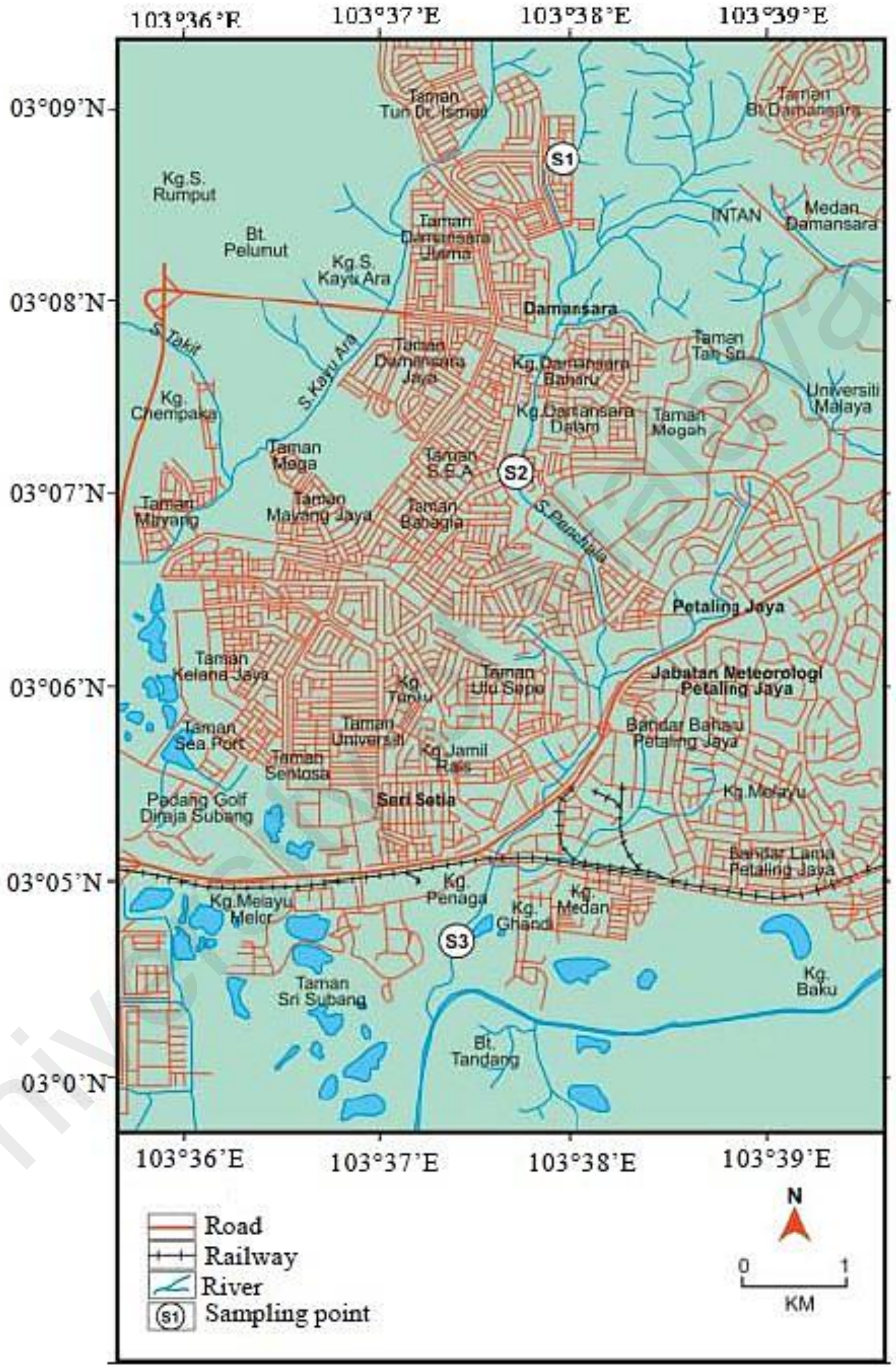


Figure 3.1: Catchment of Penchala River (Mahazar et al., 2013)

3.2.2 Selection of sampling sites

The selection of sampling site was done after taking into account of certain criteria included easy and safe accessibility all year round, at least the site were 100 meters away from any drain and it is stable which will not be washed away during floods. After taking all the above considerations, 4 sites have been identified for this study. All the identified sites were named Station 1, 2, 3 and 4 and the GPS coordinates were recorded as in Table 3.1.

Station 1, 2, 3 and 4 have different land-based uses, characteristics and sources of pollution. Station 1 is located at the upper stream which is situated at Lembah Kiara Park in Taman Tun Dr. Ismail. It is natural and less disturbed by humans. Station 2, 3 and 4 are concrete rivers. Station 2 was located at Jalan SS2/19. The station was adjacent to SSTwo mall and residential area at the other side of the river. The water bodies at this station receive discharges from anthropogenic activities. Station 3 was located in the middle of an industrial area. It receives discharges from industries along the river bank. The last station is Station 4 which is located at Kampung Ghandi.

Table 3.1: Name of stations, coordinates and description for each stations

Station	Name of the station	Coordinate	Description
Station 1	Taman Lembah Kiara, Kuala Lumpur	03°08’45.30", 101°37’54.1"	Natural river. Located at Lembah Kiara in Taman Tun Dr. Ismail, Kuala Lumpur
Station 2	SS2/19, Petaling Jaya	03°07’07.40", 101°37’42.7"	Concrete river. Located adjacent to shopping mall and residential area
Station 3	Jalan 222, Petaling Jaya	03°05'48.58", 101°38'03.98"	Concrete river. Located in the middle of an industrial area
Station 4	Kampung Ghandi, Petaling Jaya	03°04’45.40", 103°37’18.0"	Concrete river. There were squatters along the river bank

Figure 3.2 to 3.5 shows the pictures of Station 1, 2, 3 and 4. From the figures, Station 1 is the only natural river compared to other stations which has been channelised as its flow through the developed area.

Figure 3.2: Station 1

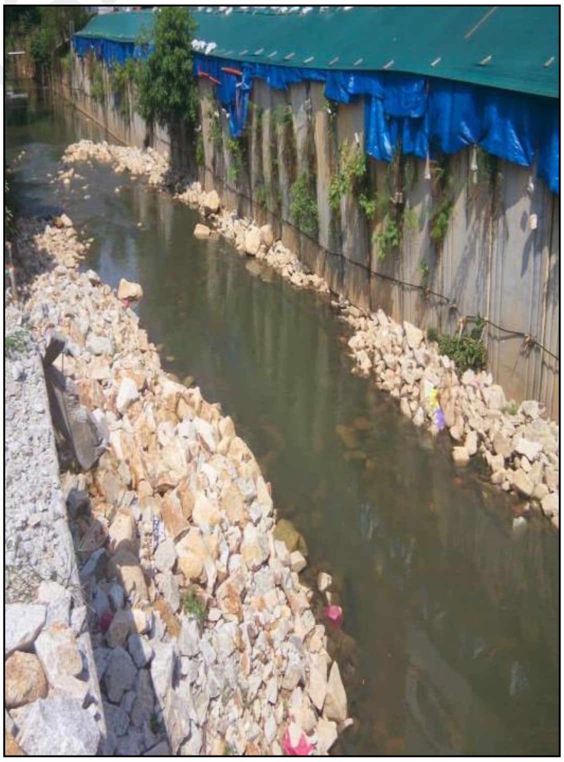


Figure 3.3: Station 2

Figure 3.4: Station 3

Figure 3.5: Station 4

Table 3.2 provides a series of sampling dates that has been conducted to collect data for this study.

Table 3.2: Sampling months and dates for data collection

No.	Month	Date
1	November	24 November 2013
2	December	16 December 2013
3	January	24 January 2014
4	February	25 February 2014
5	March	30 March 2014
6	April	29 April 2014
7	May	25 May 2014
8	June	25 June 2014
9	July	15 July 2014
10	August	29 August 2014
11	September	25 September 2014
12	October	25 October 2014

3.3 Determination of physico-chemical characteristics

Determination of physico-chemical characteristics was done at all the stations involving on-site measurement and laboratories analysis. The sampling technique, parameters, related procedure and calculation involved will be discussed in this chapter.

3.3.1 Sampling technique

Water sampling was done by collecting river water samples into a wide-mouth 1 liter polytetrafluoroethylene (PTFE) bottles. All the bottles were rinsed with chromic acid to eliminate any possible contamination that will affect the final results. All the bottles were labelled using gummed paper label to avoid sample misidentification. The label included the name of the station, date and time of collection. The samples were analysed for chemical testing as soon as possible within 24 hours to avoid deterioration of original characteristics. The water samples were kept in the ice box to maintain at 4^{o}C prior to transportation to laboratories for further analysis. Analysis of water quality was referred to American Public Health Association (APHA, 2006), 21st edition as the main reference.

3.3.2 Water quality parameters

Water quality status was determined by conducting water analysis to the river water samples. The analysis of water quality was done on-site and physical parameters of the river can be accessed by conducting site monitoring, water sampling and on-site measurement on water quality and physical parameters.

Water quality parameters such as temperature, conductivity, dissolved oxygen and pH were measured *in-situ*. Dissolved oxygen (DO) was determined by using YSI DO meter (YSI 550). Other parameters such as pH, conductivity and temperature were measured by YSI meter (Multi-sensor) Model IQ Scientific. The Biological Oxygen Demand (BOD) and Total Suspended Solids (TSS) were analysed in the laboratory by referring to APHA standard method procedures (APHA, 2006). The COD were conducted by using HANNA Instruments HI 93754B – 25 COD Reagent, Medium Range which covers results from 0 to 1,500 mg/L. Ammoniacal nitrogen (NH_3-N) and Phosphate were analysed by using Merck Spectroquant® Ammonium Test and Phosphate Test respectively by using the photometric method.

A total of six water quality variables which were DO, BOD, COD, TSS, NH_3-N and pH were analysed to derive the water quality index of the Penchala River. The calculations were done by using their sub- indices named SI_{DO}, SI_{BOD}, SI_{COD}, SI_{AN}, SI_{SS} and SI_{pH}. Finally, the WQI was calculated by using equation of Malaysian Department of Environment (DOE) (2011) as follows;

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

where, WQI = water quality index; SI_{DO} = sub-index of DO; SI_{BOD} = sub-index of BOD; SI_{COD} = sub-index of COD; SI_{AN}= sub-index of AN; SI_{SS} = sub-index of TSS; SI_{pH}= sub-index of pH. The sub-index of the respective water quality parameters is calculated according to the best fit equations as in Table 3.3.

Table 3.3: Derivation of WQI (DOE, 2013)

Sub-index for DO (in % saturation)	
SIDO	= 0 for x ≤8 = 100 for x ≤92 = -0.395 + 0.030x2 - 0.00020x3 for 8 < x < 92
Sub-index for BOD	
SIBOD	= 100.4 - 4.23x for x ≤ 5 = 108* exp(-0.055x) - 0.1x for x > 5
Sub-index for COD	
SICOD	= -1.33x + 99.1 for x ≤ 20 = 103* exp(-0.0157x) - 0.04x for x > 20
Sub-index for NH_3-N	
SIAN	= 100.5 - 105x for x ≤ 0.3 = 94* exp(-0.573x) - 5* I x - 2 I for 0.3 < x < 4 = 0 for x ≥ 4
Sub-index for SS	
SISS	= 97.5* exp(-0.00676x) + 0.05x for x ≤ 100 = 71* exp(-0.0061x) + 0.015x for 100 < x < 1000 = 0 for x ≥ 1000
Sub-index for pH	
SlpH	= 17.02 - 17.2x + 5.02x2 for x < 5.5 = -242 + 95.5x - 6.67x2 for 5.5 ≤ x < 7 = -181 + 82.4x - 6.05x2 for 7 ≤ x < 8.75 = 536 - 77.0x + 2.76x2 for x ≥ 8.75

The respective class designation for the WQI scores, in turn, is tabulated in the Table 3.4:

Table 3.4: Guidelines on INWQs specification (DOE, 2011)

Parameters	Unit	Classes				
		I	II	III	IV	V
Ammoniacal nitrogen	mg/l	<0.1	0.1 – 0.3	0.3 – 0.9	0.9 – 2.7	>2.7
BOD	mg/l	<1	1 – 3	3 – 6	6 – 12	>12
COD	mg/l	<10	10 – 25	25 – 50	50 – 100	>100
DO	mg/l	<7	5 – 7	3 – 5	1 – 3	<1
pH	mg/l	>7	6 – 7	5 – 6	<5	>5
TSS	mg/l	<25	25 – 50	50 – 150	150 – 300	>300
WQI	mg/l	>92.7	76.5 – 92.7	51.9 – 76.5	31.0 – 51.9	<31.0

Table 3.5 provides definition on the class identified. From the Table 3.5, rivers which fall under Class I, IIA, IIB and III are suitable for water supply while Class V river is prohibited for water supply and also for irrigation. Other than that, Table 3.5 also provides information on the specification of each river class. Class I – III rivers specify the water quality level necessary to sustain macro aquatic life, with varying degree of sensitivity. Class IV can be used for irrigation whereas Class V is considered to have minimal beneficial usage.

Table 3.5: INWQs specification definitions (DOE, 2011)

Class	Definition
I	Conservation of natural environment Water supply I – Practically no treatment necessary (except by disinfection or boiling only) Fishery I – Very sensitive aquatic species
IIA	Water supply II – Conventional treatment required Fishery II – Sensitive aquatic species
IIB	Recreational use with body contact
III	Water supply III – Extensive treatment required Fishery III – Common of economic value, and tolerant species, livestock drinking
IV	Irrigation
V	None of the above

3.3.3 Physical characteristics

Physical parameters of the river were divided into two parameters which are measurement of velocity and calculation of discharge.

Velocity (V)

The stream velocity for all the stations was measured by identifying the best spot which is straight, free from large objects with noticeable current with a depth as uniform as possible were selected. For this study, the current meter of propeller type was used to get the stream flow. The propeller was placed in about 2 cm from the water surface. Then it was let to move freely for 30 seconds. The current meter converted the velocity into a count of rotations. Then finally, the count was calculated to get the actual stream flow reading (Hauer and Lamberti, 2011).

$$Velocity, V = 0.1025\ N + 0.028 \qquad \text{Eq. 3.2}$$

In the case of too low velocity at Station 4, the traditional method was adopted. The traditional method was used floating polystyrene to travel at a known length and noting its position in the river. The floating polystyrene was moved with the same velocity as the surface of the water (Hauer and Lamberti, 2011). The calculations involved were;

$$Velocity, V = \frac{the\ distance\ of\ float\ polystyrene\ travelled\ (m)}{time} \qquad \text{Eq. 3.3}$$

River water discharges (Q)

The stream discharges were calculated by the following equation (Hauer and Lamberti, 2011);

$$Discharges, Q = Area\ \times Velocity \qquad \text{Eq. 3.4}$$

Calculation of area involves measurement of water depth and river width. The water level was measured by using staff gauge by placing the gauge into the river until it reaches the bottom. The river width was measured by using a measuring tape (Hauer and Lamberti, 2011). The '0' point should be anchored at the wetted edge of the stream. The end of the tape was anchored at the opposite wetted edge. Thus, after the measurement of water level and river width were collected, the data were calculated by using the equation above, with results of velocity which had calculated earlier. Measurement of river width were constant through this study as Penchala River is a concrete river.

3.4 Sampling of macrobenthos

A sampling of macrobenthos involved site selection for sampling, methods for sampling, laboratory analysis, identification and calculating the biotic index to determine its species richness and species diversity.

3.4.1 Site selection for sampling macrobenthos

The selection of sampling location is very important. The failure to identify the best location to collect the benthic will lead to inaccurate data. The location should be at least 100 m upstream from any road or bridge crossing to minimize its effect on stream velocity, depth and overall habitat quality. Other than that, the suitability also ensures that there is no major tributaries discharge to the stream nearby (Hauer and Lamberti, 2011).

3.4.2 Method for sampling macrobenthos

The macrobenthos was collected on every sampling dates from November 2013 to October 2014 by using 0.3m x 0.3m Surber sampler. Samples were taken in duplicates at each station. The Surber sampler was placed face upstream, to allow the current to push the sample into the net. The upstream were disturbed for three minutes using the heel of the boot, dislodge the upper layer of cobble or gravel and scrape the underlying bed. Larger substrate particles were picked up and rubbed by hand to remove attached organisms. All the samples were transferred from the net to nylon sealed bag and were preserved with 70% ethanol for further analysis in the laboratory (Hauer and Lamberti, 2011).

3.4.3 Identification of macrobenthos

In the laboratory, the sample was rinsed in a 500 µm mesh sieve to remove alcohol and fine sediment then was placed into a shallow white pan and a small amount of water were added to facilitate sorting. All the sorted organism was placed into labelled containers and preserved in 70% ethanol.

The macrobenthos were identified to the family level. They were identified by comparing collected specimens with illustrations of the groups as well as by using identification keys. Keys used in this study were referred to Merrit and Cumins (1996) and Mc Cafferty (1981). From the guidebook, keys generally consist of a series of paired descriptions of particular bodily features such as wings and legs. The keys were numbered and the best description that fit the specimen was chosen. After all the specimens were identified to family level, the biotic score was calculated accordingly.

3.5 Measurement of biological indices

The biological indices used in this study were as follows:

3.5.1 Shannon-Weiner Diversity Index

Shannon-Weiner Diversity Index is a fast and reliable tool to identify major changes in community structure of macrobenthos species (Pettersson, 1997). The Shannon-Weiner Diversity Index was calculated in the following way:

$$H' = -\sum p_i \ln p_i \quad \text{Eq. 3.5}$$

Where 'p_i' is the proportion of individual macrobenthos in order i. The 'p_i' also can be calculated as $p_i = n_i/N$, where n_i is the number of individual in order and N is the total numbers of individual in the community.

3.5.2 Simpson Diversity Index

Simpson's Diversity index shows the relative of rare species or common species in a community (Mandaville, 2002). It has ranged from 0 – 1, which 0 indicates high level of diversity. It was calculated as:

$$D = 1 - \frac{\Sigma\, n\,(n-1)}{N\,(N-1)} \text{ ………………………………………………………Eq. 3.6}$$

where n is the total number of macrobenthos of a particular order and N is the total number of macrobenthos of all orders. D is a measure of dominance, thus as D increases, the diversity of macrobenthos decreases.

3.5.3 Margalef Richness Index

Margalef Richness Index is the simplest measure of biodiversity and is simple count the number of different species in the study area (Gamito, 2010). It is used to get species richness which standardises the number of species encountered against the total number of individuals encountered. The Margalef richness index can be calculated as:

$$D_{Mg} = \frac{(s-1)}{\ln N} \quad \text{Eq. 3.7}$$

where s is the number of species recorded and N is the total number of individuals in the sample.

3.5.4 Pielou Evenness Index

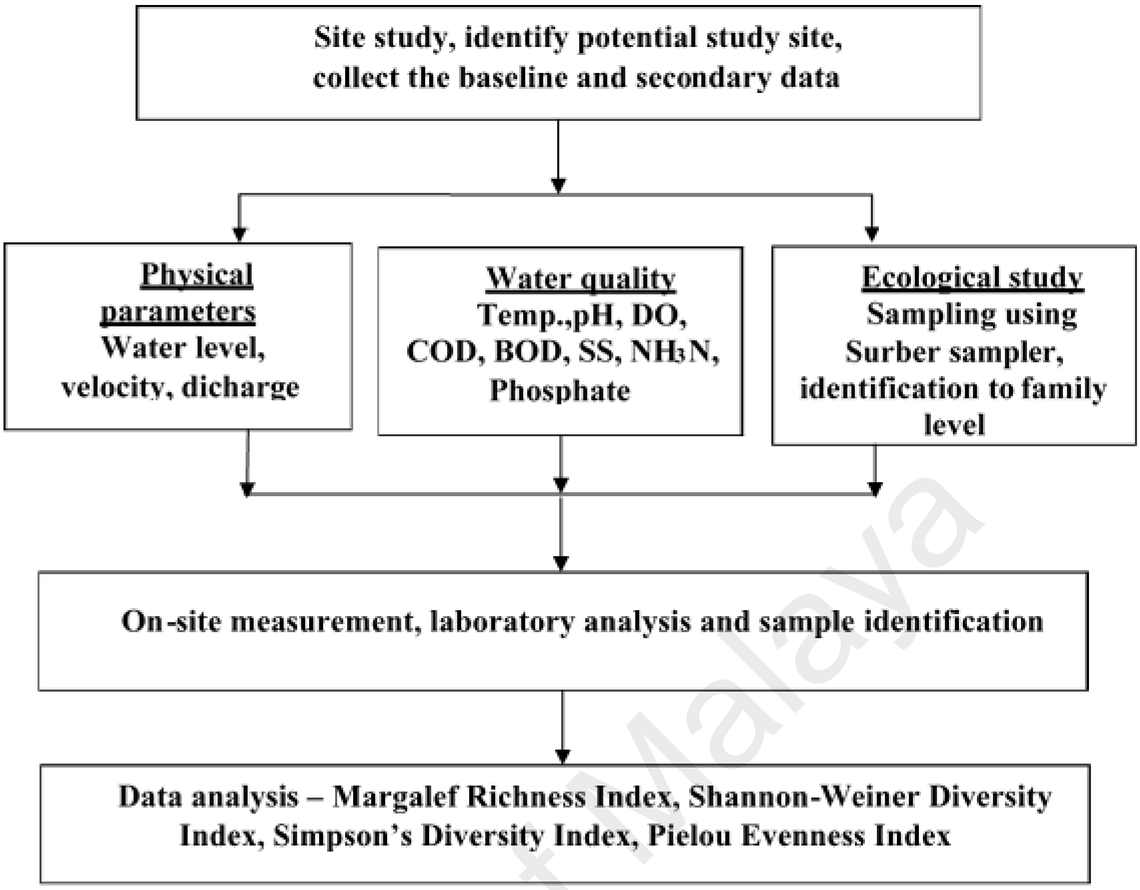
Species evenness is calculated to monitor how close in numbers each species in an area are. In this study, the evenness is represented by Pielou’s Evenness index (Pielou, 1966) which can be calculated equation below:

$$J = \frac{H\prime}{\ln(S)} \qquad \text{Eq. 3.8}$$

where H’ is the Shannon – Weiner diversity index and S is a total number of observed species in the community. The index can have values ranging from 0 – 1 where if there are frequent variations in the community, the index will have higher values.

3.6 Statistical Analysis

In this study, Pearson correlation coefficient (*r*) among the six water quality parameters in WQI formula were performed by using IBM SPSS Statistics version 22 to find degree of significance relationship among the parameters. Other than that, correlation coefficient between WQI values and parameters against biological indices was performed to investigate the effects of WQI value and parameters to richness, diversity and evenness index of macrobenthos at Penchala River. Statistical significance was tested at the alpha level of 0.05 and 0.01 with 95% and 99% confidence level, respectively.


Site study, identify potential study site, collect the baseline and secondary data
Physical parameters
Water level, velocity, dicharge
Water quality
Temp.,pH, DO, COD, BOD, SS, NH_3N, Phosphate
Ecological study
Sampling using Surber sampler, identification to family level
On-site measurement, laboratory analysis and sample identification
Data analysis – Margalef Richness Index, Shannon-Weiner Diversity Index, Simpson's Diversity Index, Pielou Evenness Index

CHAPTER 4: RESULTS

This chapter presents results on physico-chemical parameters and collection of macrobenthos from November 2013 to October 2014 at four selected stations along Penchala River. As mentioned in Chapter 3, water sampling for determination of physico-chemical characteristics and collection of macrobenthos has been done at the same point of sampling to ensure all the results can be correlated at the end of this study.

4.1 Physico-chemical characteristics at Penchala River

Physico-chemical characteristics were determined monthly in the period of the one-year interval which was from November 2013 to October 2014.

4.1.1 Chemical characteristics at Penchala River

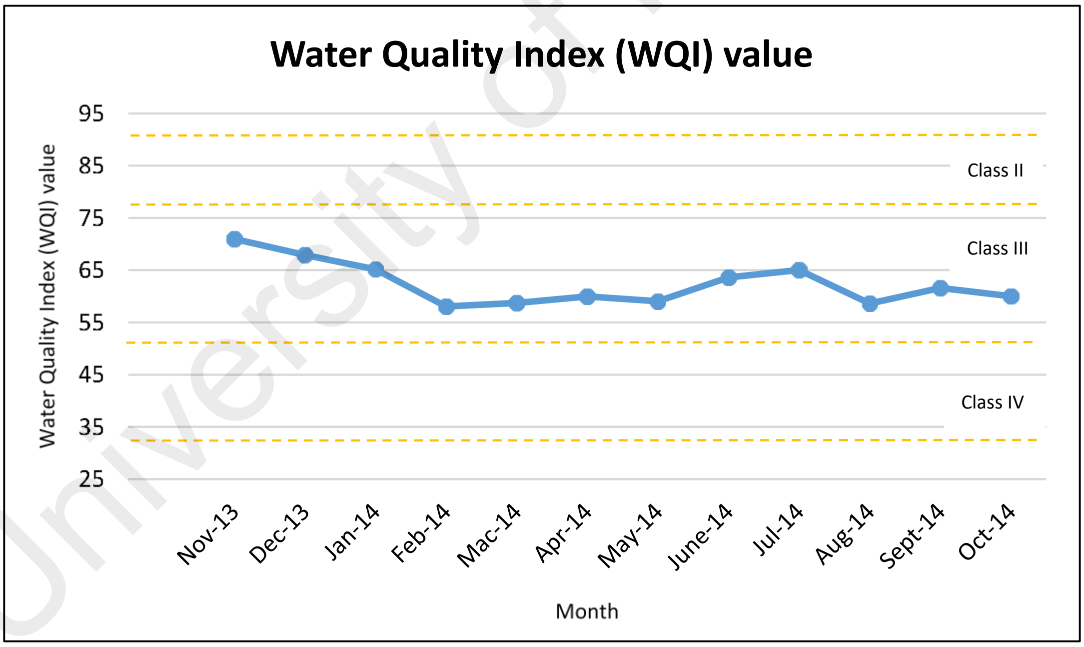


Figure 4.1: Monthly results of Water Quality Index (WQI) for the average of four sampling stations of Penchala River

Figure 4.1 shows the monthly WQI of the four stations of Penchala River from November 2013 to October 2014. According to NWQS, the WQI values of the Penchala River from November 2014 to October 2014 were classified under Class III, where the water requires extensive treatment for water supply purposes, being suitable only for very tolerant and for livestock drinking.

The highest WQI value of 71.0 was recorded in November 2013 and the lowest WQI value of 58.1 was recorded in February 2014. Starting November 2013 to February 2014, the WQI value was degraded from 71.0 to 58.1. The WQI value was improved to 58.7 in March 2014 and further increased to 60.0 in April 2014. However, the value was slightly decreased to 59.1 in May 2014. The value started to recover to 63.6 in June 2014 and 65.0 in July 2014. Again, the value was dropped in August 2014 where the WQI value of 58.6 was recorded and increased to 61.6 in September 2014 and 60.0 in October 2014. The range, mean and standards deviation for physico-chemical parameters were summarised in Table 4.1.

Table 4.1: Results of physico-chemical parameters for four sampling stations of Penchala River

Parameter	Range	Mean ± S.D	Water quality class
Temperature (℃)	26.5 – 28.7	28.0 ± 0.60	
pH	5.6 – 7.0	6.0 ± 0.47	II
DO (mg/l)	2.1 – 3.7	2.9 ± 0.48	IV
COD (mg/l)	22 – 58	34 ± 12.19	III
BOD (mg/l)	4 – 15	9 ± 3.41	IV
TSS (mg/l)	7 – 23	16 ± 5.82	I
NH_3-N (mg/l)	0.3 – 3.8	1.6 ± 1.18	IV
Phosphate (mg/l)	0.4 – 1.3	0.8 ± 0.25	
WQI	58.1 – 71.0	62.4 ± 4.16	III

Table 4.1 shows the results of physico-chemical parameters with its class according to DOE water quality classification for four sampling stations of Penchala River. The table shows variation of classification where TSS were classified under Class I, pH were classified under Class II, COD was classified under Class III and DO, BOD and NH_3-N

were classified under Class IV. Overall, the WQI were classified under Class II according to DOE water quality index classification (DOE, 1994). Below are the individual results for all the parameters by months.

Dissolved Oxygen (DO)

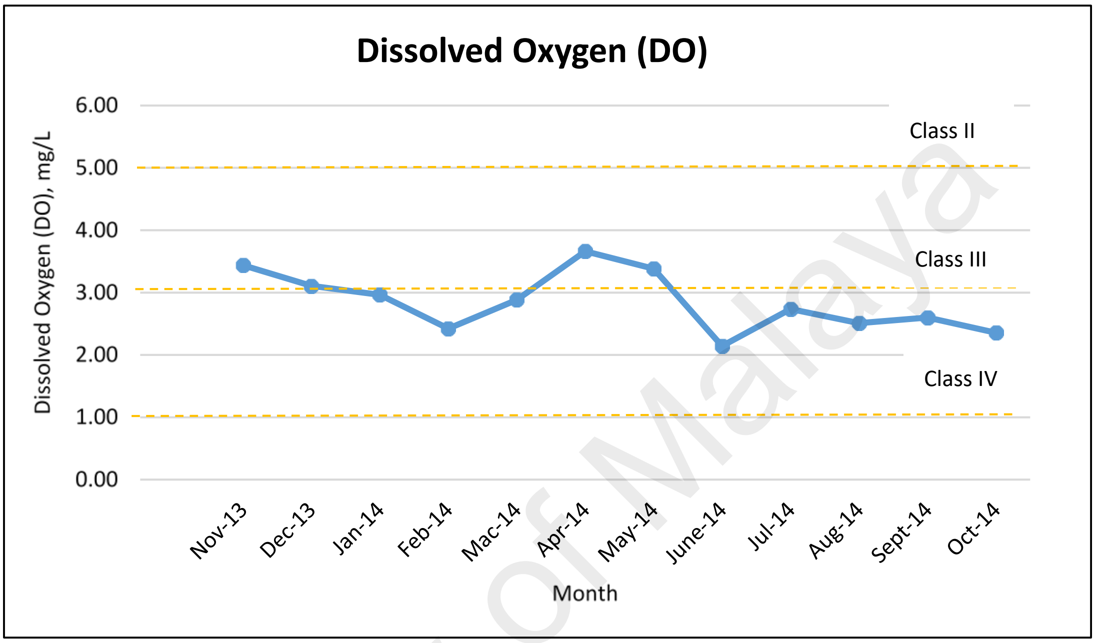


Figure 4.2: Monthly results of DO for the average of four sampling stations of Penchala River

Figure 4.2 shows the monthly results for dissolved oxygen for the average of four sampling stations of Penchala River. DO is a measure of the quantity of oxygen gas freely available in water. The concentration of DO is very important to aquatic life such as macrobenthos. The concentration of DO in an unpolluted fresh water will be close to 10 mg/L and concentration less than 2 mg/L will kill the aquatic life.

From Figure 4.2, the results were distributed under Class III and IV. The concentration of DO were at 3.44 mg/L at the beginning of the study. The concentration was decreased to 3.11 mg/L and 2.97 mg/L in December 2013 and January 2014, respectively. The concentration was further decreased to 2.42 mg/L in February 2014. The results were rose up to 2.88 mg/L in March 2014. In April and May 2014, the DO level back to Class III with result of 3.66 mg/L and 3.38 mg/L, respectively. The concentration DO fell to the lowest in June 2014 with only 2.14 mg/L was recorded. Starting July 2014, the results remain relatively stable with 2.74 mg/L in July 2014, 2.51 mg/L in August 2014, 2.60 mg/L in September and 2.36 mg/L was recorded in October 2014.

Biological oxygen demand (BOD) and chemical oxygen demand (COD)

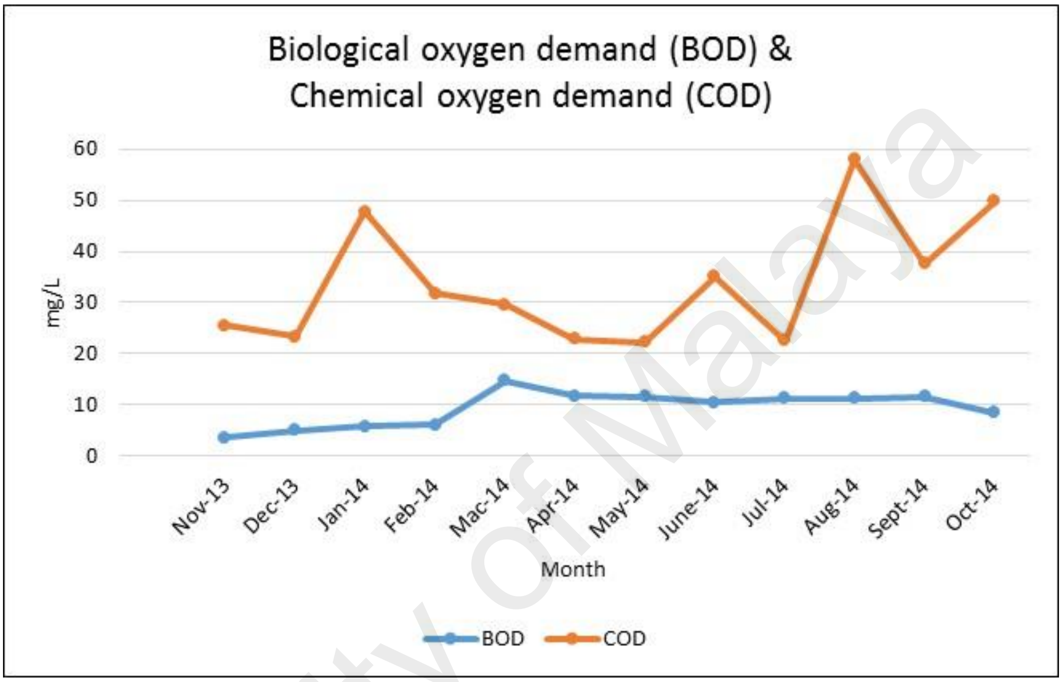


Figure 4.3: Monthly results of BOD and COD for the average of four sampling stations of Penchala River

Figure 4.3 shows monthly results for biological oxygen demand and chemical oxygen demand for the average of four sampling stations of Penchala River. The BOD of the Penchala River were categorised under Class IV and Class III for COD (Table 4.1).

BOD refer to the amount of oxygen required to decompose organic matter in a unit volume of water while COD is a measure of the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals such as ammonia and nitrite. Thus, concentration of COD is always greater than concentration of BOD as COD does not differentiate between biologically available and inert organic matter.

From Figure 4.3, the results of BOD were distributed under Class III, IV and once under Class V in March 2014. The results were in the range of 4 – 5 mg/L with average of 9 ± 3.41 mg/L. The results were stabilised in Class III from November 2013 to February 2014 and were suddenly rose up to Class V with result of 15 mg/L in March 2014. Started from April 2014, the results remain relatively stable in Class IV until October 2014.

The monthly COD concentration in the Penchala River for the period from November 2013 to October 2014 are presented in Figure 4.3. The concentration of COD were in the range of 22 – 58 mg/L with average of 34±12.19 mg/L. The results were scattered in Class II and III from November 2013 until July 2014 and suddenly rose up to 58 mg/L which classified in Class IV in August 2014. After that, the results were back to Class III with 38 mg/L was recorded in August 2014 and degraded to Class IV in October 2014.

<u>pH</u>

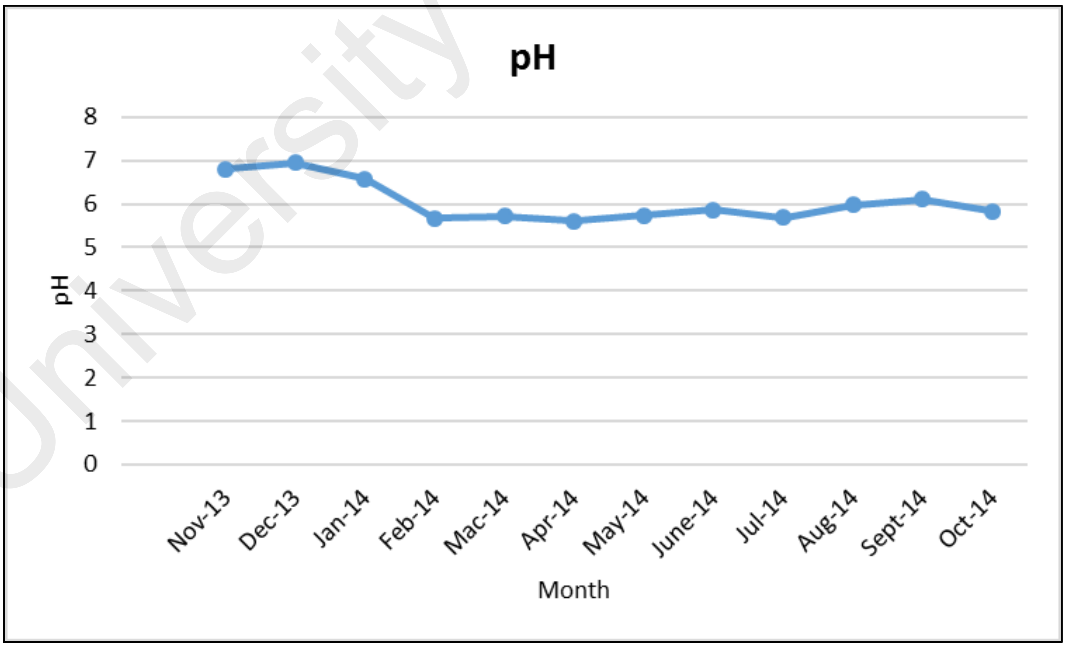


Figure 4.4: Monthly results of pH for the average of four sampling stations of Penchala River

Figure 4.4 shows monthly results for biological oxygen demand and chemical oxygen demand for the average of four sampling stations of Penchala River. In general, the pH for water should be at 7 which is neutral. pH value less than 7 indicate the water is acidic with corrosive properties and pH value more than 7 indicate alkaline properties (Ching et al., 2015). pH is very important water quality parameter as most of the aquatic life is very sensitive to pH variations especially when the pH is altered outside their tolerance limits (Courtney and Claments, 1998). From Figure 4.4, the pH values were in the range of 5.6 to 7.0 which was scattered in Class II and III. Overall, there were no significant changes in pH during the study period.

Ammoniacal nitrogen (NH_3-N)

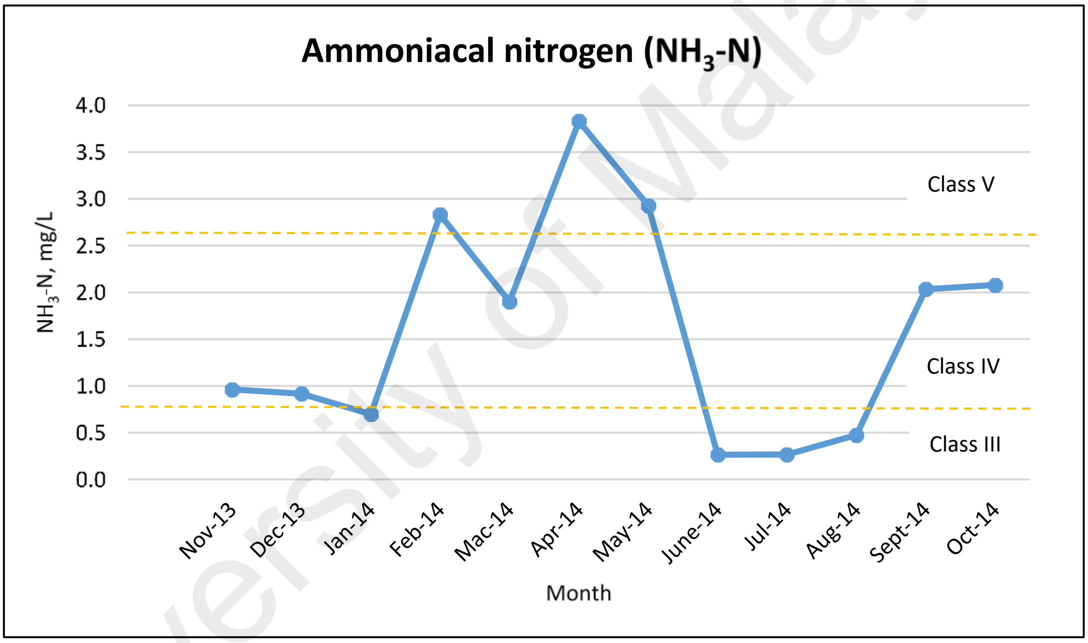


Figure 4.5: Monthly results of NH_3-N for the average of four sampling stations of Penchala River

Figure 4.5 shows monthly results for ammonical nitrogen for the average of four sampling stations of Penchala River. At the beginning of the study, the concentration of NH_3-N were classified under Class IV and Class III in January 2014. The concentration of NH_3-N was degraded to Class V with result of 2.83 mg/L was recorded in February 2014. The level of NH_3-N in March 2014 was recovered to 1.90 mg/L and suddenly the result boost up to the peak where 3.83 mg/L of NH_3-N was recorded in April 2014. In

May 2014, the level was improved to 2.93 mg/L and further improved to 0.27 mg/L in June 2014. There were no significant changes in July 2014 and August 2014 but the level was started to degrade again in September 2014 and October 2014.

Total suspended solid

Figure 4.6: Monthly results of TSS for the average of four sampling stations of Penchala River

Figure 4.6 shows monthly results for total suspended solid (TSS) for the average of four sampling stations of Penchala River. The TSS is the solid matter in a water that can retained on a glass fiber filter with a pore size less than 2 µm. It is typically consisting of fragmental minerals, silt, plankton, sand, nutrients and metal that have attached to water particles (Ching et al., 2015). From figure 4.6, the graph shows that the concentration of TSS in Penchala River were scattered in the range of 7 – 23 mg/L and it is classified under Class I. The highest level of TSS was recorded in September 2014 and June 2014 was recorded to have the lowest level of TSS.

4.1.2 Physical characteristics at Penchala River

Results for water level, velocity and water discharge for Station 1, 2, 3 and 4 from November 2013 to October 2014 which has been summarised into mean and standards deviation in Table 4.2.

Table 4.2: Mean and standard deviation of physical characteristics for Station 1, 2, 3 and 4 of Penchala River

Parameter	Station 1	Station 2	Station 3	Station 4
Water Level (m)	0.17±0.16	0.39±0.12	0.38±0.06	0.77±0.61
Velocity (m/s)	0.296±0.122	0.452±0.497	0.324±0.094	0.471±0.554
Discharge (m^3/s)	0.083±0.120	2.784±3.539	1.661±0.732	6.908±7.248
Area (m^2)	0.44±0.71	5.58±1.69	4.94±0.83	19.27±15.23
Width (m)	1.80±2.08	14.3	13	25

From Table 4.2, the water level of Penchala River ranged from 0.17 m to 0.77 m where the deepest area was measured at Station 4 (0.77 m) and the shallowest area was measured at Station 1 (0.17 m).

<u>Water level</u>

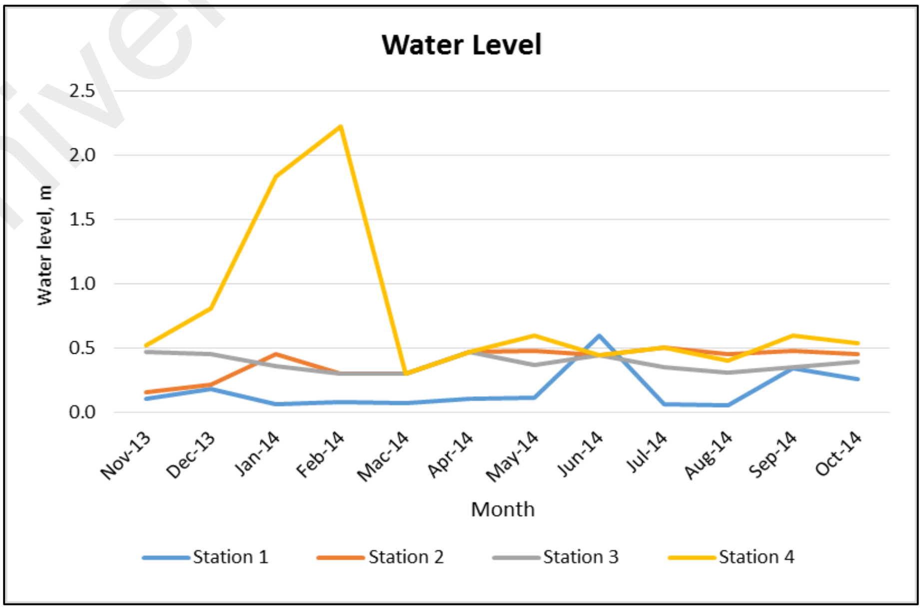


Figure 4.7: Monthly results of water level for the average of four sampling stations of Penchala River

Figure 4.7 shows the monthly results of water level for the average of four sampling stations of Penchala River. From the figure, the water level for every stations were remained relatively stable with no significance changes through the sampling activities. However, results recorded for Station 1 for June 2014 and Station 4 for January and February 2014 shows that the water level has been disturbed which cause the results were rose up to the maximum.

<u>Velocity</u>

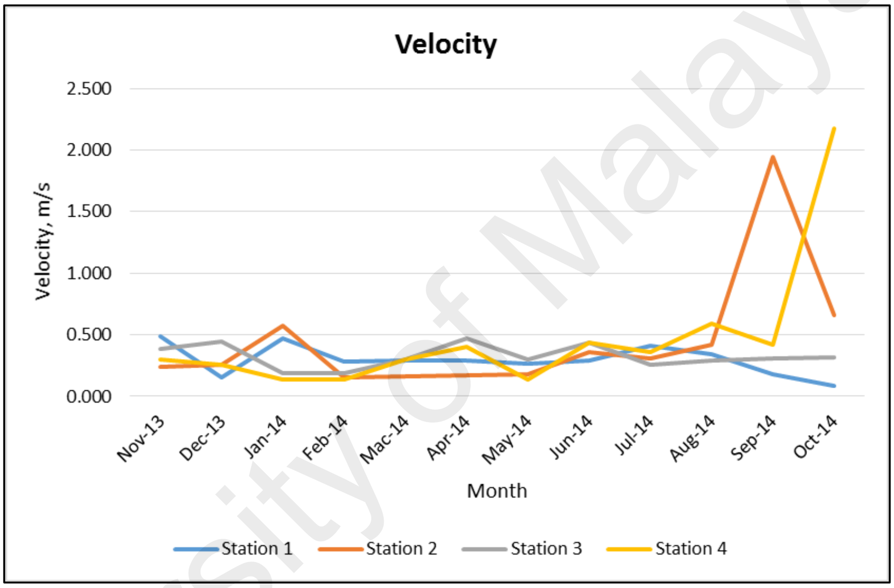


Figure 4.8: Monthly results of velocity for the average of four sampling stations of Penchala River

Figure 4.8 shows the monthly results of river velocity at Station 1, 2, 3 and 4 of Penchala River. From the figure, the river velocity for every stations were remained relatively stable with no significance changes through the sampling activities. The significant changes of the results only occur in September and October 2014.

Discharge

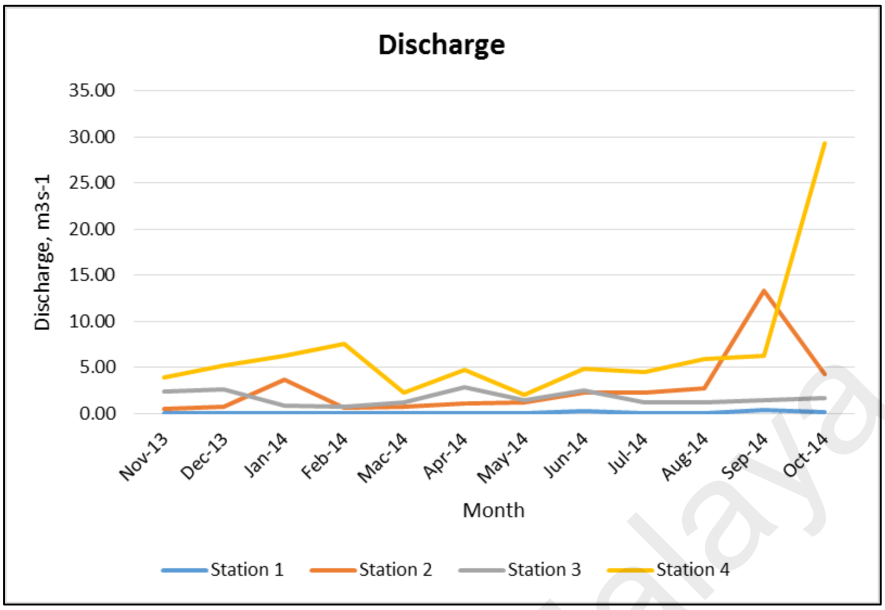


Figure 4.9: Monthly results of discharge for the average of four sampling stations of Penchala River

Figure 4.9 shows the monthly results of water discharge at Station 1, 2, 3 and 4 of Penchala River. From the figure, the water discharge for every stations were remained relatively stable with no significance changes through the sampling activities. The significant changes of the results only occur in September and October 2014.

4.2 Abundance and distribution of macrobenthos at Penchala River

A total of 1043 individual of macrobenthos were found at Station 1, 2, 3 and 4. From the number, 465 (44%) was collected at Station 1, 176 (17%) at Station 2, 372 (36%) at Station 3 and another 30 (3%) individual was found at Station 4 which presented in Table 4.3. All the collected macrobenthos were belong to 9 orders which were Ephemeroptera, Plecoptera, Trichoptera, Odonata, Decapoda, Coleoptera, Diptera, Basommatophora and Hirudinida.

Table 4.3: Abundance and distribution of macrobenthos at Station 1, 2, 3 and 4 of Penchala River

Order	Family	Station 1	Station 2	Station 3	Station 4	Total
Tricoptera	Hydropsychidae	94	-	-	-	94
	Philopotamidae	18	-	-	-	18
	Hydroptilidae	1	-	-	-	1
Ephemeroptera	Baetidae	22	-	-	-	22
	Heptageniidae	14	-	-	-	14
Plecoptera	Capniidae	14	-	-	-	14
	Peltoperlidae	9	-	-	-	9
	Perlidae	2	-	-	-	2
Odonata	Coenagrionidae	46	-	-	-	46
	Calopterygidae	4	-	-	-	4
	Aeshnidae	1	-	-	-	1
	Gomphidae	1	-	-	-	1
Diptera	Chironomidae	38	131	181	-	350
	Simuliidae	18	-	-	-	18
	Tipulidae	21	-	5	-	26
	Ceratopogonidae	1	-	-	-	1
Coleoptera	Elmidae	14	-	-	-	14
Decapoda	Potamidae	54	-	-	-	54
	Aatyidae	49	-	-	-	49
	Palaemonidae	29	-	-	-	29
Basommatophora	Physidae	9	29	79	28	145
	Lymnaeidae	4	-	3	-	7
	Planorbidae	-	16	54	-	70
	Thiaridae	2	-	8	2	12
Oligochaeta	Lumbricidae	-	-	40	-	40
Hirudinida	Hirudinidae	-	-	2	-	2
	No. of individuals (N)	465	176	372	30	1043
	No of family (S)	23	3	8	2	
	Percentage (%)	44	17	36	3	

Table 4.3 also shows the number of macrobenthos according to their family with its percentage. There were 26 families were found which belongs to 8 orders. From the results in Table 4.3, there were a high percentage of Trichoptera (Hydropsychidae;

20.2%) existed at Station 1. The percentage were followed by Decapoda (Potamidae; 11.6%), Decapoda (Atyidae; 10.5%) and Odonata (Coenagrionid; 9.9%). Other than that, it was found that Diptera (Chironomidae; 8.2%), Diptera (Palaemonidae; 6.2%), Ephemeroptera (Baetidae; 4.7%), Diptera (Simuliidae; 3.9%), Diptera (Tipulidae; 4.5%) Trichoptera (Philopotamidae; 3.9%), Plecoptera (Capniidae; 3.0%), Coleoptera (Elmidae; 3.0%), Ephemeroptera (Heptageniidae; 3.0%) and Plecoptera (Peltoperlidae; 1.9%) also were found at this station. In addition, the presence of some other macrobenthos which were less than 1 percentage were Odonata (Lymnaeidae; 0.9%), Odonata (Calopterygidae; 0.9%), Odonata (Aeshnidae; 0.2%), Odonata (Gomphidae; 0.2%), Trichoptera (Hydroptilidae; 0.2%), Diptera (Ceratopogonidae; 0.2%) and Basommatophora (Thiaridae; 0.4%).

The existence of macrobenthos at Station 2 has been shown in Table 4.3. From the table, there were only two families existed at Station 2, which were Diptera with 74.4% and Basommatophora with 25.6%. The only Dipteran existed at this station was Chironomidae (74.4%) while there were two families of Basommatophora existed which were Physidae (16.5%) and Planorbidae (9.1%).

Station 3 consist of Diptera (50.0%), Basommatophora (38.7%), Oligochaeta (10.8%) and Hirudinea (0.5%). When the order is breakdown into family level, the highest percentages of macrobenthos present at Station 3 was Chironomidae which was 48.7% followed by Physidae (21.2%), Planorbidae (14.5%), Lumbricida (10.8%), Thiaridae (2.2%), Hirunida (0.5%) and Lymnaeida (0.8%). There were only Physidae (93.3%) and Thiaridae (6.7%) existed at Station 4.

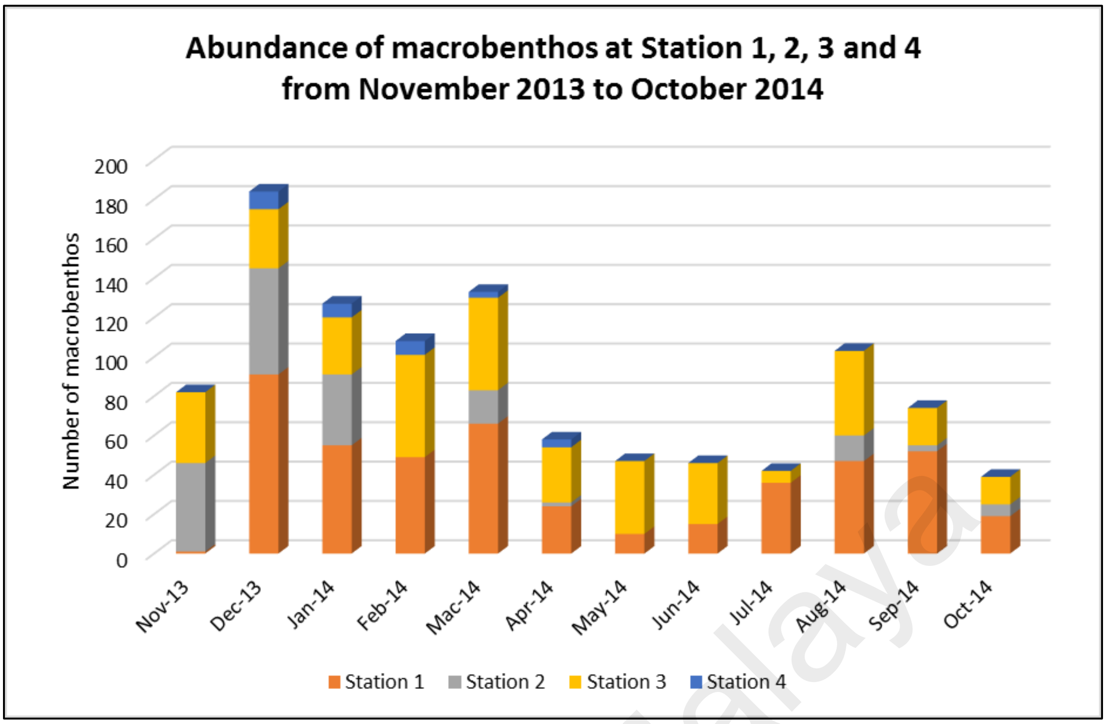


Figure 4.10: Abundance of macrobenthos at Station 1, 2, 3 and 4 from November 2013 to October 2014 of Penchala River

Figure 4.10 shows the abundance and distribution of macrobenthos collected at Station 1, 2, 3 and 4 from November 2013 and October 2014. From the figure, there were high numbers of macrobenthos presented in December 2013 to March 2014. The numbers were reduced in average of 42 to 58 in April to July 2014.

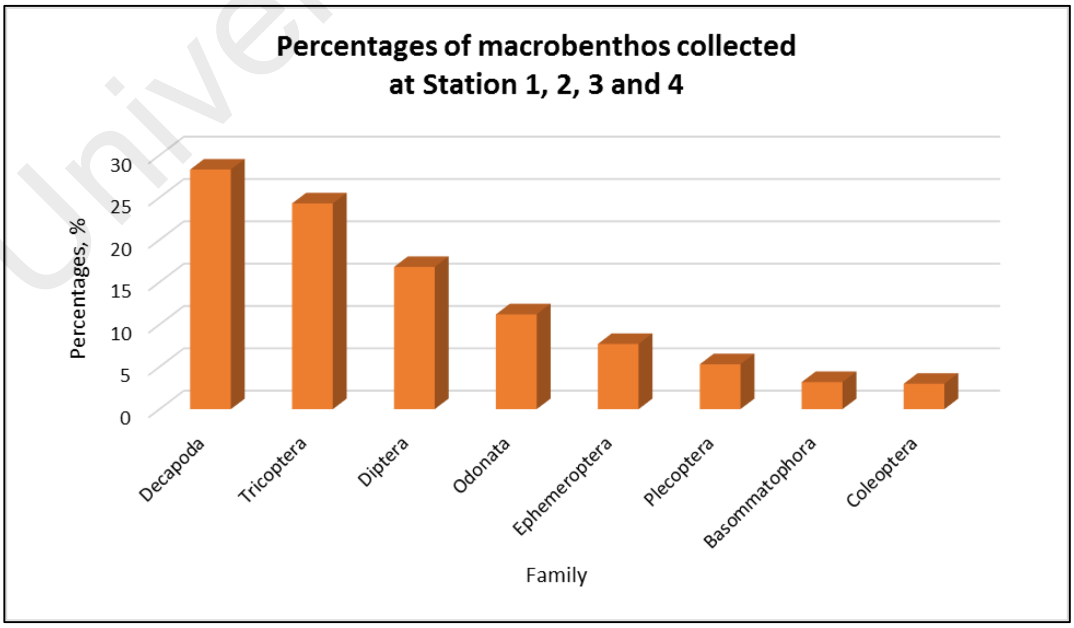


Figure 4.11: Percentages of macrobenthos collected at Station 1, 2, 3 and 4 of Penchala River

The percentages of macrobenthos according to their family is shown in Figure 4.11. The highest percentages were Decapoda which was 28.3% of all the collected samples. The percentages were followed by Trichoptera (24.3%), Diptera (16.8%), Odonata (11.2%), Ephemeroptera (7.7%), Plecoptera (5.3%), Basommatophora (3.2%) and Coleoptera (3.0%).

Numbers of collected macrobenthos were analysed through Margalef richness index, Simpson's diversity index, Shannon-Wiener diversity index and Pielou evenness index and they were presented in Table 4.4.

Table 4.4: Monthly results of richness, diversity and evenness index for the average of four sampling stations of Penchala River

Month	S	N	Margalef's richness index	Shannon-Weiner diversity index	Simpson's diversity index	Pielou's evenness index
Nov-13	2	82	0.227	0.066	0.024	0.095
Dec-13	10	184	1.726	1.932	0.815	0.839
Jan-14	11	127	2.064	1.784	0.745	0.744
Feb-14	14	108	2.777	1.916	0.748	0.726
Mac-14	19	133	3.681	2.155	0.79	0.815
Apr-14	10	58	2.217	1.953	0.823	0.848
May-14	11	47	2.597	1.883	0.789	0.785
Jun-14	10	46	2.351	1.949	0.813	0.846
Jul-14	9	42	2.14	1.856	0.812	0.845
Aug-14	12	103	2.373	2.033	0.842	0.818
Sep-14	10	74	2.091	2.055	0.851	0.744
Oct-14	6	39	1.365	1.402	0.696	0.782

Table 4.4 shows that the Margalef's richness index and Shannon-Weiner diversity index were the highest in March 2014. The highest value of Simpson's diversity index

was in September 2014 and the highest Pielou's evenness index was recorded in April 2014. All the indexes were at the lowest in November 2013.

4.3 Statistical analysis

Pearson correlation coefficient (*r*) among the WQI value with its parameter and biological indices were performed to find degree of significance relationship among the parameters. The results were summarised in Table 4.5.

From the table, the WQI value was significantly correlated with pH (*r*= 0.813; P=0.01). The pH variable was found negatively significantly affected by BOD, *r*= -0.749; P=0.005. WQI value was found negatively significantly correlated with Margalef's richness index, *r*= -0.735; P=0.007, Shannon-Weiner diversity index, *r*= -0.642; P=0.024, Simpson's diversity index, *r*= -0.618; P=0.032 and Pielou's evenness index, *r*= -0.589; P=0.044. On the other hand, the table also shown that there were high positive correlation between all the biotic indices.

Table 4.5: Pearson's correlation of coefficients (*r*) of physico-chemical parameters and biotic indices of Penchala River

Parameters	Correlation coefficient (*r*)											
	WQI	**Temp**	**pH**	**DO**	**NH_3-N**	**BOD**	**COD**	**TSS**	**Margalef**	**Shannon - Weiner**	**Simpson**	**Pielou**
WQI	1											
Temp	-0.077	1										
pH	0.813**	-0.259	1									
DO	0.292	0.307	0.245	1								
NH_3-N	-0.565	0.310	-0.482	0.399	1							
BOD	-0.649*	0.164	0.749**	-0.110	0.230	1						
COD	-0.287	0.647*	0.019	-0.579	-0.306	-0.018	1					
TSS	-0.032	-0.360	0.174	-0.47	-0.148	-0.029	0.107	1				
Margalef	-0.735**	0.066	-0.611*	-0.232	0.249	0.693*	-0.016	0.176	1			
Shannon-Weiner	-0.642*	-0.65	-0.467	-0.314	0.155	0.618*	0.101	0.444	0.844**	1		
Simpson	-0.618*	-0.080	-0.469	-0.348	0.136	0.586*	0.156	0.439	0.736**	0.976**	1	
Pielou	-0.589*	0.016	-0.490	-0.340	0.112	0.575	0.130	0.319	0.706*	0.936**	0.977**	1

**. correlation is significant at the 0.01 level (2-tailed), P<0.01
*. correlation is significant at the 0.05 level (2-tailed), P<0.05

CHAPTER 5: DISCUSSION

5.1 Variation of physico-chemical parameters at Penchala River

Water Quality at Penchala River is unique as it has a wide range of WQI. Results that come from water sampling in this study served as the current water quality status for Penchala River. The results show that the WQI were in the range of 58.1 to 71.0. Results on WQI presented in Chapter 4 shows that Station 1 has the best quality of water compared to Station 2, 3 and 4. As mentioned before, Station 1 has the natural physical characteristics with various types of gravel, rocky slopes and existence of aquatic plants. All of these elements are very important for river restoration. The cleanliness of the river gives opportunity to the local authority to build up a recreation park for the community to enjoy the panoramic view. In order to maintain the river health, a list of rules and regulations was set up and being closely monitored by the local authority.

The deterioration of WQI at Station 1 in September 2014 was caused by the temporary construction activities at the river bank. The construction was held to widen the river before the water entering the recreational park. As the construction begun, the flow has been stuck (0.1815 m/s) and the water started to overflow. The results for TDS (33.62 mg/L) was the highest and the water became cloudy (181 NTU). The situation become worst as the contractor did not cover the exposed river bank and soil erosion deposited at the river bottom.

Figure 5.1: Overflow at Station 1 during construction in September 2014

WQI at Station 2 was sometimes up and down, which is mostly caused by the anthropogenic activities. The WQI was improved at the end of the sampling routine and perhaps the improvement will be prolonged as many construction and renovation have been carried out.

Results for WQI at Station 3 were relatively stable with no drastic changes in value through the sampling dates. The data shows only small difference even though there was heavy rain a day before and construction in progress at Station 2. The results for WQI were in the range of 46.2 to 65.2, and all of the values were classified into Class III and Class IV. Results for Conductivity (471.0 µs/cm) and TDS (235.0 mg/L) were the highest in June 2014 as there were heavy rain early in the morning. It was supported by physical data on velocity. The velocity was the highest in June 2014 which was 0.4400 m/s.

Station 4 was located at the downstream. The WQI at this station was the worst among all the stations with WQI in the range of 42.4 – 61.8. This situation happened probably because of all the pollutant from the upper stream accumulated and flowing through this station. Other than that, there are squatter's area located near to the river bank. The river water quality falls into Class III and Class IV which classified under 'polluted' water.

In generally, Station 4 had the worst WQI at the beginning but the WQI were improved as the abandoned wooden cages in the middle of the river was removed. The removal made the river flows smoothly. Another factor that negatively affected the WQI data for this station was construction activities in December 2013 to build concrete river bank. During the construction, the WQI status had dropped from 'slightly polluted' to 'polluted'. The most affected parameter was turbidity. The turbidity was low which was 21.2 NTU in November 2013 but the results were suddenly rose up to 95.9 mg/L in December 2013 and reached to 123.0 mg/L in February 2014. The results were supported by results on the concentration of suspended solids. The concentration of suspended solids was 51 mg/L in December 2013 and 24 mg/L in February 2014.

The results of temperature were the highest at Station 4 which was in the range of 27.4℃ – 31.4 ℃ and lowest at Station 1 which was in the range of 24.7℃ – 26.5℃. The high temperature at Station 4 was due to direct sunlight penetrates into water. From the observation, there was no riparian vegetation cover at the river bank. This situation results in a low concentration of dissolved oxygen (0.16 – 2.41 mg/L) as the water had less ability to hold oxygen molecule.

Dissolved oxygen in the water gains from the atmosphere and also from photosynthesis by aquatic plants. In addition, the running water contains a higher concentration of DO compared to still water because it churning that can dissolve more oxygen whereas activities such as respiration by aquatic animals, decomposition of organic matter and various chemical reactions will lower the concentration of DO. Other than that, if more oxygen is consumed than is produced, DO levels will decline and some sensitive macrobenthos may move away, weaken or die (Rapport and Whitford, 1999).

The fluctuation in concentration of DO is also affected by water temperature and altitude. Cold water holds more oxygen than warm water and lower altitude will hold more oxygen compared to higher altitudes (Schmidt-Nielson, 2010). The low concentration of DO also caused by decreased amount of oxygen consumption for decomposition of biological and chemical substances. This statement was supported by the high concentration of COD and BOD at Station 2, 3 and 4.

The results of BOD and COD at Station 2 was the highest in August 2014 which was 11.64 mg/L and 81.0 mg/L, respectively. The high results were supported by the result of the concentration of DO. The results for DO were low (1.55 mg/L) in August 2014, which indicates that the concentration of oxygen that dissolved in the water was so much consumed by the bacteria to decompose organic material in the water and the high results of COD in August 2014 indicate that the decomposition of organic materials were high at this station. Other than that this situation also had caused unpleased foul odor as the anaerobic decomposition which produces methane gas.

The concentration of ammoniacal nitrogen and phosphate were the highest at Station 2 which was in the range of 0 – 6.42 mg/L and 0.4 – 1.60 mg/L, respectively. From the observation, there were direct sullage discharges from both sides and garbages floating and stuck on the river bank. Discharges from these two areas boost the concentration of nutrients such as ammoniacal nitrogen and phosphate. This data was supported by observation at the bottom of the river was green, which indicates algae was so well growing.

Table 5.1 present comparison results between previous and current study conducted at Penchala River. Study by Ismail et al., (2014) was conducted from 1997 to 2005 and Mahazar et al., (2013) was conducted from April to August 2012. From the table, the results show that there is improvement for all the parameters especially for WQI value.

Table 5.1: Comparison results between previous and current study conducted at Penchala River

	Ismail et al., (2014)	Mahazar et al., (2013)	Current study
Year of data collection	1997 - 2005	April – August 2012	November 2013 – October 2014
Temperature	-	28.20 ± 2.25	28.0 ± 0.60
pH	6.25 ± 1.67	7.08 ± 0.27	6.0 ± 0.47
DO% Saturation	16 ± 15.62	-	38.9 ± 6.98
DO (mg/L)	-	3.13 ± 2.97	2.9 ± 0.48
BOD (mg/L)	28.00 ± 18.51	15.81 ± 16.95	9.2 ± 3.41
COD (mg/L)	82.8 ± 34.84	59.0 ± 63.31	33.8 ± 12.19
TSS (mg/L)	95.2 ± 95.69	-	15.9 ± 5.82
NH_3-N (mg/L)	4.92 ± 2.77	2.26 ± 2.32	1.60 ± 1.18
WQI	34.1 ± 12.59	59.6 ± 28.11	62.4 ± 4.16

Changes in physical characteristics at Station 1, 2, 3 and 4 has been reported in Chapter 4. The most significant changes were results on the velocity of the river. The velocity of the river refers to the rate of water movement in meters per seconds. Generally, the mean flow of velocity will increase with distance from the source. Results on velocity will determine the efficiency of a river and it is highly depending on the shape of the river. When the river is deeper and wider, the river will have higher velocity as the friction from the bed and the banks reduce. Other than that, the velocity also affected by the channel roughness. The existence of pebbles, stones and boulders on the beds and banks increase the wetted perimeter thus increases the friction and further reduces the velocity of the river. The wetted perimeter is the total length of the river bed and banks in cross section that is in contact with the water.

This study shows that the velocity at Station 1 was the lowest among the stations which were in the range of 0.0821 – 0.4898 m/s. From the observation, water that was close to the bed and banks were almost stationary since the friction was high. Other than that, the low velocity at Station 1 was caused by its shape. The river is narrow, steep and uneven due to the deposition from large boulders and longer wetted perimeter. In addition, the velocity of flowing water is slower since there is more energy needed to overcome friction between the uneven river bed. Eventhough the flow at Station 1 appear to be faster it is actually all the energy is lost since a lot of energy is expended to overcome friction and uneven river bed.

Results on velocity at Station 4 show that the results for velocity were relatively low compared to other stations. From the observation, the velocity was low because of an abandoned wooden cage at the center of the river. The cages caused all the solid waste such as garbage and plastic bags were stuck at it thus slow down the water flow. On July 2014, the abandoned wooden cages have been removed thus improve the velocity from 0.0871 m/s (June 2014) to 0.3610 m/s (July 2014) and reached 0.593 m/s in August 2014.

The result of water discharge at Station 2 was the highest and become worse perhaps affected by construction activities in January 2014. The extreme results were caused by the construction activities as there was a bulk of white stone and sand at the river's edge. Results show that the water level had risen to 0.45 m. The stone has caused the width decreased circumstantially increased the velocity up to 0.5710 m/s.

Figure 5.2: White boulders at Station 2 during construction in January 2014

5.2 Variations of macrobenthos at Penchala River

Based on the results presented in Chapter 4, the results on biodiversity index, which consist of diversity index, species richness and evenness of macrobenthos at Penchala River determined that river has relatively high index for richness, diversity and evenness index.

Margalef richness index (2.13) value at Penchala River indicate that the river is clean as the index is upper than 1.0. The value at Station 2 and 3 were give us information that the river was slightly polluted (Lenat et al., 1988). Shannon-Weiner diversity index values were also high at this river with 1.75. Shannon-Weiner diversity index values above 3.0 indicate that the habitat structure is stable while values less than 1.0 indicate that the river has been polluted (Mandaville, 2002). The Simpsons index value varies from 1.0 to 0. The 1.0 indicate that the habitat is stable while 0 indicate that the habitat was degraded. The Penchala River recorded 0.73 for Simpson's index indicate that the diversity is relatively high. Values on Pielou's evenness index were 0.74. The value is closer to 1.0 indicates that the macrobenthos were evenly distributed at Penchala River (Pielou, 1966).

This study also shows that sampling method using Surber's net was suitable as many orders with different families has been collected during the sampling. As the results, there were 8 orders with 23 families were collected at Station 1, 2 orders with 3 families at Station 2, 4 orders with 8 families at Station 3 and 1 order with 2 families at Station 4. From the results, the data show that the Clean (Station 1) has the highest numbers of orders and family while Polluted (Station 4) has the lowest numbers of orders and families. The findings had proved that the clean river which the WQI falls under Class I and II was suitable for survival of macrobenthos such as Ephemeroptera, Plecoptera, Trichoptera, Odonata, Coleoptera, and Decapoda. These orders of macrobenthos were very sensitive to deterioration of water quality thus the existing of these orders indicated the water quality was good and healthy. Contrast to existing of Diptera, Oligochaeta and Basommatophora, these orders indicated that the water quality was slightly polluted and not healthy.

5.3 Relationship of physico-chemical parameters and species diversity of macrobenthos at Penchala River

The existence and diversity of macrobenthos at Station 1, 2, 3 and 4 during the sampling period appeared to respond to the physico-chemical deterioration as reported in Chapter 4. High numbers of macrobenthos at Station 1 was associated with the clean, compatible and unpolluted condition.

Poor water quality or polluted water body is one of the limiting factors of the existence and diversity of macrobenthos as they are highly responded to deterioration of water quality status (Paul and Meyer, 2001). Different species of macrobenthos were responded differently from one and another. The finding shows that the existence and distribution of macrobenthos were influenced by physico-chemical and biological characteristic as well as physical parameters of the river. The diversity was the highest at Station 1. Numbers of Ephemeroptera, Plecoptera, and Tricoptera (EPT), Odonata and Decapoda were abundant at Station 1 which was classified as clean and unpolluted area while Chironomidae and Physidae were abundant at polluted sites.

This finding was parallel to study done by Mahazar et al. (2013) who found out that the clean and unpolluted area have a high number of EPT, Crustacea and Isopoda while the Blood-red Chironomidae, as well as other Dipterans, dominated in polluted areas.

The study also agreed on the decreasing of the diversity of macrobenthos from clean to the polluted area. He also found that the Chironomidae was present consistently throughout the polluted rivers.

The numbers of macrobenthos that exist at certain values of water quality status is affected by the velocity. From the figures, it shows that a trend which the number of macrobenthos has affected by the value of WQI at every station. Another finding that could be extracted from then figure is the number of macrobenthos that is high response to velocity. From the figures, the number of macrobenthos was increasing when the velocity of the river was decreased.

The most abundance was Trichoptera on every sampling date. Trichoptera have a very low value of pollution tolerance and it was very sensitive to water pollution. The number of Trichoptera was decreased from March to July 2014 perhaps because of the deterioration of water quality at Station 1. The second-high abundances were Odonata and Ephemeroptera. Odonata and Ephemeroptera have also low values of pollution tolerance. All these three orders only exist in clean and unpolluted river water. The number decreased as the water quality index was decreased.

Ephemeroptera is very sensitive to the deterioration of water quality and their existence at Station 1 signified relatively clean conditions (Merritt and Cumins, 1978). To support the statement, the data collected shows that Ephemeroptera only exists at Station 1 and absent at Station 2, 3 and 4. The Trichopteran caddisflies were found as good biological indicators of the clean river since they also only exist at Station 1.

Station 2 and 3 were dominantly by Diptera Chironomidae. The low concentration of dissolved oxygen creates a suitable environment for Diptera Chironomidae to survive and reproduce. Diptera Chironomidae is a unique macrobenthos as it possesses haemoglobin in their blood which makes them survive in waters that have a very little oxygen (Carew et al., 2007). This theory was supported by an abundance of Chironomidae were collected during the sampling at this station, supported by the low concentration of DO which was in the range of 0.65 – 2.7 mg/L in November 2014 compared to other stations. Other than that, patterns of the existence of the Chironomidae were influenced by the available quantity and quality of larval food. In addition, the species composition may change influenced by the changes of particle composition especially the deposition of organic matter and detritus on the bottom (Galdean et al, 2000).

Nutrient in river water refers to the concentration of nitrogen and phosphate or known as eutrophication. The eutrophication and organic matter affected the existence and diversity of macrobenthos as the production of algae and other vegetation are increasing which provide substrate, shelter and food for macrobenthos. Generally, increasing of organic matter in the river will reduce the number of macrobenthos as an example of Trichoptera as high loads of organic materials promote a complete deoxygenation condition. Even though the oxygen is very limited; the Oligochaetes, Chironomidae and Simuliidae are the macroinvertebrates which still can survive in high numbers.

Numbers of Basommatophora Physidae also can be found near to the river's edge at Station 2 which the velocity was very low and nearly stagnant. The water flow had been blocked by either rock, deposition of sands or solid wastes. Even though the concentration of dissolved oxygen was low and the velocity was also low, Physidae can survive it has a lung structure for their breathing mechanism (Koopman et al., 2016).

Macrobenthos was the most abundance and high diversity at Station 1. Station 1 have a good canopy cover that maintain the temperature. The changes of temperature may result from industrial discharges, agricultural and forestry activities and removal of riparian vegetation as well as channelisation and regulation of streams. Slight changes of temperature can affect the ecology of aquatic insects as it may change the flow condition, the rate of production and mineralisation. The macrobenthos are sensitive to temperature and they will move to the optimal temperature for their survival. In addition, temperature also affects the oxygen content in the water as the oxygen levels become lower as the temperature increases. The increasing of temperature can cause by weather, removal of shading streambank vegetation, impoundments which a body of water confined by a barrier such as a dam), discharge of cooling water, urban storm water and groundwater inflows to the stream (Brungs and Jones 1977). For example, the optimum temperature of $20^{o}C$ is the lethal level for Plecoptera and Ephemeroptera. The Chironomidae and Odonata can be generally found at a slightly high temperature which is around $40^{o}C$. Other than that, the high canopy cover provides additional foods to the macrobenthos. The leaf litter in the river also create an extra habitat for macrobenthos. The Coleoptera can be found mostly in between the dried leaves.

Presence of sensitive families like Ephemeroptera, Plecoptera and Tricoptera at Station 1 and they were absent at Station 2, 3 and 4. These groups have a very low pollutant tolerance thus the presence of these group indicated clean river and the discontinuity in the presence of these group denotes that the water quality status has been degraded.

The diversity of macrobenthos was also low at Station 3. It is a low diversity because there was only free flow river water. Most of the macrobenthos attached at the gravels, rocks and even at the solid waste but all of these potential habitats were absent at this station. The dipterans were survived by attaching to secondary grass that grows at the river's edge.

There was no other macrobenthos were found at station 4 except Basommatophora Physidae and Thiaridae. The Physidae and Thiaridae can be found at the side of the river bank. The very low water velocity was not an ideal place for breeding, and low concentration of dissolved oxygen was very as well as polluted water quality status. Physidae and Thiaridae have a very high value of pollution tolerance (Nelson, 2011). Thus, even though water quality at Station 4 were poor, both still can survive.

Other than that, the study also found out that the existence and distribution of macrobenthos were also influenced by the physical characteristics of the river. The role of the substrate of the river bed and the presence of aquatic plant are very important as they serve as favoured habitat. Aquatic plant comprised of emergent, floating and submerged plants. It provides shelter, egg laying sites, nursery areas and food sources for herbivores.

For this study, the concrete river consists of sand and absence of aquatic plants make it not suitable for breeding and serving as habitat for macrobenthos. Mandaville (2000) agreed that macrobenthos has their specific preference upon the surrounding environment as well the substrate to live on. This statement is parallel to the finding obtained from this study. The same condition occurs at Station 2, 3 and 4 which the concrete shaping the river. The modification of their habitat becomes the limiting factor as it limits the ranges of a suitable niche for diverse macrobenthos to fill in the ecosystem. Other than that, the aquatic plants only occur at the river bank. In this case, water quality and the velocity become the limiting factor. The results obtained show that the numbers and diversity of macrobenthos decrease from upstream (Station 1) toward the downstream (Station 2, 3 and 4).

Significant physical factors that influence the existence and distribution of macrobenthos are streamflow, current velocity, channel shape, water depth, substrate and temperature. Increasing of water level will result in inundation of physical structures and features. When these events happened, it demolished the substrates that are important for colonisation and attachment of invertebrates and also act as habitat for feeding, shelter, current refuge and spawning and represent an increase in the quantity, diversity and complexity of physical habitat for both invertebrates and fish (Crowder and Cooper, 1982; Crook and Robertson 1999)

Low velocity and shallow areas serve as a very suitable condition for the growth of aquatic macrophytes. Macrophytes are widely recognised as important habitat for some invertebrates and fish as it is a source of food and serve as protection area from predators and current as well as increase the amount of available habitat per unit area of substrate (Crowder and Cooper, 1982; Minshall, 1988; Newman et al. 1992; Weatherhead and James, 1991).

In a different perspective, high velocity is important too. High velocity helps to flush of fine sediments and organic matter from areas of coarse streambed substrate. This flushing reduces armouring of the stream bed and leads to greater availability of interstitial spaces in the coarser substrate. These spaces are available as habitat for invertebrates.

The increasing number of solids in a river is as the result of erosion, farming, forestry or mining activities which located near to the river bank. The solids have been identified to give effect neither direct nor indirect as it affects water clarity. High concentration of solids in water body decreases the passage of light through water thus slowing photosynthesis by aquatic plants. Other than that, solids also will make the water heating up rapidly as the solids particle will hold more heat thus indirectly affected macrobenthos which intolerant with the deterioration of water temperature (APHA, 1992).

The effect from the concentration of heavy metals becomes one of the concerns as the urban river flows through the industrial area. Heavy metals are well known as a source of the toxicity problem to both aquatic organism and human (Beasley and Kneale, 2003). Generally, aquatic insects are more tolerant to heavy metals compared to fish and other invertebrates. A study by Qu et al., (2010) had found out that the total abundance and species richness of macrobenthos were decreased when the concentration of heavy metals increased. They also mentioned that although the effects were compounded by different factors such as altitude, temperature, stream width and turbidity, the influence of heavy metals on macrobenthos communities was clearly identified eventhough the concentration is not seriously high. Parallel to their study, Hickey and Clements (1998) were agreed that there were significance effects from the high concentration of heavy metals to the existence and diversity of macrobenthos. They also suggested that abundance of mayflies, species richness of mayflies, the number of EPT taxa and total taxonomic richness are the most useful indicators of heavy metal pollution in New Zealand streams.

Optimum habitat condition also plays as the important role that influences the existence and diversity of macrobenthos. The habitats are defined as a complex interaction between physical factors and the ecological requirements of aquatic flora and fauna such as light, shelter, food and flow-mediated chemical exchanges. Macrobenthos can survive all parts of the water body. Some of them live on the water's surface, in the water, in the sediment, on the bottom and also on submerged rocks, logs and leaf litter. Dudgeon (2008) had summarized that the aquatic habitat is adversely impacted by urbanization, deforestation, construction, irrigation, drainage, wetlands and pollution. Other than that, it also depends on the interactions of hydrology, geomorphology features and structural elements. Examples of geomorphological features are pools, bars, benches, overhanging banks and anabranches, and examples of structural elements are boulders, tree roots, coarse woody debris and macrophytes.

Other important physical habitat features for macrobenthos are cover and refuge as well as conditions of its river bank and shore. These features are usually provided by boulders, large wooden debris, aquatic vegetation, water turbulence and depth. It provides shelter from predators and alteration of physical condition such as fast current and sunlight. The 'slack water' area also plays as important role as habitat for macrobenthos (Marchese et al., 2002). The slack water is a typical small shallow area of still water that formed by sand bars, woody debris and bank morphology. It is important to provide refuge from current for the young stages of fish and shrimp and predation and as sites where food is abundant as it has a greater amount of benthic organic matter which a potential food resource for shrimp (Humphrises et al., 2006; Richardson et al., 2004; Burns and Walker, 2000).

CHAPTER 6: CONCLUSION

Rapid urbanisation in Malaysia causes alterations of the physico-chemicals and hydraulics characteristics that affect the existence and diversity of macrobenthos communities. This study agreed that deterioration of water quality characteristics is affected by urbanisation. Eventhough urbanisation does not affect directly to the existence and diversity of macrobenthos, it does alter the physico-chemical and hydraulics characteristics of a natural river which in turn affect the macrobenthos communities. This study also understood that any modification of the physical and chemical characteristics of a habitat had changed the existence and diversity of macrobenthos.

The current water quality status at Penchala River is in the range of WQI 58.1 to 71.0. This study found that the factors that affect the water quality are alteration of river structure and human activities in and around the river. The significant pollutant that affect the water quality for Station 1 was total dissolved solids. For Station 2 and 3, the high concentration of ammoniacal nitrogen, phosphate and organic pollutants as well as deterioration of velocity gave impact to existence and diversity of macrobenthos. Station 4 was highly affected by human such as squatters and construction activities at the river bank.

This study also shows that the macrobenthos has been successfully act as biological monitoring agent. It is useful in detecting transient and long term pollution of urban rivers. The aim of this study is achieved as macrobenthos had been proved as it serves as an alternative way in determination of water quality status at urban river, the existence and diversity of macrobenthos were highly responded to the alteration of water quality at identified stations.

Macrobenthos are very useful to determine river health status by virtue of their role in the aquatic ecosystem. It utilised minimal cost, cheap and give rapid results on deterioration of water quality at Penchala River. It gives early warnings of hazards, detecting pollutant and further provides information for monitoring and evaluating the environmental effects.

The macrobenthos were collected by using Surber net. The results show that there were 1043 macrobenthos were collected during the sampling period. Form the number, there were 465 (44%), 176 (17%), 372 (36%) and 30 (3%) macrobenthos were existed at Station 1, 2, 3 and 4 respectively. The sensitive group of Ephemeroptera, Plecoptera and Tricoptera (EPT) group at Station 1 indicated that the river is clean. Diptera Chironomidae and Basommatophora Physidae were abundance at Station 2, 3 and 4 as they can survive in slightly polluted river as they have higher level of tolerance towards pollution. In addition, Physidae has special gill structure for respiration.

The advantages of using macrobenthos as biological indicator as their abundance existence and ubiquitous in nature. In addition, the macrobenthos also have sedentary lifestyle and long lifespan thus make them suitable as pollutant indicator. Other than that, the macrobenthos also relatively rich with families that responses to environmental changes both natural and man-induced during their life cycle.

The positive results on correlation analysis support the finding. The analysis shows that there is strong correlation between water quality index with Margalef richness index (2.13), Simpsons diversity index (0.73), Shannon-Weiner diversity index (1.75) and Pielou evenness index (0.74) indicated that biological monitoring at Penchala River by using macrobenthos can be served as an alternative way to determine the river health.

For further development, a comprehensive approach is needed specially to determine the effects of human activities on aquatic ecosystems. Understanding of the contribution on the aquatic ecosystem is important such as the river continuum hypothesis, path dynamics as well as the importance of variation in the physical environment especially annual shifts in distribution and amount of rainfall and runoff. Other than that, a series of quality control provision is also highly recommended.

Other than that, the ecological principals have to be up-to-date to the current conceptual foundation as developed countries will come out with new approaches with latest research papers from time to time. The current study is suggested to be done at other urban rivers under controlled condition. This is important in order to avoid any unexpected activities from the local authorities. If this situation occurs in the future, it is suggested that the study period can be extended until the situation back to normal condition. This is to see the impact of these activities to the study area and to further understand about river restoration.

It is further suggestion to achieve the maximum numbers of healthy urban river, all the programmes need involvement of all stakeholders including the local communities, NGOs, water management professionals and scientists as well as decisions makers and policy makers at all level of government.

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