



Faculty of Resource Science and Technology

**Water Quality and Sediment Characteristics of the Rajang River at the
Pelagus Area and Its Tributary**

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Water Quality and Sediment Characteristics of the Rajang River at the Pelagus
Area and Its Tributary

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. It is original and is the results of my work, unless otherwise indicated or acknowledged as referenced work. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

Water quality and sediment characteristics in the downstream river of a hydroelectric dam may be affected by the dam operation or other activities surrounding the river. Little is known about the water quality and sediment characteristics of the Rajang River at the Pelagus area. As a hydroelectric dam was planned to be built in the area in the future, it is important to collect baseline data for future reference. Therefore, this study was conducted to mainly document the water quality and sediment characteristics along the Rajang River and its tributaries at the Pelagus area and The water quality changes due to changes in water discharge from the Bakun dam upstream and rainfall amount. A total of 30 stations were selected for the study which consisted of a total of 9 stations at upstream (St 1-9), 10 stations at midstream (St 10-19) and 11 stations at downstream (St 20-30) sections. The total length of the main Rajang River covered was approximately 130 km. For comparisons based on different water discharges, 11 stations at downstream area of the Pelagus Area were sampled three times. The results of the present study show that DO have an increasing trend from upstream toward downstream direction. The BOD was higher than 3 mg/L at most of the stations at Rajang River at upstream (4.29 – 4.91 mg/L) and downstream sections during January 2016 (4.58 – 5.03 mg/L) but not at the midstream section in December 2015 (2.31 – 2.61 mg/L), midstream sections in July 2015 (2.61 – 3.67 mg/L) and in March 2016 (2.27 – 2.56 mg/L). These were greatly influenced by the weather condition and the volume of discharge from Bakun Hydroelectric Dam. The means of conductivity, turbidity, transparency, TSS, pH, DO, and NH₃-N of the tributaries have significantly higher concentrations compared to the main river stations along the Rajang River, thus, influencing the water quality of the Rajang River. The amount of water discharge from the spillway of the

Bakun Hydroelectric Dam influenced the DO, BOD and COD values at the stations in Rajang River. The DO values at Rajang River deteriorated due to no water discharge from the spillway at the time of sampling in January 2016. Thus, increased concentrations of BOD and COD were observed among the stations at Rajang River. In terms of water quality index (WQI), the stations were classified as Class II or III and their status were considered clean or slightly polluted. Meanwhile, the textural class of sediments in Rajang River area ranged from sand, clay, sandy clay loam, sandy loam to silt. Comparatively, the mean pH of sediment shows that the sediment is more acidic (6.18) than water (6.90). The sediment characteristics results in Rajang River and its tributaries are: pH (4.50 to 6.70), TOC (0.01 to 0.9%), OM (0.32 to 5.20%), TKN (56.51 to 1597.30 mg/kg) and TP (41.41 to 120.40 mg/kg). There are significant correlations between water and sediment parameters. They are river water pH and sediment TP, sediment TP and water DO and temperature with sediment TKN. The land use such as logging and plantation activities, domestic and household waste water also influenced the water quality parameters. This study shows that the water parameters of Rajang River were influenced by the loading of pollutants from the tributaries particularly water turbidity and TSS; and sediment silt, TP and TKN. The spillway and turbine discharge from Bakun Dam changes the water quality significantly.

Keywords: Rajang River, dam tailwater quality, turbine discharge, spillway discharge, sediment classification

Kualiti Air dan Ciri-Ciri Sedimen di Batang Rajang dalam Kawasan Pelagus dan Anak-Anak Sungai

ABSTRAK

Ciri-ciri air dan ciri-ciri sedimen di sungai hilir empangan hidroelektrik mungkin terjejas oleh operasi empangan atau aktiviti lain di sekitar sungai. Pengetahuan tentang kualiti air dan ciri-ciri sedimen Batang Rajang di kawasan Pelagus adalah terhad. Oleh kerana satu empangan hidroelektrik dirancang untuk dibina di kawasan itu pada masa akan datang, maka, adalah penting untuk mengumpul data asas untuk rujukan masa depan. Oleh itu, kajian ini dijalankan untuk mendokumentasikan kualiti air dan ciri-ciri sedimen di sepanjang Batang Rajang dan anak sungai di kawasan Pelagus di bawah paras air yang berbeza kerana perubahan dalam pelepasan air dari empangan Bakun di hulu dan musim hujan. Kajian ini dijalankan untuk mendokumentasikan kualiti air dan ciri-ciri sedimen di Batang Rajang di kawasan Pelagus dan anak-anak sungainya. Sebanyak 30 stesen telah dipilih untuk kajian ini yang terdiri daripada jumlah 9 stesen di bahagian hulu (St 1-9), 10 stesen di pertengahan (St 10-19) dan 11 stesen di hilir (St 20-30). Panjang keseluruhan Batang Rajang diliputi adalah kira-kira 130 km. Kajian ini juga mendokumenkan perubahan Batang Rajang disebabkan oleh perubahan pelepasan air dari Empangan Bakun di hulu sungai. Untuk perbandingan berdasarkan pelepasan air yang berbeza, 11 stesen di kawasan hilir Kawasan Pelagus telah disampel sebanyak tiga kali. Keputusan kajian ini menunjukkan bahawa DO mempunyai trend yang meningkat dari hulu ke arah hilir. BOD adalah lebih tinggi daripada 3 mg/L di kebanyakan stesen di Batang Rajang di hulu (4.29-4.91 mg/L) dan seksyen hiliran semasa Januari 2016 (4.58-5.03 mg/L) tetapi bukan di bahagian pertengahan pada bulan Disember 2015 (2.31 - 2.61 mg/L), seksyen pertengahan pada bulan Julai 2015 (2.61-3.67 mg / L) dan pada Mac 2016 (2.27-2.56 mg / L). Ini telah banyak dipengaruhi oleh keadaan cuaca dan

isipadu air pelepasan dari empangan hidroelektrik Bakun. Purata kekonduksian, kekeruhan, kejernihan, TSS, pH, DO, dan $\text{NH}_3\text{-N}$ daripada anak sungai mempunyai kepekatan yang lebih tinggi berbanding stesen-stesen sungai utama di sepanjang Batang Rajang. Oleh itu, kualiti air di Batang Rajang telah dipengaruhi. Jumlah pelepasan air dari alur limbah daripada Empangan Hidroelektrik Bakun mempengaruhi DO, BOD dan nilai COD di stesen di Batang Rajang. Nilai DO di Batang Rajang merosot disebabkan tidak ada pelepasan air dari alur limbah pada masa persampelan pada bulan Januari 2016. Oleh itu, peningkatan kepekatan BOD dan COD diperhatikan di stesen-stesen di Batang Rajang. Dari segi indeks kualiti air (WQI), stesen-stesen dikelaskan sebagai Kelas II atau III dan status mereka dianggap bersih atau sedikit tercemar. Sementara itu, kelas tekstur sedimen di kawasan Rajang River adalah pasir, tanah liat, berpasir lempung tanah liat, lempung berpasir hingga kelodak. Secara perbandingan, purata pH menunjukkan sedimen adalah lebih berasid (6.18) daripada air (6.90). Keputusan ciri-ciri sedimen dalam Batang Rajang dan cawangannya adalah: pH (4.50-6.70), TOC (0.01- 0.9%), OM (0.32-5.20%), TKN (56,51-1.597,30 mg / kg) dan TP (41.41 -120,40 mg / kg). Terdapat korelasi yang signifikan di antara parameter air dan sedimen. Mereka adalah pH air sungai dengan TP sedimen, TP sedimen dengan oksigen terlarut dan suhu dengan TKN sedimen. Penggunaan tanah seperti aktiviti pembalakan dan perladangan, air buangan domestik dan rumah tangga dan Empangan Bakun mempunyai pengaruh ke atas kualiti air. Kajian ini menunjukkan bahawa parameter air Batang Rajang dipengaruhi oleh beban pencemar daripada anak-anak sungai terutamanya kekeruhan air dan TSS, kelodak sedimen, TP dan TKN. Pelepasan limpahan dari Empangan Bakun mengubah kualiti air dengan ketara.

Kata kunci: Batang Rajang, kualiti air bawah empangan, pelepasan air turbin, pelepasan air alur limbah, klasifikasi sedimen.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BOD ₅	Biochemical oxygen demand-5 day test
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
DO	Dissolved oxygen
DOE	Department of Environment
FAS	Ferrous Ammonium Sulfate
H ₂ SO ₄	Sulfuric acid
Inorg-N	Inorganic Nitrogen
NaOH	Sodium hydroxide
NH ₃ -N	Ammoniacal Nitrogen
NO ₂ -N	Nitrite Nitrogen
NO ₃ -N	Nitrate Nitrogen
NWQS	National Water Quality Standards for Malaysia
Org-N	Total Organic Nitrogen
pH	Potential of hydrogen ion
r.p.m	Revolutions per minute
S	Sediment
SIAN	Sub index of ammoniacal nitrogen
SIBOD	Sub index of biochemical oxygen demand
SICOD	Sub index of chemical oxygen demand
SIDO	Sub index of dissolved oxygen

SISS	Sub index of suspended solid
SIPh	Sub index of potential hydrogen
SPSS	Statistical Product and Service Solutions
TN	Total Nitrogen
TKN	Total Kjeldahl nitrogen
TP	Total phosphorus
TSS	Total suspended solids
UV-VIS	Ultraviolet visible
WQI	Water quality index

CHAPTER 1

INTRODUCTION

1.1 Research Background

Rivers have played a major role in ecosystem by providing water, food and other ecosystem services (Beck *et al.*, 2012). In Sarawak, the naturally occurring rivers play an important role in the society especially in some rural areas where rivers are the source of water and also the protein supply. However, rivers are threatened by river pollutions which is a common environmental problem faced by people worldwide. Pollutants are present in the river when any substance, either naturally occurring substance or human disposal substance are added into the river. This can alter the characteristic of that river and its catchment. The degradation of water quality due to pollution causes adverse effects to aquatic life forms and disturbs the balance of life (DOE, 2014). Therefore, it is crucial to consistently monitor and conserve the river in order to make sure that the natural rivers are sustainable.

The development of land such as conversion of land into agriculture land, logging, residential settlements and hydroelectric dams can bring negative impact to the environment in term of its water quality, sediment quality and the health of the rivers directly and indirectly. Soil erosion from logging activities, wastewater from residential area and pesticides and fertilizers in the plantation of oil palm that run into the river nearby will affect the quality of the river whereby it may cause the nutrients level in the river water to increase. Therefore, the health of the rivers nearby could be degraded. In addition, the rise of civilizations comes together with the rising need for the construction of hydroelectric dams. The construction of dams has been done for centuries for various purposes such as irrigation for and crops to provide flood

control (Wildi, 2010). In Malaysia, the construction of dams is done to fulfil the demand of the electric energy. There are a total of three hydroelectric dams in Sarawak, namely, Batang Ai Hydroelectric Dam, Murum Hydroelectric Dam and the largest is Bakun Hydroelectric Dam. Additionally, two out of the mentioned dams, namely, the Murum Dam and the Bakun Dam are located upstream of the Pelagus area of the Rajang River. There is little information published on the water and sediment quality of the river downstream of Bakun Dam.

Additionally, one of the proposed hydroelectric dam projects is located at the Pelagus area. Thus, this study aimed at documenting the water quality along with its sediment characteristics at the Pelagus area of the Rajang River. The proposed hydroelectric dam project at the Pelagus area of the Rajang River makes it important to collect baseline data on water and sediment quality of the river before the project started.

Sediments which are the soil particles that settle at the bottom of a river play an important role as they affect water quality conditions. Sediments and aquatic life are related in the context that if the quality of sediments is bad, it will affect the aquatic lives and also their habitats (USEPA, 2012). This is also mentioned by Calow & Petts (1992), that the quality of sediments can affect the aquatic life directly by damaging their organisms and habitats and indirectly by influencing the turbidity and light penetration in the river. Besides, sediment is also important because it often enriches the soil with nutrients which are the basis of support for living aquatic organisms (Ling *et al.*, 2012).

In order to understand more the quality of a river, sediment characteristics along Rajang River and its tributaries at Pelagus area need to be monitored along with water quality parameters.

Sediment characteristics include the particle size distribution, pH, organic matter (OM), total phosphorus (TP), total Kjeldahl nitrogen (TKN) and total organic carbon (TOC).

1.2 Problem statement

The residential area with direct discharge of household wastewater, man-made reservoirs and anthropogenic activities such as logging, agriculture and the use of water transportation along the river can cause potential pollution to the Rajang River at the Pelagus area. So, there is a need to know the water quality and sediment characteristics of the Rajang River at the Pelagus area. However, there is only a few research related to water quality and sediment characteristics of the Rajang river in Sarawak. Furthermore, the Pelagus area is located downstream of the Bakun Hydroelectric Dam. There is also a need to know whether the upstream dam have any significant impact on the downstream river. Additionally, one of the proposed hydroelectric dam project is located at the Pelagus area. Thus, this study aimed at documenting the water quality along with its sediment characteristics of Rajang River at the Pelagus area. The proposed hydroelectric dam project at the Rajang River of Pelagus area make it important to provide a baseline data in water and sediment quality of the river before the project started. Therefore, this study is needed to document and monitor the water and sediment in Rajang River and its tributaries.

1.3 Research Questions

The research questions of this study were:

- i. Is the rainfall amount changes the water quality of Rajang River?

- ii. Is the surrounding land use impacting the water quality and sediment characteristics of the Rajang River and its selected tributaries?
- iii. Is there any difference in water quality due to variation in discharge of the Bakun Hydroelectric Dam?
- iv. Is the water quality significantly impacted by the Bakun Hydroelectric Dam?
- v. Is the water and sediment quality of the tributaries influencing the water quality of Rajang River?

1.4 Research Hypotheses

The research hypotheses of this study were as follows:

- i. The water quality at the tributaries might be an influence on the water quality of the Rajang River at Pelagus area.
- ii. Surrounding land use might affecting the water quality and sediment characteristics of the Rajang River.
- iii. Different river discharges might be impacted the water
- iv. Bakun Hydroelectric Dam outflow might have an impact on the water quality of Rajang River downstream of the dam.

1.5 Objectives

The general objective of this study is to document and determine the status of water quality and sediment characteristics of the Rajang River at Pelagus area and its selected tributaries. Meanwhile, the specific objectives were:

- i. To investigate the impacts of surrounding land use on the water quality and sediment characteristics along Rajang River at Pelagus area and its selected tributaries;
- ii. To investigate the changes in the water quality in Rajang River at Pelagus area due to the variation of water discharges from Bakun Hydroelectric Dam upstream and rainfall amount;
- iii. To determine whether the loadings of water quality parameters at tributaries are influencing the water quality in Rajang River at Pelagus area;
- iv. To investigate the correlation between water quality and sediment characteristics in Rajang River and its tributaries. .

CHAPTER 2

LITERATURE REVIEW

2.1 Water Quality

2.1.1 Water Quality parameters

Parameter of water quality in this study refers to the physical, chemical and biological characteristics of surface water. The physical characteristics includes temperature, total suspended solids (TSS), turbidity, transparency and conductivity whereas for chemical characteristics are pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), sulphide, and nutrients (nitrogen and phosphorus). These water quality parameters are discussed in the following sections.

2.1.1.1 Physical parameters

2.1.1.1.1 Temperature

Temperature is an important water quality parameter in river quality monitoring. The chemical and biological rates can be affected by an increase or decrease of water temperature (Drolc & Koncan, 1996). According to Ling *et al.* (2006), the temperature of water also depends on the weather condition. Surface water temperature is most likely to be lower on rainy days compared to that on sunny days. A river with high temperature affects the aquatic ecosystem by increasing the metabolic activity of aquatic life and biochemical reaction rates thus reducing the ability of the water to hold the dissolved oxygen. The health and also the balance of an aquatic environment can be significantly altered by a change of about 5°C. In addition, higher temperature in water body can cause plants to grow and die faster which then

accumulates as matter that requires oxygen for decomposition. Therefore, temperature is usually found to be inversely correlated with DO concentration level.

2.1.1.1.2 Conductivity

River water conductivity is also one of the important parameters in water quality monitoring. It represents the capability of river water to conduct electricity because of the presence of the salts in the water system (Jenkins *et al.*, 2005). Fish and other organisms that live in freshwater cannot tolerate large increases in the saltiness of the water because they will not be able to keep water in their bodies (Horne & Goldman, 1994). Besides that, geological condition of the area which river water flow through can influence the amount of conductivity in rivers (USEPA, 2012). This is supported by a study conducted by Anhwange *et al.* (2012). It was reported that the discharge by the feeder streams, industries and effluents during wet season caused an elevation in organic, inorganic materials and salts. The conductivity of that study was about 60 $\mu\text{S}/\text{cm}$. Additionally, the range of conductivity for fresh river water is approximately 100-2000 $\mu\text{S}/\text{cm}$ and for distilled water it is 0.5-3 $\mu\text{S}/\text{cm}$ (USEPA, 2012). The range outside of 150-500 $\mu\text{S}/\text{cm}$ is unfavourable for certain species of macro-invertebrates and fish (USEPA, 2012).

2.1.1.1.3 Turbidity, Transparency and TSS

The clarity of river water is very important to determine because it reveals the cleanliness of a river and affects its productivity. Turbidity, transparency and TSS are the parameters that are often used as indicators of the clarity of the water such as river water. TSS consists of fine

sand or any tiny particles that are caused by soil erosion and are washed into the river. The turbidity of river water is due to the suspended particles such as organic matter or sewage, including silts, clay and plankton that make the water look not clear or muddy (Jenkins *et al.*, 2005). Water transparency also depends on the type and amount of particles present in the river water which changes due to phenomena such as natural and man-made pollution (Zhang *et al.*, 2006). Low transparency in surface water can be due to many contributing factors. Based on the research done in Changshou Reservoir, low transparency in the water body was observed which varied from 0.50 m to 1.55 m due to the soil erosion and algal growth (Zhang *et al.*, 2006).

Basically, the higher the amount of suspended solids the more polluted is the river. This makes the river water unsuitable for drinking and aquatic life (Kanu *et al.*, 2011). Yang *et al.* (2007) mentioned that during the rainy season, the suspended solids concentration was lower than usual because the large amount of water input diluted the river water and this was shown in Wusong site of the Huangpu River where there was dilution of tides at the estuary. Furthermore, the sources of TSS in Malaysia are mainly caused by active land clearing activities and improper earthworks (DOE, 2014). Ling *et al.* (2010) shows that the residential areas and on-going construction work near the Santubong river led to high TSS values which had exceeded 100 mg/L.

Similar to TSS, the reading of turbidity often shows a sharp increase when it rains because during a rainfall event the rapid increase of stream velocity speeds up the erosion rates of stream banks and channel. This condition is often observed in developed watershed areas which have relatively high proportions of loose surfaces. Extremely high turbidity and high

suspended sediment loads were detected mainly originating from upstream soil erosion due to the construction of logging roads and camps, skid trails and logging in the river basins was reported by Malaysia Department of Environment (DOE, 2014). Additionally, high turbidity has been detected at Batang Rajang (630 NTU) and Sungai Melaka (800 NTU) in 2010 due to on-going logging operations in the river basin (DOE, 2014).

2.1.1.2 Chemical parameters

2.1.1.2.1 pH

pH is also one of the important water quality parameters. pH refers to the alkalinity or acidity of water and it is a measure of the concentration of hydrogen ion in water. A simple parameter like pH plays a crucial role in biological and chemical activities in natural waters where it can affect the amount of other constituents present either indirectly or directly controlled by a change in its value thus affecting the sensitive aquatic life (Yang *et al.*, 2007).

In natural conditions, the pH of water is between 6 and 8 (Lau, 2011) whereas the optimum pH is about 7.4 (Jenkins, 2005). According to Ling *et al.* (2011), most freshwater have the pH value ranging from 6.5 to 8.0. Therefore, pH outside of this range can cause a reduction in diversity in the river by stressing the reproduction and physiological framework of a big number of organisms (USEPA, 2012).

The changes in pH of a river water system could be contributed by many factors. According to Barron *et al.* (2005), the water pH is inversely proportional to the temperature where the water pH decreases when the temperature rises. In addition, the slightly acidic condition of the river water is mainly due to dissolved carbon dioxide from the atmosphere, while slightly

alkaline condition is mainly due to the presence of calcium carbonate (limestone) (Jenkins, 2005). The reason of a high pH value in river water is because of the anthropogenic inputs of nutrients into the river that promotes algae growth and photosynthesis process (Ling *et al.*, 2010).

2.1.1.2.2 Dissolved Oxygen (DO)

An important parameter in assessing water quality is dissolved oxygen (DO). DO refer to the quantity of oxygen that is dissolved in the water body (Jenkins *et al.*, 2005). The key for the survival of aquatic organism is a sufficient supply of dissolved oxygen gas within the water body. Therefore, a lack of dissolved oxygen in river is an indication of an unhealthy river (Lawson, 1996).

Atmospheric oxygen dissolved in surface water. The solubility of oxygen in water is about 8.4 mg/L at 26 °C (Lau, 2011). Generally, 5 mg/L of DO content is considered as the lower limit for a water body to be healthy and falls within an acceptable concentration for aquatic life (Syamsidik & Santosa, 2001). Major factors affecting the level of dissolved oxygen are chemical oxidation of reduced pollutants, metabolism of pollutants by microorganism, assimilative limit of the river, and flow of the river (Drolc & Koncan, 1996).

The presence of oxygen producing plant in water will increase the DO of the water body during the day due to process of photosynthesis, but will consume the DO at the night during their respiration (Lau, 2011). The dissolved oxygen levels decline if more oxygen is consumed than is produced. The organic matters originating from decaying vegetative debris,

food wastes and sewage could consume the dissolved oxygen present in the water (Drolc & Koncan, 1996; Lau, 2011).

2.1.1.2.3 Biochemical Oxygen Demand (BOD)

BOD is one of the important parameters in water quality. The BOD refers to the proximate measure of the concentration of biochemically degradable organic matter in a water body (Bartram & Balance, 1996). This parameter is an important index used to evaluate biodegradable organic pollution in the water (Jenkins *et al.*, 2005). In natural conditions, BOD derives from decaying vegetative debris and the minimum value of unpolluted water are less than 2 mg/L (Jenkins *et al.*, 2005). The main sources of BOD are from agricultural waste, animal waste, vegetative waste and sewage (Ling *et al.*, 2010; Lau, 2011). An increase in organic material present in a water body can cause an increase in the consumption of oxygen, which can result in a higher value of BOD. Therefore, a river polluted with more organic matter has a higher level of BOD. Also, a study done by Yang *et al.* (2007) shows high BOD values at Yangpu site, suggesting high organic matter input.

The biochemical oxygen demand of the water influences the concentration of dissolved oxygen in the river water. The excessive use of chemical additives, antibiotics and fertilizers can lead to an accumulation of residues which increases the BOD level thus lowering the DO level (Yang *et al.*, 2007). In addition, the results of a study on the domestic wastewater and impacts of aquaculture at Santubong River, Malaysia shows that mean BOD values ranged from 4.9 to 9.3 mg/L and they exceeded the value of unpolluted water (2 mg/L) and DO values ranged from 2.3-4.1 mg/L and were all below the minimum recommended value (5

mg/L) (Ling *et al.*, 2010). This shows that there was a high consumption of oxygen by bacteria due to the wastewater in residential areas and organic matter from the shrimp wastes (Ling *et al.*, 2010).

2.1.1.2.4 Chemical Oxygen Demand (COD)

COD is one of the important parameter in water quality monitoring. This parameter is similar to that of BOD. However, COD refers to the concentration of oxygen that is equivalent to organic matter in water which is susceptible to chemical oxidation. This measurement can be done by refluxing water sample with potassium dichromate solution as the oxidant, at 120°C for two hours (Jenkins, 2005). In naturally unpolluted conditions, COD is normally less than 20 mg/L (Jenkins *et al.*, 2005). Theoretically, if value of COD is higher, then, the higher the demand of oxygen for oxidation process, thus the lower the value of the DO of the water (Jenkins *et al.*, 2005).

2.1.1.2.5 Nutrients (Nitrogen)

Nitrogen is one of the major nutrients for all living organisms. Organic matter contains organic nitrogen which can be converted into various nitrogen products such as ammonium ion (NH_4^+), ammonia (NH_3) nitrite (NO_2^-) and nitrate (NO_3^-) during nitrification process (Horne & Goldman, 1994) (Figure 2.1). The first stage of decomposition process involves the breakdown of amino acids by bacteria which releases ammonia (NH_3) during the process. As the ammonia molecules build up, bacteria called *nitrosomonas* will convert ammonia (NH_3) to nitrite (NO_2^-) which will then be converted to the stable nitrate (NO_3^-) by the *nitrobacter*

bacteria. The entire process of decomposing organic matter until it becomes nitrate will take about 30 to 50 days (Solomons & Fryhle, 2013).

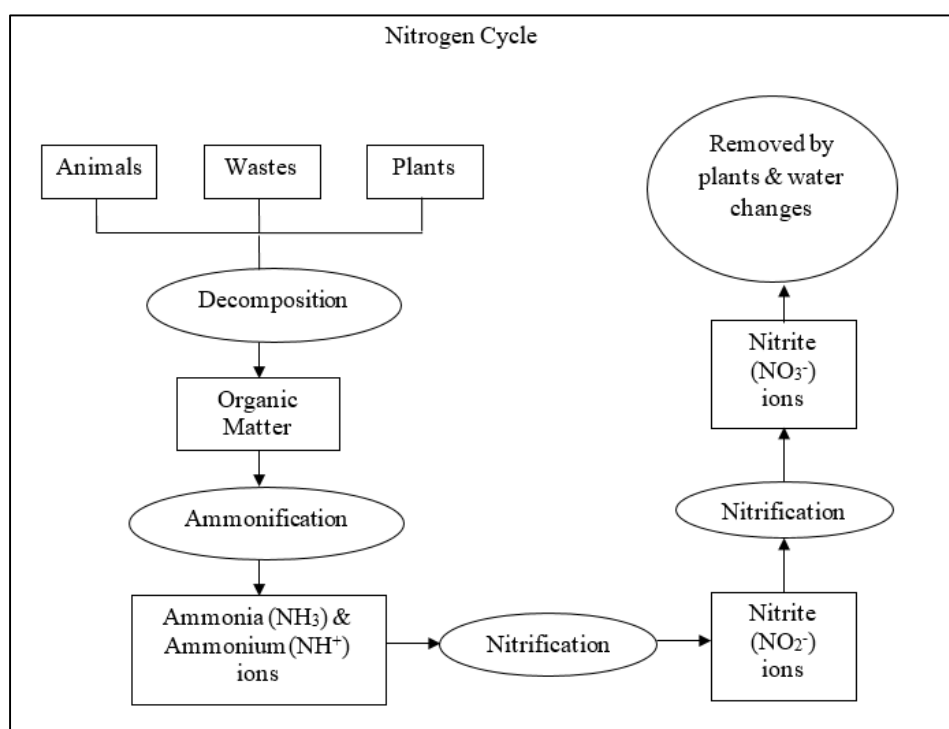


Figure 2.1: The Nitrogen Cycle in rivers (Solomons & Fryhle, 2013)

In the environment, inorganic nitrogen exists in its oxidation state as nitrate (NO_3^-), nitrite (NO_2^-) and ammonium ion (NH_4^+) (Solomons & Fryhle, 2013). The normal concentration of NH_3N in natural water is less than 0.3 mg/L and high concentration of ammonia is toxic to aquatic life (Jenkins *et al.*, 2005). According to Chapman (1996), European Union and Russia set the maximum allowable concentration of ammonia ranging from 0.5 to 2.0 mg/L for drinking purposes, and 0.004 to 1.0 mg/L respectively for aquatic life. Based on Pierzynski *et al.* (1994), USEPA has established a maximum contaminant level of 10 mg N/L (45 mg NO_3^- /L) in order to protect the safety of United States drinking water supplies whereas the health advisory for livestock was approximately 40 mg N/L (180 mg NO_3^- /L). Furthermore, for

drinking water, it should not contain higher than 50 mg NO₃/L according to the World Health Organization (WHO).

Report by Department of Environment (DOE) in 2013 revealed that the main sources of NH₃N in Malaysia were found to be from livestock farming and domestic waste (DOE, 2014). In natural environment, the sources of ammonia (NH₃) are from vegetative debris and animal waste (DOE, 2014). But when anthropogenic influences are present, the source of NH₃N are from food and kitchen wastes, untreated sewage discharge and animal waste discharge from animal farms (DOE, 2014). At the Huangpu River, Yangpu site have the lowest NO₃N values due to the low DO values because nitrification process needs the presence of nitrogen and oxygen in the water body (Yang *et al.*, 2007).

The study of nutrients such as nitrate (NO₃⁻) can help us to detect the release of fertilisers from agriculture fields and estimate the potential of eutrophication in a water body (Jenkins *et al.*, 2005). A rapid development of algae and other vegetation, depletion of DO, increased turbidity and a degradation of water quality are indications of a rise in the nutrient status of the water (Pierzynski *et al.*, 1994).

2.1.2 Standards for water quality in Malaysia

In Malaysia, there are two primary methods or standards that have been used extensively to classify the monitored water quality. They include the Water Quality Index (WQI) and National Water Quality Standards (NWQS). The NWQS refers to the set of standards obtained based on beneficial uses of water whereas the WQI is an indexing system used to simplify the wide amount of parameter in NWQS (DOE, 2014).

Based on NWQS, the water quality for within the range of particular designated classes is considered to be suitable for specific use (DOE, 2014). For example, Class I–III of NWQS stated that the water quality level is important to maintain the macro aquatic life, with varying level of sensitivity. Fish was used as a pointer because of its economic value. Similarly, for water supply, designated Class II can be treated using conventional treatment system whereas for Class III more advanced treatment system are required for water source (DOE, 2014). Also, the water source can still be utilised as irrigation for Class IV and below while Class V are considered to have minimal beneficial usage (DOE, 2014).

On the other hand, there are a total of six parameters chosen for the computation of WQI which are dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total ammoniacal nitrogen (TAN) and pH (DOE, 2014). However, the calculation was not performed on the parameters themselves but on their sub-indices namely SIDO, SIBOD, SICOD, SIAN, SISS and SIpH.

2.1.3 Status of rivers in Malaysia

Water quality in the river can be influenced by natural conditions such as point and non-point source and the conditions of flow (Mamum & Zainudin, 2013). Point sources include manufacturing, domestic sewage discharge, agro-based industries, factories effluent and animal farms while non-point sources refer to diffused sources, for example surface runoff and agricultural activities due to soil erosion.

In Malaysia, the high amount of rainfall received every year makes rivers abundant. Among them, a total of 473 rivers all over Malaysia were monitored by the Department of Environment (DOE) in year of 2013. Statistics published by the Department of Environment (DOE, 2014) for the year 2013 reveals that 58.1% out of 473 rivers monitored were asserted to be clean, 36.6% were slightly polluted and another 5.3% were found to be polluted. Meanwhile, 25 of the monitored stations are considered polluted rivers where a total of 11 rivers were classified under Class III and 14 rivers as Class IV (DOE, 2014). In addition, the studies indicate that major pollutants were identified as biochemical oxygen demand (BOD), suspended solids (SS) and ammoniacal nitrogen (NH₃-N).

2.1.4 Impact of domestic and household wastewater

Domestic and household wastes are common source of river pollution. Wastewater from the residential areas nearby the river can easily pollute it (Ling *et al.*, 2012; Ling *et al.*, 2016). This is due to improper wastewater management where wastewater from the residential areas is directly discharged into the river without proper treatment. Wastewater from the residential areas can also contribute oil and grease from cooking and washing to the river system. A study done at the Santubong River by Ling *et al.* (2010), which shows that the highest BOD₅ (9.3 mg/L), TSS (134.9 mg/L) and NO₃⁻ N (0.51 mg/L) values near the residential site was attributed to the overflow from septic tank. Also, Ling *et al.* (2009) reported that grey water from a residential area in Kuching City have high BOD₅, COD and nutrients but low in DO before it undergoes biofilters treatment. These indicate that wastewater from the residential areas will affect water and sediment the quality of a river.

In addition, people who live along the river catchments commonly dispose of their domestic waste as well as discharge human excreta into the river. This is further supported by a study of Ling *et al.* (2012), where the individual septic tank is the common form of sewage system in the residential areas in Malaysia and the septic tank effluent was directly discharged into the rivers nearby. The household wastewater from the residential area upstream of the river can cause pollution to the river. There are some longhouses upstream of the river and the wastewater can be classified into black water which consists of urine and feces and grey water which is from the kitchen and bathroom. The discharge of the wastewater may produce high biochemical demand oxygen, high nutrient input, high suspended solids, ecosystem disturbance and health hazard which also increases as the population increases (Ling *et al.*, 2012). Also, more inputs of nutrients into the river lead to more microorganisms needed to decompose the wastes. As the amount of microorganisms increase in the river, the BOD value will tend to increase too (Yang *et al.*, 2007). Besides, high concentration of nutrients will also lead to algal blooms which can release toxic substances into the river water.

2.1.5 Impact of logging and plantation activities

Along Rajang River, the potential source of pollution is the logging activities that. There are a few logging camps at the riverside and those logging activities can affect the water quality. During rainfall events, debris from logging activities can be transported into the river through runoff. This changes the river water especially during rainy season when the river becomes more turbid. The impact from logging was reported by Lau (2011) where at Durin area in Rajang River at some point the TSS value exceeded 1000 mg/L due to the changes of land use at Balui catchment area mainly through logging activities. Other than that, the runoff from the

plantation area plus the use of fertilizers during the plantation can lead to high nutrients level in the river (Eisakhani & Malakahmad, 2009).

2.1.6 The Rajang River

Rajang River or called Batang Rajang by the locals is well known as the longest river in Malaysia. It is located at the northwest of Borneo in state of Sarawak and flows approximately 563 km passing towns of Belaga, Kapit, Song, Durin and Sibu to the South China Sea. The uppermost part of the Rajang River upstream of Kapit includes four well-known of Murum, Bakun, Belaga and Pelagus.

Previous study conducted by Lau (2011) from Belaga to Sibu recorded the value of turbidity consistently above 260 NTU and TSS measurements staying between 583 and 763 mg/L during rainy season. Meanwhile, the DO values at the same area shows lower concentrations of between 5.4 and 5.9 mg/L due to slower rapids. Nevertheless, the DO is still considered in good condition and ideal for aquatic organism (Lau, 2011). Furthermore, Rajang River was classified under Class III during July to November 1994 (Lau, 2011).

According to the Malaysia Environmental Quality Report (DOE, 2014), the monitoring stations which are located in Rajang River are Daro River, Jemoreng River, Pakan River and Pila Parit River. Studies at Daro River, Jemoreng River, Pakan River and Pila Parit River recorded WQI of Class III, III, II and III respectively. However, among these stations monitored, none was near to the Pelagus area or closer to the Bakun Hydroelectric Dam.

2.1.7 Dams on Rajang River

The construction of a renewable power source such as hydroelectric dams bring a lot of benefits to human but also have a negative impact on the environment. They might happen at downstream, upstream and reservoirs (Beck *et al.*, 2012). Obviously, the dam wall acts as a significant barrier by blocking the downstream flow of nutrients and sediment (Lessard & Hayes, 2003). Furthermore, temperature, dissolved oxygen and flow rates both within the reservoirs and its outflows which is altered by the construction of dam may negatively impact the aquatic organism (Lessard & Hayes, 2003).

Sarawak owns the largest hydropower projects in Malaysia with a total of three fully functional hydroelectric dams known as Batang Ai Hydroelectric Dam, Bakun Hydroelectric Dam, and Murum Hydroelectric Dam. Two of those operational hydroelectric dams are located upstream of Rajang River namely the Murum Hydroelectric Dam and Bakun Hydroelectric Dam. The Murum Hydroelectric Dam was located on Murum River, a tributary at the uppermost part of Rajang River whereas the Bakun Hydroelectric Dam downstream of Murum Dam is located on the Balui River, another tributary of Rajang River. Among them, Bakun Hydroelectric Dam is created earlier where the construction began in the year of 1996 and was fully functional in the year 2011. Murum Hydroelectric Dam construction begun in the year 2008 and started operation in the year 2014.

During the construction of Murum Hydroelectric Dam, a study related to water quality assessments was conducted by Nyanti *et al.* (2015) in Bakun Hydroelectric Dam. It was reported that over time, there was some improvement of water quality for stations in the

Bakun reservoir compared to previous study in term of pH and DO but turbidity was still high in deeper regions. In addition, the DO recorded at 0.5 m depth ranged from 6.25 to 7.02 mg/L and pH between 7.37 and 7.73 but, extremely high turbidity was recorded at Murum River and its downstream area which was attributed to the construction of the Murum Hydroelectric Dam, making it unsuitable for sensitive aquatic organisms (Nyanti *et al.*, 2015).

Water quality of a river downstream of a hydroelectric dam can be affected by the operation and structural design of the hydroelectric dam (Ling *et al.*, 2016). A study conducted at Balui River downstream of Bakun Hydroelectric Dam reveals that the dam plays an important role in regulating the rivers downstream of it (Ling *et al.*, 2016). It was reported that DO level was found less than 5 mg/L in the river below the dam (Ling *et al.*, 2016). In addition, five-day biochemical oxygen demand (BOD₅) deteriorated after the water from the Bakun Hydroelectric Dam was discharged into the river. Ling *et al.* (2016) also concluded that the water quality impact was seen up to a distance of 32 km, the whole stretch studied and the water discharge changed the water quality significantly.

2.1.8 Rainfall Data

Figure 2.2 shows the record of total monthly rainfall amount according to the months of the samplings for the upstream and midstream sections at the Pelagus Area. The highest total monthly rainfall amount, 574 mm was recorded in January 2015 which was also during the sampling conducted at upstream section (Punan Bah) where station 1 to station 9 were located. Meanwhile, the monthly rainfall amount of 331 mm was recorded during the month of the sampling conducted at the midstream section (Peraran Area).

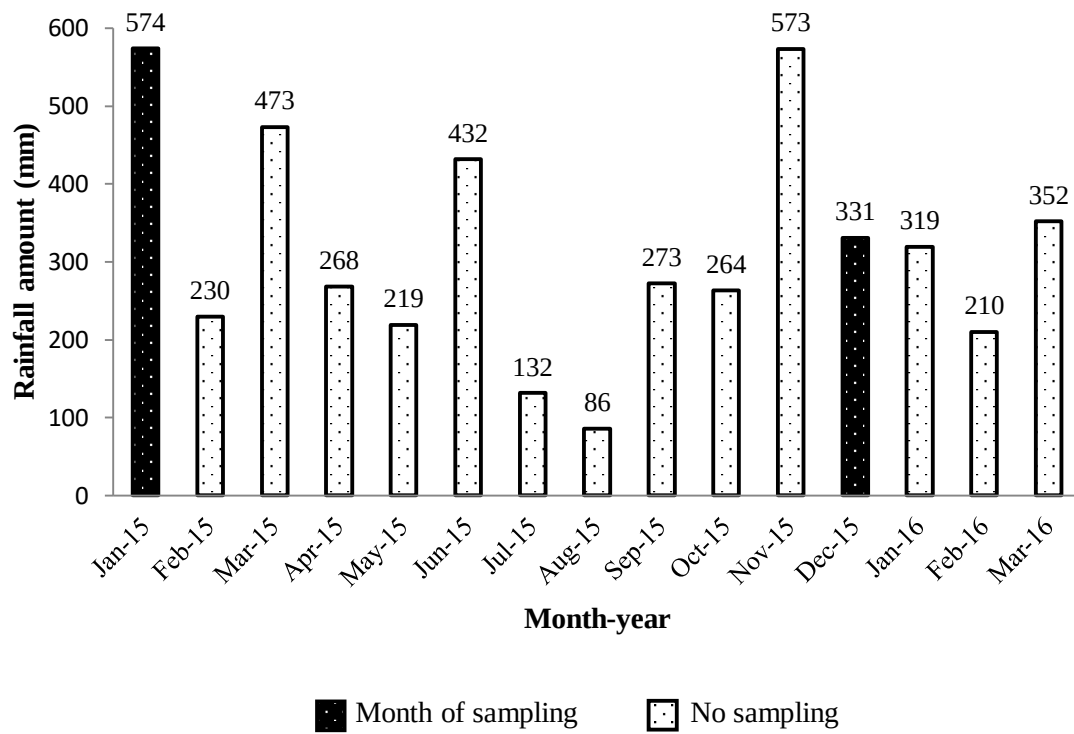


Figure 2.2: The monthly total rainfall at Kapit Town of Rajang River for upstream and midstream sections

Figure 2.3 shows the record of total monthly rainfall amount according to the month of the sampling conducted at the downstream section of the study area. The samplings for the downstream section were conducted in the month of July 2015, January 2016 and March 2016. Among them, the lowest total rainfall amount was recorded in July 2015 (132 mm) followed by January 2016 (319 mm) and the highest was recorded in March 2016 (352 mm).

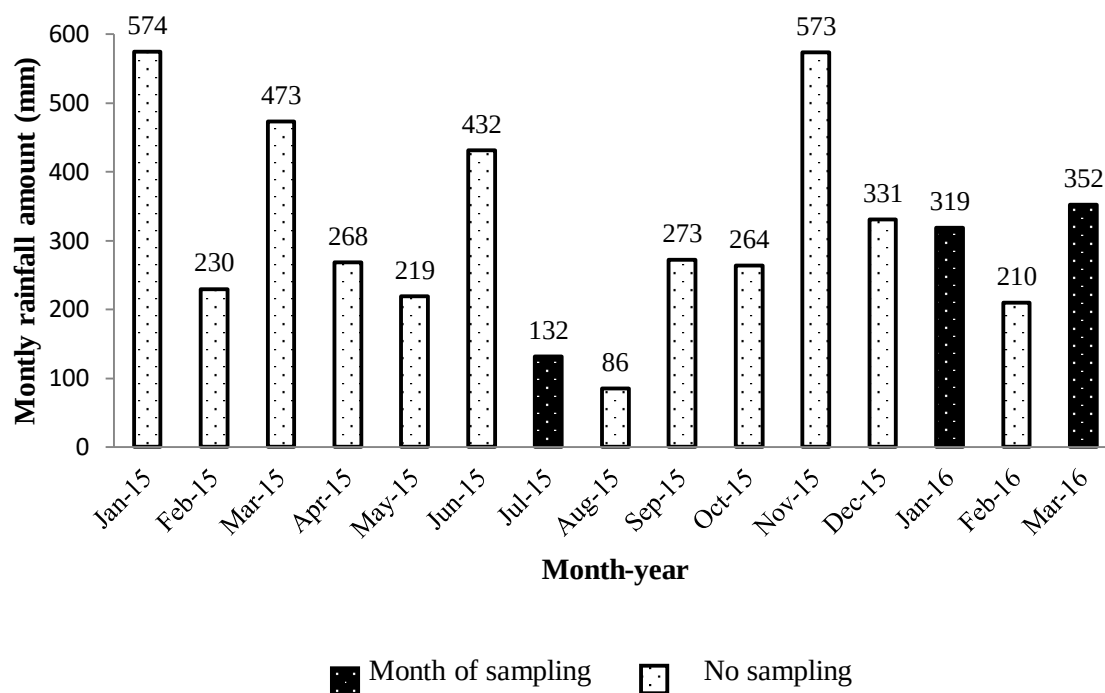


Figure 2.1: Monthly total rainfall at Kapit Town of Rajang River at the downstream section

Table 2.1 shows the total daily rainfall amount at the time of sampling. For the upstream section, the total amount of rainfall recorded on the days of samplings were 1.8 mm and 87.4 mm for the 14th and 15th of January 2015, respectively. For the midstream section, the total amount of rainfall recorded on the days of samplings were 4.4 mm and 5.8 mm on the 9th and 10th of December 2015, respectively. In July 2015, the total daily rainfall amount on the days of sampling conducted were 2.8 mm and 13.4 mm on the 8th and 9th respectively. In January 2016, the total daily rainfall amount on the day sampling was conducted, which was on the 22nd January 2016, was 51.6 mm. In March 2016, the total daily rainfall amount on the 19th March 2016 was 15.2 mm.

Table 2.1: The daily total rainfall amount (mm) during the month when sampling was conducted at upstream and midstream sections

Date	Upstream section	Midstream section	Downstream section		
	January-15	December-15	July-15	January-16	March-16
	4.6	8.6	0.0	45.8	33.8
1	0.2	0.0	0.0	2.2	6.2
2	1.2	0.0	0.0	13.6	47.6
3	0.0	0.0	0.0	0.0	17.0
4	19.0	0.0	0.0	8.6	11.0
5	36.0	0.0	0.0	6.6	0.2
6	34.0	0.0	0.0	0.8	0.0
7	16.4	25.4	2.8	1.8	0.0
8	18.4	4.4	13.4	0.6	20.6
9	33.2	5.8	15.6	1.8	98.0
10	14.0	9.4	0.0	0.2	0.0
11	0.6	0.0	0.0	0.0	38.0
12	4.6	24.4	0.0	46.0	12.8
13	1.8	52.6	3.6	0.0	T
14	87.4	9.2	0.0	24.8	6.0
15	39.8	18.4	0.0	0.8	2.8
16	21.4	34.4	14.4	9.6	1.4
17	115.0	3.6	0.2	4.4	2.8
18	16.0	0.0	0.0	16.0	15.2
19	0.2	16.2	23.4	0.9	0.0
20	21.1	0.0	0.0	51.6	0.2
21	2.0	0.0	1.6	2.6	7.0
22	0.0	0.6	1.4	0.0	1.4
23	11.4	24.0	0.0	18.2	0.4
24	9.2	17.0	0.4	34.6	16.6
25	7.2	0.0	3.4	0.0	0.0
26	0.0	0.0	9.0	15.0	0.0
27	54.8	39.2	23.6	8.2	2.2
28	0.6	17.2	0.0	0.6	9.8
29	1.6	19.8	16.0	0.8	0.8
30	2.6	0.6	2.8	3.0	0.0
31	574.3	330.8	131.6	319.1	351.8
Total monthly rainfall	28	19	15	26	23

* Bold indicated the rainfall amount when sampling was conducted.

2.2 Sediment Characteristics

Sediment is defined as the solid particles that had settled at the bottom of a river (Boyd, 1995). The solid particles consist of rock, sand, silt, clay, finely divided organic matter, and remains of plants and animals (Boyd, 1995). Sediment is a primary site for the decomposition process of organic matter in a river and it is mostly carried out by bacteria (Ezekiel *et al.*, 2011). Besides, sediments are important natural sinks in which many pollutants are removed from the water system (Bai & Reji, 2015). The occurrence and abundance of species distribution of aquatic life could be influenced by the physio-chemical parameters of the sediments such as pH, dissolved oxygen, conductivity, salinity, organic carbon and percentage solids (Ezekiel *et al.*, 2011). Therefore, it is important to conduct sediment study to know the status of the river sediments.

2.2.1 Parameters of sediment characteristics

The sediment characteristic parameters include pH, particle size analysis (PSA), total organic carbon (TOC), organic matter (OM), total phosphorus (TP) and total Kjeldhal nitrogen (TKN).

2.2.1.1 pH

pH or hydrogen ion activity of sediment is an important parameter in evaluating the sediment acidity. This is because pH has a strong effect on the availability and solubility of nutrient elements by controlling the activity of micro-organisms (Boyd, 1995). The value obtained for deionised water is considered closer to the true pH value in the nature (Tan, 2010). The lowest mean of pH value was found is due to lots of dead tree debris around the station that

contributes to the decomposing process thus lower pH of the sediment (Moore & Leoppert, 1987).

2.2.1.2 Particle Size Analysis

Particle size analysis (PSA) is important in sediment analysis because it is the most fundamental physical property of sediment. PSA is a method used to measure the size distribution of particles in a soil sample and to evaluate the soil texture (Gee & Bauder, 1986). The particle size of sediment can be divided into three main categories, namely, sand, silt and clay. According to Esu (1999), the soil texture mainly refers to the proportion of silt, sand and clay that is unable to pass through 2000 μm in diameter in a mass of soil. Among them, sand is mostly coarse and gritty whereas silt is smooth like flour and clay is sticky and plastic when wet (Esu, 1999).

The flow of water in the river system can influence the sediment particle size distributions (Rosli & Yahya, 2013). The capacity of soil in nutrient's holding ability, water retention and runoff potential are affected by the soil texture (Ling *et al.*, 2011). Therefore, soil that is rich with nutrients or organic matter has strong chemical bonds with the soil (Toriman *et al.*, 2009).

2.2.1.3 Total Organic Carbon and Organic matter

Other important parameters in sediment evaluation are sediment organic matter (OM) and total organic carbon (TOC). TOC and OM are related to each other. They refer to the amount of organic matter preserved in the sediment that originate from the remains of organisms such as plants and animals and their waste products varying from household wastes and decaying

leaves to decomposed, rotten manure in the environment (Tan, 2010; Pierzynski *et al.*, 1994). OM is the loss of weight of sediment from heating and burning is the measurement for the organic fraction. Meanwhile, total organic carbon (TOC) is another parameter to quantify organic matter of sediment, the ratio between TOC and OM is approximately 2.5 (Pierzynski *et al.*, 1994). According to Avramidis *et al.* (2015), the sediments and soil organic carbon and matter are primarily made up of the decomposition of the plankton or plants, animal and anthropogenic sources such as fertilizers or organic rich waste and chemical contaminants. TOC may also be deduced indirectly from the organic matter (OM) content determined by ignition loss, applying a suitable factor of transformation. A high content of organic matter originating from faeces, excessive nutrients and plankton die-offs will accumulate and form a high load of organic matter that is normally found at the bottom of the river (Matias *et al.*, 2002). According to a study conducted by Zhao & Cheng (2011), significantly higher concentrations of total organic matter in a sewage area suggested that there is more serious organic pollution in the sewage related area sediment.

2.2.1.4 Nutrients

Nutrients exist in river's sediment. Nitrogen in sediment is mainly derived from the decomposition of the plant and animal or plankton or anthropogenic sources such as fertilizers, chemical contaminants or organic rich waste (Avramidis *et al.*, 2015.). Nutrient pollution of sediment come from point sources such as industrial effluent and wastewater treatment plants and nonpoint sources such as agricultural fields, urban runoff and septic systems. One of the nonpoint source of nutrient pollution in sediment is the inclusion of fertilizers and animal manure, which are both rich in nitrogen and phosphorus which are necessary for plant growth (Pulatsú *et al.*, 2003; Pavanelli & Selli, 2013; Wang *et al.*, 2015).

The use of fertiliser in agriculture and plantation in the river basin could cause the nutrient pollutions in the river's sediment through runoff. The nutrients could be introduced into the river by the soil runoff brought by wind and rainwater. According to a study conducted by House & Denison (2002), the concentration of phosphorus in the sediment at the Thames catchment the River Swale in Yorkshire increased from 19 $\mu\text{mol/g}$ at the upstream sites to 131 $\mu\text{mol/g}$ at downstream of the sewage inflow. This indicates phosphorus is accumulated in sediments downstream of sewage outfalls.

2.2.2 Standards for sediment

Standards for sediment are very useful tools to screen sediment contamination by comparing the concentration of sediment contaminants with the sediment quality guidelines. Over the years, there have been many sediment quality guidelines developed to monitor the sediment. Among them, the guide used in this study is the Guideline for the Protection and Management of Aquatic Sediment Quality in Ontario (Persaud *et al.*, 1993).

2.2.3 Sources of sediment pollution

The pollution of sediment in a river may come from a variety of sources. One of the main sources of sediment pollution is caused by the release of pollutants into the sediment which is a result of human activities. This process may be intentional such as landfills, chemical contamination through the excessive use of pesticides and fertilisers, and unintentional such as spills or leaks or spray irrigation of sewage (Pierzynski *et al.*, 1994; Mirsal, 2004).

Erosion refers to the transportation and removal of soil or rock (Tan, 2010). The loose soil from the surface of land can be carried to the river by environmental factors such as wind and rain water. According to David *et al.* (1981), nearby stream and rivers can be affected by a large amount of sediment that are introduced by land activities into the water body. Land activities such as logging and agriculture can cause soil erosion easily due to land clearing which results in easy erosion of the soil into water streams by environmental factors.

Most of Sarawak forests have been subjected to logging and timber extraction as timber have been a major contributor to the Malaysian economy (Ling *et al.*, 2016). Logging activities in forest can cause disturbance to the original soil surfaces (Lee *et al.*, 2004). High intensities of logging roads and skid trails drastically change the original soil surface of the forest floor (Lee *et al.*, 2004). This condition worsens if it is followed by soil erosion. Soil erosion may happen when the rate of loss of soil by wind or water exceeds the rate of soil formation (Mirsal, 2004). In areas with extensive land use, the extend of soil erosion is amplified when some land use activities such as large scale plantation, logging and deforestation, which remove the ground covers thus exposing the soil (David *et al.*, 1981). In addition, Satrio *et al.* (2009) observed a great amount of soil carbon storage is reduced resulting from the logging operation in a tropical peat swamp forest in Batang Igan, Sibuluan. This also indicated that the loose soil is lost through runoff and could end up in rivers nearby.

The natural rain and wind then will carry the loose soil particles namely sand, silt and clay into the nearby river during surface runoff. This is supported by a study by Diab *et al.* (2014), where it was reported that the physicochemical properties of sediments showed seasonal variation. Besides, the rain and wind could also cause the accumulation of sediment, wood

and detritus (leaves and small branches) in the river nearby (Gomi *et al.*, 2006) which is not good for river health.

Ismail & Ibrahim (2015) mentioned that land conversion into agricultural land also has been reported the main cause of an increase in nutrient loads in many rivers causing the environmental contaminations. Other than that, transports activities near and along the rivers constitute as one of the main sources of water pollution through the petrol spills and the emissions from the internal combustion engines which include the oxide of nitrogen, sulphur and carbon (Mirsal, 2004).

Other factors that also can affect the river sediment are environmental factor such as flood which could reshape the river and bring the sediment from river banks into the river (Mah *et al.*, 2013). Such events generate large sources of sediment to river systems. Other than that, the flow of the river also can affect the sediment distribution in the river water body. According to Toriman *et al.* (2009), pollutant loading and sediment deposition are dependent on the amount of river discharge and the speed of the water flow where; high flow causes them to be well mixed and during slow flow the sediment settled and accumulated at the bottom of the river. Based on Pierzynski *et al.* (1994), most soils are capable of absorbing and neutralizing many pollutants to harmless levels through chemical and biochemical process. However, there are limits to the soil being able to absorb the wastes without any negative effects. Thus, the sediment pollution needs to be controlled.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study Area

The present study was located at the Rajang River at the Pelagus area. A total of 30 stations were studied. Among them, a total of 13 stations were located at Rajang River, the main river, whereas 17 stations were located at selected tributaries. In this study, the focus of the study area was at the Rajang River of the Pelagus area as that is the location of the proposed hydroelectric dam. The study area was divided into three sections. They are upstream, midstream and downstream. They were sampled during three different periods due to the limitation of distance travelled by using small longboats, logistics and accessibility of the area. Upstream, also called, Punan Ba consisted of stations 1 to 9, midstream, namely, Peraran consisted of stations 10 to 19 and downstream, namely, Nanga Benin consisted of stations 20 to 30.

The location of each sampling station is shown in Figure 3.1. Meanwhile the GPS locations, coordinates and descriptions of each station are tabulated in Table 3.1. The date, time and observation recorded at each station along the Rajang River and its tributaries for upstream and midstream sections are shown in Table 3.2. Table 3.3 shows the date, time and observation recorded at each station along the Rajang River and its tributaries for downstream sections at three different sampling months.

Table 3.4 shows the discharge from Bakun Hydroelectric Dam during the sampling dates. The volume of water discharges from the turbine and spillway of Bakun Dam were varied during each sampling. The turbine was releasing water during all the sampling but the spillway opened occasionally. There was no water discharge from the spillway during the sampling in January 2015 (station 1 to 9) and in January 2016 (station 20 to 30).

Table 3.5 shows the stations located at Rajang River and the distance from upstream to downstream. The most upstream station (station 1) was located approximately 135 km upstream of Kapit town and 85 km downstream Bakun Hydroelectric dam. The upstream section covered approximately 48 km of the Rajang River length. Meanwhile, the midstream section covered approximately 42 km total river length. The most downstream station (station 30) was located 5 km upstream of Kapit town. The downstream section covered approximately 40 km of river length. The total length of river covered in this study was approximately 130 km along the Rajang River.

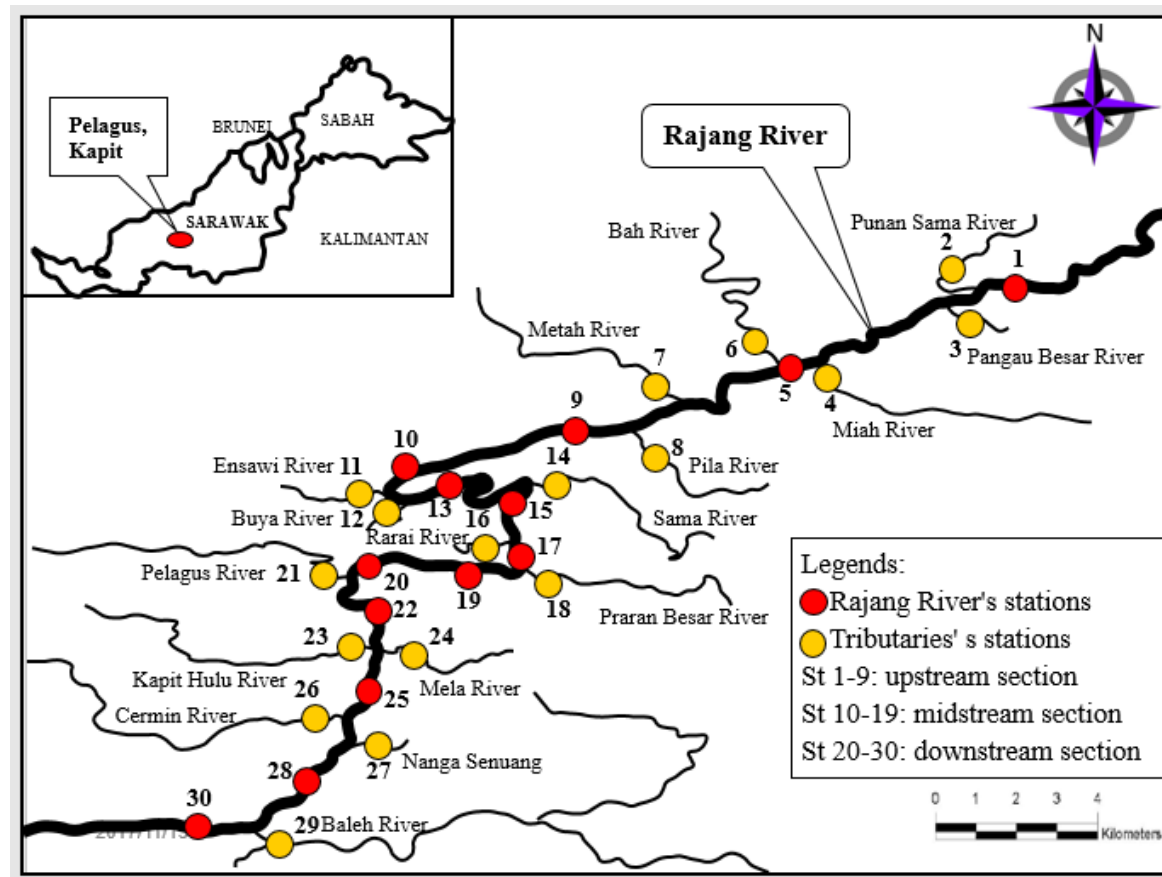


Figure 3.1: The location of the sampling stations at Pelagus area of the Rajang River

Table 3.1: GPS locations, coordinates and descriptions of each station along the Rajang River and its tributaries

Station	Name of River	GPS Location	Descriptions
Upstream (Punan Ba)			
1	Rajang	N 02°29'04.9" E 113°31'27.5"	Downstream of Punan Sama Village Presence of logging operation Presence of subsistence farming
2	Punan Sama	N 02°28'10.8" E 113°30'13.0"	Presence of logging activities and replantation Active logging operation Presence of early stage of palm oil plantation
3	Pengau Besar	N 02°29'11.6" E 113°31'22.9"	Presence of logging activities and replantation
4	Miah	N 02°23'29.8" E 113°21'49.2"	Presence of logging activities and replantation
5	Rajang	N 02°22'59.3" E 113°20'54.5"	In front of Punan Bah village Presence of longhouses and residential area Presence of small agriculture
6	Bah	N 02°23'05.6" E 113°20'42.1"	Presence of longhouses and residential area Presence of small agriculture Presence of logging activities
7	Metah	N 02°20'42.7" E 113°16'38.9"	Presence of longhouses Presence of small agriculture Presence of logging activities
8	Pila	N 02°19'08.9" E 113°13'39.3"	Presence of longhouses and residential area Presence of small agriculture Presence of logging activities
9	Rajang	N 02°18'55.4" E 113°11'12.9"	Presence of longhouses Presence of small agriculture Presence floating houses
Midstream (Peraran)			
10	Rajang	N 02°15'25.1" E 113°05'50.2"	Upstream of Ensawi River Presence of longhouses
11	Ensawi	N 01°34'05.6" E 114°21'14.3"	Old secondary forest
12	Buya	N 02°15'03.2" E 113°07'46.9"	Old secondary forest with canopy cover
13	Rajang	N 02°15'10.9" E 113°08'08.9"	Downstream of Buya River (2 km) Presence of longhouses
14	Sama	N 02°15'54.3" E 113°09'39.9"	Presence of longhouse Old secondary forest
15	Rajang	N 02°15'13.0" E 113°09'26.2"	Presence of longhouses
16	Rarai	N 02°13'13.2" E 113°18'59.3"	Old secondary forest with canopy cover
17	Rajang	N 02°12'43.1" E 113°09'22.8"	In front of Rh Jengoh Presence of longhouses
18	Peraran Besai	N 02°11'23.8" E 113°07'40.8"	Old secondary forest with canopy cover
19	Rajang	N 02°11'41.2" E 113°06'32.9"	Downstream of Sebingol River (above rapids) Presence of longhouses
Downstream (Nanga Benin)			
20	Rajang	N02°10'57.2" E113°03'25.0"	Downstream of rapids Presence of longhouses
21	Pelagus	N02°10'38.1" E113°03'12.6"	Presence of longhouses Active logging operation

Table 3.1 continued

22	Rajang	N02°08'51.4" E113°04'43.8"	Near to rock formation Presence of longhouses
23	Kapit Hulu	N02°08'33.2" E113°04'27.4"	Next to Rh Melintang Presence of longhouses
24	Mela	N02°07'52.9" E113°04'43.5"	Next to Rh Jengin longhouse Presence of longhouses
25	Rajang	N02°04'59.0" E113°03'56.5"	Upstream of SK Encheremin Presence of longhouses
26	Cermin	N02°04'51.6" E113°03'50.8"	Next to SK Encheremin Presence of longhouses
27	Nanga Senuang	N02°03'14.8" E113°03'39.2"	Downstream of Sg Anya Old secondary forest
28	Rajang	N02°03'08.3" E113°03'12.3"	Upstream of SK Encheremin Presence of longhouses
29	Baleh	N02°00'56.2" E113°01'26.9"	Downstream of SK Bakun and longhouses Presence of logging activities and replantation Active logging operation Presence of heavy erosion on riverbanks
30	Rajang	N02°01'03.8" E113°00'24.1"	Visible (1 km) logging camp Presence of arang batu (400m) Presence of residential longhouses

Table 3.2: Date, time and observation recorded at each station along the Rajang River and its tributaries for upstream and midstream sections

St	Date & Time of Sampling	Observations at the time of sampling
Upstream (Punan Ba)		
1	15 th Jan 15 1106	Hot and sunny but cloudy upstream, muddy water, rained the night before sampling (1.8 mm).
2	15 th Jan 15 1008	Sunny, rained the night before sampling (1.8 mm).
3	15 th Jan15 1042	Sunny, rained the night before sampling (1.8 mm).
4	15 th Jan 15 1145	Hot and sunny, rained the night before sampling (1.8 mm).
5	15 th Jan 15 1422	Hot and sunny, muddy water, rained the night before sampling (1.8 mm).
6	15 th Jan 15 1324	Hot but cloudy, muddy water, rained the night before sampling (1.8 mm).
7	14 th Jan 15 1332	Hot and sunny, muddy water, rained the night before sampling (4.6 mm).
8	14 th Jan 15 1135	Hot and sunny, rained the night before sampling (4.6 mm).
9	14 th Jan 15 1056	Hot and sunny, muddy water, rained the night before sampling (4.6 mm).
Midstream (Peraran)		
10	09 th Dec15 1525	Hot and sunny, muddy water, no rain for a week but rained the night before sampling (25.4 mm).
11	09 th Dec 15 1458	Hot and sunny, no rain for a week but rained the night before sampling (25.4 mm).
12	09 th Dec 15 1614	Hot and sunny, no rain for a week but rained the night before sampling (25.4 mm).
13	09 th Dec 15 1642	Hot and sunny, muddy water, no rain for a week but rained the night before sampling (25.4 mm).
14	09 th Dec 15 1710	Hot and sunny, no rain for a week but rained the night before sampling (25.4 mm).
15	09 th Dec 15 1730	Sunny, muddy water, no rain for a week but rained the night before sampling (25.4 mm).
16	10 th Dec 15 1315	Hot and sunny, rained the night before sampling (4.4 mm).
17	10 th Dec 15 1340	Hot and sunny, muddy water, rained the night before sampling (4.4 mm).
18	10 th Dec 15 1412	Hot and sunny, rained the night before sampling (4.4 mm).
19	10 th Dec 15 1732	Hot and sunny, muddy water, rained the night before sampling (4.4 mm).

Table 3.3: Date, time and observation recorded at each station along the Rajang River and its tributaries for downstream sections at three different sampling months

St	Trip A (Jul 15)		Trip B (Jan 16)		Trip C (Mar 16)	
	Date & Time	Observations	Date & Time	Observations	Date & Time	Observations
20	08 th Jul 15 1350	Hot and sunny, muddy water, no rain for more than a week, low water level.	21 st Jan 16 0908	Hot and sunny, muddy water, no rain the night before sampling (0.9 mm).	19 th Mar 16 0905	Not hot and cloudy, muddy water, rained the night before sampling (2.8 mm), high water level.
21	08 th Jul 15 1420	Hot and sunny, no rain for more than a week, low water level.	21 st Jan 16 0959	Hot and sunny, no rain the night before sampling (0.9 mm).	19 th Mar 16 1002	Not hot and cloudy.
22	08 th Jul 15 1250	Hot and sunny, muddy water, no rain for more than a week, low water level.	21 st Jan 16 1103	Hot and sunny, muddy water, no rain the night before sampling (0.9 mm).	19 th Mar 16 1108	Not hot and cloudy, rained the night before sampling (2.8 mm), high water level.
23	09 th Jul 15 1435	Hot and sunny, rained the night before sampling (2.8 mm), low water level.	21 st Jan 16 1126	Hot and sunny, no rain the night before sampling (0.9 mm).	19 th Mar 16 1140	Not hot and cloudy, rained the night before sampling (2.8 mm).
24	09 th Jul 15 1405	Hot and sunny, rained the night before sampling (2.8 mm), low water level.	21 st Jan 16 1207	Hot and sunny, no rain the night before sampling (0.9 mm).	19 th Mar 16 1215	Not hot and cloudy, rained the night before sampling (2.8 mm)
25	09 th Jul 15 1140	Hot and sunny, muddy water, rained the night before sampling (2.8 mm), low water level.	21 st Jan 16 1320	Hot and sunny, muddy water, no rain the night before sampling (0.9 mm).	19 th Mar 16 1309	Not hot and sunny, muddy water, rained the night before sampling (2.8 mm), high water level
26	09 th Jul 15 1328	Hot and sunny, rained the night before sampling (2.8 mm), low water level.	21 st Jan 16 1341	Hot and sunny, no rain the night before sampling (0.9 mm).	19 th Mar 16 1330	Not hot and cloudy, rained the night before sampling (2.8 mm)
27	09 th Jul 15 1227	Hot and sunny, clear water, rained the night before sampling (2.8 mm), low water level, cannot enter further upstream.	21 st Jan 16 1427	Hot and sunny, no rain the night before sampling (0.9 mm).	19 th Mar 16 1400	Not hot and cloudy, rained the night before sampling (2.8 mm)
28	08 th Jul 15 1049	Hot and sunny, muddy water, no rain for more than a week, low water level.	21 st Jan 16 1505	Hot and sunny, muddy water, no rain the night before sampling (0.9 mm).	19 th Mar 16 1440	Hot and sunny, muddy water, rained the night before sampling (2.8 mm), high water level.
29	08 th Jul 15 0945	Hot and sunny, muddy water, no rain for more than a week, low water level.	21 st Jan 16 1532	Hot and sunny, muddy water, water flow fast and high level.	19 th Mar 16 1500	Hot and sunny, muddy water, rained the night before sampling (2.8 mm), high water level.
30	08 th Jul 15 0900	Hot and sunny, muddy water, no rain for more than a week, low water level.	21 st Jan 16 1552	Hot and sunny, muddy water, no rain the night before sampling (0.9 mm).	19 th Mar 16 1552	Not hot and cloudy, muddy water rained the night before sampling (2.8 mm), high water level.

Table 3.4: The discharge from Bakun Hydroelectric Dam during the sampling dates

Date of sampling	Volume of turbine outflow (m ³ /s)	Volume of spillway outflow (m ³ /s)	Total volume of outflow (m ³ /s)	Note
14 th Jan-15	679.0	0.0	679.0	Spillway closed
15 th Jan-15	695.8	0.0	695.8	Spillway closed
8 th Jul-15	353.9	614.0	967.9	Spillway opened
9 th Jul-15	361.5	614.0	975.5	Spillway opened
9 th Dec-15	679.5	2002.0	2681.5	Spillway opened
10 th Dec-15	651.5	2002.0	2653.5	Spillway opened
21 st Jan-16	970.0	0.0	970.0	Spillway closed
19 th Mar-16	733.9	2060.0	2793.9	Spillway opened

Table 3.5: Stations located at Rajang River and the distance from upstream to downstream

Monitored Rajang River Stations	Distance between station (km)	Distance from the most upstream station (km)	Distance from Bakun Hydroelectric dam (km)
1	0	0	85.0
5	27.3	27.3	112.3
9	20.5	47.8	132.8
10	14.5	62.4	147.4
13	12.3	74.7	159.7
15	5.4	80.1	165.1
17	4.3	84.4	169.4
19	5.3	89.6	174.6
20	11.2	100.9	185.9
22	6.0	107.0	192.0
25	6.6	113.5	198.5
28	6.2	119.7	204.7
30	10.3	130.0	215.0

3.2 Sampling plans

The sampling area in this study was divided into three sections; upstream, midstream and downstream and sampling at each section was conducted separately. The samplings were greatly influenced by the accessibility of study area and the availability and mode of the transportation. Furthermore, the downstream section and midstream section were separated by a rapid called Pelagus rapid which is not accessible during low water level. Data collection for upstream and midstream sections was conducted once whereas the data collection for the downstream section was conducted thrice. During sampling, a total of three replicates were taken for each analysis.

In the upstream and midstream sections, a total of 19 stations were studied. The upstream section was located at Punan Ba area with a total of 9 stations, followed by 10 stations at the midstream section at Peraran area. The data for water quality and sediment characteristics at upstream and midstream were collected separately at two different time periods which had similar weather conditions.

In the upstream, the sampling was conducted in January 2015 with 679.0 and 695.8 m³/s volume of discharge from the turbine of Bakun Hydroelectric Dam on the days when samples were taken (Table 3.4). In the midstream, the sampling was conducted in December 2015 with 679.5 and 651.5 m³/s volume of discharge from the turbine of Bakun Hydroelectric Dam on the days of sampling (Table 3.4). Additionally, the spillway was opened on both days of sampling with a volume of 2002.0 m³/s (Table 3.4). The monthly total rainfall amounts recorded during the upstream and midstream sections samplings were considered high which were 574 mm and 331 mm, respectively.

There were a total of 11 stations at the downstream section at Nanga Benin area. The water samplings in those stations at the downstream section of the study area were completed under three different discharge conditions.

The first sampling was done in July 2015 in low Bakun Dam discharge condition as shown in Table 3.4 and 132 mm of total monthly rainfall. In that sampling, the river was in relatively stable flow rate.

The second sampling was done in January 2016 during medium discharge of Bakun Dam as shown in Table 3.4 and 319 mm monthly total rainfall. In that sampling, the river was relatively unstable and rapidly increasing flow rates with visible surface runoff from the surrounding land.

The third was in March 2016 where there was the highest total monthly rainfall of 352 mm. The volume of turbine outflow, spillway outflow and total outflow during this sampling was the highest among the trips (Table 3.4). At that time, the level of water was reported to be high for weeks and heavy rains occurred occasionally. Also, higher flow rate was observed during the sampling.

3.3 Preparation before sampling

All the sampling bottles were soaked overnight in 10% of nitric acid (HNO_3) or 10% of hydrochloric acid (HCl). Then, the bottles were rinsed several times with tap water followed by distilled water before they were used for keeping the sample. The types of the sampling bottles were made of polyethylene (PE). Each sample was taken in the middle of the river and approximately 10 cm from the surface water. The bottles were rinsed with river water before taking the subsurface water as the sample. Biochemical oxygen demand (BOD) bottles were

rinsed several times with tap water and followed by distilled water. The filters were washed and dried for this analysis prior to use by rinsing the filter with demonized (DI) water three times and was placed in drying oven with a temperature of $110 \pm 5^{\circ}\text{C}$ for a minimum of one hour.

3.4 Rainfall data

The rainfall data was obtained from the Meteorology Department of Malaysia, Sarawak Branch. The data was obtained from the meteorological at the station at Kapit Airport (34 m above sea level) which is located near to the Kapit Town with latitude of 02 degree 0' N and longitude of 112 degree 55' E. Personal observations of weather and surrounding conditions were also recorded during the time of each sampling.

3.5 Hydrogeometric data

Hydrogeometric data were collected during field trips. They consisted of river's length, width, cross-sectional area and depth of the river system and hydraulic characteristics which included velocity and flow rate. The river was divided into a number of equal width intervals where the depth and water velocity were measured in every interval. The measurement of river width, depth and water velocity were carried out using a range finder, Hondex, PS-7 LCD Digital Sounder and flow meter respectively. The water velocity was measured at each depth intervals by using flow meters (Flowatch® Flowmeter and Geopacks Flowmeter). The field measurements data obtained were then used to determine cross sectional area. Then, the volume of water moving per unit time, also known as, flow rate or discharge was calculated.

All the data calculation was conducted using Microsoft® Office Excel® 2007. Meanwhile, the measurement of the monitored river length was carried out by estimation using Google Earth Version 6.1.

The river was divided into five to ten segments across the river depending on how wide the river was. In this approximation it was assumed that each segment is trapezoidal in shape and therefore the summation of those areas give the cross sectional area. Also, mean width and depth were determined to estimate the cross-sectional area of each particular segment. According to Chapra (1997), segment geometry can be represented as a trapezoid with constant dimensions and bottom slope as shown in Figure 3.2:

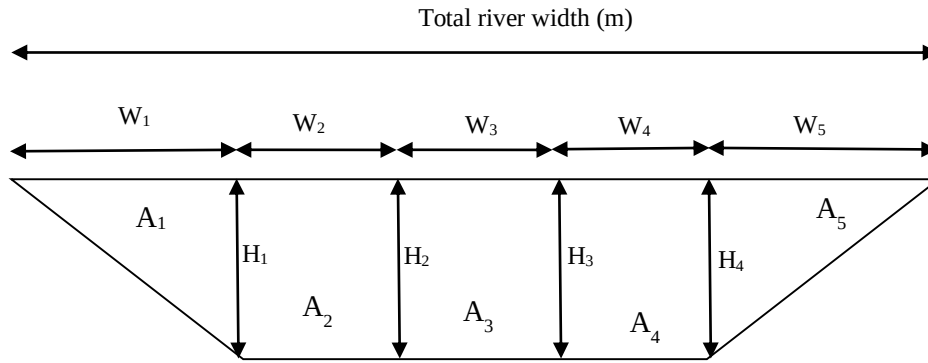


Figure 3.2: A cross section of a trapezoidal channel

The cross sectional area of position i (A_c) was calculated using equation [1]:

$$A_i = \frac{1}{2} (H_i + H_{i+1}) \times W$$

[1]

where,

A_c = Cross sectional area (m^2),

H_i = Left depth of the partition (m),

H_{i+1} = Right depth of the partition (m),

W_i = Width of the partition (m).

3.6 *In-situ* field measurement

In-situ measurements taken were temperature (°C), DO (mg/L), DO saturation (%), pH, specific conductivity ($\mu\text{S}/\text{cm}$), turbidity (NTU), and transparency (m). For the first trip, *in-situ* measurements of temperature and DO were performed by using a DO meter (YSI, Pro 20), specific conductivity was measured by using a conductivity meter (Cyberscan CON 11, EUTECH INSTRUMENTS), pH value was measured by using a pH meter (TI9000 WalkLab, Trans Instruments) and turbidity was measured by using a turbidity meter (TU 2016, Lutron).

YSI Multiparameter Sonde series 6920 V2-2 Water Quality Monitoring Unit was used to measure temperature (°C), DO (mg/L), DO saturation (%), pH, and specific conductivity ($\mu\text{S}/\text{cm}$), and turbidity (NTU) for all subsequent trips. A GPS Reader (GPS map 62s, Garmin) was used for the determination of coordinates of the sampling stations.

3.7 *Ex-situ* water collection and preservations

Ex-situ analysis water samples were taken and preserved for laboratory analysis. A total of three replicate water samples were collected from the subsurface of river water at each station using polyethylene bottles. Three polyethylene bottles of 1.2 L used for TSS. Meanwhile, a total of three replicate of 250 mL polyethylene bottles was used to kept sample for COD, TP,

Org-N and $\text{NH}_3\text{-N}$. Then, 2 mL of concentrated sulphuric acid (H_2SO_4) were added as a preservative to make the $\text{pH} < 2$. After collections, samples were placed right away to a cooler box at temperature 4°C or below before transferring to a refrigerator upon arriving at the laboratory.

For water analysis, three replicates were needed for each parameter and the sample was composited before being analyzed. Preservative was not added for the samples that were used for the analyses of $\text{NO}_3\text{-N}$, $\text{NO}_2\text{-N}$, TSS, and BOD. BOD bottles were wrapped with aluminium foil to prevent the exposure of the sunlight after measuring the initial DO. TSS was filtered immediately in the field. The water filtered were taken and used for the sample for $\text{NO}_3\text{-N}$ and $\text{NO}_2\text{-N}$.

3.8 *Ex-situ* water analysis

Ex-situ water analyses in this study were categorised into two sections which are physical, and chemical. The physical parameter is TSS, whereas chemical parameters are BOD, COD, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, $\text{NH}_3\text{-N}$ and Org-N. TSS, $\text{NH}_3\text{-N}$, Org-N, BOD and COD were analysed using Standard Methods according to Jenkins (2005). COD analysis was conducted by using closed reflux, titrimetric method; $\text{NO}_2\text{-N}$ analyzed by using Hach, the Method 8507 Diazotization Method, $\text{NO}_3\text{-N}$ analyzed by using Hach Method 8192, the Cadmium Reduction Method, $\text{NH}_3\text{-N}$ was analyzed by using preliminary distillation step followed by Nessler's method, Org-N analyzed by using macro-Kjeldahl method then followed by Nessler's method and TP analyzed by using $\text{H}_2\text{SO}_4\text{-HNO}_3$ digestion then followed by ascorbic acid method. In addition,

nutrients such as NO₂-N and NO₃-N were analysed directly in the field and concentrations were determined by using DR 900 (Hach, 2003).

3.8.7.1 Physical parameters

3.8.7.1.1 Total suspended solids (TSS)

The first step of determining total suspended solids was the preparation of the filter paper (Jenkins, 2005). A 47 mm diameter with 1.0 µm pore size of glass microfiber filter paper (Whatman®, GF/B) was rinsed with distilled water and was dried in an oven at 105°C. Then, it was cooled in desiccators and weighted using electronic balance (A&D Company, FX-300i). The filter paper was dried and weight and dry was repeated until a constant weight was obtained. The filter paper was then used during the filtration process.

One litre of water sample was mixed well, poured into the funnel and filtered by passing through the prepared glass microfiber filter paper (Whatman®, GF/B). The filtration set was connected to a vacuum pump (GAST, DOA-P504-BN). Then, the filter paper was removed and wrapped with an aluminium foil after the filtration process was completed. Then, the filter with sample residue was dried in an oven at 105 °C in a Memmert oven overnight, cooled in a desiccator to room temperature and weighted with an electronic balance. To obtain a constant weight of the filter paper, the drying, cooling, desiccating, and weighing cycle was repeated. Lastly, the constant weight of the filter paper and residue was recorded.

Equation [2] was used in the calculation of total suspended solids:

$$\text{TSS} = \frac{(A - B)}{V}$$

[2]

where,

TSS = Total suspended solids (mg/L)

A = weight of filter paper + dried residue (mg)

B = weight of filter paper (mg)

V= Filtered sample volume (L).

3.8.7.2 Chemical parameters

3.8.7.2.1 Biochemical Oxygen Demand (BOD)

BOD was measured according to 5-Day BOD Test of Standards Method (5210B) (Jenkins, 2005). BOD refers to the amount of oxygen consumed by microorganisms under specified conditions (Jenkins, 2005). BOD bottle was rinsed thoroughly with tap water followed by distilled water. A 1000 mL of water sample was placed in a plastic container. The initial DO was determined using a DO meter (YSI, Pro 20). The water was shaken vigorously a few times if the value of DO was less than 4.0 mg/L. Then, the initial value of DO was taken. After that, the water sample was filled into 300 mL BOD bottles with no air bubbles trapped in the bottles. The BOD bottles were wrapped with aluminium foil to avoid light and incubated at $20 \pm 1^\circ \text{C}$ for 5 days. The light was excluded from entering the bottle to prevent the photosynthetic production of DO. The final reading of DO was measured after the five days incubation period using a DO meter (YSI, Pro 20).

The BOD_5 concentration was calculated by using Equation [3]:

$$BOD_5 = \frac{D_1 - D_5}{P}$$

[3]

where,

D_1 = Initial dissolved oxygen (DO) of sample (mg/L)

D_2 = Dissolved oxygen (DO) of sample after 5 days incubation at $20 \pm 1^\circ\text{C}$ (mg/L)

P = Decimal volumetric fraction of sample used as shown in Equation [4],

$$p = \frac{\text{volume of sample}}{\text{total volume}}$$

[4]

Conversion of BOD_5 to BOD concentration was calculated by using Equation [5] (Zainudin *et al.*, 2012):

$$BOD = \frac{BOD_5}{(1 - e^{(-kt)})}$$

[5]

where,

BOD = Biochemical oxygen demand (mg/L)

k = Decay rate in bottles at designated temperature (0.23), (Bowie *et al.*, 1985)

t = Incubation time (5 days).

3.8.7.2.2 Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) refers to the measure of a specified oxidant that reacts under controlled conditions with the sample (Jenkins, 2005). The Closed Reflux, Titrimetric

method of the Standard Methods of Examination of Water and Wastewater was used in this analysis (Jenkins, 2005).

Firstly, a 10 mL culture tubes together with caps were washed and soaked overnight with 20% H_2SO_4 before use to avoid any contamination. Then, the culture tubes and caps were rinsed properly with tap water followed by distilled water. In the meantime, a block digester (HANNA, C9800 Reactor) and a block heater (Stuart®, SBH200D) were preheated for 30 minutes at 150°C. Next, a total of 2.5 mL of water sample was placed into the culture tube and 1.5 mL of digestion solution was added. Next, 3.5 mL sulphuric acid (H_2SO_4) reagent was carefully run down inside the tube at 45°C so that an acid layer formed at the bottom of the solution under the sample-digestion solution layer. Then, the culture tube was capped and inverted for several times to mix completely. Then, the tubes were placed in Hanna C9800 reactor block digester preheated to 150°C and refluxed for two hours behind a protective shield. Then, they were placed in sand to left to cool to room temperature. After that, the culture tubes were placed in a test tube rack. The sample was transferred into a volumetric flask and two drops of ferroin indicator was added. After that, a standardized 0.025 M ferrous ammonium sulfate (FAS) solution was used to titrate the sample. Although the blue-green may reappear within minutes, the end point of the sample was determined by a sharp color change from blue-green to reddish brown.

A 2.5 mL of distilled water was used as a blank. Blank was prepared by adding 1.5 mL digestion solution and 3.5 mL H_2SO_4 reagent into the culture tube. Then, the tube was capped tightly and inverted several times to mix completely. The blank was heated together with the sample. After that, the tube was also cooled to room temperature.

The FAS solution was standardized daily by adding 5 mL of digestion solution to 10 mL of distilled water in a volumetric flask. Then, two drops of ferroin indicator were added into the flask. The solution was titrated against the 0.025 M FAS solution. The end point of the solution was a sharp colour change from blue-green to reddish brown. The volume of 0.025 M FAS titrated was recorded. The molarity of FAS solution must fall in between 0.024 M to 0.026 M.

The molarity of FAS solution was calculated by using Equation [6]:

$$M = \frac{5.0 \text{ mL} \times 0.1}{\text{vol FAS titrated}} \quad [6]$$

The calculation of COD was done using Equation [7]:

$$COD \text{ as } mgO_2/L = \frac{(A - B) \times M \times 8000}{2.5 \text{ mL sample}} \quad [7]$$

where,

A = volume of FAS used for blank (mL)

B = volume of FAS used for sample (mL)

M = molarity of FAS (0.025 M)

8000 = milliequivalent weight of oxygen $\times$ 1000 mL/L.

3.8.7.2.3 Nitrite-Nitrogen (NO₂-N)

The nitrite-nitrogen (NO₂-N) is an intermediate stage in the biological decomposition of organic matter (Jenkins, 2005). For the analysis NO₂-N, Method 8507 Nitrate Low Range

(USEPA diazotization method) was used (Hach, 2003). The detection concentration range of the $\text{NO}_2\text{-N}$ for the HACH DR 900 colorimeter is in the range of 0.005 to 0.350 mg/L.

First, program 371 N, Nitrite LR PP was started. A 10 mL of filtered water sample using dried 47 mm diameter 0.7 μm pore size glass microfiber filter was placed into the sample cell. After that, one NitriVer 3 Nitrite Reagent Powder Pillow was added to the sample cell. Then, it was capped and shaken for three minutes to allow the powder to dissolve. The reaction period was 20 minute. A pink color indicated that the nitrite was present in the sample.

In the meantime, distilled water was used as a blank followed by the same procedures as the sample. Then, the blank sample cell and the prepared sample were read using HACH DR900 colorimeter at 520 nm measurement wavelength showing $\text{NO}_2\text{-N}$ in mg/L. The concentration of $\text{NO}_2\text{-N}$ was recorded.

3.8.7.2.4 Nitrate-Nitrogen ($\text{NO}_3\text{-N}$)

The nitrate-nitrogen ($\text{NO}_3\text{-N}$) is the completed oxidized state of nitrogen (Jenkins, 2005). The $\text{NO}_3\text{-N}$ was analyzed using HACH Method 8192 Nitrate Low Range Cadmium Reduction Method (Hach, 2003). The detection concentration range of the $\text{NO}_3\text{-N}$ for the HACH DR 900 colorimeter is in the range of 0.01 to 0.50 mg/L.

Firstly, program 351 N, Nitrate LR was started. A 15 mL of filtered water sample using dried 47 mm diameter 0.7 μm pore size glass microfiber filter was filled in a mixing cylinder. After that, NitriVer 6 Nitrite Reagent Powder pillow was added and shaken vigorously for 3 minutes. Then, the solution was left for another 2 minutes for the reaction time. Then, 10 mL

was taken from the solution without transferring the cadmium particles to the sample cell and NitriVer 3 Nitrite Reagent Powder pillow was added and shake vigorously. The solution sample cell was shaken gently for 30 seconds and given 15 minutes for the reaction time. A pink colour developed which indicated the presence of nitrate.

A second sample cell was filled with 10 mL of the original filtered water sample using dried 47 mm diameter 0.7 μm pore size glass microfiber filter. Then, the blank sample cell and the prepared sample were read using HACH DR900 colorimeter at 520 nm measurement wavelength which showing $\text{NO}_3\text{-N}$ in mg/L. The concentration of $\text{NO}_3\text{-N}$ was recorded.

The $\text{NO}_3\text{-N}$ concentration was calculated by using Equation [8]:

$$\text{NO}_3 - \text{N} = \text{NO}_3 - \text{N (DR900)} - [\text{NO}_2 - \text{N (DR900)}] \quad [8]$$

where,

$\text{NO}_3\text{-N}$ = Concentration of nitrate-nitrogen (mg/L)

$\text{NO}_3\text{-N (DR900)}$ = Concentration of nitrate-nitrogen obtained from DR900 (mg/L)

$\text{NO}_2\text{-N (DR900)}$ = Concentration of nitrite-nitrogen obtained from DR900 (mg/L)

3.8.7.2.5 Ammoniacal-Nitrogen ($\text{NH}_3\text{-N}$)

The ammoniacal-nitrogen ($\text{NH}_3\text{-N}$) was analyzed using Preliminary Distillation Step from the Standard Methods for the Examination of Water and Wastewater followed by the Nessler's method (Jenkins, 2005; Hach, 2003).

Firstly, a volume of 100 mL of unfiltered water sample was placed in distillation flask and 10 mL borate buffer solution was added to the sample. The sample then was adjusted to pH 9.5

by using 6N Sodium Hydroxide (NaOH) drop by drop. Then, the flask was placed in a semi-automatic distillation unit (VELP SCIENTIFICA, UDK139). The timer was set for two and a half minutes. After that, the distillate was collected in 250 mL Erlenmeyer flask containing 10 mL of indicating boric acid (H_3BO_3) solution. Then, 1 N NaOH was used to adjust the pH to 7 to neutralize it. After that, the distillate was top up using ammonia free water to 100 mL.

After distillation, Nessler's method was used to analyze the concentration of ammonia (Hach, 2003). The sample was prepared by filling a 25-mL mixing graduated cylinder to the 25-mL mark with sample. On the other hand, the preparation of a blank was done by filling a 25-mL mixing graduated cylinder to the 25-mL mark with ammonia free water. Then, three drops of Mineral Stabilizer were added to each cylinder. The cylinders were stopper and inverted several times to mix. Subsequently, three drops of Polyvinyl Alcohol Dispersing Agent were added to each cylinder. The cylinder was stoppered and inverted several times to mix. Then, 1.0 mL of Nessler's Reagent was pipette into each cylinder. The cylinder was stoppered and inverted several times to mix. After 3-minute reaction time, the sample was analyzed using UV Jasco V-630 spectrophotometer or HACH DR2800 as alternative and absorbance at 425 nm was observed and recorded.

A series of standards with different concentrations was used to prepare the calibration curve. First, the standard stock ammonium chloride solution was prepared by dissolving 3.819 mg of anhydrous NH_4Cl (dried at 105°C for 2 hours, cooled in dessicator) and diluted to 1000 mL using ammonia free water. One mL of this solution contained 1 mg of N equivalent to 1.22 mg NH_3 . At least five different standard concentrations were prepared from the solution. The different concentrations of N were prepared by using the volume of 0.0, 2.0, 4.0, 6.0, 8.0 and 10.0 mL. The standards were analysed using same procedure as the sample. The colour

density of the standards after reactions were then measured using UV-VIS spectrophotometer (JASCO, V630) or DR2800 at 425 nm. An equation that was derived from the calibration curve was used in determining the NH₃-N concentration. The formula that used to calculate NH₃-N was as Equation [9]:

$$\text{NH}_3 - \text{N (mg/L)} = \frac{\text{abs} - \text{intercept (C)}}{\text{slope(m)}} \quad [9]$$

where,

Abs = the absorbance reading from UV Jasco V-630 spectrophotometer

C = the intercept of the calibration curve

m = the slope of the calibration curve.

3.8.7.2.6 Organic-Nitrogen (Org-N)

Organic-nitrogen (Org-N) was analyzed using method 4500 N_{Org} B, Macro Kjeldahl Method as stated in the Standard Methods for the Examination of Water and Wastewater (Jenkins, 2005). The method had a concentration range between 1 to 150 mg/L. This method also involved two parts which were digestion and distillation.

Firstly, a total volume of 50 mL of unfiltered water sample was transferred into digestion tube and 5 mL of borate buffer with was added. The pH was adjusted to pH 9.5 using 6N Sodium Hydroxide (NaOH). Then, 5 mL of digestion reagent was added. After that, the mixture was boiled in a heating digester (VELP SCIENTIFICA, DKL Heating Digester) and the sample was digested at 250 °C until volume reduced to about 30 mL. After that, the sample was digested until the volume was greatly reduced to about 5 to 10 mL and a copious white fume

was observed. The digestion process was continued for an additional 30 minutes to complete as the sample became transparent pale green. Then, the sample was allowed to cool and it was diluted with ammonia free water to 30 mL and mixed well.

For distillation, 5 mL sodium hydroxide-sodium thiosulphate reagent ($\text{NaOH-Na}_2\text{S}_2\text{O}_3$) solution was added into the diluted sample to form alkaline layer at the tube bottom. The flask was placed in a semi-automatic distillation unit (VELP SCIENTIFICA, UDK139). The timer was set for two and a half minutes. The distillate was collected into 25 mL Erlenmeyer flask which contained 5 mL of indicating boric acid (H_3BO_3) solution. Then, the pH was adjusted to pH 7 by adding 1N NaOH to neutralize it. The distillate then was top up to 100 mL using ammonia free water.

After top-up, the Nessler's Method was carried out (Jenkins, 2005). Twenty-five mL of distillate was poured into 25 mL mixing culture tube and deionised water was poured into the second mixing culture tube as a blank. Three drops of Mineral Stabiliser, three drops of Polyvinyl Alcohol Dispersing Agent and lastly, 1 mL of Nessler's reagent was placed into each tube. The tube was inverted twice after addition of each reagent to mix completely. After the one-minute reaction time, the sample was analyzed using UV Jasco V-630 spectrophotometer or DR2800 as alternative. Lastly, the absorbance reading at 425 nm was taken.

A series of standards with different concentration was used to prepare the calibration curve. First, the standard stock glutamic acid solution was prepared by dissolving 1.05 mg of glutamic acid (dried at 105°C for 24 hours, cooled in dessicator) and diluted to 1000 mL using ammonia free water. One mL of this solution contained 100 µg of N. Then, an intermediate glutamic acid solution was prepared by diluting 100 mL of the stock solution to

1000 mL using ammonia free water. Hence, 1 mL of intermediate solution contained 10 µg of N. At least five different standard concentrations were prepared from the intermediate solution. The standards went the same procedure as the sample. The standards were then measured using UV-VIS spectrophotometer (JASCO, V630) or DR2800 at 425 nm. An equation that was derived from the calibration curve was used in determining the Org-N concentration. The amount of Org-N was calculated using equation [10]:

$$\text{Org - N (mg/L)} = \frac{\text{abs} - \text{intercept (C)}}{\text{slope(m)}} \quad [10]$$

Abs = the absorbance reading from UV Jasco V-630 spectrophotometer

C = the intercept of the calibration curve

m = the slope of the calibration curve.

3.9 Water quality classification

The quality of surface water was classified using the Water Quality Index (WQI) and National Water Quality Standard (NWQS) set by the Department of Environment (DOE), Malaysia (DOE, 2014). Based on DOE (2014), the WQI was calculated from six water quality parameters involving pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS) and Ammoniacal Nitrogen (NH₃ N). The formula used to calculate the WQI was as Equation [11]:

$$WQI = 0.22 \times SIDO + 0.19 \times SIBOD + 0.16 \times SICOD + 0.15 \times SIAN + 0.16 \times SISS + 0.12 \times SIpH \quad [11]$$

where,

SI indicates the sub index for each parameter, SIDO is sub index DO (% saturation), SIBOD is sub index BOD (mg/L), SICOD is sub index COD (mg/L), SIAN is sub index AN (mg/L), SISS is sub index SS (mg/L), and SIpH is sub index pH.

3.10 Pollutant Loading

The loading of each pollutant is important to determine the amount of pollutant being discharged into the river. The pollutant loading is defined as the mass of a substance that passes a particular point of river at specific amount of time (USEPA, 2012).

The loading of the pollutant was calculated by using Equation [12]:

$$L = Q \times \bar{x} \times F \quad [12]$$

where,

L = Loading of pollutant (kg/day)

Q = Flow rate of river (m³/s)

$\bar{x}$ = Mean concentration of the pollutant (mg/L)

F = Conversion unit (86.4)

3.11 Sediment analysis

Submerged sediment samples was taken by using grab sampler or scoop and then put in a plastic bag, stored tightly and preserved under 4°C. For sediment analysis, the sample was taken for particle size and sediment physio-chemical parameters. All the glassware was soaked with 10% HNO₃ and rinsed with distilled water. Sediment sample was air dried for

two weeks inside the laboratory. After two weeks, the air dried sample was grounded with pestle and mortar and then sieved through 2.0 mm sieve. The sample was stored in a plastic beaker and covered using parafilm. The sediment samples for the determination of TOC, OM, TP and TKN were sieved using a 0.355 mm sieve.

3.11.1 pH

The pH of the sediment was determined by the method of Thomas (1996). A glass electrode pH Meter (Eutech, pH 700) was used to determine the soil pH value. The pH meter was calibrated with pH value of 7 first then followed by pH 4, and 10. A volume of 10 mL of distilled water was used to dilute a 10 g of air-dried sediment to produce a ratio of 1:1 mixture in a 100 mL beaker. The mixture was homogenized using a stirring rod and then left stand for 10 minute to settle. After 10 minutes passed, the suspension in the beaker was swirled. The pH readings were obtained by inserting the pH electrodes in the soil mixture which was labelled as pH. Between pH readings, the electrodes were rinsed with distilled water.

3.11.2 Particle Size Analysis (PSA)

According to Gee & Bauder (1986), the particle size analysis (PSA) refers to the measurement of the size distribution of the individual particles in the soil sample. In this study, the PSA was conducted according to the pipette method in Gee & Bauder (1986).

3.11.2.1 Pre-treatment: Removal of Organic Matter

A 20 g air-dried sediment sample was added into 600 mL beaker. Then, 25 mL distilled water was added to the sediment and stirred to mix well. Then, the soil suspension was added with a volume 5 mL of hydrogen peroxide (H_2O_2). After that, the mixture was stirred, covered and observed closely for a few minutes. The beaker was put in cold water but if any excessive frothing was observed. After the reaction subsided, more hydrogen peroxide (H_2O_2) was added. The sample was left to stand to overnight.

The next day, the suspension was heated to 90°C in a water bath and when frothing has ceased, the cover was removed, and the sample was evaporated to remove excess water but not left to dryness. The heating and hydrogen peroxide treatment were continued until the majority of the organic matter has been destroyed. This was determined by the bleached colour and the rate of reaction of the sample. The side of the reaction vessel was rinsed down occasionally.

3.11.2.2 Removal of Iron Oxides

After the final addition of peroxide, the heating of the suspension was continued for approximately an hour to destroy the excess peroxide and then left overnight. A total volume of 10 mL sodium hexametaphosphate, HMP (dispersant) and 400 mL of distilled water was added and the mixture was left overnight.

3.11.2.3 Separation of the sand fraction

The suspension from the pre-treatment was poured through 53 μm sieve into 1 L measuring cylinder. The sieve was placed above a large funnel which held by a retort stand on top of the measuring cylinder. Then, the sand fraction was poured thoroughly on the sieve by tap the large funnel gently. The washings in the cylinder were collected. The sand in the sieve was dried (105°C), transferred into Petri dish and weighed using an analytical balance.

3.11.2.4 Determination of clay ($<2\mu\text{m}$)

A 10 mL of HMP solution was poured into the cylinder and made up with distilled water to 1 L volume. Then, the mouth of the cylinder was covered using a watch glass. After that, they were equilibrated by letting it stand for at least two hours. After equilibration, the suspension was stirred in ups and down motion using a hand stirrer for at least 30 seconds. Time at completion of stirring and temperature of the suspension were recorded and noted. It is convenient to complete stirring of adjacent suspensions at intervals of about 3 minutes.

A 25 mL of sample was withdrawn using 25 mL pipette. The pipette was lowered until 10 cm from the surface of sample and was withdrawn after 4 minutes (20 μm) and 7 hours (2 μm) of stirring interval. The pipette was rinsed with distilled water and the rinsed water was added into the beaker. The sample was discharged into a tarred and numbered 50 mL beaker. The pipette was rinsed with distilled water and the rinsed water was added to the beaker. The water was evaporated, the clay was dried at 105°C , cooled in the desiccators and weigh.

3.11.2.5 Determination of the weight of treated sediment

A volume of 1 mL of 1 M HCl and a 10 mL of 1 M CaCl₂ was added to the suspension leftover in the measuring cylinder to avoid CaCO₃ formation. Then, clear solution part was the siphon off after flocculation has occurred. The soil at the bottom of the measuring cylinder was placed to a tarred beaker, evaporated, dried in Memmert oven at 105°C, and weighed then recorded.

3.11.2.6 The calculation of the sand, clay and silt fractions

The percentage of sand, clay and silt in PSA was determining using calculation. They were as shown below: The calculation for sand fraction was calculated as Equation [13]:

$$\text{Sand(g)} = (W_B + \text{sand (g)}) - W_B \text{ (g)}$$

[13]

where,

W_B = Weight of beaker

Meanwhile, the calculation for silt and clay was according to the following Equation [14], [15] and [16]:

$$\text{Silt + Clay } \left(\frac{\text{g}}{\text{L}} \right) = \left[[(W_B + \text{pipet sample(g)}) - W_B] \times \frac{1000}{25} \right] - 0.5$$

[14]

where, clay in g/L is calculated using Equation [15]:

$$\text{Clay } \left(\frac{\text{g}}{\text{L}} \right) = \left[[(W_B + \text{pipet sample(g)}) - W_B \text{ (g)}] \times \frac{1000}{25} \right] - 0.5$$

[15]

Therefore, the clay is calculated as Equation [16]:

$$\text{Silt } \left(\frac{g}{L}\right) = \left(\text{silt} + \text{clay } \left(\frac{g}{L}\right)\right) - \text{clay } \left(\frac{g}{L}\right)$$

[16]

The sand, clay and silt fractions were presented in percentages which were individually calculated as Equation [17]:

$$\text{Sand or Clay or Silt (\%)} = \frac{(\text{weight of sand or clay or silt in } \frac{g}{L})}{\text{Total weight of sand} + \text{clay} + \text{silt } (\frac{g}{L})} \times 100$$

[17]

3.11.3.7 The determination of the textural class

The textural class of the sediment was determined according to the soil texture classification diagram in Figure 3.3. The three sides of the textural triangle represent increasing or decreasing percentages of sand, silt and clay particles. The percent of clay is identified on the left side of the triangle. The percent silt is identified along the right side of the triangle. The bottom of the triangle identifies the percent sand. The point at which these three lines intersect will define the soil's texture.

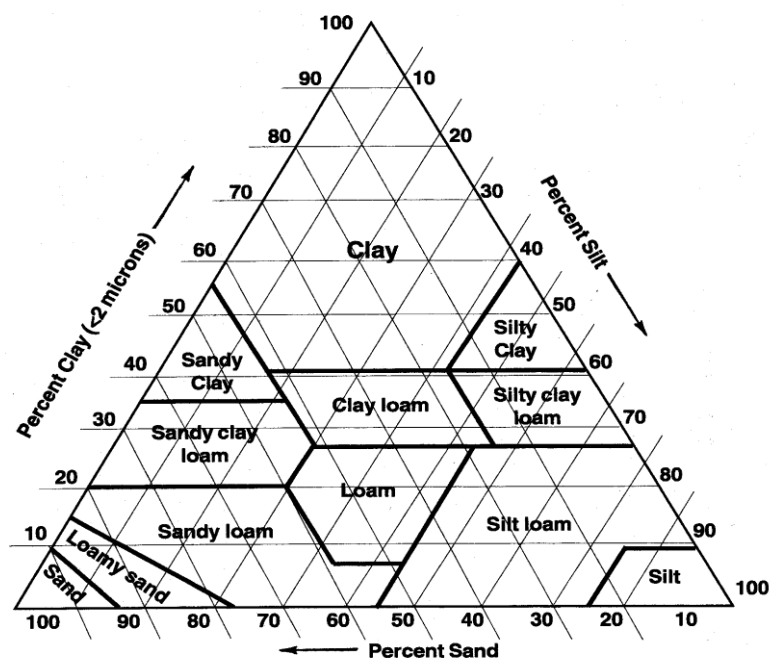


Figure 3.3: Soil Texture Classification Ternary Diagram for fine-grained sediments

3.11.3 Total Organic Carbon (TOC)

The total organic carbon (TOC) content of the sediment sample was obtained by using the method of Walkey-black (Nelson & Sommers, 1996). The sediment sample was ground using a mortar to go through a 0.5 mm sieve. A 2.0 g of sediment sample was transferred into a 2500 mL wide-mouth Erlenmeyer flask. Then, 10 mL of 0.167 M potassium dichromate ($K_2Cr_2O_7$) and 20 mL H_2SO_4 was added into the suspension. Then, it was swirled vigorously for one minute. The suspension was then left to stand for 30 minutes. A 200 mL of distilled water was added. The suspension was filtered by using a vacuum pump and through a 0.45 μm membrane filter paper. To this was added 5 drops of 0.025 M of o-phenanthroline-ferrous complex and titrated using 0.5 M ferrous sulphate heptahydrate ($FeSO_4 \cdot 7H_2O$) solution. The solution changed from a greenish cast to a dark green as the end point approached.

FeSO₄.7H₂O solution was added drop by drop until a sharp colour changed from blue to red. A blank was made in the same manner but without soil to standardize the K₂Cr₂O₇ solution. The determination with less soil was repeated if >75% of dichromate was reduced. Total organic carbon calculation was expressed as Equation [18]:

$$\text{TOC (\%)} = \frac{(\text{mL}_{\text{blank}} - \text{mL}_{\text{sample}})(\text{M}_{\text{Fe}^{2+}})(0.003)(100)}{\text{wt of water} - \text{free soil}} \times f$$

[18]

where,

TOC = Total Organic Carbon (%)

Wt = weight of oven-dried sample

f = correction factor (1.30)

Concentration of FeSO₄.7H₂O was calculated by using Equation [19]:

$$\text{FeSO}_4 \cdot 7\text{H}_2\text{O} = \frac{6 \times \text{mol of K}_2\text{Cr}_2\text{O}_7 \times \text{vol of K}_2\text{Cr}_2\text{O}_7}{\text{vol FeSO}_4}$$

[19]

where,

FeSO₄.7H₂O = Ferrous sulphate heptahydrate, M

K₂Cr₂O₇ = Potassium dichromate, M

3.11.4 Organic Matter (OM)

Organic matter in sediment was analysed using Loss-on-Ignition (LOI) method according to Nelson and Sommers (1996). Empty crucibles were first heated in a furnace (Carbolite) at 400 °C for two hours. Then, the crucibles were cooled down and tare weight recorded to 0.1 mg. Then, 3 g of air-dried sediment which grounded less than 0.4 mm was added into the crucible and been heated in microwave oven at 105 °C for twenty-four hours. Then, the crucibles were cooled in desiccators. After that, the weights were recorded to 0.1 mg. The weight of oven-dried samples was obtained by using subtraction. The samples were then heated in a furnace for 16 hours at 400 °C. Later, the crucible was placed in desiccators over CaCl₂ to cool down.

The organic matter content calculation is as Equation [20]:

$$\text{OM \%} = \frac{\text{weight}_{105} - \text{weight}_{400}}{\text{weight}_{105}} \times 100$$

[20]

where,

Weight₁₀₅ = the weight of the sediment heated at 105 °C

Weight₄₀₀ = the weight of sediment after ignition at 400°C

OM = organic matter content (%)

3.11.5 Total Kjeldahl Nitrogen (TKN)

Total Kjeldahl Nitrogen in sediment was determined by using regular Kjeldahl method to detect the content according to Bremner (1996).

3.11.5.1 Digestion Process

A 0.3 g of air-dried soil was weighed and 1.1 g of potassium sulphate (K_2SO_4) catalyst mixture was added. After that, 3 mL of concentrated H_2SO_4 were mixed with the sample and then transferred to a micro-Kjeldahl digestion flask. The flask was put in a heating digester (VELP SCIENTIFICA, DKL Heating Digester). Next, the sample was heated at 200 °C for two hours until the sample became bleached. The flask was heated gently for another one hour.

3.11.5.2 Distillation Process

After the completion of digestion, the flask was allowed to cool to room temperature. Then, 20 mL of ammonia-free water was poured slowly into the digestion flask and with shaking. A total volume of 10 mL of ammonia-free water was used to rinse the flask. The suspension was filtered through the filtration set with a vacuum pump. Next, 20 mL of 10 M NaOH was added to the filtrate. The solution was transferred to the semi-automatic distillation unit (VELP SCIENTIFICA, UDK139). The timer was set for two and half minutes. Then, the distillate was measured and collected in a 250 mL Erlenmeyer flask which contained 5 mL of boric acid (H_3BO_3) solution. The collection tube was placed into the H_3BO_3 solution to prevent the loss of ammonia gas. The sample was adjusted to pH 7 by using 1 N of NaOH. Then, top up to 100 ml with ammonia free water.

3.11.5.3 Nessler's Method

Sample with a volume of 25 mL was placed into a culture tube. Then, 3 drops of polyvinyl alcohol dispersing agent, 3 drops of mineral stabilizer and 1 mL of Nessler's reagent were added. The tube was inverted to mix completely. The sample was analyzed by using DR3900 425 nm.

3.11.5.4 Calibration curve preparations

A series of standards with different concentration was used to prepare the calibration curve. First, the standard stock ammonium chloride solution was made by using 3.819 mg of anhydrous NH_4Cl (dried for 2 hours at 105°C , cooled in dessicator) and diluted to 1000 mL using ammonia free water. One mL of this solution contained 1 mg of N equivalent to 1.22 mg NH_3 . The intermediate NH_4Cl was prepared by diluting 25 mL of the stock solution to 1 L (1 mL = 0.025 mg N). At least five different standard concentrations were prepared from the solution. The different concentrations of N were prepared by using the volume of 0, 5, 10, 15, 20, 25, and 30 mL. The different volumes were diluted to 250 mL in a standard flask. Next, the standard solutions were treated the same manner as the sample. A reagent blank was carried out through all the steps of the procedure. The standards then were measured using DR3900 colorimeter at 425 nm. An equation was derived from the calibration curve was used in determining the TKN concentration. The TKN concentration was calculated by using Equation [21]:

$$\text{TKN} \left(\frac{\text{mg}}{\text{kg}} \right) = \left[\frac{(\text{absorbance at } 425\text{nm} - C)}{m} \right] \times \frac{\text{Distillate}(ml)}{1000} \times \frac{1}{0.0003}$$

[21]

where,

TKN = Total Kjeldahl Nitrogen (mg/kg)

m = slope of standard calibration curve

c = intercept of standard calibration curve

3.11.6 Total Phosphorus (TP)

Total phosphorus in sediment was determined by using digestion with perchloric acid followed by ascorbic acid method (Kuo, 1996).

3.11.6.1 Perchloric Acid (HClO₄) Digestion

In the digestion with perchloric acid (HClO₄), a 2 g of air-dried sediment was mixed with 30 mL of 70% HClO₄ in a micro-Kjeldahl digestion flask. The flask was put in a heating digester (VELP SCIENTIFICA, DKL Heating Digester). The heating digester was preheated at 130°C for 30 minutes. The mixture was digested at 130 °C until the dark colour due to organic matter disappeared. In other words, the mixture was digested until bleached colour. Then, the mixture was digested at 203 °C for another 20 minutes. Digestion was completed when white fumes of HClO₄ appeared. Then, any black particles that were left on the sides of the micro-Kjeldahl digestion flask were washed down using a 2 mL of HClO₄.

After the digestion, the mixture was cooled and diluted to 250 mL with distilled water and mixed well. Then, the solid materials in the mixture were allowed to settle. A 50 mL of aliquot in the flask was transferred into a 250 mL of Erlenmeyer flask. The aliquot was mixed

with five drops of 0.25% p-nitrophenol indicator and adjusted the pH with drops of 5 M NaOH until colour changed from colourless to yellow. Then, the solution was marked up to 250 mL.

3.11.6.2 Ascorbic Acid Method

A 50 mL of the solution was transferred to an Erlenmeyer flask. An 8 mL of combined reagent was added to the solution. The solution left for 10 minutes for the reaction time. Distilled water was used as a blank. After 10 minutes, the absorbance was determined at 880 nm by using DR3900. The absorbance was recorded.

3.11.6.3 Calibration curves preparation

A series of standards with different concentration was used to prepare the calibration curve. Firstly, the standard stock P solution was prepared by dissolving 219.5 mg of anhydrous KH_2PO_4 (dried at 105°C for 1 hour, cooled in dessicator) and diluted to 1000 mL using distilled water. One mL of this solution contained 50 μg of P. Then, an intermediate P solution was made using 50 mL of the stock solution which was diluted to 1000 mL using distilled water. Hence, 1 mL of intermediate solution contained 2.5 μg of P. The intermediate KH_2PO_4 solution was prepared by diluting 50 mL of the stock solution to 1 L (1 mL = 2.5 μg P). At least five different standard concentrations were prepared from the solution. The different concentrations of P were prepared by using the volume of 0, 25, 50, 75, 100, 125, 150, 200, 225, and 250 mL. The different volumes were diluted up to 250 mL in a standard flask. Next, the standard solutions were treated the same manner as the sample. A reagent blank was carried out through all the steps of the procedure. The standards were then measured using DR3900 colorimeter at 425 nm. An equation was derived from the calibration

curve was used in determining the TP concentration. Predicted concentration of TP was calculated as Equation [22]:

$$TP \left(\frac{\mu g}{kg} \right) = \left[\frac{\text{absorbance} + c}{m} \right] \times \frac{1}{1000} \times \frac{250}{1000} \times \frac{1}{0.002}$$

[22]

where,

TP = Total Phosphorus (mg/kg)

m = The slope of standard calibration curve

c = The intercept of standard calibration curve

3.12 Sediment Classification Guidelines

The sediment classification guideline that is used in this study is the Guideline for the Protection and Management of Aquatic Sediment Quality in Ontario (Table 3.6) (Persaud *et al.*, 1993) This sediment guideline is the most appropriate due to the suitability criteria and the presence of the classification standards for the sediment contaminant in this study. This guideline was made to protect the aquatic environment by setting a safe level for nutrients, metals and organic compound in the river sediment. So they may help researchers to determine which sediments are in the safe level or contaminated.

Table 3.6 Sediment Guideline for the protection and management of Aquatic Sediment Quality in Ontario (Persaud *et al.*, 1993)

Compound name	Units	Lowest effect level	Severe effect level
Total Phosphorous	mg/kg	600	2000
Ammonia	mg/kg	100	-
Total Organic Carbon	%	1	10
Total Kjeldahl Nitrogen	mg/kg	550	4800

There are three levels of effect in this guideline which includes the No Effect Level, the Lowest Effect Level and the Severe Effect Level. The No level effect indicate that there is no toxic effects on fish or sediment-dwelling organisms; there is no expected food chain bio magnification, and all water quality guidelines will be met. The Lowest Effect Level indicates the level of contamination at which there is no effect on the majority of the sediment dwelling organism and the contamination in the sediment that exceeds this level may require further testing and a management plan. Meanwhile, the sediment at the severe effect level is considered heavily polluted and likely to affect the health of the sediment dwelling organisms. Furthermore, testing is required to determine whether or not the sediment is acutely toxic (Persaud *et al.*, 1993).

3.13 Statistical Analysis

Statistical analysis of the data obtain was conducted using IBM SPSS Statistics 22 package. One-way ANOVA was chosen to compare the means at the 5% significant level and Tukey's test was used for pairwise comparisons. A correlation matrix was constructed by means of Pearson correlation analysis to compare the relationships between the water parameters, between the sediment parameters and between the water and sediment parameters. The differences between stations at the Rajang River with the tributaries were tested by using independent t-test. The independent *t*-test was used to determine whether there was a statistically significant difference between the means in two unrelated groups, stations at the main river and the stations at tributaries. A total of eight sediment characteristics of all the 30 stations located along Rajang River and its tributaries were used in this correlation analysis..

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Water quality in Rajang River of the Pelagus Area

4.1.1 Hydrogeometric Data

The hydrogeometric data of all the studied stations for the upstream and midstream section of Rajang River at Pelagus area are illustrated in Table 4.2. The hydrogeometric data show that the mean depth of the stations at the Rajang River was in the range of 4.16 m to 16.29 m, while, the tributaries ranged from 0.78 m to 9.08 m. Besides, the mean velocity of the stations at the main river ranged from 0.1322 to 1.77 m/s, whilst, the tributaries is in the range of 0.06 to 1.76 m/s. The average width of Rajang River station ranged from 160 m to 305 m whereas the monitored tributaries ranged from 18 m to 58 m.

Additionally, the hydraulic data show the velocity of the stations along the Rajang River ranged from 0.31 m/s to 0.55 m/s while the stations located at its tributaries ranged from 0.01 m/s to 0.27 m/s. The discharge for the monitored tributaries ranged from 1.0 m³/s to 19.9m³/s. Meanwhile, the discharge recorded at the stations along Rajang River ranged from 534.6 m³/s to 590.9 m³/s for the upstream section and ranged from 1126.0 m³/s to 1406.4 m³/s for the midstream section. The lowest was observed at the furthest upstream whereas the highest was observed at the most midstream station. The trend of the discharge of the stations at the Rajang River was increasing from upstream to downstream direction. There was a significant increase of discharge observed from station 9 to 10. This difference was largely due to the volume of discharge by Bakun Hydroelectric Dam at the time of samplings (Table 3.2). For

upstream, the volume of outflow from the turbine on the days of sampling were 679.9 m³/s and 695.8 m³/s with no discharge from the spillway. During mid-stream sampling, the volume of outflow from the turbine on the days of sampling were 679.5 m³/s and 651.5 m³/s with 2002.0 m³/s discharge from spillway on both days. The increase in discharge at the main river for all stations was due to the addition of point sources of water from the tributaries along the river.

The hydrogeometric data of all the 11 stations of three different sampling trips at the downstream section are illustrated in the Table 4.2. Comparatively, the width, depth, velocity and river discharge was different during the three samplings.

For the sampling in July 2015, the mean width ranged from 110 m to 190 m at the stations at the Rajang River and ranged from 12 m to 120 m at the stations at the tributaries. Meanwhile, the depth of the stations at the Rajang River ranged from 2.40 m to 5.76 m, whereas, stations at the tributaries ranged from 0.57 m to 3.81. For the velocity, the station at the Rajang River in the range of 0.12 m/s to 0.59 m/s, while, the station at the tributaries ranged from 0.06 m/s to 0.58 m/s. For the discharge of the river, the stations at the Rajang River ranged from 113.30 m³/s to 831.44 m³/s, whilst, the stations at the tributaries were in the range of 0.98 m³/s to 221.39 m³/s. For the sampling in January 2016, the mean width ranged from 218 m to 277 m at the stations at the Rajang River and ranged from 20 m to 155 m at the stations at the tributaries. Meanwhile, the depth of the stations at the Rajang River ranged from 9.67 m to 10.80 m, whereas, stations at the tributaries ranged from 0.85 m to 6.29. For the velocity, the station at the Rajang River in the range of 0.58 m/s to 1.33 m/s, while, the station at the tributaries ranged from 0.03 m/s to 0.97 m/s. For the discharge of the river, the stations at the

Rajang River ranged from 1413.11 m³/s to 2984.37 m³/s, whilst, the stations at the tributaries were in the range of 0.67 m³/s to 1577.57 m³/s.

For the sampling in March 2016, the mean width ranged from 267 m to 310 m at the stations at the Rajang River and ranged from 27 m to 191 m at the stations at the tributaries. Meanwhile, the depth of the stations at the Rajang River ranged from 12.15 m to 21.40 m, whereas, stations at the tributaries ranged from 1.32 m to 11.84. For the velocity, the station at the Rajang River in the range of 1.19 m/s to 1.57 m/s, while, the station at the tributaries ranged from 0.00 m/s to 0.73 m/s. For the discharge of the river, the stations at the Rajang River ranged from 4246.85 m³/s to 6768.14 m³/s, whilst, the stations at the tributaries were in the range of 0.78 m³/s to 2684.59 m³/s.

From the Table 4.2, it was clearly seen that the discharge in July 2015 was observed to be lower than the discharge in January 2016 and March 2016. This is because in July 2015 the water sampling was done during low rainfall period, whereas, in January 2016 and March 2016 was during high rainfall period (Table 2.1). The river discharge was ranked as low in July 2015, medium in January 2016 and high in March 2016. The trend of the discharge at stations at Rajang River was increasing from upstream to downstream section. This is due to the addition of the river water discharge from the tributaries.

Table 4.1: The depth, width, velocity and discharge of the Rajang River and its tributaries for upstream and midstream section at Pelagus Area

Section	Station	Width (m)	Depth (m)	Velocity (m/s)	Discharge (m ³ /s)
Upstream	1	226	4.2	0.55	534.6
	2	36	1.8	0.13	8.8
	3	18	0.8	0.07	0.9
	4	28	2.2	0.08	5.1
	5	160	8.6	0.39	590.9
	6	50	2.4	0.27	34.5
	7	28	1.6	0.13	5.6
	8	58	1.9	0.18	19.9
	9	194	6.2	0.48	689.6
Midstream	10	305	9.8	0.41	1126.0
	11	54	6.9	0.01	4.1
	12	18	4.3	0.01	2.6
	13	168	13.4	0.49	1268.8
	14	26	9.1	0.01	2.3
	15	186	16.3	0.36	1320.5
	16	21	3.6	0.02	1.4
	17	256	11.0	0.37	1371.4
	18	22	4.2	0.01	2.4
	19	184	10.6	0.96	1406.4

*Bold indicates the stations along Rajang River

Table 4.2: The width, depth, velocity and discharge of the Rajang River and its tributaries at the downstream section of Pelagus Area

Station	Width (m)			Depth (m)		
	July-15	January-16	March-16	July-15	January-16	March-16
20	118	218	283	4.08	10.30	12.62
21	23	38	42	1.18	1.43	5.81
22	134	250	310	2.56	10.80	12.68
23	23	27	39	0.76	0.85	3.17
24	18	27	28	0.87	0.93	3.92
25	110	248	267	2.40	9.67	12.15
26	23	31	35	1.01	1.76	4.17
27	12	20	27	0.57	0.85	1.32
28	130	219	234	5.34	10.71	16.51
29	120	155	191	3.81	6.29	11.84
30	190	277	294	5.76	10.10	21.40
Station	Velocity (m/s)			Discharge (m ³ /s)		
	July-15	January-16	March-16	July-15	January-16	March-16
20	0.12	0.58	1.19	113.3	1,413.1	4,246.8
21	0.08	0.53	0.09	2.4	48.1	24.3
22	0.22	1.08	1.34	233.6	1,552.3	4,445.0
23	0.14	0.19	0.03	4.6	4.7	5.6
24	0.06	0.05	0.00	1.7	1.1	0.3
25	0.59	1.21	1.23	273.0	1,694.1	4,496.8
26	0.58	0.03	0.02	33.6	1.5	4.0
27	0.06	0.05	0.02	0.9	0.6	0.7
28	0.33	0.99	1.57	584.0	1,702.2	5,039.0
29	0.31	0.97	0.73	221.3	1,577.5	2,684.5
30	0.29	1.33	1.17	831.4	2,984.3	6,768.1

*Bold indicates the stations along Rajang River

The volume of discharge from the turbine and the spillway of the Bakun Hydroelectric Dam during the time of sampling are shown in Table 4.3. The discharge from the turbine was the highest during the sampling in January 2016 with a volume of 970.00 m³/s, followed by the sampling in March 2017 with a volume of 733.92 m³/s. The lowest discharge from the turbine was during the sampling in July 2015 with volumes of 353.88 m³/s on the 8th July 2015 and 361.47 m³/s on the 9th July 2015. Meanwhile, the volume of the discharge from the spillway was the highest during the sampling in March 2016 with a volume of 2060.00 m³/s, followed by the sampling in July 2015 with a volume of 614.00 m³/s. There was no discharge from the spillway during the sampling in January 2016. The total discharge from the Bakun Hydroelectric Dam was the highest in March 2016 (2973.9 m³/s) followed by in July 2015 (967.9 m³/s on the 8th and 975.5 m³/s on the 9th) and the lowest total discharge was recorded in January 2016 (970.0 m³/s). The low total discharge in January 2016 is due to the closure of the spillway.

Table 4.3: The discharge from Bakun Hydroelectric Dam during the three samplings at the downstream section

Month of sampling	Date of sampling	Volume of turbine outflow (m ³ /s)	Volume of spillway outflow (m ³ /s)	Volume of turbine + outflow (m ³ /s)	Note
July	08 th Jul-15	353.88	614.00	967.88	Spillway opened
	09 th Jul-15	361.47	614.00	975.47	Spillway opened
January	21 st Jan-16	970.00	0.00	970.00	Spillway closed
March	19 th Mar-16	733.92	2060.00	2793.92	Spillway opened

4.1.2 Water quality

4.1.2.1 Physical parameters

4.1.2.1.1 Temperature

Figure 4.1 shows the mean river temperature at upstream and midstream section at Rajang River of the Pelagus area. For the upstream section, the mean river temperature ranged from 25.00 °C to 27.63 °C. Among the stations along the Rajang River, the mean temperature ranged from 27.20 °C to 27.63 °C, whereas among its tributaries, it ranged from 25.00 °C to 26.37 °C. Stations located along the Rajang River shows significantly higher mean temperature than the stations located at the tributaries at the upstream section ($p < 0.05$). The highest mean temperature recorded was at station 5 at Rajang River. Meanwhile, station 3 at Pengau Besar River, a tributary, shows the lowest mean temperature at the upstream section.

For the midstream section, the mean river temperature ranged from 26.25 °C to 27.12 °C. Among the stations along the Rajang River, the mean temperature ranged from 26.86 °C to 27.12 °C, whereas, tributary temperature ranged from 26.25°C to 26.74 °C. At the midstream section, the mean temperature of stations along the Rajang River was significantly higher compared to the stations at the tributaries. The highest mean temperature was recorded at station 19 which was located along the Rajang River. Meanwhile, the mean temperature was found lowest at station 18 at Peraran Besar River, a tributary, compared to the other stations at the midstream section.

Among the stations located along the Rajang River, there was a significant decrease in temperature observed from station 9 to station 10. This was because Bakun Dam spillway discharge and the river's discharge during that trip, that is, from stations 10 to 19, the

discharge was higher than the trip of stations 1 to 9 was due to the less discharge from the Bakun Dam as the spillway was closed (Table 3.4).

Generally, the mean temperatures were observed higher at the stations in the Rajang River compared to its tributaries both when the spillway was closed (Station 1 to 9) and when the spillway was open (Station 10 to 19). Those differences might be attributed to the differences in the condition of river such as the exposure and size of the river to solar radiation. Rajang River was the main river and had bigger water body which absorbs more heat and does not easily cool down. Besides, the surroundings of the Rajang River were less shaded compared to the small tributaries of Rajang River, which were observed to have more canopy cover at its riverbank. Thus, they are not exposed directly to solar radiation. Direct exposure to solar radiation can increase the water and sediment temperature (Fulton & West, 2002).

The temperature measured in this study was close to the results reported in the other studies conducted by Ling *et al.* (2006) (23.50 - 26.20 °C) and Nyanti *et al.* (2015) (24.20 - 25.20 °C) at the rivers that flow into Bakun Hydroelectric Dam Reservoir but temperature detected at Rajang River stations shows slightly higher value.

Figure 4.2 shows the comparison of the mean temperature obtained during trips of three different river discharge amount. During sampling in July 2015, the mean temperature ranged from 25.08 °C to 29.66 °C. In July 2015, the mean temperature among the stations at Rajang River ranged from 28.69 °C to 29.37°C, whereas, among the stations at its tributaries ranged from 25.08 °C to 29.66 °C. The highest reading occurring at station 21 at Pelagus River, a tributary, (29.66 °C) and the lowest reading was recorded at station 24 at a tributary called Mela River (25.08 °C). There was a decreasing trend observed among the stations at the

Rajang River from upstream towards the downstream directions during the sampling in July 2015 (Table 4.4).

Besides, the mean temperature was between 26.32 °C and 28.83 °C in January 2016. In January 2016, the mean temperature among the stations at Rajang River ranged from 28.23 °C to 28.83°C, whereas, among the stations at its tributaries ranged from 26.32 °C to 27.79 °C. The highest temperature was observed at station 28 at the main river (28.83 °C), whereas the lowest at station 21 at Pelagus River (26.32 °C). In January 2016, an increasing trend was observed among the stations at the Rajang River from upstream to downstream up to station 28 but a slight decrease in temperature was observed at station 30 (Table 4.4). This is most likely due to the dilution of cooler water from the tributary upstream with a temperature of 26.42 °C.

In March 2016 sampling, the mean temperature ranged from 26.42 °C to 28.06 °C. In March 2016, the mean temperature among the stations at Rajang River ranged from 26.94 °C to 27.30°C, whereas, among the stations at its tributaries ranged from 26.42 °C to 28.06 °C. The highest mean recorded at station 26 at Cermin River (28.06 °C) and the lowest mean observed at station 29 at Baleh River (26.42°C). An increasing trend was observed among the stations at the Rajang River from upstream to downstream directions in March 2016 (Table 4.4).

Comparatively, temperature data taken in July 2015 were relatively higher compared to those taken in January 2016 and March 2016. This is due to the fact that July 2015 was dry season with obviously low water level at the stations (Table 4.2). Rainfall data in Figure 4.16 and Table 2.1 show that the total monthly rainfall amount was the lowest in that month (131.6 mm) compared to the other two months which are 319.1 mm and 351.8 mm respectively. The temperature was mostly consistently higher at Rajang River stations compared to the stations

located at the tributaries except in March 2016. This is because the Rajang River is much wider compared to its tributaries. Thus, more solar radiation absorbed by the open surface water heated the river. However, there are two stations at the tributaries showing significantly higher temperatures compared to the other tributaries especially in July 2015. They are station 21 at Pelagus River and station 29 at Baleh River. This is because those stations are much wider compared to the other tributaries.

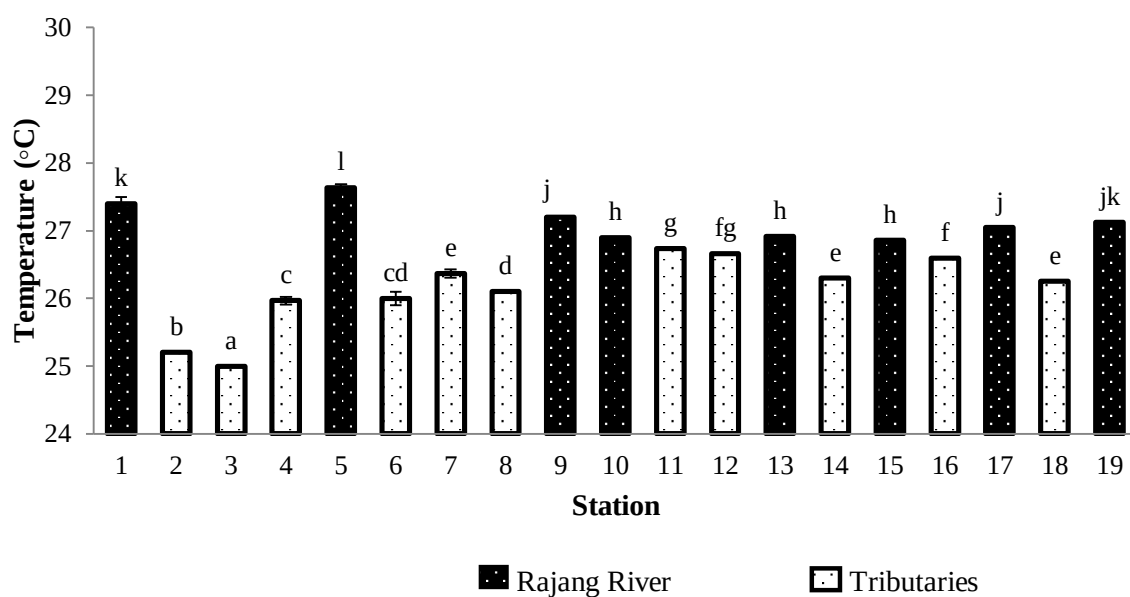


Figure 4.1: The mean temperature at upstream (St 1-9) and midstream (St 10-19). *The same letters among all stations indicate no significant difference ($p < 0.05$).

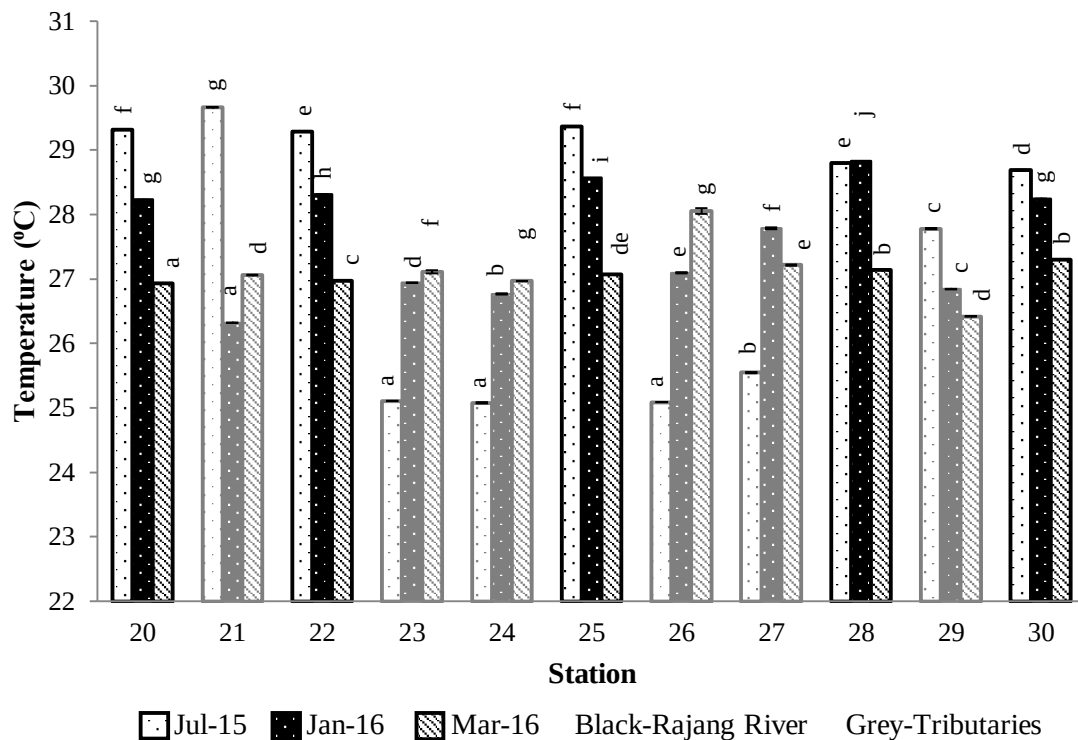


Figure 4.2: The comparison of mean temperature within and among stations in three different sampling periods. The same letters among stations in the same month indicate no significant difference ($p < 0.05$).

Table 4.4: The comparison of mean temperature at Rajang River stations in the downstream section.

Rajang River Stations	Mean Temperature (°C)			Mean
	Jul-15	Jan-16	Mar-16	
20	29.32±0.01	28.23±0.00	26.94±0.00	28.16 ^b
22	29.29±0.00	28.31±0.00	26.97±0.00	28.19 ^b
25	29.37±0.01	28.57±0.00	27.08±0.00	28.34 ^d
28	28.80±0.00	28.83±0.00	27.14±0.00	28.26 ^c
30	28.69±0.01	28.25±0.00	27.30±0.00	28.08 ^a
Mean ± SD	29.09±0.32 ^C	28.44±0.26 ^B	27.09±0.15 ^A	

Different capital letters show significant difference between the different sampling months ($p < 0.05$). Different small letters show significant difference among the stations ($p < 0.05$).

4.1.2.1.2 Conductivity

Figure 4.3 shows the mean conductivity at the Rajang River of the Pelagus area and its tributaries at the upstream and midstream sections. The mean conductivity ranged from 24.00 $\mu\text{S}/\text{cm}$ to 33.30 $\mu\text{S}/\text{cm}$ at the upstream section. Among the stations along the Rajang River, the mean conductivity ranged from 31.20 $\mu\text{S}/\text{cm}$ to 31.50 $\mu\text{S}/\text{cm}$, whereas, among its tributaries, the mean conductivity ranged from 24.00 $\mu\text{S}/\text{cm}$ to 33.30 $\mu\text{S}/\text{cm}$. Station 7 at Metah River, a tributary, recorded the lowest mean conductivity value at the upstream section. Meanwhile, the highest mean conductivity was found at station 8 at Pila River for the upstream section. For the upstream section, there was an increasing trend of mean conductivity observed among the stations at the main river, the Rajang River, from upstream to the downstream direction.

For the midstream section, the mean concentration of conductivity ranged from 2.00 $\mu\text{S}/\text{cm}$ to 33.00 $\mu\text{S}/\text{cm}$. Among the stations along the Rajang River, the mean conductivity ranged from 30.00 $\mu\text{S}/\text{cm}$ to 32.00 $\mu\text{S}/\text{cm}$, whereas, among its tributaries, the mean conductivity ranged from 2.00 $\mu\text{S}/\text{cm}$ to 33.00 $\mu\text{S}/\text{cm}$ for the midstream section. The lowest reading occurred at station 18, a tributary called Peraran Besar River, whereas, the highest of mean conductivity was recorded at station 11 at a tributary called Ensawi River. For the midstream section, the trend of the mean conductivity of the stations at the Rajang River was increasing from upstream to downstream with a slight but significant decrease of the mean conductivity at station 15 (30.00 $\mu\text{S}/\text{cm}$).

Conductivity in rivers or streams is influenced by the area's geology through which the water flows (Jenkins *et al.*, 2005). According to USEPA (2012), the conductivity range outside of 15.00-50.00 $\mu\text{S}/\text{cm}$ is unsuitable for certain species of fish and macro invertebrates.

Conductivity value recorded in this study fall in Class I ($< 1000 \mu\text{S/cm}$) of NWQS according to DOE (DOE, 2014) as shown in Table 4.6. The value of conductivity is similar to the value of conductivity found in Bertam River and its tributaries in Cameron Highlands, Malaysia in a study conducted by Eisakhani & Malakahmad (2009) which ranged from 9.00 to 66.00 $\mu\text{S/cm}$. The range outside of 150-500 $\mu\text{S/cm}$ is unfavourable for certain species of macro-invertebrates and fish (USEPA, 2012). In the present study, the mean conductivity at the upstream and midstream sections were below the range of the unfavourable for certain species of macro-invertebrates.

Figure 4.4 illustrates the comparison of the mean conductivity between the three different sampling months. For the sampling in July 2015, the mean pH ranged from 31.00 $\mu\text{S/cm}$ to 74.00 $\mu\text{S/cm}$. In July 2015, the mean conductivity among the stations at Rajang River ranged from 31.00 $\mu\text{S/cm}$ to 42.67 $\mu\text{S/cm}$, whereas, among the stations at its tributaries ranged from 38.00 $\mu\text{S/cm}$ to 74.00 $\mu\text{S/cm}$. The highest occurred at station 27 at Nanga Senuang, whereas, the lowest was observed at station 21 at the Pelagus River. In July 2015, the trend of the mean conductivity of the stations at the Rajang River was constant from upstream to downstream with a slight decrease of the mean conductivity at station 25 (31.00 $\mu\text{S/cm}$) (Table 4.5).

Meanwhile, mean conductivity ranged from 24.00 $\mu\text{S/cm}$ to 82.00 $\mu\text{S/cm}$ during the sampling in January 2016. In January 2016, the mean conductivity among the stations at Rajang River ranged from 32.10 $\mu\text{S/cm}$ to 33.00 $\mu\text{S/cm}$, whereas, among the stations at its tributaries ranged from 25.00 $\mu\text{S/cm}$ to 82.00 $\mu\text{S/cm}$. Station 27 at Nanga Senuang recorded the highest mean conductivity among all the stations and the lowest mean was observed at station 21 at Pelagus River. In January 2016, the trend of the mean conductivity of the stations at the Rajang River was constant from upstream to downstream stations (Table 4.5).

In March 2016 sampling, the mean conductivity ranged from 29.09 $\mu\text{S}/\text{cm}$ to 39.58 $\mu\text{S}/\text{cm}$. In March 2016, the mean conductivity among the stations at Rajang River ranged from 31.00 $\mu\text{S}/\text{cm}$ to 31.05 $\mu\text{S}/\text{cm}$, whereas, among the stations at its tributaries ranged from 29.09 $\mu\text{S}/\text{cm}$ to 39.58 $\mu\text{S}/\text{cm}$. The highest mean recorded at station 27 at Nanga Senuang, while, the lowest was observed at station 21 at Pelagus River. In March 2016, the trend of conductivity at the stations at the Rajang River was constant from upstream to downstream stations (Table 4.5).

There are a few tributary stations recording significantly higher conductivity values compared to the other stations. They are station 23 at Kapit Hulu River, station 24 at Mela River, station 26 at Cermin River and station 27 at Nanga Senuang River. The higher values of conductivity at these tributaries may be contributed through the runoff due to the higher rainfall amount at the time of the sampling. However, these concentrations did not affect the conductivity values at the main river, the Rajang River stations at downstream section as there was no significant increase in conductivity value. Besides, the conductivity in the river water depends on the geological conditions around the area where water flow into those tributaries. This is because the salts come from rocks that have been broken down by water flowing over them, and the types of rock and soil around waterbodies control conductivity (Tan, 2010).

Conductivity is an indirect measure of the saltiness of the water (Horne & Goldman, 1994). Fish and other organisms that live in freshwater cannot tolerate large increases in the saltiness of the water because they will not be able to keep water in their bodies (Horne & Goldman, 1994). In the present study, the conductivity was considered low and classified under Class I of NWQS according to DOE (Table 4.7). Low conductivity (0 to 200 $\mu\text{S}/\text{cm}$) is an indicator of pristine or background conditions (Horne & Goldman, 1994).

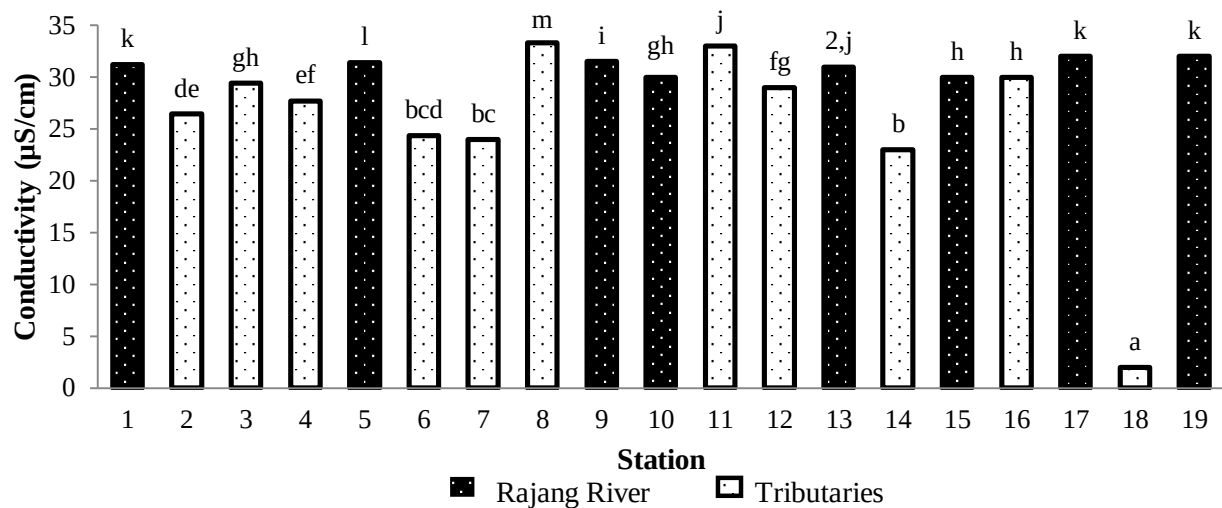


Figure 4.3: The mean conductivity at upstream (St 1-9) and midstream (St 10-19). The same letters among all stations indicate no significant difference ($p < 0.05$).

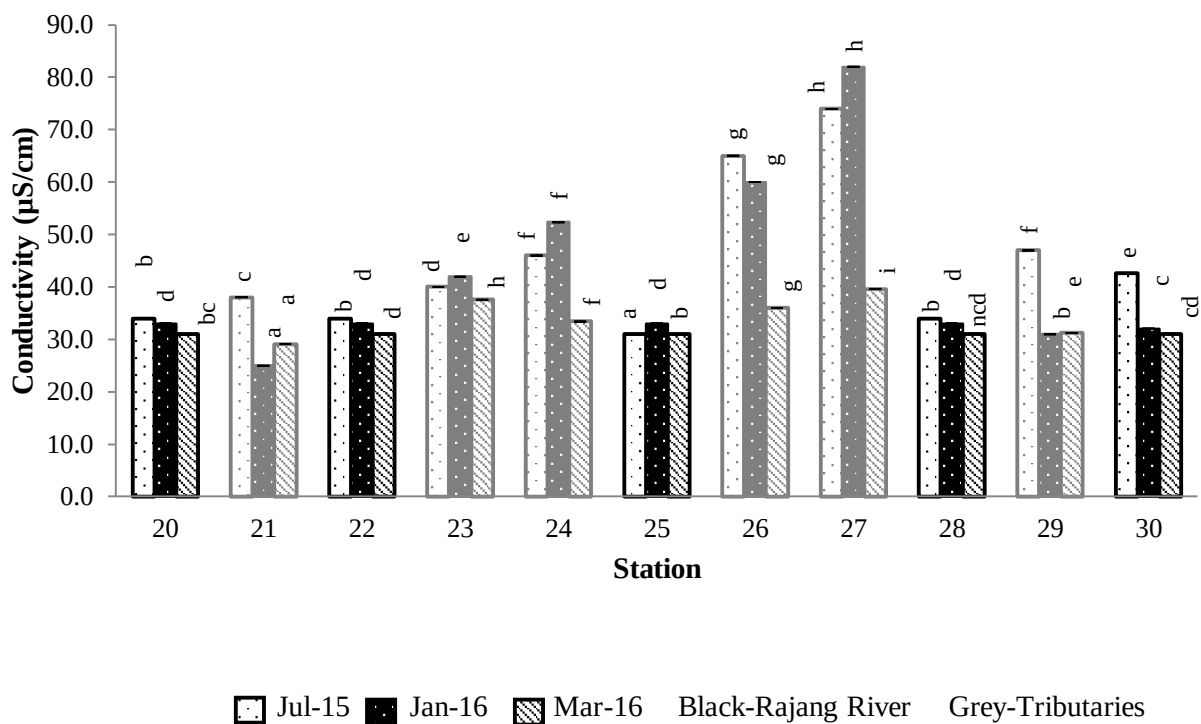


Figure 4.4: The comparison of mean conductivity within and among stations in three different sampling periods. The same letters among stations in the same month indicate no significant difference ($p < 0.05$).

Table 4.5: The comparison of mean conductivity at Rajang River stations in the downstream section.

Rajang River Stations	Mean Conductivity($\mu\text{S}/\text{cm}$)			Mean
	Jul-15	Jan-16	Mar-16	
20	34.00 $\pm$ 0.00	33.00 $\pm$ 0.00	31.00 $\pm$ 0.00	32.67 ^b
22	34.00 $\pm$ 0.00	33.00 $\pm$ 0.00	31.06 $\pm$ 0.00	32.69 ^b
25	31.00 $\pm$ 0.00	33.00 $\pm$ 0.00	31.00 $\pm$ 0.00	31.67 ^a
28	34.00 $\pm$ 0.00	33.00 $\pm$ 0.00	31.05 $\pm$ 0.00	32.68 ^b
30	42.67 $\pm$ 0.00	32.00 $\pm$ 0.00	31.05 $\pm$ 0.00	35.24 ^c
Mean $\pm$ SD	35.13 $\pm$ 4.41 ^C	32.80 $\pm$ 0.45 ^B	31.03 $\pm$ 0.03 ^A	

Different capital letters show significant difference between the different sampling months ($p < 0.05$). Different small letters show significant difference among the stations ($p < 0.05$).

Table 4.6: NWQS classification of the water quality parameters for upstream and midstream sections

Section	St	NH ₃ N	BOD	COD	DO	pH	Cond.	TSS	Turb.	NO ₂ N	NO ₃ N
Upstream	1	II	III	IV	II	I	I	II	>II	I	I
	2	II	III	III	II	I	I	V	>II	I	I
	3	II	II	III	I	I	I	I	II	I	I
	4	II	II	III	I	I	I	II	>II	I	I
	5	II	III	IV	II	I	I	III	>II	I	I
	6	II	II	II	I	I	I	IV	>II	I	I
	7	II	II	III	I	I	I	I	II	I	I
	8	II	II	III	I	I	I	II	II	I	I
	9	II	III	IV	II	I	I	II	>II	I	I
Midstream	10	II	II	III	I	II	I	III	>II	I	I
	11	II	III	III	I	II	I	III	>II	I	I
	12	II	II	II	I	II	I	III	>II	I	I
	13	III	II	III	I	II	I	III	>II	I	I
	14	III	II	II	I	II	I	IV	>II	I	I
	15	III	II	III	I	I	I	IV	>II	I	I
	16	II	III	III	II	I	I	II	>II	I	I
	17	II	II	III	I	I	I	III	>II	I	I
	18	II	II	II	I	I	I	II	II	I	I
	19	II	II	III	I	I	I	III	>II	I	I

*Bold indicates the stations along Rajang River

Table 4.7: Classification of downstream water quality in July 2015, January 2016 and March 2016 according to NWQS

July 2015										
St	NH ₃ N	BOD	COD	DO	pH	Cond.	TSS	Turb.	NO ₂ N	NO ₃ N
20	I	III	III	II	I	I	III	>II	I	I
21	II	II	III	I	I	I	III	II	I	I
22	I	III	III	II	I	I	III	>II	I	I
23	I	II	III	I	I	I	V	>II	I	I
24	II	II	II	I	I	I	III	II	I	I
25	II	II	III	II	I	I	II	>II	I	I
26	II	II	III	I	I	I	V	>II	I	I
27	I	III	III	II	I	I	III	>II	I	I
28	II	III	IV	II	I	I	III	>II	I	I
29	II	II	II	I	I	I	II	II	I	I
30	II	III	III	II	I	I	III	>II	I	I
January 2016										
St	NH ₃ N	BOD	COD	DO	pH	Cond.	TSS	Turb.	NO ₂ N	NO ₃ N
20	II	III	IV	III	I	I	IV	>II	I	I
21	II	III	IV	II	I	I	V	>II	I	I
22	II	III	IV	III	I	I	IV	>II	I	I
23	II	III	III	II	I	I	II	II	I	I
24	II	III	III	II	I	I	I	I	I	I
25	II	III	IV	III	I	I	IV	>II	I	I
26	II	III	III	II	I	I	I	I	I	I
27	II	III	III	II	I	I	I	I	I	I
28	II	III	IV	III	I	I	III	>II	I	I
29	II	III	III	II	I	I	V	>II	I	I
30	II	III	IV	II	I	I	V	>II	I	I
March 2016										
St	NH ₃ N	BOD	COD	DO	pH	Cond.	TSS	Turb.	NO ₂ N	NO ₃ N
20	II	II	III	I	II	I	V	>II	I	I
21	III	III	IV	II	I	I	V	>II	I	I
22	II	II	IV	I	II	I	V	>II	I	I
23	II	II	III	II	II	I	II	II	I	I
24	II	III	III	II	II	I	III	>II	I	I
25	II	II	III	I	II	I	V	>II	I	I
26	III	III	III	I	II	I	V	>II	I	I
27	II	III	III	II	II	I	IV	>II	I	I
28	II	II	III	I	II	I	V	>II	I	I
29	II	II	IV	I	II	I	V	>II	I	I
30	III	II	III	I	II	I	V	>II	I	I

*Bold indicated the stations at Rajang River

4.1.2.1.3 Turbidity, Transparency and TSS

Figure 4.5 shows the reading of mean turbidity for the upstream and midstream sections. For the upstream section, the range of mean turbidity falls between 13.4 NTU and 716.0 NTU. Among the stations along the Rajang River, the mean turbidity ranged from 72.2 NTU to 87.1 NTU, whereas, among its tributaries, the mean turbidity ranged from 13.4 NTU to 716.0 NTU for this section. Among the stations at the upstream section, the lowest mean turbidity was observed at station 3 at Pengau Besar, a small tributary of Rajang River. Meanwhile, the highest mean turbidity was found at station 2 at Punan Sama River. For the midstream section, the mean of turbidity ranged from 2.6 NTU to 291.5 NTU. Among the stations along the Rajang River, the mean turbidity ranged from 107.4 NTU to 162.1 NTU, whereas, among its tributaries, the mean turbidity ranged from 2.6 NTU to 291.5 NTU for this section. Among the stations at the midstream section, the highest mean turbidity was recorded at station 14 at Sama River, whereas, the lowest mean reading of turbidity was observed at station 18.

The mean values of transparency for the upstream and midstream sections are shown in Figure 4.7. The range of transparency of the upstream section was between 0.05 m and 0.71 m. Among the stations along the Rajang River, the mean transparency ranged from 0.18 m to 0.22 m, whereas, among its tributaries, the mean transparency ranged from 0.05 m to 0.71 m for this section. The highest mean transparency was recorded at station 3 at Pengau Besar River. Meanwhile, the lowest mean transparency occurred at station 2 at Punan Sama River. Meanwhile, the range of transparency of the midstream section was between 0.01 m and 0.15 m. Among the stations along the Rajang River, the mean transparency ranged from 0.05 m to 0.10 m, whereas, among its tributaries, the mean transparency ranged from 0.01 m to 0.15 m

for this section. The highest mean transparency was recorded at station 11 at Ensawi River, while, the lowest mean transparency occurred at station 14 at Sama River.

Figure 4.9 shows the mean TSS according to stations at the upstream and midstream section. Its mean concentrations ranged from 17.3 mg/L to 510.0 mg/L for the upstream section. Among the stations along the Rajang River, the mean TSS ranged from 41.7 mg/L to 76.4 mg/L, whereas, among its tributaries, the mean TSS ranged from 17.3 mg/L to 510.0 mg/L for this section. The highest mean TSS was found at station 2 at Punan Sama River, while, the lowest mean TSS was recorded at station 7 at Metah River. For the midstream section, the range of mean TSS was between 28.0 mg/L and 260.0 mg/L. Among the stations along the Rajang River, the mean TSS ranged from 78.7 mg/L to 158.7 mg/L, whereas, among its tributaries, the mean TSS ranged from 28.0 mg/L to 260.0 mg/L for this section. The highest mean TSS was recorded at station 14 at Sama River, whereas, the lowest mean TSS was found at station 18 at Pila River.

Among the stations at the Rajang River, decreasing trend was observed at the upstream section for the turbidity and TSS. For the midstream section, the decreasing trend was also observed among the stations at the Rajang River for the turbidity and TSS. However, a slight increase in turbidity and TSS was observed at station 13 to station 15. This is most likely due to the addition of the suspended solids reflected by value of turbidity and TSS from station 14 at Sama River, a tributary, upstream of station 15. A total of three of the studied tributaries also shows significantly higher reading of mean turbidity than the other stations. They are station 2 (716.0 NTU) at Punan Sama River and station 6 (308.3 NTU) at Bah River for the upstream section, station 14 (291.0 NTU) at Sama River for the midstream section. Similarly, there are significantly higher values of TSS found in three stations at the tributaries. They are

station 2 at Punan Sama River (510.0 mg/L) and station 6 at Bah River (204.7 mg/L) for the upstream section, whereas, station 14 at Sama River (260.0 mg/L) for the midstream section. The common land use in those stations are active logging activities. Therefore, they are affected by the runoff carrying the loose soil resulting from the logging operation into the river.

Generally, the higher the concentration of TSS the more polluted is the river system. Clear rivers recorded TSS of less than 40 mg/L (Jenkins *et al.*, 2005) and most of the stations in the present study exceeded that value except for only seven stations. They are station 3 (9.0 mg/L) at Penggau Besar, station 7 (17.3 mg/L) at Metah River, station 8 (39.0 mg/L) at Pila River and station 18 (28.00 mg/L) at Peraran Besar River. The turbidity is classified as Class II or >II according to NWQS of DOE (Table 4.6). Meanwhile, the TSS parameter is classified between Class I and V according to NWQS of DOE (Table 4.6). The station that was classified as Class V is the station located at Punan Sama River which was an active site for logging activities during the time of the sampling. The logging activities were contributed to the soil erosion which could brought by rain water into the river.

The comparison of mean turbidity among three different trips and stations is shown in Figure 4.6, whereas, Figure 4.8 shows the comparison of mean transparency among different trips and stations. The range of the mean turbidity in July 2015 falls in between 19.8 NTU and 411.6 NTU. In July 2015, the mean turbidity among the stations at Rajang River ranged from 55.57 NTU to 61.47 NTU, whereas, among the stations at its tributaries ranged from 19.87 NTU to 411.63 NTU. The highest mean observed at station 26 (411.6 NTU) whereas the lowest mean was recorded at station 29 (19.8 NTU). Meanwhile, the mean turbidity in January 2016 ranged from 0.0 NTU to 1183.7 NTU. The mean turbidity among the stations at

Rajang River ranged from 70.06 NTU to 198.50 NTU, whereas, among the stations at its tributaries ranged from 0.00 NTU to 1183.72 NTU. The highest mean occurred at station 21 (1183.7 NTU) while the lowest was observed at station 24 (0.0 NTU). In March 2016, the mean turbidity ranged between 33.1 NTU and 797.4 NTU. The mean turbidity among the stations at Rajang River ranged from 109.18 NTU to 117.02 NTU, whereas, among the stations at its tributaries ranged from 33.13 NTU to 794.40 NTU. The highest mean was observed at station 29 (797.4 NTU) while the lowest mean was recorded at station 23 (33.1 NTU).

Significantly higher turbidity detected at station 21 in January 2016 was due to the soil erosions from the exposed land due to active logging of planted forest site and exposed soil from oil palm plantation upstream of the river. The highest turbidity at station 21 (1183.7 NTU), Pelagus River sampling during rainy season is higher than that recorded at the rivers that flow into Bakun Dam Reservoir, that ranged from 5.60 to 126.8 NTU (Ling *et al.*, 2015) during rainy season. But, value in the present study were similar to the turbidity reading recorded at Murum River (611 - 1141 NTU) at depths of 0.2 m to 30 m in study conducted 13 months after Bakun reservoir reached its full supply level (Nyanti *et al.*, 2015).

Besides, the mean transparency in July 2015 ranged from 0.05 m to 0.38 m. The mean transparency among the stations at Rajang River ranged from 0.09 m to 0.71 m, whereas, among the stations at its tributaries ranged from 0.05 m to 0.57 m. The highest mean observed at station 21 (0.38 m) whereas the lowest mean (0.05 m) was found at station 23 and station 26. In January 2016, the mean transparency ranged in between 0.00 m and 1.55 m. The mean transparency among the stations at Rajang River ranged from 0.01 m to 0.21 m, whereas, among the stations at its tributaries ranged from 0.05 m to 0.38 m. The highest mean at station

26 (1.55 m) and lowest mean was found at station 29 (0.04 m). In March 2016, the mean transparency ranged in between 0.05 m and 0.30 m. The mean transparency among the stations at Rajang River ranged from 0.05 m to 0.30 m, whereas, among the stations at its tributaries ranged from 0.05 m to 0.30 m. The highest mean at station 22, 26 and 28 (0.3 m) and lowest mean was found at station 20 and 23 (0.05 m). The low transparency is most likely because of soil erosion from the anthropogenic activities near the river basin. A study done in Changshou Reservoir also found that low transparency in the water body was observed which varied from 0.50 m to 1.55 m due to the soil erosion (Zhang *et al.*, 2006).

The comparison of the mean TSS among the stations during three different trips is shown in Figure 4.10. The range of mean TSS in July 2015 sampling was 33.3 mg/L to 392.0 mg/L. In July 2015, the mean TSS among the stations at Rajang River ranged from 48.00 mg/L to 84.00 mg/L, whereas, among the stations at its tributaries ranged from 33.33 mg/L to 392.00 mg/L. In July 2015, station 26 (392.0 mg/L) was observed with the highest mean whereas the lowest mean was recorded at station 29 (33.3 mg/L). On the other hand, the mean TSS in January 2016 ranged from 4.0 mg/L to 1696.0 mg/L. In January 2016, the mean TSS among the stations at Rajang River ranged from 56.00 mg/L to 388.00 mg/L, whereas, among the stations at its tributaries ranged from 4.00 mg/L to 1696.00 mg/L. In March 2016, the mean TSS among the stations at Rajang River ranged from 672.00 mg/L to 1617.33 mg/L, whereas, among the stations at its tributaries ranged from 32.00 mg/L to 1674.67 mg/L. The highest mean at station 21 (1696.0 mg/L) and the lowest mean was found at station 24 (4.0 mg/L). Meanwhile, the mean TSS in March 2016 ranged from 32.0 mg/L to 1674.7 mg/L. The highest mean was observed at station 29 (1674.7 mg/L) whereas the lowest mean was found at station 23 (32.0 mg/L).

During the sampling in July 2015 only station 29 (33.3 mg/L) at Baleh River recorded TSS value lower than 40 mg/L which indicates the clear river (Jenkins *et al.*, 2005). Meanwhile, in January 2016, station 23 (36.0 mg/L) at Kapit Hulu River, station 24 (4.0 mg/L) at Mela River, station 26 (20.0 mg/L) at Cermin River and station 27 (16.0) at Nanga Senuang recorded TSS value lower than 40 mg/L. Significantly higher values of TSS found in January and March 2016 due to the high erosion as the amount of rainfall before and at the time of the sampling were higher (Figure 2.3).

The TSS levels in this study were highly influenced by logging activities and land erosion during rainy season. In fact, TSS levels response to the rate of soil erosion, soil types and intensity (Jenkins, 2005). Higher TSS are contributed by more inorganic and organic particles which affected the turbidity of the river water. This was supported by the highly significant positive correlation of TSS value with turbidity ($r = +0.855$, p value < 0.05 , $n=29$) at the tributaries.

According to the NWQS, the turbidity is classified as Class I, II and >II (Table 4.7). Meanwhile, TSS is classified as Classes I to V (Table 4.7). NWQS classification is clearly changed from July 2015 to January 2016 and March 2016. The changes in NWQS classification was observed at all the tributaries stations. Station 21 at Pelagus River and station 29 at Baleh River deteriorates from Class II in July 2015 to Class III in January 2016 and March 2016. This is because both stations are active sites for harvesting and replanting trees that exposed forest soil floor easily for erosions. This observation is similar to results in Baleh River after a rainfall event and active logging site where the NWQS classification changed from Class I to Class III and IV (Ling *et al.*, 2016). Meanwhile, the other tributaries at station 23, 24, 26 and 27 improved from Class II or III in July 2015 to Class I or II in

January and March 2016 (Table 4.7). The changes could be influenced by the weather condition at the time of the sampling which is raining season. The soil erosion brought by rain water into the river can increase the TSS and turbidity reading.

Similar to turbidity, the reading of TSS often shows a sharp increase when it rains because during a rainfall event the rapid increase of stream velocity speeds up the erosion rates of stream banks and channel. This condition is often observed in developed watershed areas which have relatively high proportions of loose surfaces. Extremely high turbidity and high suspended sediment loads were detected mainly originating from upstream soil erosion due to the construction of logging roads and camps, skid trails and logging in the river basins was reported by Malaysia Department of Environment (DOE, 2014). The turbidity values are highly significant and positively correlated with TSS ($r = +0.799$, p value < 0.05 , $n=30$). On the other hand, the transparency has the opposite trend with turbidity. As the turbidity is high, the river transparency is low.

For the stations among the Rajang River, the comparison of mean turbidity at in the downstream section was shown in Table 4.8. The comparison of mean transparency at Rajang River stations in the downstream section was shown in Table 4.9. Table 4.10 shows the comparison of mean TSS at Rajang River stations in the downstream section. Overall, the mean turbidity and mean TSS of the stations along the Rajang River at the downstream section was significantly lower in value in July 2015 than in January 2016 and March 2016 (Table 4.8 and Table 4.10). Meanwhile, the mean transparency of the stations along the Rajang River at the downstream section was significantly higher in value in July 2015 compared to that in January 2016 and March 2016 (Table 4.9).

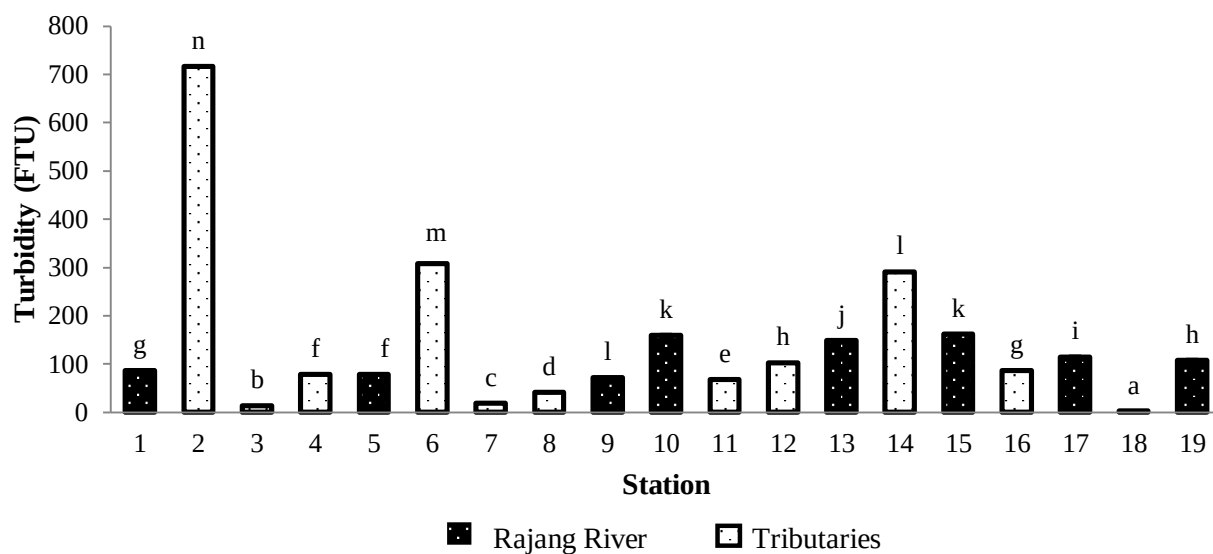


Figure 4.5: The mean turbidity at upstream (St 1-9) and midstream (St 10-19). The same letters among all stations indicate no significant difference ($p < 0.05$).

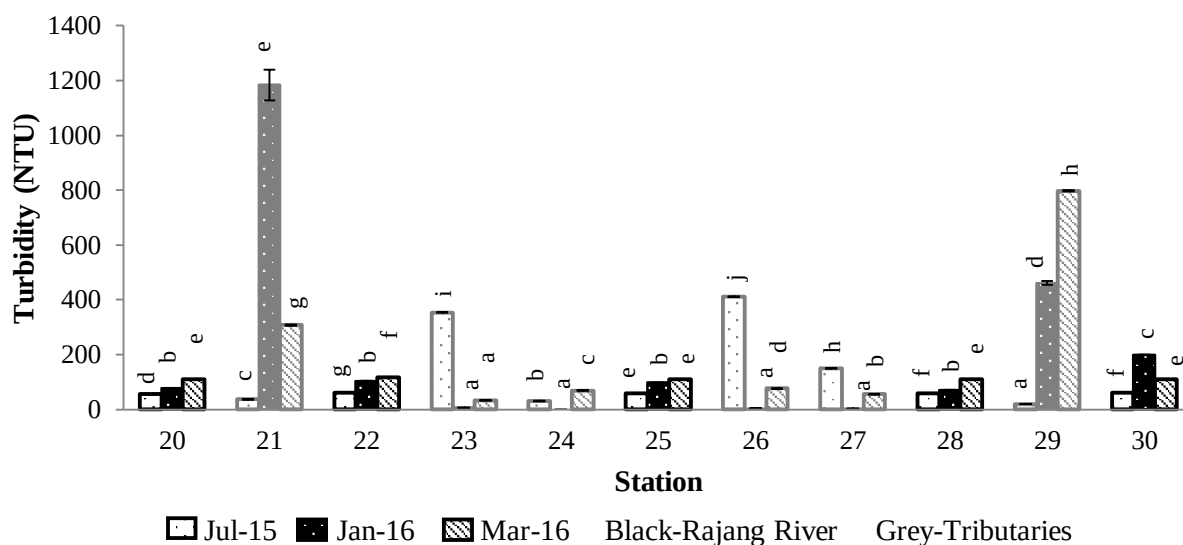


Figure 4.6: The comparison of mean turbidity within and among stations in three different sampling periods. The same letters among stations in the same month indicate no significant difference ($p < 0.05$).

Table 4.8: The comparison of mean turbidity at Rajang River stations in the downstream section.

Rajang River Stations	Mean Turbidity			Mean
	Jul-15	Jan-16	Mar-16	
20	55.57±0.42	76.88±0.21	109.53±1.41	80.66 ^b
22	61.47±0.58	104.18±0.30	117.02±0.48	94.22 ^d
25	58.03±0.21	98.01±0.20	109.71±0.65	88.59 ^c
28	59.87±0.25	70.06±0.46	109.18±0.25	79.70 ^a
30	60.17±0.59	198.50±1.32	110.04±0.41	122.90 ^e
Mean ± SD	59.02±2.29 ^A	109.53±51.72 ^B	111.10±3.32 ^C	

Different capital letters show significant difference between the different sampling months ($p < 0.05$). Different small letters show significant difference among the stations ($p < 0.05$).

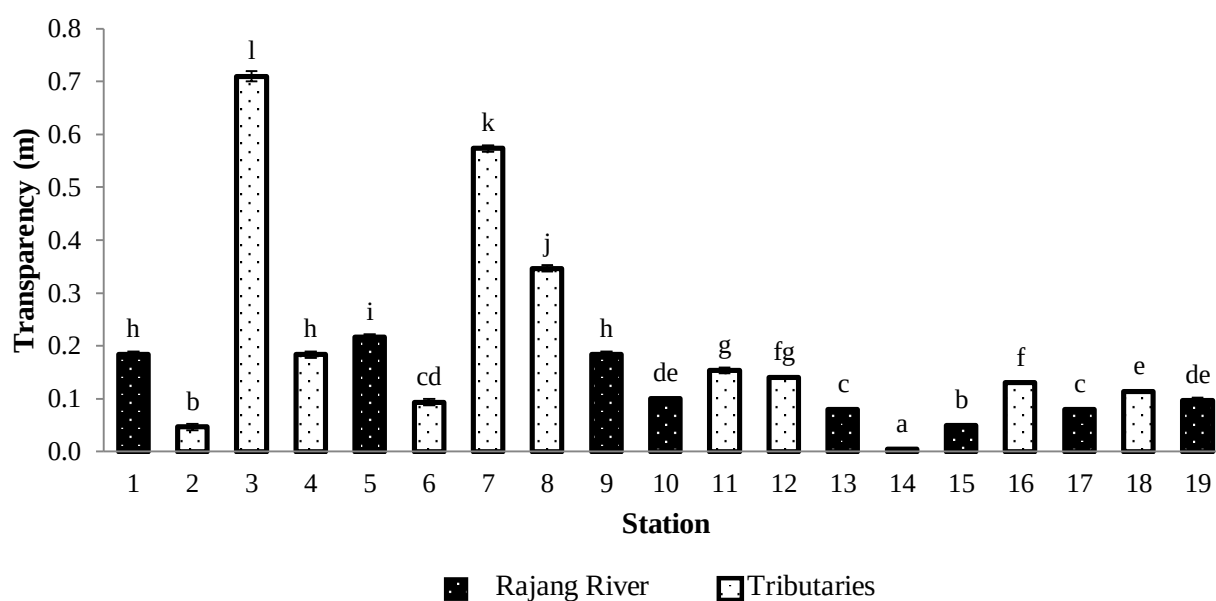


Figure 4.7: The mean transparency at upstream (St 1-9) and midstream (St 10-19). The same letters among all stations indicate no significant difference ($p < 0.05$).

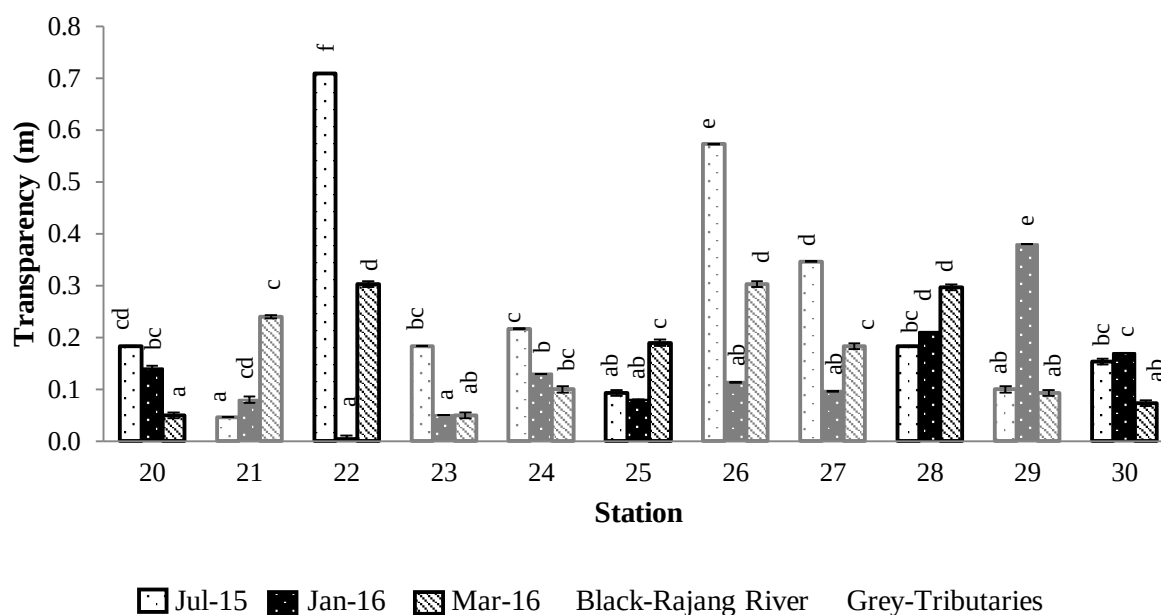


Figure 4.8: The comparison of mean transparency within and among stations in three different sampling periods. The same letters among stations in the same month indicate no significant difference ($p < 0.05$).

Table 4.9: The comparison of mean transparency at Rajang River stations in the downstream section.

Rajang River Stations	Mean Transparency			Mean
	Jul-15	Jan-16	Mar-16	
20	0.18±0.00	0.14±0.01	0.05±0.01	0.12 ^a
22	0.71±0.00	0.01±0.01	0.30±0.01	0.34 ^c
25	0.09±0.01	0.08±0.00	0.19±0.01	0.12 ^a
28	0.18±0.00	0.21±0.00	0.30±0.01	0.23 ^b
30	0.15±0.01	0.17±0.00	0.07±0.01	0.13 ^a
Mean ± SD	0.26±0.25 ^C	0.12±0.08 ^A	0.18±0.12 ^B	

Different capital letters show significant difference between the different sampling months ($p < 0.05$). Different small letters show significant difference among the stations ($p < 0.05$).

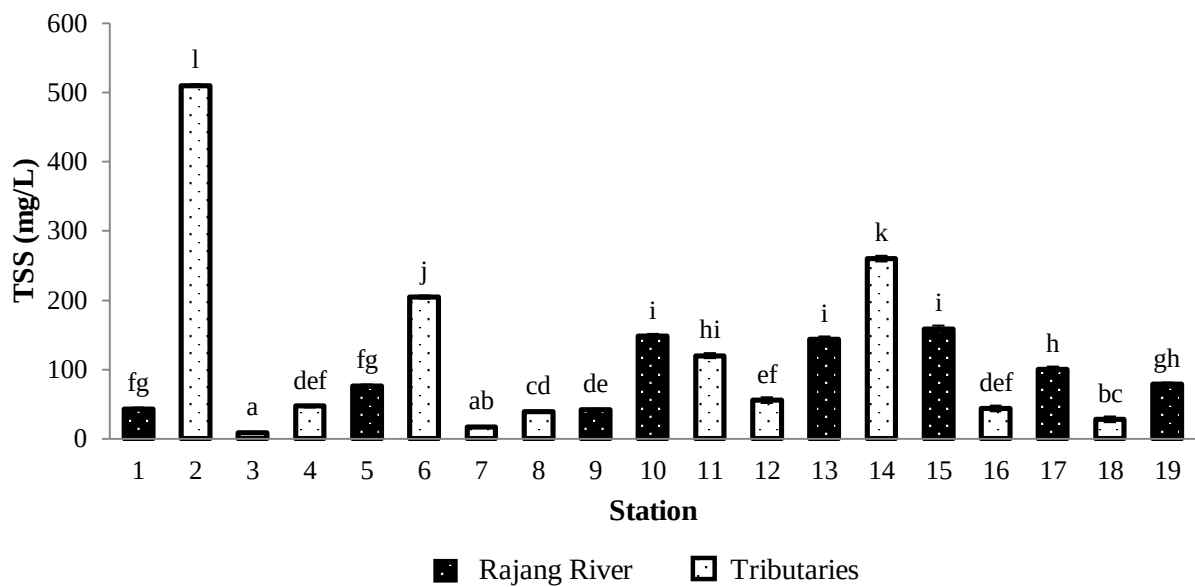


Figure 4.9: The mean TSS at upstream (St 1-9) and midstream (St 10-19). The same letters among all stations indicate no significant difference ($p < 0.05$).

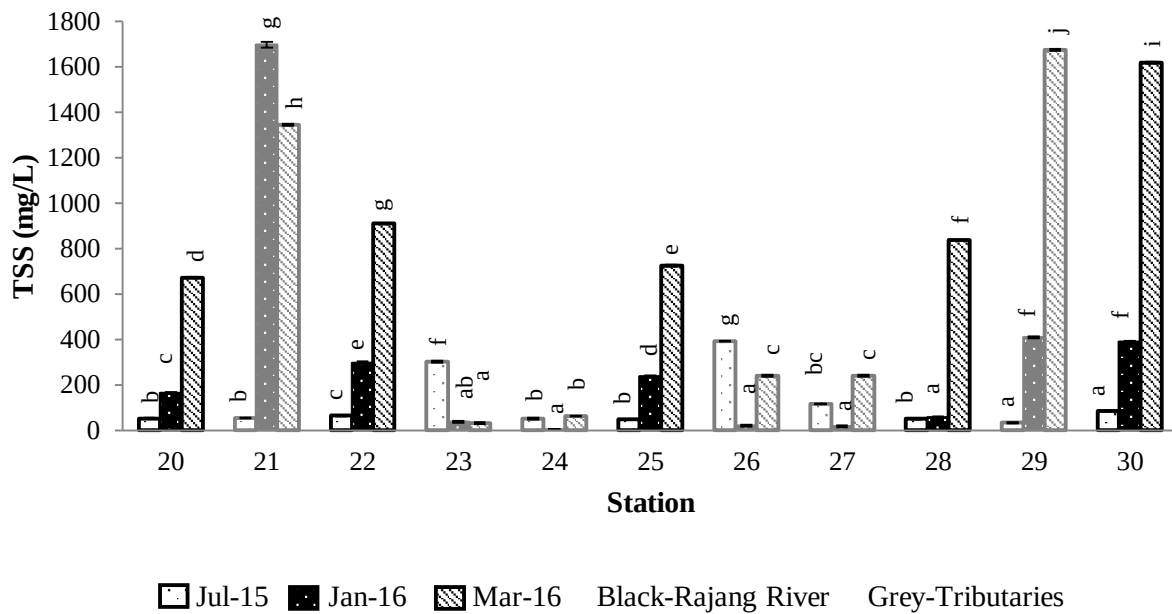


Figure 4.10: The comparison of mean TSS within and among stations in three different sampling periods. The same letters among stations in the same month indicate no significant difference ($p < 0.05$).

Table 4.10: The comparison of mean TSS at Rajang River stations in the downstream section.

Rajang River Stations	Mean TSS			Mean
	Jul-15	Jan-16	Mar-16	
20	51.33±3.06	164.00±3.06	672.00±3.06	295.78 ^a
22	64.67±3.06	297.33±2.11	909.33±2.31	423.78 ^d
25	48.00±2.00	236.00±3.06	724.00±3.06	336.00 ^b
28	50.67±3.06	256.00±3.06	837.33±2.31	381.33 ^c
30	84.00±2.00	388.00±3.06	1617.33±3.06	696.44 ^e
Mean ± SD	59.73±15.03 ^A	228.27±126.64 ^B	952.00±383.41 ^C	

Different capital letters show significant difference between the different sampling months ($p < 0.05$). Different small letters show significant difference among the stations ($p < 0.05$).

4.1.2.2 Chemical parameters data

4.1.2.2.1 pH

The mean pH of the stations at upstream and midstream section is shown in Figure 4.11. The mean pH at the upstream section ranged from 6.65 to 7.61. Among the stations along the Rajang River, the mean pH ranged from 6.65 to 7.13 whereas, among its tributaries, the mean pH ranged from 6.70 to 7.61 for this section. For the upstream section, significantly higher pH was recorded at station 2 at Punan Sama River. Meanwhile, significantly lower pH value was found at station 5 at Rajang River. The mean pH at the midstream section ranged from 6.20 to 6.86. Among the stations along the Rajang River, the mean pH ranged from 6.20 to 6.86 whereas, among its tributaries, the mean pH ranged from 6.25 to 6.81 for this section. Significantly higher reading occurred at station 17 at Rajang River. Meanwhile, significant lower pH was in station 10 at Rajang River station.

Generally, the stations along the Rajang River shows lower pH compared to the stations at the tributaries. The slightly acidic nature of water at the stations at the Rajang River (station 5, 10,

13, 15 and 19) might be explained by the contribution of human activities such as logging and improper waste disposal from residential areas along the river. This is because the increase in the rate of decomposition of organic matter can lead to acidification and lowered pH values (Chetana *et al.*, 1997). Besides, the slightly acidic nature of water among the stations at Rajang River at the midstream section was influenced by the high discharge from the spillway with 2002.0 m³/s (Table 3.2). This indicates that the water discharge from the outflow of Bakun Hydroelectric Dam was slightly acidic.

The pH of the aquatic system is an important indicator of the water quality and the extent of pollution in the watershed. Normally, unpolluted streams give an almost neutral or slightly alkaline pH. But, if surface water has a pH value below 6, it can be hazardous to aquatic life (Jenkins *et al.*, 2005). The pH value in this study was close to the optimum pH for the unpolluted streams. Those readings were similar to the study at Serin River which recorded a mean pH range of 6.5 to 7.1 (Ling *et al.*, 2006). The pH of most of the stations was classified as Class I or II according to NWQS of DOE (Table 4.6).

Figure 4.12 shows the comparison of mean pH within and among stations in three different sampling periods. The mean pH taken in July 2015 sampling ranged from 6.83 to 7.32. In July 2015, the mean pH among the stations at Rajang River ranged from 6.83 to 7.00, whereas, among the stations at its tributaries ranged from 7.14 to 7.32. The highest reading recorded at station 29 at Baleh River, whereas, the lowest reading was recorded at station 20 at Rajang River. Meanwhile, in January 2016 sampling ranged from 6.55 to 7.03. In January 2016, the mean pH among the stations at Rajang River ranged from 6.55 to 6.89, whereas, among the stations at its tributaries ranged from 6.81 to 7.03. The highest reading occurred at station 24 at Mela River, while, the lowest occurred at station 22 at Rajang River. During the sampling

in March 2016, the mean pH ranged from 6.21 to 6.43. In March 2016, the mean pH among the stations at Rajang River ranged from 6.21 to 6.34, whereas, among the stations at its tributaries ranged from 6.33 to 6.52. The highest reading was observed at station 26 at Cermin River whereas the lowest reading was observed at station 20 at Rajang River.

The comparison of mean pH at Rajang River stations in the downstream section is shown in Table 4.11. The pH at Rajang River stations in March 2016 were the lowest compared to the pH in July 2015 and January 2016. The pH is the lowest in March 2016 because of the higher discharge from Bakun Hydroelectric Dam (2794 m³/m). The total discharge is significantly higher compared to the discharge in July 2015 (974 m³/m) and January 2016 (970 m³/m). Therefore, it lowered the acidity of the Rajang River.

Generally, pH is recorded consistently higher in July 2015 followed by January 2016 and the lowest was in March 2016 (Table 4.11). The pH observed during July 2015 is significantly higher than the other two sampling trips ($p < 0.005$). pH is classified as Class I during July 2015 and January 2016 only whereas in March 2016 only one station remained in Class I the other 10 stations deteriorated to Class or II of NWQS (Table 4.7).

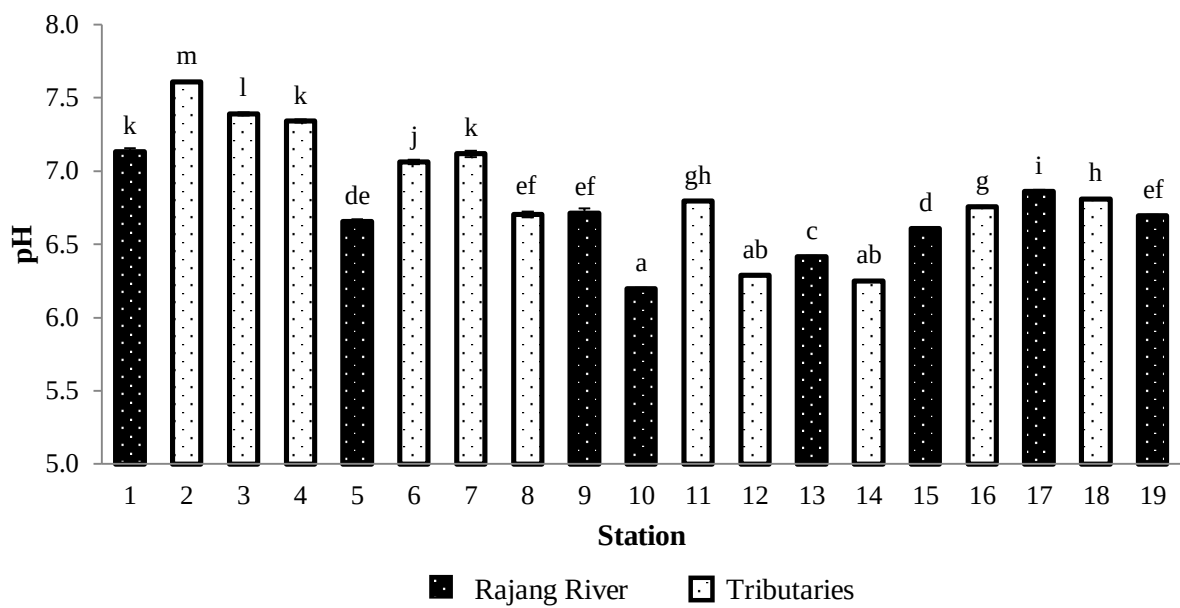


Figure 4.11: The mean pH at upstream (St 1-9) and midstream (St 10-19). The same letters among all stations indicate no significant difference ($p < 0.05$).

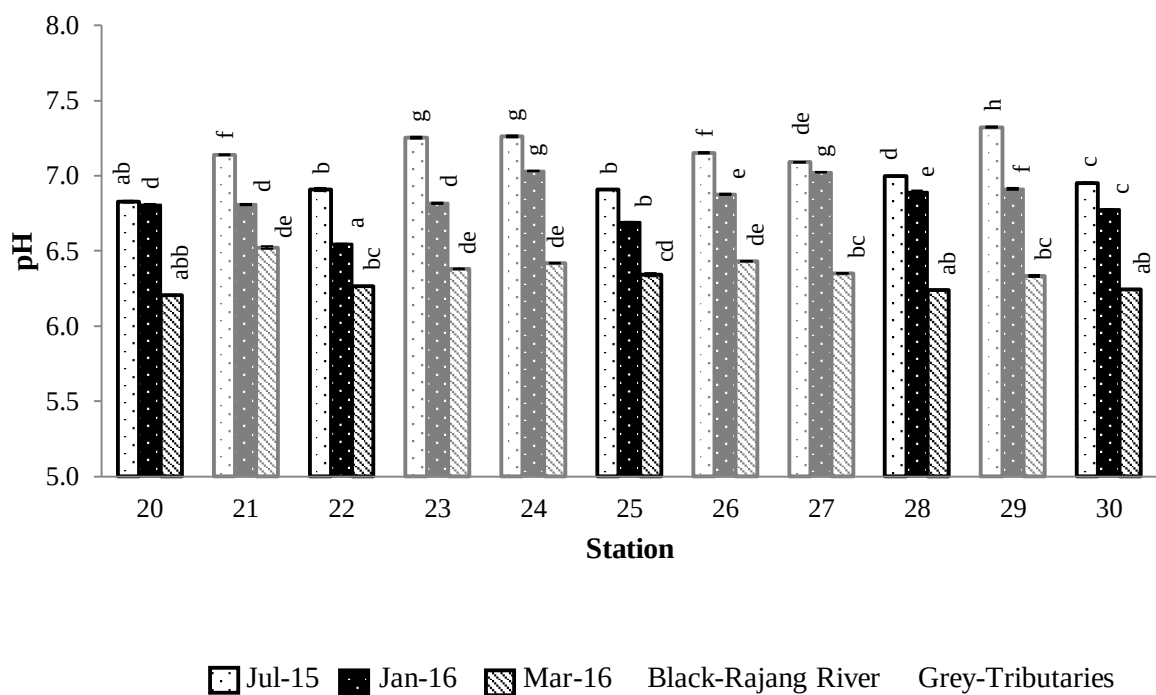


Figure 4.12: The comparison of mean pH within and among stations in three different sampling periods. The same letters among stations in the same month indicate no significant difference ($p < 0.05$).

Table 4.11: The comparison of mean pH at Rajang River stations in the downstream section.

Rajang River Stations	Mean pH			Mean
	Jul-15	Jan-16	Mar-16	
20	6.83±0.01	6.81±0.01	6.21±0.00	6.61 ^b
22	6.91±0.01	6.55±0.00	6.27±0.00	6.57 ^a
25	6.91±0.00	6.69±0.00	6.34±0.01	6.65 ^b
28	7.00±0.00	6.89±0.01	6.24±0.01	6.71 ^c
30	6.95±0.01	6.78±0.01	6.24±0.00	6.66 ^b
Mean ± SD	6.92±0.06 ^C	6.74±0.13 ^B	6.26±0.05 ^A	

Different capital letters show significant difference between the different sampling months ($p < 0.05$). Different small letters show significant difference among the stations ($p < 0.05$).

4.1.2.2.2 Dissolved oxygen (DO)

Figure 4.13 shows that the measured mean DO at the studied stations at upstream and midstream sections. For the upstream section, the range of the studied stations was between 5.20 mg/L and 7.77 mg/L. Among the stations along the Rajang River, the mean DO ranged from 5.20 mg/L to 5.90 mg/L whereas, among its tributaries, the mean DO ranged from 6.20 mg/L to 7.77 mg/L for this section. The highest value of mean DO was observed at station 6 at Bah River. Meanwhile, the lowest value of mean DO was recorded at station 9 which is located at the most downstream among stations at Rajang River. For the midstream section, the range of the studied stations was between 5.94 mg/L and 7.52 mg/L. Among the stations along the Rajang River, the mean DO ranged from 7.23 mg/L to 7.41 mg/L whereas, among its tributaries, the mean DO ranged from 5.94 mg/L to 7.52 mg/L. The highest value of mean DO was observed at station 18 at Peraran Besar. Meanwhile, the lowest value of mean DO was recorded at station 11 at Ensawi River. Significantly lower mean DO concentration recorded at stations 11 at Ensawi River than other stations are mainly due to the low flowing river water at this station which recorded the mean velocity 0.01 m/s (Table 4.1). The low

flowing river water resulted in lower exchange rate of oxygen gas from the atmosphere into the river.

For the upstream section, along the Rajang River, station 5 DO was higher compared to station 9 because of the higher DO water from the tributaries upstream of the station. For the midstream section, a decreasing trend but not significant was observed at stations along the Rajang River. This indicates the DO values were deteriorating as the water runs downstream but slightly increased at the most downstream station, station 19. The decreasing trend was influenced by the low DO at the tributaries (station 11, 12, 14 and 17), while, the slight increase at the most downstream station was influenced by the higher DO at tributary upstream of the station, station 18.

Comparatively, higher DO reading was observed at the main river at midstream section compared to the upstream section. This is because of the higher total discharge from the Bakun Dam as the spillway was opened during the time of sampling in December 2016 at the midstream section (Table 3.4). At the upstream section, lower DO readings were observed at the main Rajang River stations compared to its tributaries as shown in Figure 4.13. This could be explained by the low discharge from the Bakun Hydroelectric Dam because the spillway was closed at the time of the sampling (Table 3.4). In addition, the lower DO value can be influenced by the higher value of temperature. This is also supported by the highly negative correlation of DO with temperature ($r = -0.559$, p value < 0.05 , $n=23$) for Rajang River (Table 4.33) and ($r = -0.559$, p value < 0.05 , $n=29$) for its tributaries (Table 4.34). This finding is similar to Ling *et al.* (2016) in Baleh River which stated that cooler water holds more oxygen. Comparatively, the DO value is within the range of DO found in Baleh River, Sarawak (6.00-

8.05 mg/L) (Ling *et al.*, 2016) except for four stations. The DO most of the stations was classified as Class I or II according to NWQS of DOE (Table 4.3).

Figure 4.14 shows the comparison of mean DO within and among stations in three different sampling periods. In July 2015, the mean DO was between 6.43 mg/L to 7.42 mg/L. In July 2015, the mean DO among the stations at Rajang River ranged from 6.43 mg/L to 6.56 mg/L, whereas, among the stations at its tributaries ranged from 6.51 mg/L to 7.42 mg/L. The lowest mean occurred at station 20 (6.43 mg/L) and the highest at station 23 (7.42 mg/L). Meanwhile, the mean DO for January 2016 ranged from 4.74 mg/L to 6.28 mg/L. In January 2016, the mean DO among the stations at Rajang River ranged from 4.74 mg/L to 5.28 mg/L, whereas, among the stations at its tributaries ranged from 5.20 mg/L to 6.28 mg/L. The lowest reading observed at station 20 (4.74 mg/L) and the highest at station 21 (6.28 mg/L). In March 2016, the mean DO range from 5.88 mg/L to 7.88 mg/L. In March 2016, the mean DO among the stations at Rajang River ranged from 7.71 mg/L to 7.88 mg/L, whereas, among the stations at its tributaries ranged from 5.88 mg/L to 7.53 mg/L. The lowest recorded at station 27 (5.88 mg/L) and the highest occurred at station 20 (7.88 mg/L).

The comparison of mean DO at Rajang River stations in the downstream section is shown in Table 4.12. In July 2015 and January 2016, among the stations at the Rajang River, a significant increase was observed from station 20 to station 22 and 25. Then, the DO shows significant decrease from station 25 to station 28, which later increased again from station 28 to station 30. This indicated that the DO were improving as it moves in downstream direction. However, in March 2016, an opposite trend was observed among the stations along the Rajang River. This is because of the addition of the low DO water from the tributaries (station 21, 23, 24 and 27).

According Chapman (1996), DO values above 5 mg/L is the minimum requirement for healthy aquatic organisms. However, there are a total of four stations where DO values are lower than that minimum value of 5 mg/L. They are station 20 (4.74 mg/L), 22 (4.84 mg/L), 25 (4.92 mg/L) and 28 (4.94 mg/L) during the sampling in January 2016. All of these stations are located in Rajang River. The dissolved oxygen levels decline if more oxygen is consumed than is produced. The organic matters originating from decaying vegetative debris, food wastes and sewage could consume the dissolved oxygen present in the water (Drolc & Koncan, 1996).

Lower values of DO were found at Rajang River stations compared to the tributary stations in July 2015 and January 2016. The lower values in Rajang River stations was due to the low discharge from the turbine of Bakun Hydroelectric Dam (970 m³/s) and spillway was closed. The DO are influenced by the discharge from Bakun Hydroelectric Dam Reservoir at the time of the sampling. The increasing trend DO values towards downstream in March 2016 is because of the addition of higher DO water from the tributaries. Other than that, the increasing trend of DO is due to the fast flowing river water at Rajang River (Table 3.5). The high turbulence of the river caused higher exchange rate of oxygen gas from the atmosphere into the river water. Therefore, the DO improved after the reaeration of the river water in a long distance and addition from the tributaries.

DO is classified as Class I or II in July 2015 and March 2016 but a total four out of five station at Rajang River changed from Class II to Class III in January 2016 (Table 4.7). The DO is classified as Class II at most of the downstream stations of the Rajang River.

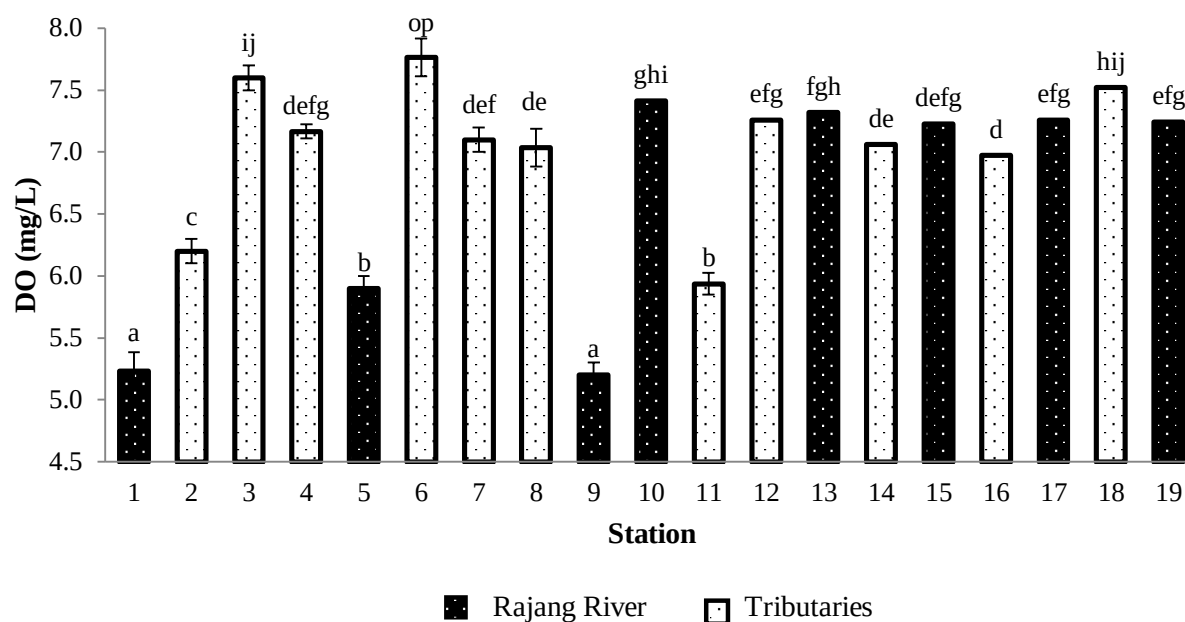


Figure 4.13: The mean DO at upstream (St 1-9) and midstream (St 10-19). The same letters among all stations indicate no significant difference ($p < 0.05$).

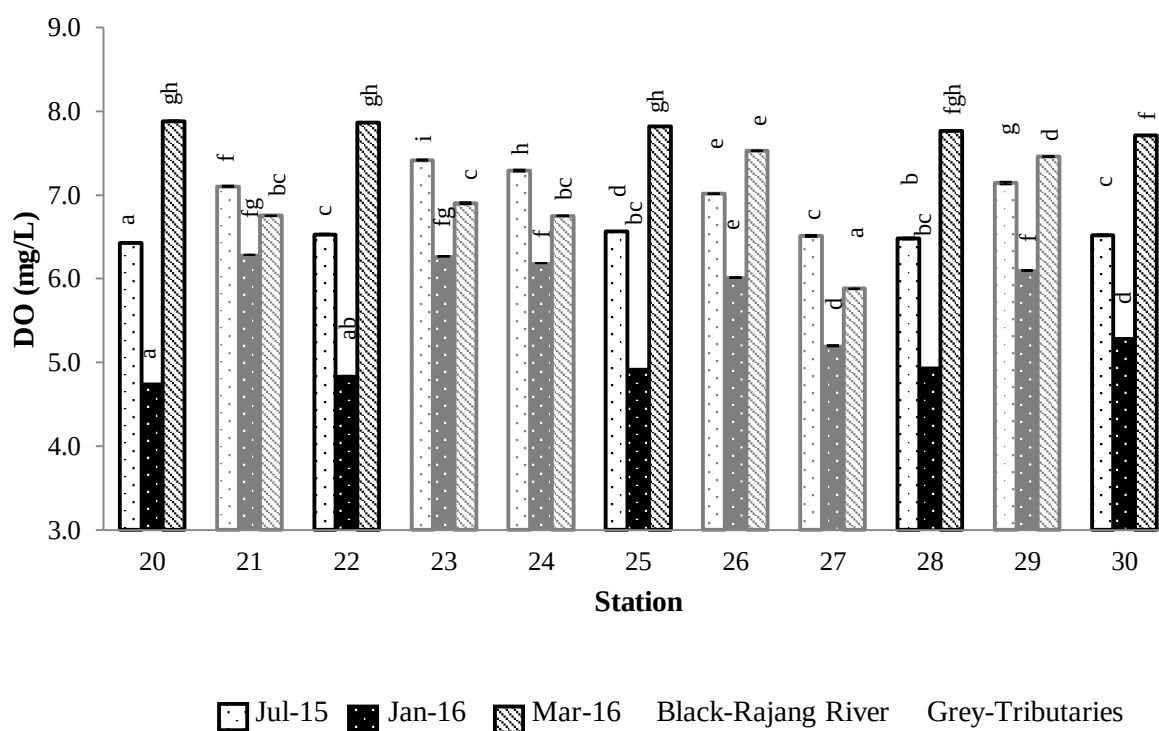


Figure 4.14: The comparison of mean DO within and among stations in three different sampling periods. The same letters among stations in the same month indicate no significant difference ($p < 0.05$).

Table 4.12: The comparison of mean DO at Rajang River stations in the downstream section.

Rajang River Stations	Mean DO			Mean
	Jul-15	Jan-16	Mar-16	
20	6.43±0.00	4.74±0.00	7.88±0.01	6.35 ^a
22	6.53±0.01	4.84±0.00	7.86±0.00	6.41 ^c
25	6.56±0.01	4.92±0.00	7.82±0.00	6.43 ^c
28	6.48±0.01	4.94±0.00	7.77±0.00	6.39 ^b
30	6.52±0.01	5.28±0.00	7.71±0.00	6.51 ^d
Mean ± SD	6.50±0.05 ^B	4.94±0.21 ^A	7.81±0.07 ^C	

Different capital letters show significant difference between the different sampling months ($p < 0.05$). Different small letters show significant difference among the stations ($p < 0.05$).

4.1.2.2.3 Biochemical oxygen demand (BOD)

In natural conditions, BOD derives from decaying vegetative debris and the minimum value of unpolluted water are less than 2 mg/L (Jenkins *et al.*, 2005). The mean BOD of stations at upstream and midstream sections are as shown in Figure 4.15. At upstream section, the range of mean BOD falls in between 2.08 mg/L and 4.91 mg/L. Among the stations along the Rajang River, the mean BOD ranged from 4.29 mg/L to 4.91 mg/L whereas, among its tributaries, the mean BOD ranged from 2.08 mg/L to 3.73 mg/L. Station 6 at Bah River was recorded the lowest mean BOD concentration compared the other stations at the upstream section. However, station 1 at the Rajang River, which is the most upstream station, has the highest mean BOD concentration than the other stations at the upstream section. At midstream section, the mean BOD ranged from 2.15 mg/L to 3.81 mg/L. Among the stations along the Rajang River, the mean BOD ranged from 2.31 mg/L to 2.61 mg/L whereas, among its tributaries, the mean BOD ranged from 2.15 mg/L to 3.81 mg/L. Station 14 at Sama River recorded the lowest mean BOD concentration compared the other stations at the midstream section. Meanwhile, station 11 at the Ensawi River, a tributary, has the highest mean BOD concentration than the other stations at the midstream section. This is most likely due to the

increase in organic material present in the water body. The increase of organic material caused an increase in the consumption of oxygen, which can result in a higher value of BOD.

The mean BOD concentration of the stations along the main river of the Rajang River shows a significant decrease from station 1 to station 5, then, increased from station 5 to station 9 for the upstream section (Figure 4.15). Meanwhile, at the midstream section, the mean BOD concentration of the stations along the Rajang River shows a general slight decreasing trend but not significant from upstream to downstream direction, but, a slight increase BOD concentration was observed at stations at the most downstream which are station 17 and station 19 (Figure 4.15).

The mean BOD for the upstream and midstream sections exceeded the value of unpolluted water (2 mg/L). Besides, the BOD values were higher than 3 mg/L (Class II limit) at most of the stations at Rajang River at upstream but not at the midstream section. The higher BOD at stations at the Rajang River located upstream sections is because of the low water level and low discharge from the Bakun Hydroelectric Dam as the spillway was closed at the time of the sampling. This resulted in the low dilution of organic matter in the river water which increases the BOD level.

The BOD in the present study is classified as Class II or III according to NWQS of DOE (Table 4.3). A total of 13 stations fall in Class II, while, 6 stations fall in Class III of BOD class from upstream to midstream section. The range of BOD in this study is inside the range of 1.00 to 9.80 mg/L found in Huangpu River, China (Yang *et al.*, 2007) and is lower than most of the BOD value found in Usma River (4.12-20.64 mg/L) during rainy season which was also subjected to logging activities (Ugwu & Wakawa, 2012). In addition, BOD value in

this study is similar in comparison with BOD value (2.70 mg/L – 4.0 mg/L) in Batang Baleh, Sarawak (Ling *et al.*, 2016).

The comparison of mean BOD according to trips and stations at the downstream section was shown in Figure 4.16. The mean BOD in July 2015 sampling ranged from 2.36 mg/L to 3.73 mg/L. In July 2015, the mean BOD among the stations at Rajang River ranged from 2.61 mg/L to 3.67 mg/L, whereas, among the stations at its tributaries ranged from 2.36 mg/L to 3.73 mg/L. Station 27 at Nanga Senuang recorded the highest value of mean BOD, whereas the lowest mean BOD was in station 29 located at Baleh River during sampling on July 2015. Meanwhile, mean BOD falls in between 3.34 mg/L and 5.03 mg/L for the sampling in January 2016. In January 2016, the mean BOD among the stations at Rajang River ranged from 4.58 mg/L to 5.03 mg/L, whereas, among the stations at its tributaries ranged 3.34 mg/L to 4.08 mg/L. Station 21 at Pelagus River shows the lowest value of BOD and the highest was station 28 at Rajang River. The range of mean BOD in March 2016 ranged in between 2.27 mg/L and 3.88 mg/L. In March 2016, the mean BOD among the stations at Rajang River ranged from 2.27 mg/L to 2.56 mg/L, whereas, among the stations at its tributaries ranged from 2.69 mg/L to 3.88 mg/L. The highest value of BOD was recorded at station 27 at Nanga Senuang during the last sampling in March 2016, whereas, the lowest was observed in station 30 at Rajang River.

The comparison of mean BOD at Rajang River stations in the downstream section is shown in Table 4.13. There is no clear trend observed among the stations at the Rajang River towards downstream direction in July 2015 and March 2016. In January 2016, among the stations along the Rajang River, significant increase trend was observed from station 22 towards downstream direction but decrease from station 28 to 30.

Among the stations located at the Rajang River, the BOD in January 2016 is significantly higher compared to those in July 2015 and March 2016. This condition may be contributed by the presence of debris and soil runoff brought by the rain water as there is high amount of rainfall recorded at the month of the sampling. The debris from the logging activities and soil erosions upstream were flushed down to the river through runoff thus increasing the contribution of organic matter concentration in the river which lead to higher consumption of oxygen by microorganism. Furthermore, the higher BOD at the Rajang River in January 2016 is also influence by the closing of spillway of upstream dam, the Bakun Hydroelectric Dam at the time of sampling. Thus, the total discharge from the Bakun Hydroelectric Dam was low and less dilution of organic matter occurred at the downstream river. Besides, high BOD concentration most likely due to the discharge of untreated wastewater from residential area and logging sites upstream. Ling *et al.* (2010) reported that untreated and partially treated household waste flushed into the river water led to higher BOD concentration. Furthermore, high mean BOD concentration corresponded to low mean DO concentration. This is supported by the negative correlation between BOD and DO ($r = -0.962$, p value < 0.05 , $n=23$) at Rajang River (Table 4.33) and its tributary ($r = -0.875$, p value < 0.05 , $n=29$) (Table 4.34). This is because higher DO is needed for the decomposition of organic matter.

The BOD is higher than 3 mg/L at most of the stations at Rajang River. The range of mean BOD for the downstream sections exceeded the value of unpolluted water (2 mg/L). The BOD in the present study is classified as Class II or III according to NWQS of DOE (Table 4.3). The mean BOD concentration observed mostly exceeded Class II due to the runoff from the logging site and residential areas upstream of the river especially organic pollutants. Organic pollutants discharged into the river lead to oxygen depletion as the decomposition process by

microorganism consumes oxygen. This is supported by Gandaseca *et al.* (2011) by saying that high BOD concentration in the river was because of more organic matter such as debris that enter the river through wastewater and storm runoff.

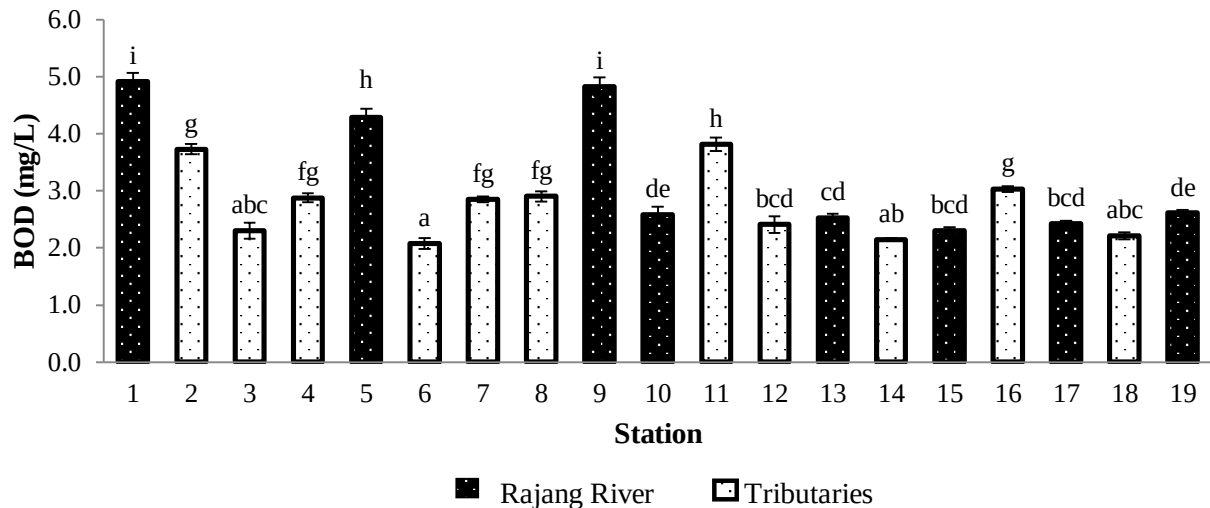


Figure 4.15: The mean BOD at upstream (St 1-9) and midstream (St 10-19). The same letters among all stations indicate no significant difference ($p < 0.05$).

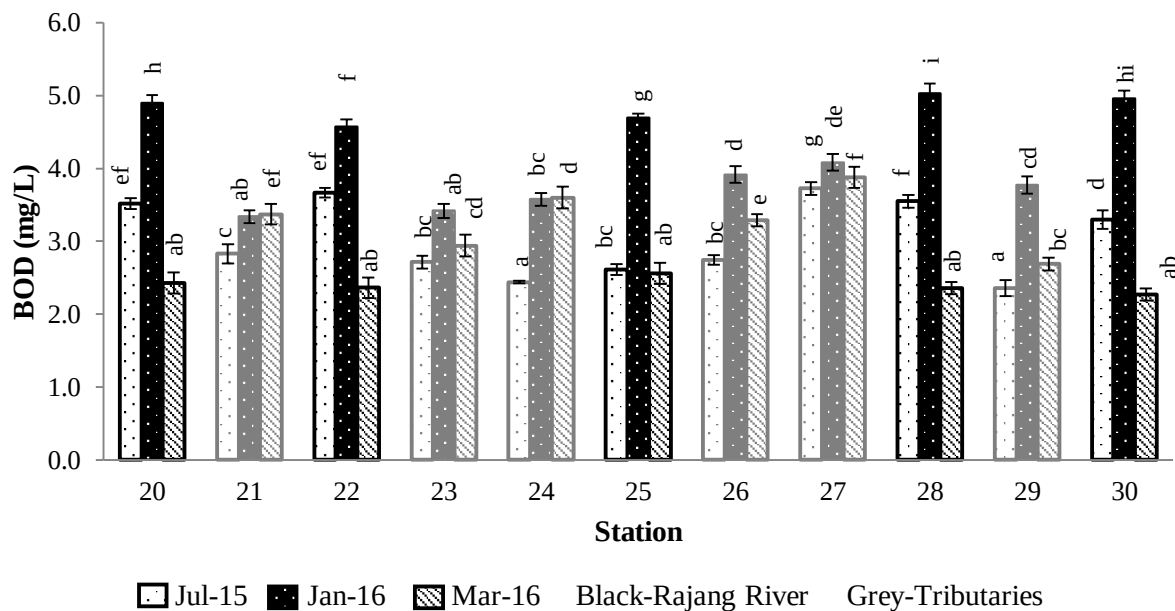


Figure 4.16: The comparison of mean BOD within and among stations in three different sampling periods. The same letters among stations in the same month indicate no significant difference ($p < 0.05$).

Table 4.13: The comparison of mean BOD at Rajang River stations in the downstream section.

Rajang River Stations	Mean BOD			Mean
	Jul-15	Jan-16	Mar-16	
20	3.52±0.08	4.89±0.12	2.43±0.15	3.61 ^c
22	3.67±0.06	4.58±0.10	2.37±0.14	3.54 ^b
25	2.61±0.07	4.70±0.05	2.56±0.15	3.29 ^a
28	3.55±0.09	5.03±0.14	2.36±0.08	3.65 ^c
30	3.30±0.13	4.96±0.11	2.27±0.08	3.51 ^b
Mean ± SD	3.33±0.42 ^B	4.83±0.19 ^C	2.40±0.11 ^A	

Different capital letters show significant difference between the different sampling months ($p < 0.05$). Different small letters show significant difference among the stations ($p < 0.05$).

4.1.2.2.4 Chemical oxygen demand (COD)

The mean COD of stations at upstream and midstream sections are shown in Figure 4.17. The mean concentration of COD varied from 22.4 mg O₂/L to 59.36 mg O₂/L for the upstream section. Among the stations along the Rajang River, the mean COD ranged from 52.64 mg O₂/L to 59.36 mg O₂/L whereas, among its tributaries, the mean COD ranged from 22.40 mg O₂/L to 38.08 mg O₂/L. The lowest of mean COD concentration was observed in station 6 at Bah River. Meanwhile, the highest of mean COD concentration occurred at station 1 at the most upstream station of Rajang River. For the midstream section, the mean concentration of COD varied from 21.28 mg O₂/L to 41.44 mg O₂/L. Among the stations along the Rajang River, the mean COD ranged from 29.12 mg O₂/L to 32.48 mg O₂/L whereas, among its tributaries, the mean COD ranged from 21.28 mg O₂/L to 41.44 mg O₂/L. The lowest of mean COD concentration was found at station 14 at Sama River. Meanwhile, the highest mean COD concentration was recorded at station 16 at Rarai River. This is likely due to the oxygen concentration consumed by the microorganism to undergo decomposition of organic matter.

For upstream section, the mean COD concentration of the stations along the main river of the Rajang River shows a significant decrease from station 1 to station 5, then, increase from station 5 to station 9. Among all stations at Rajang River at the midstream section, there is no significant difference COD value along the Rajang River in downstream direction. This is probably due to the dilution of river water from the tributaries. Besides, for COD classification, all the stations at the upstream and midstream section fall in Class II or III or IV of NWQS for Malaysia (Table 4.3). A total of 4 stations fall in Class II, while, 12 stations fall in Class III and 3 stations fall in Class IV of COD class from upstream to midstream section. The COD classification of the tributary stations that were exceeded Class II is most likely contributed by their common land use which were logging and residential area. This is because the discharge of untreated effluent and human waste from the logging sites and residential areas resulting in the high mean COD and low mean DO concentration. This is supported by Nor Zaiha et al. (2015) who reported high COD concentration in the river due to the runoff from logging sites during heavy precipitation. Comparatively, the COD value found in these sections was mostly similar to the study in Bertam River and its tributaries (8.00 to 55.00 mg O₂/L) in Cameron Highland, Malaysia which subjected to logging activities and agriculture (Eisakhani & Malakahmad, 2009) with exception of a total of three stations. They are station 1, 5 and 9.

Figure 4.18 shows the mean concentration of COD among stations in three different trips. Its mean COD in July 2015 sampling ranged from 24.6 mg O₂/L to 68.3 mg O₂/L. In July 2015, the mean COD among the stations at Rajang River ranged from 33.48 mg/L to 68.32 mg/L, whereas, among the stations at its tributaries ranged from 24.64 mg/L to 38.08 mg/L. Meanwhile, the mean COD was in between 34.7 mg O₂/L and 89.6 mg O₂/L during the

sampling in January 2016. In January 2016, the mean COD among the stations at Rajang River ranged from 71.68 mg/L to 89.60 mg/L, whereas, among the stations at its tributaries ranged 34.72 mg/L to 62.72 mg/L. In March 2016, the mean COD varied from 29.1 mg O₂/L to 58.2 mg O₂/L. The mean COD among the stations at Rajang River ranged from 45.92 mg/L to 51.52 mg/L, whereas, among the stations at its tributaries ranged from 29.12 mg/L to 58.24 mg/L. The lowest mean COD occurred at station 24 (24.6 mg O₂/L), station 24 (34.7 mg O₂/L) and station 23 (29.1 mg O₂/L) for the samplings conducted in July 2015, January 2016 and March 2016 respectively. Meanwhile, the highest mean COD occurred at station 28 (68.3 mg O₂/L), station 20 (89.6 mg O₂/L) and station 21 (58.2 mg O₂/L) for the samplings conducted in July 2015, January 2016 and March 2016 respectively. The high COD at those stations points to a deterioration of the water quality likely caused by the direct discharge of wastewater from longhouses and residential area. In addition, there are longhouses located at the side of those rivers. The discharge of untreated effluent and human waste caused the high mean COD and low mean DO concentration. It is due to the oxygen concentration consumed by the microorganism to undergo decomposition of organic matter.

Comparatively, the COD of the stations at Rajang River were found higher in January 2016 compared to the COD in July 2015 and March 2016 (Table 4.14). This observation is similar with the BOD. The increase in the COD in January 2016 was most likely influenced by the discharge from Bakun Dam upstream because the spillway was closed during the time of sampling and thus all the discharge was through turbine.

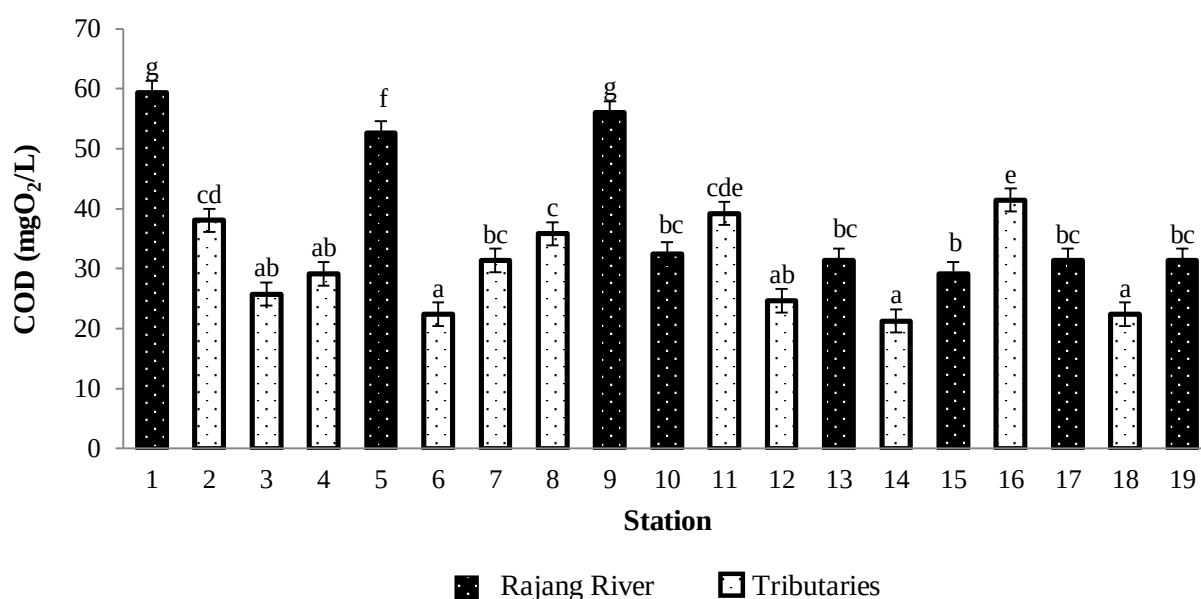


Figure 4.17: The mean COD at upstream (St 1-9) and midstream (St 10-19). The same letters among all stations indicate no significant difference ($p < 0.05$).

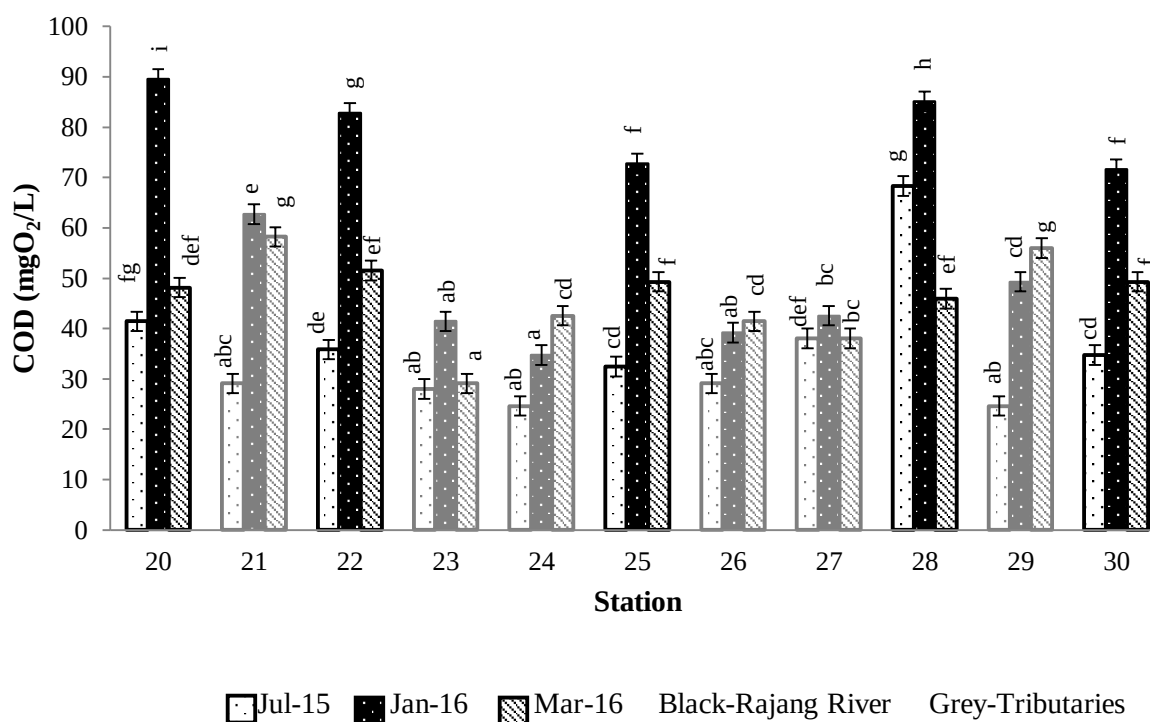


Figure 4.18: The comparison of mean COD within and among stations in three different sampling periods. The same letters among stations in the same month indicate no significant difference ($p < 0.05$).

Table 4.14: The comparison of mean COD at Rajang River stations in the downstream section.

Rajang River Stations	Mean COD			Mean
	Jul-15	Jan-16	Mar-16	
20	41.44±1.94	89.60±1.94	48.16±1.94	59.73 ^b
22	35.84±1.94	82.88±1.94	51.52±1.94	56.75 ^b
25	32.48±1.94	72.80±1.94	49.28±1.94	51.52 ^a
28	68.32±1.94	85.12±2.94	45.92±1.94	66.45 ^c
30	34.72±1.94	71.68±1.94	49.28±1.94	51.89 ^a
Mean ± SD	42.56±14.77 ^A	80.42±7.86 ^C	48.83±2.03 ^B	

Different capital letters show significant difference between the different sampling months ($p < 0.05$). Different small letters show significant difference among the stations ($p < 0.05$).

The BOD/COD ratio of the Rajang River and its tributaries at Pelagus Area at upstream and midstream sections is shown in Table 4.15. The ratio of BOD to COD of the stations at upstream section ranged from 0.08 to 0.10, while, the ratio at the midstream section ranged from 0.07 to 0.10. Based on Dahamsheh & Wedyan (2017), the ratio of BOD to COD that is less than 0.3 means that biodegradation in the river cannot proceed, thus, it cannot be treated biologically. All the stations from the upstream and midstream section were less than 0.3 in the biodegradability index (BI). Therefore, all these stations cannot be treated biologically.

The BOD/COD ratio of the Rajang River and its tributaries at Pelagus Area of the downstream section are shown in Table 4.16. The ratio of BOD to COD ranged from 0.05 to 0.10 in July 2015. Meanwhile, in January and March 2016, the range ratio of BOD to COD was between 0.05 and 0.10. The biodegradability index (BI) the river that is less than 0.3. Therefore, biodegradation will not proceed and it is not possible to be treated biologically. This is due to the wastewater generated from those activities inhibits the metabolic activity of bacterial seed due to their toxicity (Abdalla & Hammam, 2014). In addition, the ratio of BOD to COD that is less than 0.3 also means that biodegradation in the river cannot proceed, thus,

it cannot be treated biologically (Dahamsheh & Wedyan, 2017). All the stations from the downstream section were less than 0.3 in the biodegradability index (BI). Therefore, this indicated that all of these stations cannot be treated biologically.

Table 4.15: The BOD/COD ratio of the Rajang River and its tributaries at Pelagus Area at upstream and midstream sections

Section	Station	BOD (mg/L)	COD (mgO ₂ /L)	BOD/COD	BOD:COD Ratio
Upstream	1	4.91	59.36	0.08	1:12
	2	3.73	38.08	0.10	1:10
	3	2.30	25.76	0.09	1:11
	4	2.88	29.12	0.10	1:10
	5	4.29	52.64	0.08	1:12
	6	2.08	22.40	0.09	1:11
	7	2.85	31.36	0.09	1:11
	8	2.90	35.84	0.08	1:12
	9	4.83	56.00	0.09	1:11
Midstream	10	2.58	32.48	0.08	1:12
	11	3.81	39.20	0.10	1:10
	12	2.41	24.64	0.10	1:10
	13	2.53	31.36	0.08	1:12
	14	2.15	21.28	0.10	1:10
	15	2.31	29.12	0.08	1:12
	16	3.03	41.44	0.07	1:13
	17	2.42	31.36	0.08	1:12
	18	2.21	22.40	0.10	1:10
	19	2.61	31.36	0.08	1:12

*Bold indicates the stations along Rajang River.

Table 4.16: The BOD/COD ratio of the Rajang River and its tributaries at Pelagus Area of the downstream section

July 2015				
Station	BOD(mg/L)	COD (mgO ₂ /L)	BOD/COD	BOD:COD Ratio
20	3.52	41.44	0.08	1:12
21	2.83	29.12	0.10	1:10
22	3.67	35.84	0.10	1:10
23	2.71	28.00	0.10	1:10
24	2.44	24.64	0.10	1:10
25	2.61	32.48	0.08	1:12
26	2.75	29.12	0.09	1:11
27	3.73	38.08	0.10	1:10
28	3.55	68.32	0.05	1:20
29	2.36	24.64	0.10	1:10
30	3.30	34.72	0.10	1:10
January 2016				
Station	BOD(mg/L)	COD (mgO ₂ /L)	BOD/COD	BOD:COD Ratio
20	4.89	89.60	0.05	1:20
21	3.34	62.72	0.05	1:20
22	4.58	82.88	0.06	1:14
23	3.42	41.44	0.08	1:12
24	3.58	34.72	0.10	1:10
25	4.70	72.80	0.06	1:14
26	3.92	39.20	0.10	1:10
27	4.08	42.56	0.10	1:10
28	5.03	85.12	0.06	1:14
29	3.77	49.28	0.08	1:12
30	4.96	71.68	0.07	1:13
March 2016				
Station	BOD(mg/L)	COD (mgO ₂ /L)	BOD/COD	BOD:COD Ratio
20	2.43	48.16	0.05	1:20
21	3.37	58.24	0.06	1:14
22	2.37	51.52	0.05	1:20
23	2.94	29.12	0.10	1:10
24	3.60	42.56	0.08	1:12
25	2.56	49.28	0.05	1:20
26	3.29	41.44	0.08	1:12
27	3.88	38.08	0.10	1:10
28	2.36	45.92	0.05	1:20
29	2.69	56.00	0.05	1:20
30	2.27	49.28	0.05	1:20

*Bold indicates the stations along Rajang River

4.1.2.2.5 Nutrients (Nitrogen)

4.1.2.2.5.1 Nitrite Nitrogen (NO₂-N) and Nitrate Nitrogen (NO₃-N)

The mean nitrite nitrogen (NO₂-N) at upstream (St 1-9) and midstream (St 10-19) are shown in Figure 4.19. Meanwhile, Figure 4.21 shows the mean nitrate nitrogen (NO₃-N) at upstream (St 1-9) and midstream (St 10-19). A close to zero concentrations of NO₂-N and NO₃-N were found in all the studied river water for the upstream and midstream section. For the upstream section, the mean NO₂-N ranged from 0.006 to 0.009 mg/L meanwhile NO₃-N ranged from 0.01 to 0.04 mg/L. Among the stations along the Rajang River, the mean NO₂-N ranged from 0.006 mg/L to 0.009 mg /L whereas, among its tributaries, the mean NO₂-N ranged from 0.006 mg/L to 0.008 mg/L. Among the stations along the Rajang River, the mean NO₃-N ranged from 0.02 mg/L to 0.04 mg /L whereas, among its tributaries, the mean NO₃-N ranged from 0.01 mg/L to 0.03 mg/L.

For the midstream section, the mean NO₂-N ranged from 0.000 to 0.005 mg/L meanwhile NO₃-N ranged from 0.00 to 0.02 mg/L. Among the stations along the Rajang River, the mean NO₂-N ranged from 0.002 mg/L to 0.003 mg /L whereas, among its tributaries, the mean NO₂-N ranged from 0.000 mg/L to 0.005 mg/L. Among the stations along the Rajang River, the mean NO₃-N ranged from 0.01 mg/L to 0.02 mg /L whereas, among its tributaries, the mean NO₃-N ranged from 0.00 mg/L to 0.02 mg/L. The highest mean of NO₂-N was found in station 9. Meanwhile, the highest mean of NO₃-N was found at station 5.

According to Jenkins *et al.* (2005), NO₃-N level of over 10 mg/L in natural waters normally indicate man made pollution, but the measured value in this study were within the limit range. Furthermore, the concentrations of NO₂-N in all the studied station were found to be lower than the amount of NO₃-N and NH₃-N in the present study. This result was in correlation with

the statement by Horne & Goldman (1994) that the $\text{NO}_2\text{-N}$ is lower than $\text{NO}_3\text{-N}$ and $\text{NH}_3\text{-N}$, explained by the fact that $\text{NO}_2\text{-N}$ is the by-product of natural water. $\text{NO}_2\text{-N}$ is also an intermediate product in between the conversion of ammonia to nitrate or nitrate to ammonia. Therefore, it is unstable and easily converted to either of $\text{NO}_3\text{-N}$ and $\text{NH}_3\text{-N}$ depending on the water condition. All the stations are classified under Class I according to NWQS of DOE for conductivity, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ (Table 4.3).

The comparison of mean $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ at the downstream sections are shown in Figure 4.20 and Figure 4.22 respectively. In July 2015, the range of mean $\text{NO}_2\text{-N}$ falls between 0.003 mg/L and 0.013 mg/L whereas the mean $\text{NO}_3\text{-N}$ ranged from 0.00 mg/L to 0.03 mg/L. In July 2015, the mean $\text{NO}_2\text{-N}$ among the stations at Rajang River ranged from 0.009 mg/L to 0.013 mg/L, whereas, among the stations at its tributaries ranged from 0.003 mg/L to 0.011 mg/L. The mean $\text{NO}_3\text{-N}$ among the stations at Rajang River ranged from 0.001 mg/L to 0.011 mg/L, whereas, among the stations at its tributaries ranged from 0.010 mg/L to 0.021 mg/L.

The range of mean $\text{NO}_2\text{-N}$ varied from 0.004 mg/L to 0.007 mg/L and the range of mean $\text{NO}_3\text{-N}$ was 0.02 mg/L to 0.03 mg/L in January 2016 sampling. In January 2016, the mean $\text{NO}_2\text{-N}$ among the stations at Rajang River ranged from 0.005 mg/L to 0.007 mg/L, whereas, among the stations at its tributaries ranged 0.004 mg/L to 0.006 mg/L. The mean $\text{NO}_3\text{-N}$ among the stations at Rajang River ranged from 0.014 mg/L to 0.025 mg/L, whereas, among the stations at its tributaries ranged 0.015 mg/L to 0.029 mg/L.

During the sampling in March 2016, the range of mean $\text{NO}_2\text{-N}$ was varied from 0.001 mg/L to 0.006 mg/L whereas the range of mean $\text{NO}_3\text{-N}$ was 0.01 mg/L to 0.03 mg/L. In March 2016, the mean $\text{NO}_2\text{-N}$ among the stations at Rajang River ranged from 0.002 mg/L to 0.006 mg/L, whereas, among the stations at its tributaries ranged from 0.001 mg/L to 0.006 mg/L.

The mean $\text{NO}_3\text{-N}$ among the stations at Rajang River ranged from 0.013 mg/L to 0.028 mg/L, whereas, among the stations at its tributaries ranged from 0.014 mg/L to 0.029 mg/L.

In addition, the range of mean $\text{NO}_2\text{-N}$ was generally lower during the sampling in January 2016 and March 2016 compared to the range of mean $\text{NO}_2\text{-N}$ in July 2015 (Table 4.17). This is most likely influenced by the high rainfall amount recorded during these months which were shown in Table 2.1. This caused the dilution of mean $\text{NO}_2\text{-N}$ occurred during the samplings. Meanwhile, the high concentration of $\text{NO}_3\text{-N}$ recorded was contributed by the organic matter from the runoff during rainy season in January 2016 and March 2016 (Table 4.18). The organic matters originated from the land which was runoff to the nearby river resulting from the land use activities contributed high $\text{NO}_3\text{-N}$ concentration in the river and increase the pollution burden on the river (Ismail & Ibrahim, 2015). Decay organic matter and excretion that undergoes decomposition and nitrification which converted to ammonia and ammonia oxidized to nitrite and nitrite further oxidized to nitrate. According to the NWQS, the $\text{NO}_2\text{-N}$ and $\text{NO}_2\text{-N}$ were classified as Class I for all the stations (Table 4.7).

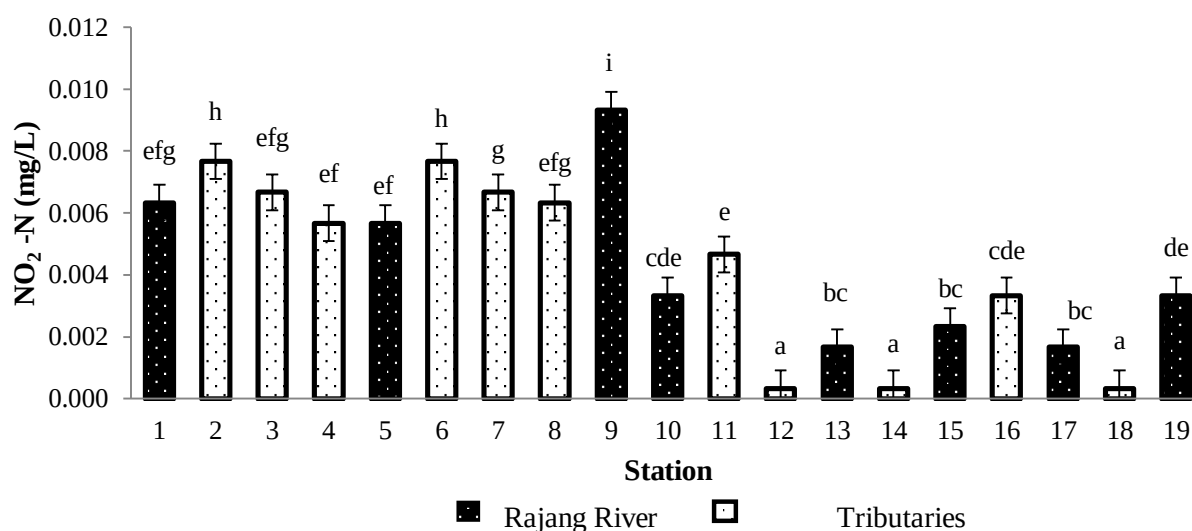


Figure 4.19: The mean $\text{NO}_2\text{-N}$ at upstream (St 1-9) and midstream (St 10-19). The same letters among all stations indicate no significant difference ($p < 0.05$).

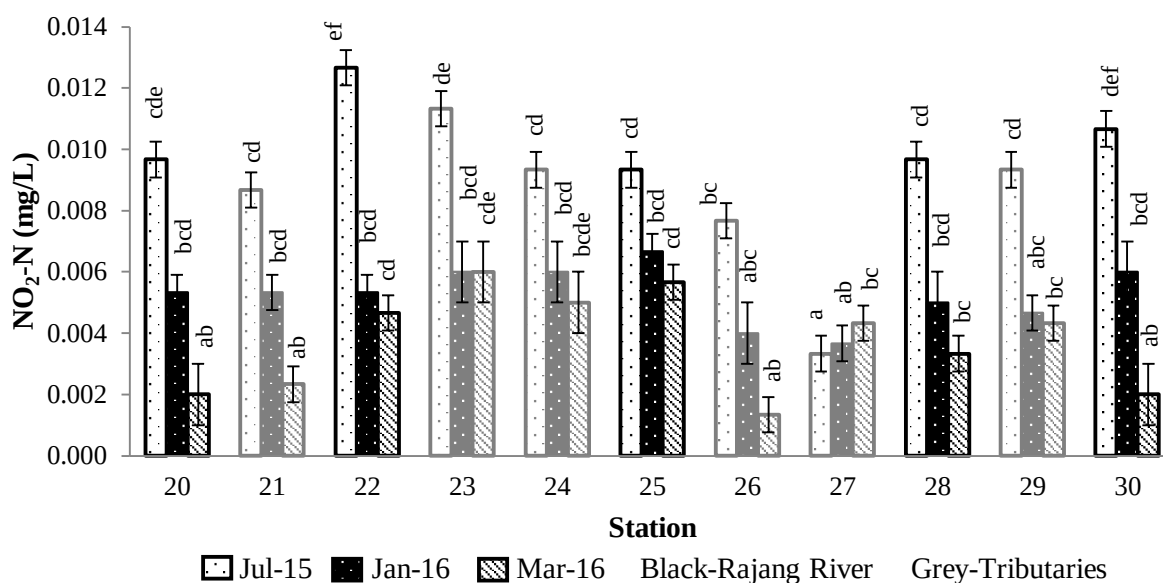


Figure 4.20: The comparison of mean NO₂-N within and among stations in three different sampling periods. The same letters among stations in the same month indicate no significant difference ($p < 0.05$).

Table 4.17: The comparison of mean NO₂-N at Rajang River stations in the downstream section.

Rajang River Stations	Mean NO ₂ -N			Mean
	Jul-15	Jan-16	Mar-16	
20	0.010±0.001	0.005±0.001	0.002±0.001	0.006 ^a
22	0.013±0.001	0.005±0.001	0.005±0.001	0.008 ^c
25	0.009±0.001	0.007±0.001	0.006±0.001	0.007 ^b
28	0.010±0.001	0.005±0.001	0.003±0.001	0.006 ^a
30	0.011±0.001	0.006±0.001	0.002±0.001	0.006 ^a
Mean ± SD	0.011±0.00 ^C	0.006±0.00 ^B	0.003±0.00 ^A	

Different capital letters show significant difference between the different sampling months ($p < 0.05$). Different small letters show significant difference among the stations ($p < 0.05$).

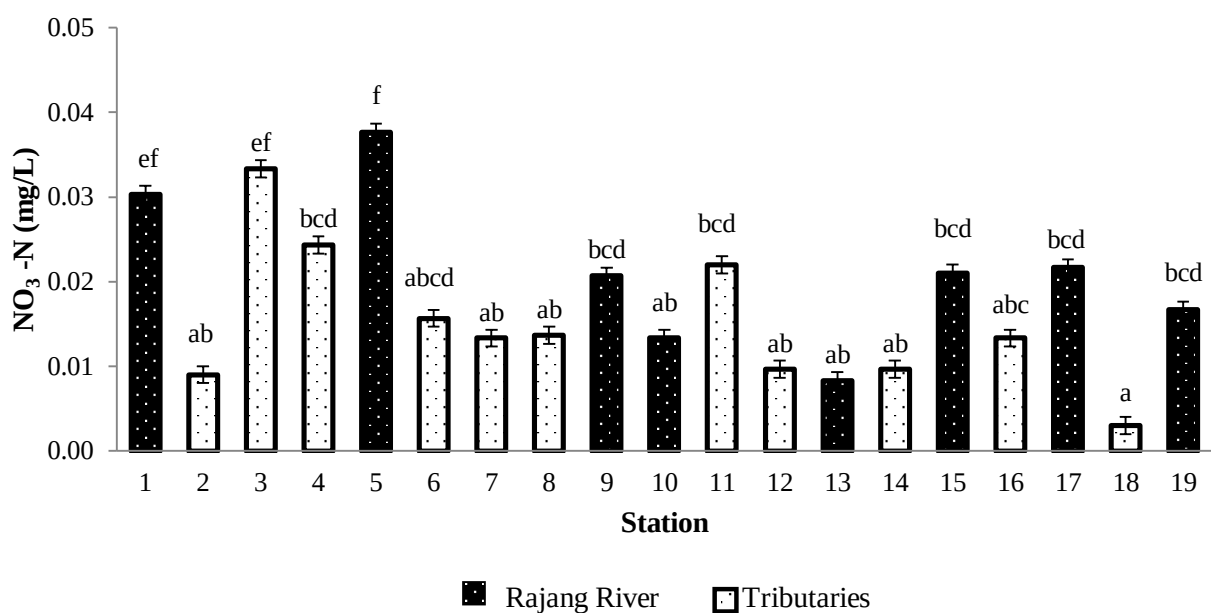


Figure 4.21: The mean NO₃-N at upstream (St 1-9) and midstream (St 10-19). The same letters among all stations indicate no significant difference ($p < 0.05$).

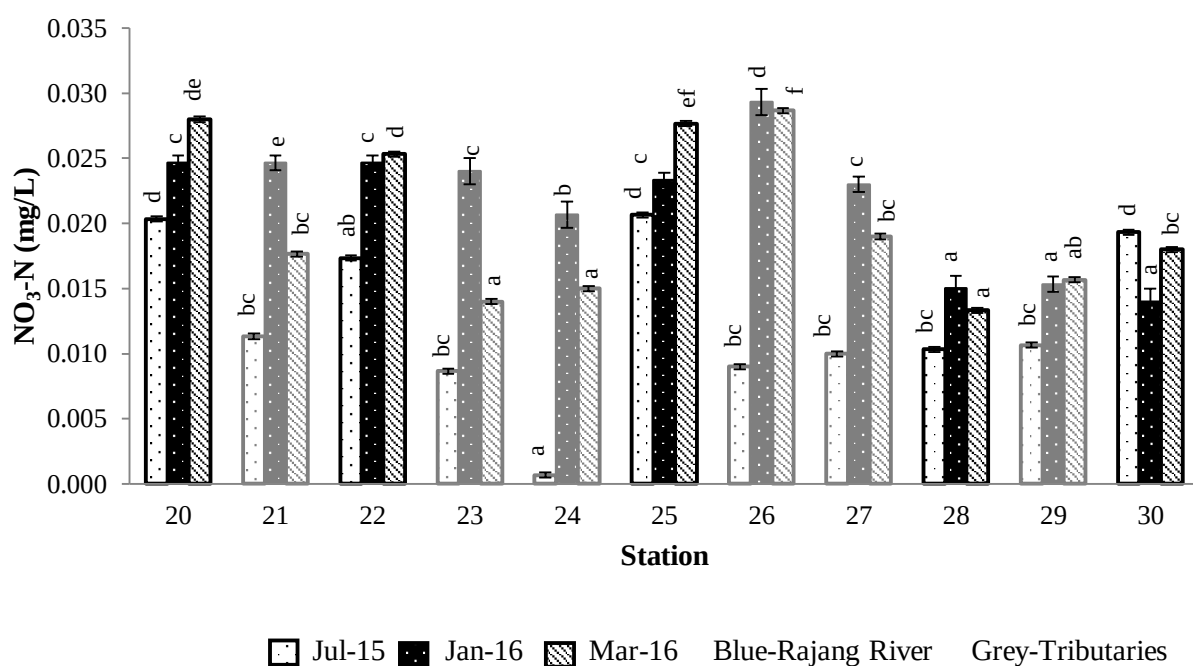


Figure 4.22: The comparison of mean NO₃-N within and among stations in three different sampling periods. The same letters among stations in the same month indicate no significant difference ($p < 0.05$).

Table 4.18: The comparison of mean NO₃-N at Rajang River stations in the downstream section.

Rajang River Stations	Mean NO ₃ -N			Mean
	Jul-15	Jan-16	Mar-16	
20	0.020±0.01	0.025±0.00	0.028±0.00	0.024 ^c
22	0.017±0.00	0.025±0.00	0.025±0.00	0.022 ^c
25	0.021±0.01	0.023±0.00	0.028±0.00	0.023 ^c
28	0.010±0.01	0.015±0.00	0.013±0.00	0.013 ^a
30	0.019±0.01	0.014±0.00	0.018±0.00	0.017 ^b
Mean ± SD	0.017±0.01 ^A	0.020±0.01 ^B	0.022±0.01 ^C	

Different capital letters show significant difference between the different sampling months (p<0.05). Different small letters show significant difference among the stations (p<0.05).

4.1.2.2.5.2 Total Ammoniacal Nitrogen (NH₃-N)

The mean concentrations of NH₃-N at Rajang River and its tributaries at the upstream and midstream section are shown in Figure 4.23. Its mean concentration ranged from 0.12 mg/L to 0.20 mg/L for the upstream section. Among the upstream stations along the Rajang River, the mean NH₃-N ranged from 0.19 mg/L to 0.20 mg /L whereas, among its tributaries, the mean NH₃-N ranged from 0.12 mg/L to 0.44 mg/L. The NH₃-N concentration ranged from 0.11 mg/L to 0.44 mg/L for the midstream section. Among the stations along the Rajang River, the mean NH₃-N ranged from 0.19 mg/L to 0.20 mg /L whereas, among its tributaries, the mean NH₃-N ranged from 0.12 mg/L to 0.19 mg/L. The highest mean NH₃-N was found at station 14 which is located at Sama River, midstream section, with 0.44 mg/L of NH₃-N concentration. Meanwhile, the lowest mean NH₃-N were recorded at 3 different stations. They are station 9 at the most downstream station along the Rajang River at the upstream section, station 10 at Rajang River, station 12 at Buya River and station 18 at Peraran Besar River.

Among the stations at the Rajang River, the $\text{NH}_3\text{-N}$ is mostly higher at the midstream section compared to the upstream section. The trend was opposite to the trend of $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$. The $\text{NH}_3\text{-N}$ value was decreasing but not significant from the upstream section towards downstream direction. However, the $\text{NH}_3\text{-N}$ value is increasing at station 13 and 15 but then start to decrease again but not significant at its following station 17 and station 19. This is because of the input from the nearby tributaries which added and diluted the river water at the Rajang River.

The normal concentration of $\text{NH}_3\text{-N}$ in natural water is less than 0.3 mg/L (Jenkins *et al.*, 2005). The detection of higher than 0.3 mg/L of $\text{NH}_3\text{-N}$ value in water body indicates the presence of freshly discharged organic waste to the water body. The freshly discharged organic waste in this present study could come from the direct discharge of household wastewater and sanitation system. A total of 4 studied stations recorded the value of $\text{NH}_3\text{-N}$ exceeding 0.3 mg/L. They are station 13 (0.33 mg/L), station 14 (0.44 mg/L) and station 15 (0.34 mg/L). This is due to the surface runoff from the logging sites to the river during heavy rainfall. In addition, high $\text{NH}_3\text{-N}$ for station 15 was most likely contributed by the tributaries upstream (station 13 and station 14).

The $\text{NH}_3\text{-N}$ range in this study is lower than the range recorded in Benar River, Malaysia (19.00-42.00 mg/L) which is subjected to logging activities and industrial activities (Elewa *et al.*, 2009; Ghani *et al.*, 2009). The $\text{NH}_3\text{-N}$ in that study was much higher because of the direct discharge of wastewater from the nearby industrial area. The stations in this study are classified as Class II or III for $\text{NH}_3\text{-N}$ according to NWQS of DOE (Table 4.3).

Figure 4.24 shows the comparison of mean $\text{NH}_3\text{-N}$ among the three different samplings. The mean $\text{NH}_3\text{-N}$ ranged from 0.06 mg/L to 0.14 mg/L in July 2015. The mean $\text{NH}_3\text{-N}$ among the

stations at Rajang River ranged from 0.06 mg/L to 0.12 mg/L, whereas, among the stations at its tributaries ranged from 0.07 mg/L to 0.17 mg/L. Meanwhile, the range of mean $\text{NH}_3\text{-N}$ in January 2016 was between 0.19 mg/L and 0.28 mg/L. The mean $\text{NH}_3\text{-N}$ among the stations at Rajang River ranged from 0.19 mg/L to 0.25 mg/L, whereas, among the stations at its tributaries ranged 0.23 mg/L to 0.28 mg/L. In March 2016, the range of mean $\text{NH}_3\text{-N}$ was between 0.24 mg/L and 0.44 mg/L. The mean $\text{NH}_3\text{-N}$ among the stations at Rajang River ranged from 0.24 mg/L to 0.38 mg/L, whereas, among the stations at its tributaries ranged from 0.25 mg/L to 0.44 mg/L.

In July 2015, the highest mean $\text{NH}_3\text{-N}$ was recorded at station 2 at Pelagus River. Meanwhile, the highest mean $\text{NH}_3\text{-N}$ was the highest at station 20 at the most upstream station along the Rajang River in January 2016. In March 2016, station 30 at the most downstream station along the Rajang River shows the highest value of $\text{NH}_3\text{-N}$ when compared to all the other stations. The high mean at these stations were due to the contributions from the logging sites to the river during rainfall.

Among the stations along the Rajang River, the mean $\text{NH}_3\text{-N}$ was significantly higher during the sampling in March 2016, followed by January 2016 and the lowest mean $\text{NH}_3\text{-N}$ was in July 2015 (Table 4.19). This is most likely due to the high surface runoff from the nearby longhouses and logging sites during high rainfall in March 2016 (Table 2.1). $\text{NH}_3\text{-N}$ is classified as Class I and II during July 2015, and then deteriorates to Class II during January 2016 (Table 4.7). The change from Class I to Class II were shown by station 20, 22, 23, 27, 28 and 30 (Table 4.7). Furthermore, station 21, 26 and 30 deteriorates from Class II to Class III in March 2016 (Table 4.7).

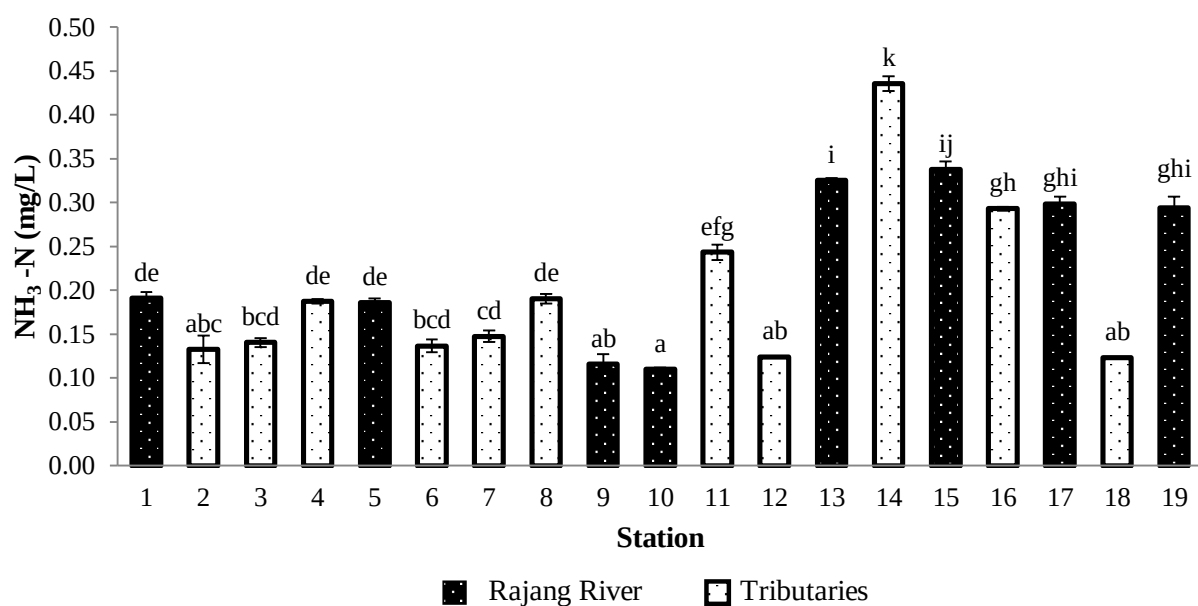


Figure 4.23: The mean $\text{NH}_3\text{-N}$ at upstream (St 1-9) and midstream (St 10-19). The same letters among all stations indicate no significant difference ($p < 0.05$).

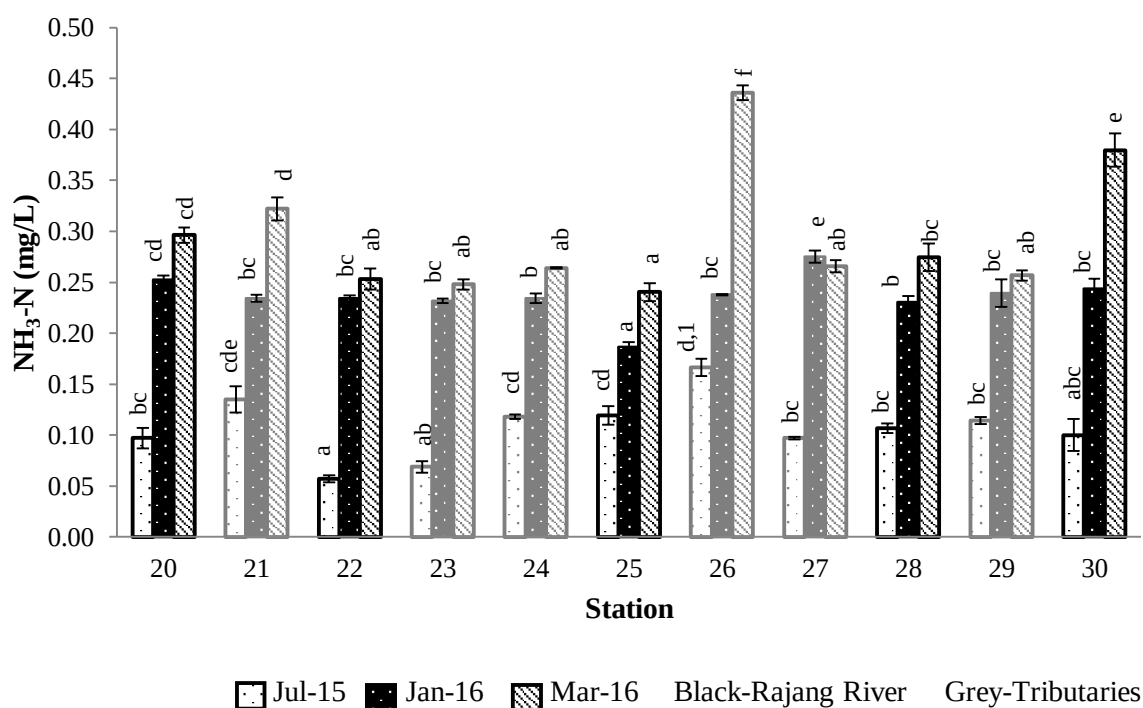


Figure 4.24: The comparison of mean $\text{NH}_3\text{-N}$ within and among stations in three different sampling periods. The same letters among stations in the same month indicate no significant difference ($p < 0.05$).

Table 4.19: The comparison of mean NH₃-N at Rajang River stations in the downstream section.

Rajang River Stations	Mean NH ₃ -N			Mean
	Jul-15	Jan-16	Mar-16	
20	0.10±0.01	0.25±0.00	0.30±0.01	0.22 ^c
22	0.06±0.00	0.23±0.01	0.25±0.01	0.18 ^a
25	0.12±0.01	0.19±0.01	0.24±0.00	0.18 ^a
28	0.11±0.01	0.23±0.01	0.27±0.00	0.20 ^b
30	0.10±0.01	0.24±0.00	0.38±0.00	0.24 ^d
Mean ± SD	0.10±0.02 ^A	0.23±0.03 ^B	0.29±0.06 ^C	

Different capital letters show significant difference between the different sampling months (p<0.05). Different small letters show significant difference among the stations (p<0.05).

4.1.2.2.5.3 Organic Nitrogen (Org-N)

The mean Org-N at upstream (St 1-9) and midstream (St 10-19) is shown in Figure 4.25. The range of mean Org-N concentration in this study varied from 0.15 mg/L to 1.34 mg/L for the upstream section. Among the stations along the Rajang River, the mean Org-N ranged from 0.15 mg/L to 0.50 mg /L whereas, among its tributaries, the mean Org-N ranged from 0.27 mg/L to 1.34 mg/L. Station 1 along the Rajang River recorded the lowest mean concentration of Org-N, whereas, the highest mean Org-N was observed at station 8 at Pila River. The high mean Org-N concentration of the stations was likely due to the waste disposal and surface runoff from the nearby longhouses and logging sites during heavy rainfall. For the midstream section, the mean Org-N ranged from 0.70 mg/L to 0.97 mg/L. Among the stations along the Rajang River, the mean Org-N ranged from 0.70 mg/L to 0.97 mg /L whereas, among its tributaries, the mean Org-N ranged from 0.81 mg/L to 0.85 mg/L. The highest mean Org-N reading occurred at station 15 at Rajang River. Meanwhile, the lowest mean Org-N was in station 1 at located at uppermost part among Rajang River stations.

The trend of mean Org-N was opposite to mean $\text{NH}_3\text{-N}$. This was likely due to the decomposition of Org-N to $\text{NH}_3\text{-N}$. There is a significant increase observed from station 1 to station 15 at the stations along the main river, the Rajang River. This is most likely contributed by the inflow of Org-N from the tributaries upstream. The discharge and velocity of the tributaries at the upstream section (station 2 to station 14) are relatively higher toward midstream direction (Table 4.2). However, significantly higher mean Org-N was observed among the tributary from station 8 to 18, compared to the tributaries at station 2 to 7. This is due to the source of the Org-N could be from the nearby longhouse and also the nearby residential area. This is supported by a study on organic matter, nutrients and trace metals of Serin River which it was reported that Org-N ranged from 0.24 to 3.90 mg/L (Ling *et al.*, 2010).

The range of Org-N concentration in this study is mostly lower than the range of Org-N in the study conducted by Ling *et al.* (2010) in Serin River, Malaysia (0.24-3.90 mg/L). In addition, the concentration of Org-N in this study is not exceeding the TN concentration found in Bertam River, Cameron Highland which is ranged from 9.70 to 17.00 mg/L (Eisakhani & Malakahmad, 2009). Furthermore, the range in this study is comparable and also not exceeding the value of TN found in Huangpu River, China which ranged from 0.80 to 6.00 mg/L (Yang *et al.*, 2007).

In this study, the mean Org-N taken in the three different samplings are shown in Figure 4.26. The range of mean Org-N in July 2015 sampling was 0.42 mg/L and 0.95 mg/L. In July 2015, the mean Org-N among the stations at Rajang River ranged from 0.42 mg/L to 0.84 mg/L, whereas, among the stations at its tributaries ranged from 0.48 mg/L to 0.95 mg/L. Meanwhile, the range of mean Org-N in January 2016 was 0.65 mg/L to 0.94 mg/L. In

January 2016, the mean Org-N among the stations at Rajang River ranged from 0.66 mg/L to 0.94mg/L, whereas, among the stations at its tributaries ranged 0.65mg/L to 0.93 mg/L. In March 2016, the mean Org-N varied from 0.79 mg/L to 0.96 mg/L. The mean Org-N among the stations at Rajang River ranged from 0.87 mg/L to 0.96mg/L, whereas, among the stations at its tributaries ranged from 0.79 mg/L to 0.96 mg/L. Station 21 at Pelagus River shows a significantly higher concentration of Org-N, while station 28 in Rajang River had the lowest Org-N concentration during the sampling in July 2015. Meanwhile, the highest Org-N was found at station 20 along the Rajang River, whereas, the lowest Org-N was recorded at station 24 at Mela River during the sampling in January 2015. During the sampling in March 2016, station 20 and 30 along Rajang River and station 24 at Mela River shows a significantly higher concentration of Org-N, while station 23 at Kapit Hulu River had the lowest Org-N concentration. The higher mean Org-N concentration is most likely due to the sewage discharge from longhouses and animal waste.

Interestingly, there is a decreasing trend of Org-N concentration starting from station 25 to station 30 during samplings in July 2015 and January 2016observed among the Rajang River station (Table 4.20). This can be explained due to the dilution of pollutants as the river water is diluting from the cleaner river water from the tributaries.

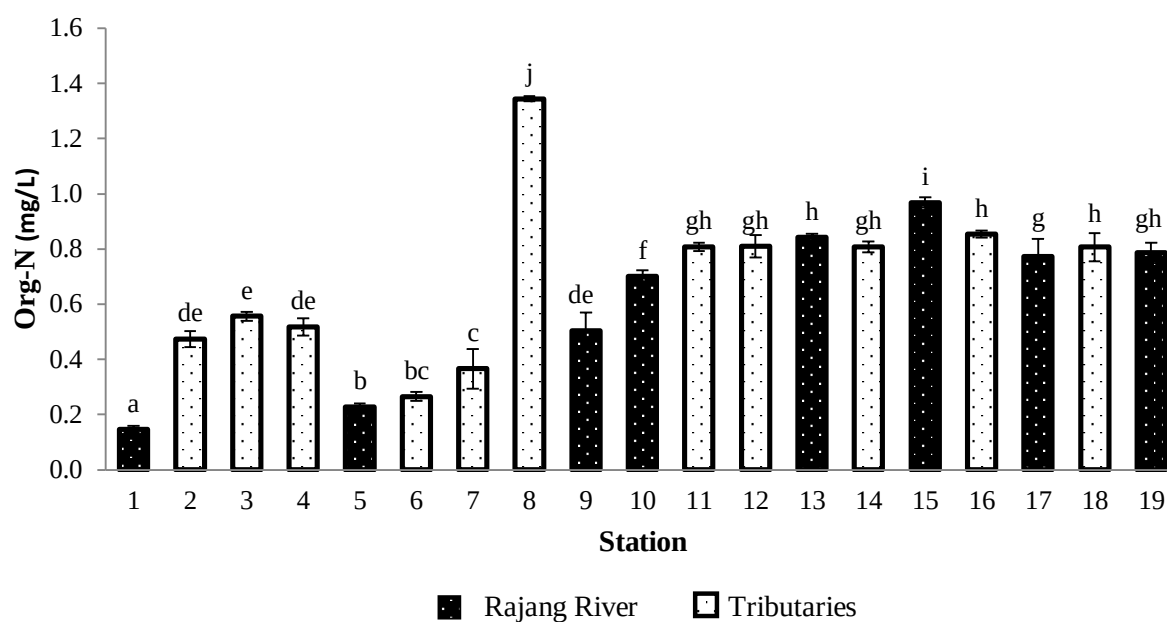


Figure 4.25: The mean Org-N at upstream (St 1-9) and midstream (St 10-19). The same letters among all stations indicate no significant difference ($p < 0.05$).

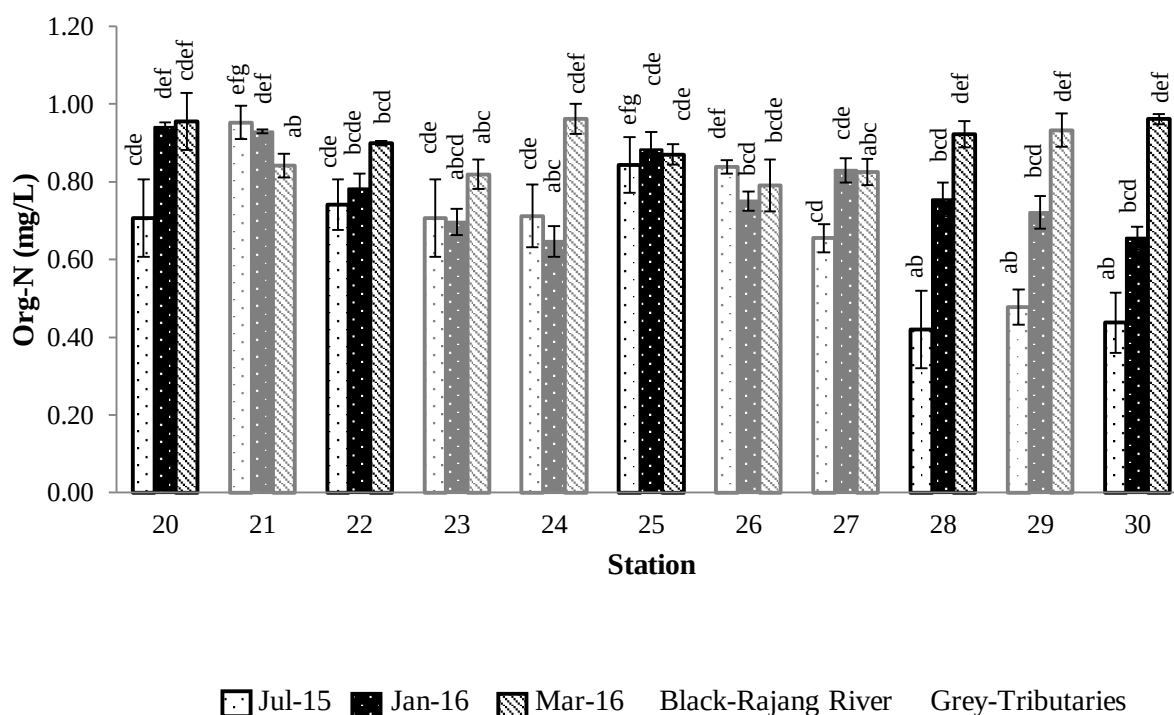


Figure 4.26: The comparison of mean Org-N within and among stations in three different sampling periods. The same letters among stations in the same month indicate no significant difference ($p < 0.05$).

Table 4.20: The comparison of mean Org-N at Rajang River stations in the downstream section.

Rajang River Stations	Mean Org-N			Mean
	Jul-15	Jan-16	Mar-16	
20	0.71±0.10	0.94±0.01	0.96±0.07	0.87 ^d
22	0.74±0.07	0.78±0.04	0.90±0.01	0.81 ^c
25	0.84±0.07	0.88±0.04	0.87±0.03	0.87 ^d
28	0.53±0.06	0.76±0.04	0.92±0.03	0.74 ^b
30	0.44±0.08	0.66±0.03	0.96±0.01	0.68 ^a
Mean ± SD	0.65±0.16 ^A	0.80±0.11 ^B	0.92±0.04 ^C	

Different capital letters show significant difference between the different sampling months ($p < 0.05$). Different small letters show significant difference among the stations ($p < 0.05$).

4.1.2.2.5.4 Total Nitrogen (TN) and its fraction

In this study, total nitrogen (TN) is the total value of mean $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, $\text{NH}_3\text{-N}$ and Org-N. The mean TN in all studied stations at upstream (St 1-9) and midstream (St 10-19) are illustrated Figure 4.27. The amount of TN in the present study ranged from 0.37 mg/L to 1.55 mg/L for the upstream section. Among the stations along the Rajang River, the mean TN ranged from 0.37 mg/L to 0.65 mg /L whereas, among its tributaries, the mean TN ranged from 0.43 mg/L to 1.55 mg/L. Station 8 at Pila River shows a higher concentration of TN, while station 1 in Rajang River had the lowest TN concentration for the upstream section. Meanwhile, the mean TN ranged from 0.83 mg/L to 1.33 mg/L for the midstream section. Among the stations along the Rajang River, the mean TN ranged from 0.83 mg/L to 1.33 mg /L whereas, among its tributaries, the mean TN ranged from 0.93 mg/L to 1.25 mg/L. The highest TN was found at station 15 along the Rajang River, whereas, the lowest TN was recorded at station 10 along the Rajang River for the midstream section. An increasing trend towards downstream direction was observed among the stations along the Rajang River for the upstream section. Meanwhile, an increasing trend towards downstream direction was also

observed among the stations along the Rajang River for the midstream section with a slight decrease at station 17 and the it remained constant from station 17 to station 19.

Nitrogen in water consists of the fraction of organic nitrogen and inorganic nitrogen. The mean TN, percentage of Org-N and percentage of Inorg-N at upstream (St 1-9) and midstream (St 10-19) was shown in Table 4.21. In this study, organic nitrogen ranged from 38.99% to 86.47% for the upstream section. Meanwhile, organic nitrogen is found to be the most dominant in total nitrogen which ranged from 64.44% to 86.43% for midstream section. Generally, the Org-N are higher at most of the tributaries (>70%). This is because of the presence of longhouses and logging sites nearby the river. Therefore, waste disposal and surface runoff from the nearby longhouses and logging sites contributed to the high Org-N. The inorganic nitrogen is found to be the mostly dominant which ranged from 13.53% to 61.01% for the upstream section. For the midstream section, inorganic nitrogen ranged from 13.57% to 35.56%.

In this study, the comparison of mean TN in downstream stations in July 2015, January 2016 and March 2016 is illustrated in Figure 4.28. In July 2015 sampling, the mean TN ranged from 0.55 mg/L to 1.11 mg/L. In July 2015, the mean TN among the stations at Rajang River ranged from 0.55 mg/L to 0.99 mg/L, whereas, among the stations at its tributaries ranged from 0.61mg/L to 1.11 mg/L. Meanwhile, the mean TN varied from 0.91 mg/L to 1.22 mg/L in January 2016 sampling. In January 2016, the mean TN among the stations at Rajang River ranged from 0.92 mg/L to 1.22 mg/L, whereas, among the stations at its tributaries ranged 0.91mg/L to 1.19 mg/L. The range of mean TN in March 2016 sampling was 1.09 mg/L and 1.36 mg/L. In March 2016, the mean TN among the stations at Rajang River ranged from 0.1.14 mg/L to 1.36 mg/L, whereas, among the stations at its tributaries ranged from 1.09

mg/L to 1.26 mg/L. Station 21 at Pelagus River shows a significantly high concentration of TN, while station 28 in Rajang River had the lowest TN concentration during the sampling in July 2015. Meanwhile, the highest TN was found at station 20 along the Rajang River, whereas, the lowest TN was recorded at station 24 at Mela River during the sampling in January 2015. During the sampling in March 2016, station 30 along Rajang River shows a significantly high concentration of TN, while station 23 at Kapit Hulu River had the lowest TN concentration.

There is no clear trend of TN towards downstream direction was observed among the stations along the Rajang River for the downstream section. The percentage of inorganic nitrogen for the sampling on July 2015 during low water flow is higher compared to January and March of 2016 where both were measured during high water flow (Table 4.21).

The range of mean TN in this study is within the range value of TN found in Huangpu River, China which ranged from 0.80 to 6.00 mg/L (Yang *et al.*, 2007) and lower than the TN concentration found in Bertam River, Cameron Highland, Malaysia which ranged from 9.70 to 17.00 mg/L (Eisakhani & Malakahmad, 2009).

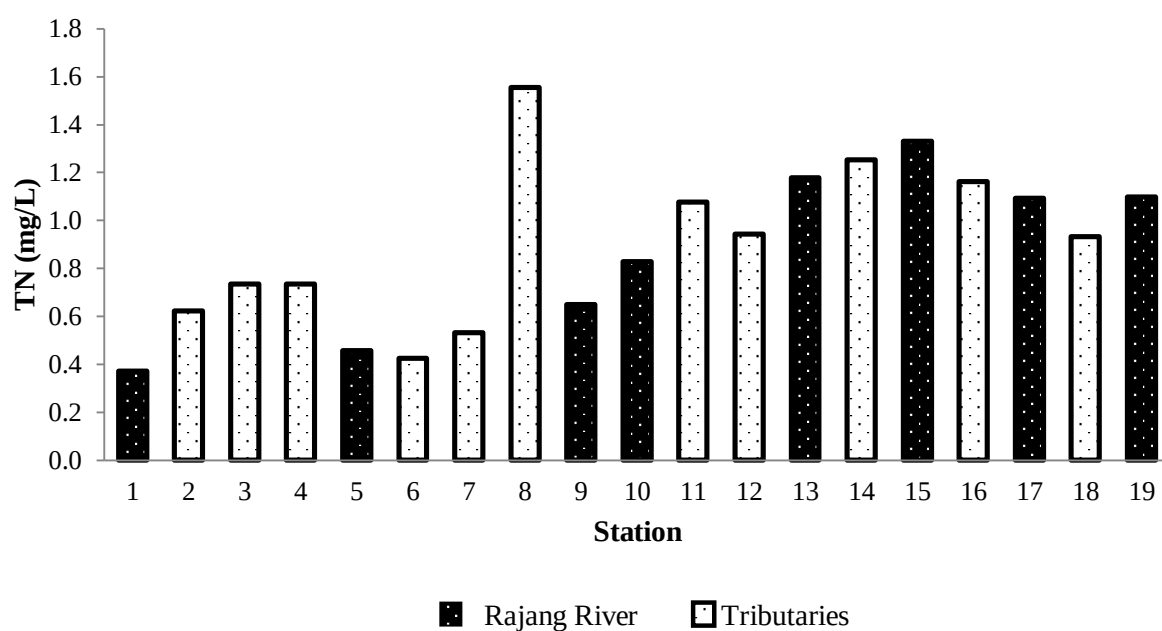


Figure 4.27: The mean TN at upstream (St 1-9) and midstream (St 10-19).

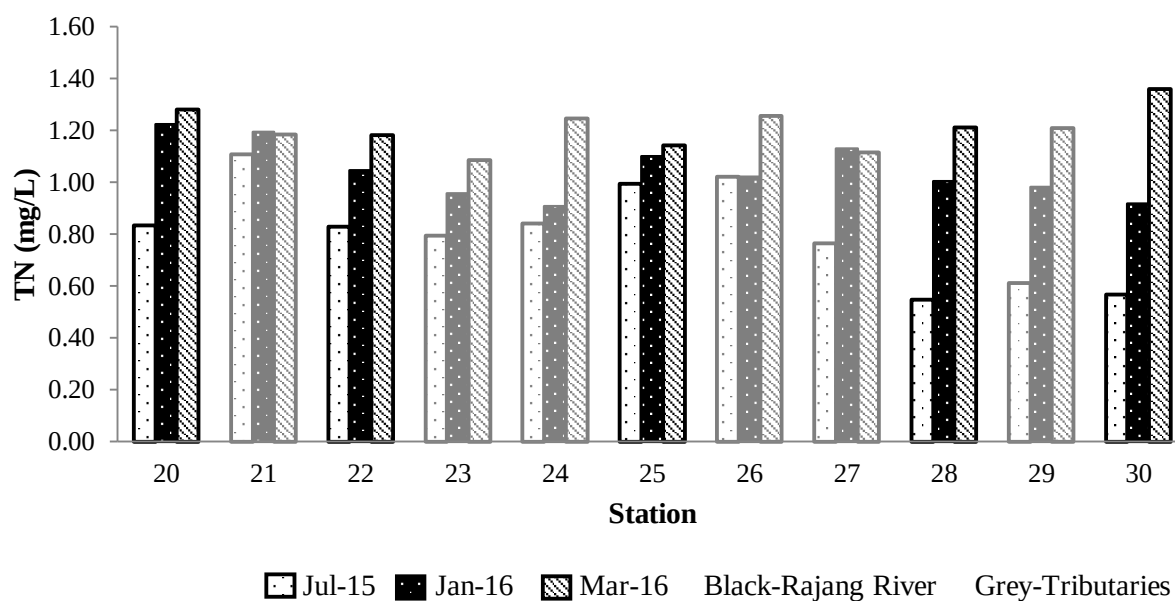


Figure 4.28: The comparison of mean TN within and among stations in three different sampling periods. The same letters among stations in the same month indicate no significant difference ($p < 0.05$).

Table 4.21: The mean TN, percentage of Org-N and percentage of Inorg-N at upstream (St 1-9), midstream (St 10-19) and downstream (St 20-30) sections

Section	Station	Total Nitrogen (mg/L)			Org-N (%)			Inorg-N (%)		
Upstream	1	0.37			38.99			61.01		
	2	0.62			76.05			23.95		
	3	0.74			75.50			24.50		
	4	0.73			70.37			29.63		
	5	0.46			49.79			50.21		
	6	0.43			62.39			37.61		
	7	0.53			68.58			31.42		
	8	1.55			86.47			13.53		
	9	0.65			77.52			22.48		
Midstream	10	0.83			84.69			15.31		
	11	1.08			74.93			25.07		
	12	0.94			85.80			14.20		
	13	1.18			71.54			28.46		
	14	1.25			64.44			35.56		
	15	1.33			72.83			27.17		
	16	1.16			73.36			26.64		
	17	1.09			70.56			29.44		
	18	0.93			86.43			13.57		
	19	1.10			71.46			28.54		
Downstream	Station	July 2015			January 2016			March 2016		
		Org-N (%)	Inorg-N (%)	TN (mg/L)	Org-N (%)	Inorg-N (%)	TN (mg/L)	Org-N (%)	Inorg-N (%)	TN (mg/L)
	20	84.75	15.25	0.83	76.90	23.10	1.22	74.54	25.46	1.28
	21	86.00	14.00	1.11	77.84	22.16	1.19	71.11	28.89	1.18
	22	89.50	10.50	0.83	74.73	25.27	1.05	76.06	23.94	1.18
	23	88.84	11.16	0.80	72.68	27.32	0.96	75.35	24.65	1.09
	24	84.77	15.23	0.84	71.26	28.74	0.91	77.19	22.81	1.25
	25	84.96	15.04	0.99	80.29	19.71	1.10	76.06	23.94	1.14
	26	82.08	17.92	1.02	73.45	26.55	1.02	62.92	37.08	1.26
	27	85.57	14.43	0.77	73.31	26.69	1.13	74.05	25.95	1.12
	28	76.83	23.17	0.55	75.09	24.91	1.01	76.01	23.99	1.21
	29	78.06	21.94	0.61	73.58	26.42	0.98	77.13	22.87	1.21
	30	77.08	22.92	0.57	71.28	28.72	0.92	70.64	29.36	1.36

*Bold indicates the stations along Rajang River

4.1.3 Pollutant and DO Loads of the upstream and midstream sections

The loading of TSS, DO, BOD and COD of all stations at Rajang River of upstream and midstream sections of Pelagus Area are shown in Table 4.22. Meanwhile, Table 4.24 show the loading of NO₂-N, NO₃-N, NH₃-N and Org-N of all stations at Rajang River of upstream and midstream section of Pelagus Area. Among the stations along Rajang River, the loading of all the pollutants and DO shows an increasing concentration from the uppermost station (station 1) compared to the most downstream station (station 9) for upstream section except for NO₃-N loading and NH₃-N loading (Table 4.22 and Table 4.24). Among the stations along Rajang River, the loading of all the pollutants and DO shows an increased concentration from the upmost station (station 10) compared to the most downstream station (station 19) for midstream section except for TSS loading (Table 4.22 and Table 4.24).

The comparisons of loading of pollutants and DO loading of all stations at downstream section are tabulated in Table 4.23 and Table 4.25. The loading of TSS, DO, BOD and COD of all stations at Rajang River of downstream sections of Pelagus Area for July 2015, January 2016 and March 2016 are shown in Table 4.23. Meanwhile, Table 4.25 shows the loading of NO₂-N, NO₃-N, NH₃-N and Org-N of all stations at Rajang River of downstream section of Pelagus Area for July 2015, January 2016 and March 2016 respectively.

The positive difference in the loading at downstream section between the first station and the last station of each section show that the pollutants are contributed from the loadings from the tributaries. Meanwhile, the negative value in the loading difference between the first station and the last station of each section indicates that the pollutants in the Rajang River have undergone dilution by the addition of cleaner water from the tributaries and the assimilation in

the river section. These negative loadings are shown by TSS for midstream section, and NO₃-N and NH₃-N for upstream section.

Among the stations along Rajang River, the loading of all the pollutants shows a gradual increasing trend towards the downstream direction in July 2015, January 2016 and March 2016. Comparatively, the loading of pollutants was higher in March 2016 compared to the other in July 2015 and January 2016. This is because the total rainfall amount and total discharge from Bakun Hydroelectric Dam was the highest in March 2016. Thus, the increase loading of the pollutants was contributed by the runoff due the high density of rain and the Bakun Hydroelectric Dam upstream. There is a significant correlation between the amount of rainfall and the increase of loading of TSS. This is shown by the positive correlation between the river discharge and TSS ($r = 0.534$, p value < 0.05 , $n=29$) at the non-regulated rivers data taken at the tributaries (Table 4.34). Meanwhile, the loading of TSS along Rajang River stations showed no significant trend towards downstream direction. However, there are significant changes such as increases in loadings of TSS among the Rajang River stations which are likely contributed from the tributaries upstream of the stations.

Among the stations along the Rajang River, the loadings of DO, BOD, COD, NO₂-N, NO₃-N, NH₃-N and Org-N was show increasing trend towards downstream direction. Meanwhile, the loading of TSS along Rajang River stations showed no significant trend towards downstream direction. However, there are significant changes such as increases in loading of TSS among the Rajang River stations which may contributed from the tributaries upstream of the stations.

Table 4.22: The loading of TSS, DO, BOD and COD of all stations at Rajang River of upstream and midstream sections.

Section	Station	Pollutants Loading (kg/day)			
		TSS (kg/day)	DO (kg/day)	BOD (kg/day)	COD (kg/day)
Upstream	1	2001706	241744	226928	2742029
	2	386650	4700	2830	28870
	3	747	631	191	2137
	4	20594	3118	1252	12670
	5	4548776	351514	255378	3136216
	6	610088	23152	6200	66772
	7	8445	3459	1390	15279
	8	67195	12118	5002	61751
	9	2127122	265465	246424	2858851
	St 9 – St 1	125416	23720	19496	116822
Midstream	10	14397800	721187	251265	3159733
	11	42030	2079	1335	13730
	12	12321	1597	531	5421
	13	15785600	802435	277108	3437753
	14	51147	1389	423	4186
	15	18102077	824481	263150	3322264
	16	5336	846	368	5025
	17	11848912	860231	287060	3715819
	18	5807	1560	459	4645
	19	9558971	880154	317283	3810627
	St 19 – St 10	-4838828	158967	66017	650894

*Bold indicates the stations along Rajang River

Table 4.23: The comparison of loading of TSS, DO, BOD and COD of all stations at the downstream section of at Rajang River at Pelagus Area

July 2015				
Station	TSS (kg/day)	DO (kg/day)	BOD (kg/day)	COD (kg/day)
20	502496	62943	34455	405651
21	11265	1482	590	6075
22	1305389	131817	74006	723481
23	122085	2998	1097	11319
24	7573	1090	365	3683
25	1132254	154820	61621	766159
26	1137919	20368	7973	84531
27	9822	551	315	3224
28	2556776	326998	179084	3447610
29	637608	136639	45113	471319
30	6034282	468375	236964	2494170
St 30–St 30	5531786	405433	202510	2088519
January 2016				
20	20023244	578971	597323	10939529
21	7056208	26141	13893	260947
22	39877846	648865	613627	11115726
23	14878	2590	1412	17126
24	407	629	364	3531
25	34543790	719929	687688	10655881
26	2750	827	538	5389
27	919	299	235	2445
28	8235921	725793	739506	12518600
29	55611097	831179	514241	6716948
30	100045614	1362567	1278179	18482654
St 30–St 20	80022370	783596	680857	7543125
March 2016				
20	246575309	2892570	891326	17671230
21	2824073	14194	7082	122377
22	349233820	3019384	908578	19786503
23	15477	3338	1423	14084
24	1736	187	100	1179
25	281295818	3036523	994973	19146765
26	84560	2652	1158	14601
27	16262	399	263	2580
28	364551582	3382224	1027858	19992287
29	388436410	1730137	623405	12989116
30	945763474	4509241	1329218	28817327
St 30–St 20	699188165	1616671	437891	11146097

*Bold indicates the stations along Rajang River

Table 4.24: The loading of NO₂-N, NO₃-N, NH₃-N, Org-N and TN of all stations at Rajang River of upstream and midstream section.

Section	Station	Pollutants Loading (kg/day)			
		NO ₂ -N (kg/day)	NO ₃ -N (kg/day)	NH ₃ -N (kg/day)	Org-N (kg/day)
Upstream	1	292	1401	8816	6716
	2	5	7	101	359
	3	0	3	12	46
	4	2	11	82	225
	5	337	2244	11104	13573
	6	22	47	408	792
	7	3	6	72	178
	8	10	24	328	2316
	9	476	1055	5916	25679
	St 9 – St 1	184	-346	-2900	18962
Midstream	10	324	1297	10706	68204
	11	1	8	85	283
	12	0	2	27	178
	13	182	914	35672	92419
	14	0	2	86	159
	15	266	2396	38545	110473
	16	0	2	36	103
	17	197	2567	35375	91430
	18	0	1	26	167
	19	405	2025	35694	95450
	St 19 – St 10	81	728	24988	27246

*Bold indicates the stations along Rajang River

Table 4.25: The comparison of loading of NO₂-N, NO₃-N, NH₃-N, Org-N and TN of all stations at the downstream segment of at Rajang River at Pelagus Area

July 2015				
Station	NO ₂ -N (kg/day)	NO ₃ -N (kg/day)	NH ₃ -N (kg/day)	Org-N (kg/day)
20	94	199	951	6917
21	1	2	28	199
22	255	350	1149	14958
23	4	4	28	286
24	1	0	18	106
25	220	487	2818	19910
26	22	26	483	2434
27	0	1	8	55
28	487	521	5389	21210
29	178	204	2185	9135
30	766	1389	7190	31428
St 30–St 30	672	1190	6239	24511
January 2016				
20	651	3012	30838	114883
21	22	103	976	3867
22	715	3308	31439	104873
23	2	10	96	288
24	0	2	24	66
25	975	3415	27354	129338
26	0	4	33	103
27	0	1	16	48
28	735	2206	33889	111041
29	636	2090	32605	98382
30	1547	3610	62893	168899
St 30–St 20	896	598	32055	54016
March 2016				
20	733	10274	108765	350604
21	4	37	677	1769
22	1792	9729	97261	345604
23	2	7	120	396
24	0	0	7	27
25	2201	10749	93426	337981
26	0	10	154	279
27	0	1	18	56
28	1451	5805	119469	401449
29	1005	3634	59533	216422
30	1169	10526	222006	562347
St 30–St 20	436	252	113241	211743

*Bold indicates the stations along Rajang River

4.1.4 Water Quality Index (WQI)

In this study, water quality is classified according to Water Quality Index (WQI) of Department of Environment (DOE). Table 4.26 shows the WQI classification of water quality parameters for the upstream and midstream sections. Based on WQI of station 1 to 19 at the upstream and midstream sections are classified as Class II or III (Table 4.26). The status of the stations according to Department of Environment (DOE) of Malaysia varies from Clean to Slightly Polluted.

A total of 7 out of 19 stations are in the Clean status while the rest are Slightly Polluted. The stations along the Rajang River are classified as Class II at the upstream section, whereas, classified as Class II or III for the midstream section. All of them are considered Slightly Polluted. At the midstream section, the changes of Class II to Class III from station 10 to station 13 is most likely due to the contribution from the tributary upstream of station 13, which is station 11 at Ensawi River (Class III). The Class III was improved to Class II from station 15 to station 17 which is caused by the dilution from tributary, station 16 (Class II).

There are a total of four stations among the tributary which were considered Slightly Polluted for the upstream and midstream sections (Table 4.26). They are station 2 at Punan Sama River and station 6 at Bah River for the upstream section, whereas, station 11 at Ensawi River and station 11 at Sama River for the midstream section (Table 4.26). Pollutants that contributed to the deterioration of the status of these stations are COD and TSS for station 2 (SICOD=55.13 and SISS=10.81) and station 6 (SICOD=71.57 and SISS=23.44) at the upstream section (Table 4.27). Meanwhile, for the midstream section, they are COD, NH₃-N and TSS for station 11 (SICOD=55.13, SIAN=74.94 and SISS=10.81) and station 14 (SICOD=71.57, SIAN=65.40 and SISS=23.44) at the upstream section (Table 4.27). Tributary station 3, 4, 7,

8, 12, 16 and 18 are considered Clean which can be used as water supply after conventional treatment. This result is similar to the study conducted by Zaina *et al.* (2015) at Berasau River, Johor, Malaysia which is classified between Class II (good) and III (moderate) of river water quality.

Classification using WQI for water quality in July 2015, January 2016 and March 2016 are shown in Table 4.28. Meanwhile, the Sub-Index (SI) of DO, pH, BOD, COD, AN and SS of stations at downstream section for the three samplings are shown in Table 4.29. Overall, the WQI for the total of eleven sampling stations at downstream section of study area are classified as Class II or Class III. The stations that are classified under Class II are considered clean and can be used as water supply after conventional treatment. Meanwhile, classification of Class III is considered slightly polluted and can be used as water supply after extensive treatment. Therefore, the status of the stations in the present study is classified as clean or slightly polluted based on Department of Environment (DOE).

In July 2015, a total of nine stations were classified as Class II whereas the other two stations fall in Class III. The two Class III stations are station 23 at Kapit Hulu River and station 26 at Cermin River. In January 2016, the WQI value of most of the stations decreased except for station 27 at Nanga Senuang. The WQI classification of the seven stations changed to Class III whereas the other stations are maintained in Class II. The seven stations are station 20, 21, 22, 25, 28, 29 and 30. In March 2016, most of the stations fall in Class III except for station 23 at Kapit Hulu and station 24 at Mela River which fall in Class II.

In July 2015, there are a total of five stations with the status of slightly polluted whereas the other six station are considered clean. The five stations with Slightly Polluted status in July 2015 are station 23 at Kapit Hulu, 25 at Rajang River, 26 at Cermin River, 27 at Nanga

Senuang and 28 at Rajang River. In January 2016, the status of those five stations maintained as Slight polluted. In March 2016, station 23 at Kapit Hulu changed from slightly polluted to clean. For the six clean stations in July 2015, all changed from clean to slightly polluted. The most obvious change can be seen in the Rajang River stations where all the five stations changed from Class II in July 2015 to Class III in both January and March 2016. Those changes are mostly contributed by BOD, COD, NH₃-N and TSS parameters (Table 4.29).

Table 4.26: WQI classification of water quality parameters for the upstream and midstream sections.

Section	Station	WQI	Class	Status
Upstream	1	76.93	II	Slightly polluted
	2	73.10	III	Slightly polluted
	3	88.86	II	Clean
	4	84.58	II	Clean
	5	77.75	II	Slightly polluted
	6	79.43	II	Slightly polluted
	7	87.30	II	Clean
	8	84.09	II	Clean
	9	78.41	II	Slightly polluted
Midstream	10	78.23	II	Slightly polluted
	11	71.79	III	Slightly polluted
	12	85.15	II	Clean
	13	75.45	III	Slightly polluted
	14	74.06	III	Slightly polluted
	15	75.62	III	Slightly polluted
	16	80.10	II	Clean
	17	79.45	II	Slightly polluted
	18	88.90	II	Clean
	19	79.78	II	Slightly polluted

*Bold indicates the stations along Rajang River

Table 4.27: The Sub-Index of the WQI classification for the upstream and midstream sections.

Section	Station	SIDO	SIBOD	SICOD	SIAN	SISS	SIpH
Upstream	1	89.84	79.62	38.19	80.46	74.91	98.94
	2	100.00	84.61	55.13	86.58	10.81	95.73
	3	97.64	90.67	67.71	85.75	92.19	97.53
	4	100.00	88.23	64.04	80.79	73.17	97.87
	5	97.32	82.27	42.97	80.93	62.01	98.13
	6	100.00	91.60	71.57	86.14	23.44	99.18
	7	100.00	88.33	61.70	85.01	87.59	99.00
	8	100.00	88.12	57.24	80.51	76.85	98.45
	9	88.88	79.98	40.52	88.33	75.65	98.51
Midstream	10	100.00	89.47	60.56	88.94	31.01	93.66
	11	100.00	84.27	54.09	74.94	35.95	93.66
	12	97.05	90.19	68.97	87.47	69.57	94.76
	13	97.65	89.71	61.70	69.64	31.66	96.16
	14	95.31	91.30	72.90	65.40	18.44	94.33
	15	97.05	90.64	64.04	69.14	29.35	97.80
	16	94.91	87.57	52.08	69.72	74.61	98.76
	17	97.40	90.15	61.70	69.15	54.59	99.24
	18	100.00	91.04	71.57	87.56	82.09	99.03
	19	94.91	89.35	61.70	69.66	61.22	98.39

*Bold indicates the stations along Rajang River

Table 4.28: WQI classification of downstream stations at the three different sampling periods

St	July 2015			January 2016			March 2016		
	WQI	Class	Status	WQI	Class	Status	WQI	Class	Status
20	81.88	II	Clean	60.59	III	Slightly polluted	70.02	III	Slightly polluted
21	85.13	II	Clean	64.57	III	Slightly polluted	64.96	III	Slightly polluted
22	82.63	II	Clean	59.84	III	Slightly polluted	70.84	III	Slightly polluted
23	76.94	II	Slightly polluted	79.82	II	Slightly polluted	83.30	II	clean
24	85.74	II	Clean	83.09	II	clean	78.06	II	Slightly polluted
25	84.18	II	Clean	62.53	III	Slightly polluted	70.91	III	Slightly polluted
26	74.01	III	Slightly polluted	80.22	II	clean	71.34	III	Slightly polluted
27	75.78	III	Slightly polluted	76.79	II	Slightly polluted	68.59	III	Slightly polluted
28	78.62	II	Slightly polluted	69.14	III	Slightly polluted	71.03	III	Slightly polluted
29	87.36	II	Clean	67.29	III	Slightly polluted	67.87	III	Slightly polluted
30	81.18	II	Clean	61.62	III	Slightly polluted	67.97	III	Slightly polluted

*Bold indicates the stations along Rajang River

Table 4.29: The Sub-Index (SI) of DO, pH, BOD, COD, AN and SS of stations at downstream section for the three samplings

Station	SIDO			SIpH		
	Jul-15	Jan-16	Mar-16	Jul-15	Jan-16	Mar-16
20	92.82	65.59	100.00	99.10	99.01	93.80
21	100.00	87.11	92.01	98.91	99.02	97.14
22	93.81	67.51	100.00	99.43	97.34	94.53
23	96.75	87.85	94.81	98.38	99.07	95.80
24	95.88	86.54	93.34	98.32	99.27	96.19
25	94.20	69.31	100.00	99.43	98.37	95.38
26	93.61	84.58	100.00	98.86	99.31	96.32
27	88.92	72.89	83.00	99.09	99.29	95.47
28	92.74	69.93	100.00	99.35	99.36	94.19
29	97.22	85.42	100.00	97.97	99.44	95.29
30	93.04	75.21	100.00	99.56	98.86	94.24
Station	SIBOD			SICOD		
	Jul-15	Jan-16	Mar-16	Jul-15	Jan-16	Mar-16
20	85.51	79.71	90.12	52.08	21.65	46.43
21	88.43	86.28	86.14	64.04	35.97	38.95
22	84.89	81.05	90.39	57.24	24.72	43.81
23	88.92	85.95	87.96	65.24	52.08	64.04
24	90.08	85.26	85.17	68.97	58.33	51.10
25	89.35	80.53	89.57	60.56	29.93	45.54
26	88.78	83.84	86.49	64.04	54.09	52.08
27	84.64	83.13	84.00	55.13	51.10	55.13
28	85.39	81.40	90.41	32.50	23.66	48.25
29	90.42	84.44	89.03	68.97	45.54	40.52
30	86.45	79.43	90.78	58.33	30.56	45.54
Station	SIAN			SISS		
	Jul-15	Jan-16	Mar-16	Jul-15	Jan-16	Mar-16
20	90.30	73.98	69.38	71.48	28.57	11.26
21	86.32	75.87	69.77	70.38	0.00	0.00
22	94.53	75.89	73.91	66.21	16.04	13.92
23	93.27	76.15	74.46	15.78	78.24	80.13
24	88.11	75.91	72.77	71.76	95.10	66.96
25	87.96	80.88	75.25	72.88	20.37	11.72
26	83.03	75.52	65.40	12.38	86.17	20.02
27	90.30	71.59	72.57	36.73	88.30	20.02
28	89.29	76.31	71.69	71.76	69.57	12.99
29	88.50	75.38	73.55	79.50	12.01	0.00
30	89.99	74.89	67.52	59.46	12.48	0.00

*Bold indicates the stations along Rajang River

4.1.5 The comparison of water quality parameters

The comparison of the means of water quality parameter values at the stations at Rajang River and its tributaries conducted using independent *t*-test for the upstream and midstream sections are shown in Table 4.30. Meanwhile, for downstream sections are shown in Table 4.31.

The means of temperature, conductivity, BOD, COD, NO₃-N, and NH₃-N of the main river stations along the Rajang River are significantly higher compared to tributaries for the upstream section. Meanwhile, at the midstream section, the means of temperature, conductivity, NO₃-N and Org-N of the main river stations along the Rajang River are significantly higher compared to tributaries. The means of turbidity, transparency, TSS, pH, DO, Org-N and TN of the stations at Rajang River were significantly lower in concentrations than the tributaries for the upstream section. Meanwhile, for the midstream section, the means of turbidity, TSS, COD and NH₃-N of the stations at Rajang River were significantly lower in concentrations than the tributaries.

In July 2015, the means of temperature, transparency, DO, BOD and COD of the main river stations along the Rajang River are significantly higher compared to the tributaries. Meanwhile, the means of conductivity, turbidity, TSS, TN, NH₃-N and pH of the tributaries have significantly higher compared to the main river stations along the Rajang River. In January 2016, the means of temperature, TN, BOD and COD of the main river stations along the Rajang River are significantly higher compared to the tributaries. Meanwhile, the means of conductivity, turbidity, transparency, TSS, pH, NH₃-N and DO of the tributaries have significantly higher compared to the main river stations along the Rajang River. In March 2016, the means of transparency, TSS, TN, DO, BOD and COD of the main river stations along the Rajang River are significantly higher compared to the tributaries. Meanwhile, the

means of conductivity, turbidity, NH₃-N and pH of the tributaries have significantly higher compared to the main river stations along the Rajang River. The means of temperature, NO₂-N, NO₃-N and Org-N were not significant different between the Rajang River stations and tributaries stations.

Table 4.30: The comparisons of the water quality parameters of the stations between the Rajang River and its tributaries for the upstream and midstream sections

Parameters	Section	Range at Rajang River	Mean range	Range at tributaries	Mean range	<i>p</i> -value
Temperature	Upstream	27.20 – 27.63	27.42	25.00 – 26.37	25.69	<i>p</i> <0.05
	Midstream	26.86 – 27.12	26.99	26.25 – 26.74	26.50	<i>p</i> <0.05
Conductivity	Upstream	31.20 – 31.50	31.35	24.00 – 33.30	28.65	<i>p</i> <0.05
	Midstream	30.00 – 32.00	31.00	2.00 – 33.00	17.50	<i>p</i> <0.05
Turbidity	Upstream	72.23 – 87.07	79.65	13.40 – 716.00	364.70	<i>p</i> <0.05
	Midstream	107.40 – 162.13	134.77	2.60 – 291.50	147.05	<i>p</i> <0.05
Transparency	Upstream	0.18 – 0.22	0.20	0.05 – 0.71	0.38	<i>p</i> <0.05
	Midstream	0.05 – 0.10	0.08	0.01 – 0.15	0.08	<i>p</i> >0.05
TSS	Upstream	41.67 – 76.35	59.01	17.33 – 510.00	263.67	<i>p</i> <0.05
	Midstream	78.67 – 158.67	118.67	28.00 – 260.00	144.00	<i>p</i> <0.05
pH	Upstream	6.65 – 7.13	6.89	6.70 – 7.61	7.16	<i>p</i> <0.05
	Midstream	6.20 – 6.86	6.53	6.25 – 6.81	6.53	<i>p</i> >0.05
DO	Upstream	5.20 – 5.90	5.55	6.20 – 7.77	6.99	<i>p</i> <0.05
	Midstream	7.23 – 7.41	7.32	5.94 – 7.52	6.73	<i>p</i> <0.05
BOD	Upstream	4.29 – 4.91	4.60	2.08 – 3.73	2.91	<i>p</i> <0.05
	Midstream	2.31 – 2.61	2.46	2.15 – 3.81	2.98	<i>p</i> <0.05
COD	Upstream	52.64 – 59.36	56.00	22.40 – 38.08	30.24	<i>p</i> <0.05
	Midstream	29.12 – 32.48	30.80	21.28 – 41.44	31.36	<i>p</i> >.05
NO ₂ -N	Upstream	0.006 – 0.009	0.01	0.006 – 0.008	0.01	<i>p</i> >0.05
	Midstream	0.002 – 0.003	0.00	0.000 – 0.005	0.00	<i>p</i> >0.05
NO ₃ -N	Upstream	0.02 – 0.04	0.03	0.01 – 0.03	0.02	<i>p</i> <0.05
	Midstream	0.01 – 0.02	0.02	0.00 – 0.02	0.01	<i>p</i> <0.05
NH ₃ -N	Upstream	0.19 – 0.20	0.20	0.12 – 0.19	0.16	<i>p</i> <0.05
	Midstream	0.11 – 0.34	0.23	0.12 – 0.44	0.28	<i>p</i> <0.05
Org-N	Upstream	0.15 – 0.50	0.33	0.27 – 1.34	0.81	<i>p</i> <0.05
	Midstream	0.70 – 0.97	0.84	0.81 – 0.85	0.83	<i>p</i> <0.05
TN	Upstream	0.37 – 0.65	0.51	0.43 – 0.55	0.99	<i>p</i> <0.05
	Midstream	0.83 – 1.33	1.08	0.93 – 1.25	1.09	<i>p</i> >0.05

Upstream: Rajang River (n=3), tributary = (n=6); Midstream: Rajang River (n=5), tributary = (n=5).

Table 4.31: The comparison of the water quality parameters of the stations between Rajang River and its tributaries at the downstream sections at the three different month of samplings

Parameters	Sampling	Range at Rajang River	Mean range	Range at tributaries	Mean range	p-value
Temperature	July 2015	28.69 – 29.37	29.03	25.08–29.66	27.37	$p<0.05$
	January 2016	28.23–28.83	28.53	26.32–27.79	27.06	$p<0.05$
	March 2016	26.94–27.30	27.12	26.42–28.06	27.24	$p<0.05$
Conductivity	July 2015	31.00–42.67	36.84	38.00–74.00	56.00	$p>0.05$
	January 2016	32.00–33.00	32.50	25.00–82.00	53.50	$p>0.05$
	March 2016	31.00–31.06	31.03	29.09–39.58	34.34	$p>0.05$
Turbidity	July 2015	55.57–61.47	58.52	19.87–411.63	215.75	$p>0.05$
	January 2016	70.06–198.50	134.28	0.00–1183.72	591.86	$p>0.05$
	March 2016	109.18–117.02	113.10	33.13–797.40	415.27	$p<0.05$
Transparency	July 2015	0.09–0.71	0.40	0.05–0.57	0.31	$p<0.05$
	January 2016	0.01–0.21	0.11	0.05–0.38	0.22	$p>0.05$
	March 2016	0.05–0.30	0.18	0.05–0.30	0.18	$p<0.05$
TSS	July 2015	48.00–84.00	66.00	33.33–392.00	212.67	$p>0.05$
	January 2016	56.00–388.00	222.00	4.00–1696.00	850.00	$p>0.05$
	March 2016	672.00–1617.33	1144.67	32.00–1674.67	853.34	$p<0.05$
pH	July 2015	6.83–7.00	6.92	7.09–7.32	7.21	$p>0.05$
	January 2016	6.55–6.89	6.72	6.81–7.03	6.92	$p>0.05$
	March 2016	6.21–6.34	6.28	6.33–6.52	6.43	$p>0.05$
DO	July 2015	6.43–6.56	6.50	6.51–7.42	6.97	$p<0.05$
	January 2016	4.74–5.28	5.01	5.20–6.28	5.74	$p>0.05$
	March 2016	7.71–7.88	7.80	5.88–7.53	6.71	$p<0.05$
BOD	July 2015	2.61–3.67	3.14	2.36–3.73	3.05	$p<0.05$
	January 2016	4.58–5.03	4.81	3.34–4.08	3.71	$p<0.05$
	March 2016	2.27–2.56	2.42	2.69–3.88	3.29	$p<0.05$
COD	July 2015	32.48–68.32	50.40	26.64–38.08	32.36	$p<0.05$
	January 2016	71.68–89.60	80.64	34.72–62.72	48.72	$p<0.05$
	March 2016	45.92–51.52	48.72	29.12–58.24	43.68	$p<0.05$
NO ₂ -N	July 2015	0.003–0.013	0.01	0.003–0.011	0.01	$p<0.05$
	January 2016	0.005–0.007	0.01	0.004–0.005	0.00	$p<0.05$
	March 2016	0.002–0.006	0.00	0.001–0.006	0.00	$p<0.05$
NO ₃ -N	July 2015	0.01–0.02	0.02	0.00–0.01	0.01	$p<0.05$
	January 2016	0.02–0.02	0.02	0.02–0.03	0.03	$p<0.05$
	March 2016	0.01–0.03	0.02	0.01–0.03	0.02	$p<0.05$
NH ₃ -N	July 2015	0.06–0.12	0.09	0.07–0.14	0.11	$p>0.05$
	January 2016	0.19–0.25	0.22	0.23–0.28	0.26	$p>0.05$
	March 2016	0.24–0.38	0.31	0.25–0.44	0.35	$p>0.05$
Org-N	July 2015	0.42–0.84	0.63	0.48–0.95	0.72	$p>0.05$
	January 2016	0.66–0.94	0.80	0.65–0.93	0.79	$p<0.05$
	March 2016	0.87–0.96	0.92	0.79–0.96	0.88	$p<0.05$
TN	July 2015	0.55–0.99	0.77	0.61–1.11	0.86	$p>0.05$
	January 2016	0.92–1.22	1.07	0.91–1.19	1.05	$p<0.05$
	March 2016	1.14–1.36	1.25	1.09–1.26	1.18	$p<0.05$

4.1.6 Comparison of water quality with previous study

The water quality in this present study at Rajang River was compared with the water quality during the pre-impoundment condition which was conducted by Mohamed *et al.* (1997). They are shown in Table 4.32. Overall, the mean range in this present study was higher in most of the parameters except for the DO. This indicated that the water quality deteriorated compared to before the impoundment of Rajang River for the Bakun Hydroelectric Dam.

Table 4.32: The comparison of the range of water quality in the present study with the pre-impoundment condition (Mohamed *et al.* 1997)

Parameter	Pre-impoundment (Mohamed et al. 1997)		This present study (Rajang River)	
	Range	Mean	Range	Mean
Temperature (°C)	24.7-25.5	25.1	27.1-29.3	28.2
DO (mg/L)	7.0-8.0	7.5	4.7-7.9	6.7
pH	6.0-7.9	7.0	6.2-7.1	7.1
Conductivity (µS/cm)	12-50	31	30-42	36
TSS (mg/L)	170-300 290-1400	235 845	41-1617	831
COD (mg/L)	2-19 90-171	8.5 130	29-89	59
NO ₃ -N (mg/L)	0.047	0.047	0.01-0.04	0.03
TAN (mg/L)	0.009	0.009	0.06-0.38	0.22

4.1.7 Water quality parameters correlations

In this study, correlation using SPSS is used to investigate the relationship between the water quality parameters in Rajang River and its tributaries. For Rajang River, a total of 16 water quality parameters in 23 stations along Rajang River were subjected to the correlation analysis. The 23 stations are 3 stations at upstream section, 5 stations at the midstream section, followed by the triplicate sampling of 5 stations at the downstream section. The output is shown in Table 4.33. Meanwhile, for the tributaries, a total of 16 water quality parameters in 29 stations at the tributaries were subjected to the correlation analysis. The 29 stations are 6 stations at upstream section, 5 stations at the midstream section, followed by the triplicate sampling of 6 stations at the downstream section. The results are shown in Table 4.34.

Among stations at Rajang River, pH was in high negative correlation with both velocity ($r = -0.531$, p value < 0.05 , $n=23$) and discharge ($r = -0.733$, p value < 0.05 , $n=23$) (Table 4.33). This indicates that the increase in river pH have improved during low water level maybe due to less water discharge from Bakun Dam which contain acidic water. Furthermore, TSS was in highly and positively correlation with both velocity and discharge ($r = +0.684$, p value < 0.05 , $n=23$) and ($r = +0.960$, p value < 0.05 , $n=23$) respectively and TN ($r = +0.529$, p value < 0.05 , $n=23$) and ($r = +0.619$, p value < 0.05 , $n=23$) respectively (Table 4.33). This indicates that TN and TSS were likely contributed by the surface soil through runoff brought by rain water and resuspension of bottom sediment. However, these water quality parameters correlations with velocity and discharge are not significant for the tributaries except TSS. This is because the addition of the rain water may have diluted the concentrations more than the input. Both velocity and discharge in tributaries are in high

positive correlation with TSS ($r = +0.552$, p value < 0.05 , $n=29$) and ($r = +0.534$, p value < 0.05 , $n=29$) respectively (Table 4.34). These positive correlations could be indicating that the contributions of sediment from the erosion process in tributaries exceeded the dilutions by rainwater.

Table 4.33: Correlation coefficients between the water parameters along Rajang River stations at Pelagus Area ($n=23$).

		Velocity	Discharge	Temperature	pH	DO	Turb	Trans	Cond	BOD	NO ₂ -N	NO ₃ -N	TSS	COD	NH ₃ -N	Org-N	TN
Velocity	Pearson Correlation	1															
	Sig. (2-tailed)																
Discharge	Pearson Correlation	.798**	1														
	Sig. (2-tailed)	.000															
Temp	Pearson Correlation	-.269	-.468*	1													
	Sig. (2-tailed)	.214	.024														
pH	Pearson Correlation	-.531**	-.733**	.649**	1												
	Sig. (2-tailed)	.009	.000	.001													
DO	Pearson Correlation	.129	.503*	-.521*	-.621**	1											
	Sig. (2-tailed)	.558	.014	.011	.002												
Turbidity	Pearson Correlation	.341	.364	-.601**	-.503*	.276	1										
	Sig. (2-tailed)	.111	.088	.002	.014	.202											
Trans	Pearson Correlation	-.113	-.089	.311	.182	.025	-.309	1									
	Sig. (2-tailed)	.607	.688	.149	.405	.909	.152										
Cond	Pearson Correlation	-.292	-.295	.539**	.472*	-.235	-.470*	.146	1								
	Sig. (2-tailed)	.176	.171	.008	.023	.280	.024	.506									
BOD	Pearson Correlation	-.065	-.412	.458*	.566**	-.962**	-.253	.108	.217	1							
	Sig. (2-tailed)	.769	.051	.028	.005	.000	.244	.624	.320								
NO ₂ -N	Pearson Correlation	-.423*	-.516*	.778**	.614**	-.375	-.657**	.550**	.593**	.399	1						
	Sig. (2-tailed)	.045	.012	.000	.002	.078	.001	.006	.003	.059							
NO ₃ -N	Pearson Correlation	.066	.071	-.144	-.008	-.008	-.307	.069	-.077	.078	.023	1					
	Sig. (2-tailed)	.764	.749	.512	.972	.971	.154	.755	.725	.722	.917						
TSS	Pearson Correlation	.684**	.960**	-.388	-.709**	.503*	.271	-.055	-.267	-.431*	-.415*	.094	1				
	Sig. (2-tailed)	.000	.000	.067	.000	.014	.211	.805	.218	.040	.049	.668					
COD	Pearson Correlation	.358	.071	.304	.192	-.739**	-.147	-.071	.051	.774**	.084	.039	.021	1			
	Sig. (2-tailed)	.094	.749	.158	.379	.000	.505	.747	.819	.000	.702	.861	.923				
NH ₃ -N	Pearson Correlation	.522*	.634**	-.645**	-.492*	.337	.555**	-.450*	-.452*	-.357	-.874**	.056	.553**	-.005	1		
	Sig. (2-tailed)	.011	.001	.001	.017	.115	.006	.031	.031	.094	.000	.798	.006	.984			
Org-N	Pearson Correlation	.451*	.526**	-.169	-.564**	.396	.320	-.149	-.306	-.482*	-.449*	-.238	.483*	-.082	.527**	1	
	Sig. (2-tailed)	.031	.010	.441	.005	.061	.137	.499	.156	.020	.032	.274	.020	.711	.010		
TN	Pearson Correlation	.529**	.619**	-.332	-.605**	.415*	.422*	-.256	-.384	-.491*	-.626**	-.159	.561**	-.059	.730**	.965**	1
	Sig. (2-tailed)	.009	.002	.122	.002	.049	.045	.238	.070	.017	.001	.468	.005	.790	.000	.000	

**, Correlation is significant at the 0.01 level (2-tailed).

Table 4.34: Correlation coefficients between the water parameters among tributaries stations at Pelagus Area (n=29).

		Correlations															
		Velocity	Discharge	Temperature	pH	DO	Turb	Trans	Cond	BOD	NO ₂ -N	NO ₃ -N	TSS	COD	NH ₃ -N	Org-N	TN
Velocity	Pearson Correlation	1															
	Sig. (2-tailed)																
Discharge	Pearson Correlation	.646	1														
	Sig. (2-tailed)	.000															
Temp	Pearson Correlation	-.121	.017	1													
	Sig. (2-tailed)	.532	.929														
pH	Pearson Correlation	.069	-.214	-.347	1												
	Sig. (2-tailed)	.722	.265	.065													
DO	Pearson Correlation	-.008	.072	-.245	.011	1											
	Sig. (2-tailed)	.965	.709	.201	.953												
Turbidity	Pearson Correlation	.647**	.452*	-.285	-.004	-.034	1										
	Sig. (2-tailed)	.000	.014	.134	.983	.862											
Trans	Pearson Correlation	.197	-.008	-.398*	.292	.218	-.122	1									
	Sig. (2-tailed)	.306	.965	.032	.125	.256	.530										
Cond	Pearson Correlation	-.019	-.101	.095	.211	-.492**	-.210	.102	1								
	Sig. (2-tailed)	.923	.603	.624	.272	.007	.275	.598									
BOD	Pearson Correlation	-.012	-.011	.264	-.052	-.875**	.035	-.099	.468*	1							
	Sig. (2-tailed)	.951	.956	.166	.788	.000	.859	.610	.010								
NO ₂ -N	Pearson Correlation	.207	-.056	-.197	.706**	.090	.055	.153	.197	-.105	1						
	Sig. (2-tailed)	.282	.772	.307	.000	.642	.776	.430	.305	.587							
NO ₃ -N	Pearson Correlation	.091	.145	.230	-.144	-.266	.053	.130	.142	.433*	-.131	1					
	Sig. (2-tailed)	.639	.454	.230	.457	.163	.784	.502	.462	.019	.499						
TSS	Pearson Correlation	.552**	.534**	-.082	-.242	-.006	.855**	-.111	-.204	.062	-.125	.181	1				
	Sig. (2-tailed)	.002	.003	.671	.206	.977	.000	.567	.288	.748	.519	.347					
COD	Pearson Correlation	.413*	.425*	.192	-.287	-.469*	.546**	-.085	.074	.630**	-.223	.451*	.728**	1			
	Sig. (2-tailed)	.026	.022	.319	.131	.010	.002	.661	.704	.000	.246	.014	.000				
NH ₃ -N	Pearson Correlation	-.060	.106	.385*	-.660**	-.230	.037	-.199	-.042	.286	-.580**	.456*	.221	.411*	1		
	Sig. (2-tailed)	.756	.583	.039	.000	.229	.851	.301	.827	.133	.001	.013	.250	.027			
Org-N	Pearson Correlation	.028	.118	.252	-.556**	-.147	.058	-.128	.050	.179	-.312	-.069	.211	.361	.334	1	
	Sig. (2-tailed)	.884	.544	.187	.002	.447	.765	.509	.796	.353	.099	.722	.272	.055	.076		
TN	Pearson Correlation	.002	.134	.352	-.689**	-.213	.061	-.174	.030	.265	-.456*	.138	.255	.458*	.641**	.937**	1
	Sig. (2-tailed)	.993	.487	.061	.000	.268	.752	.366	.877	.165	.013	.476	.182	.012	.000	.000	
*. Correlation is significant at the 0.05 level (2-tailed).																	
**. Correlation is significant at the 0.01 level (2-tailed).																	

4.2 Sediment characteristics in Rajang River at Pelagus area

4.2.1 Sediment pH

Figure 4.29 illustrate the potential of hydrogen (pH) of sediment of the 30 sampling stations. The mean pH value of all stations ranged from 4.66 to 6.70 which are below pH 7 across all the stations. Comparatively, the mean pH of sediment is more acidic (6.18) than water (6.90). The lowest pH value was found in station 16 while the highest value found in station 26. The lowest mean value of sediment pH was found in station 16 due to higher organic matter which decreased the pH. Around station 16, there were lots of dead tree debris that contributed to the organic matter where the decomposing process lowered pH of the sediment. This is supported by the negative correlation with OM, TOC and TKN ($r = -0.280$, $r = -0.255$ and $r = -0.303$, p value < 0.05 , $n=30$) (Table 4.35).

Among station in Rajang River, lower trend of pH was observed at the midstream section. The lower trend of pH was observed at station 10, 13, 15, 17, 19 and 20. In addition, significantly lower pH of sediment also observed at station 5 compared to station 1 and 9. The lower pH values at these stations were probably due to the discharge of untreated human and animal wastes such as manure and urine into the river. Other than that, the lower pH values at those stations were probably also contributed from the tributaries upstream of those stations.

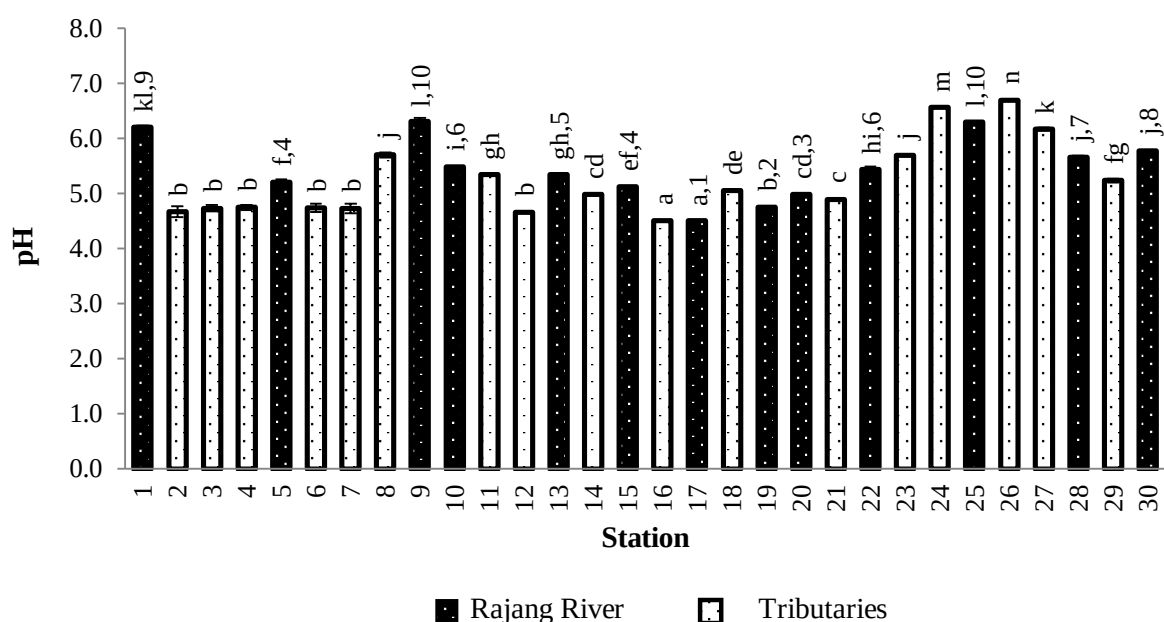


Figure 4.29: The mean pH in sediment. The same letters indicate no significant difference ($p < 0.05$) among the stations, same numbers indicate no significant difference ($p < 0.05$) among the stations along the main river only.

Table 4.35: The relationships between sediment characteristics in Rajang River and its tributaries based on correlation analysis (p value < 0.05) ($n=30$)

Correlations									
		pH	Sand	Clay	Silt	TOC	OM	TP	TKN
pH	Pearson Correlation	1							
	Sig. (2-tailed)								
Sand	Pearson Correlation	.113	1						
	Sig. (2-tailed)	.553							
Clay	Pearson Correlation	-.340	-.671**	1					
	Sig. (2-tailed)	.066	.000						
Silt	Pearson Correlation	-.013	-.872**	.483**	1				
	Sig. (2-tailed)	.947	.000	.007					
TOC	Pearson Correlation	-.255	-.526**	.438*	.609**	1			
	Sig. (2-tailed)	.174	.003	.015	.000				
OM	Pearson Correlation	-.280	-.675**	.522**	.645**	.923**	1		
	Sig. (2-tailed)	.135	.000	.003	.000	.000			
TP	Pearson Correlation	.136	-.844**	.453*	.749**	.281	.401*	1	
	Sig. (2-tailed)	.472	.000	.012	.000	.133	.028		
TKN	Pearson Correlation	-.303	-.629**	.559**	.553**	.862**	.899**	.381*	1
	Sig. (2-tailed)	.104	.000	.001	.002	.000	.000	.038	
*. Correlation is significant at the 0.05 level (2-tailed).									
**. Correlation is significant at the 0.01 level (2-tailed).									

4.2.2 Particle Size Analysis (PSA)

Figure 4.30 shows the percentage of sand silt and clay of the stations at the Rajang River of the Pelagus area. Table 4.36 shows the percentage of sand, clay and silt with their textural class. In this study, sand ranged from 18.62% to 99.31%. Meanwhile, clay varied from 0.20% to 43.88%, whereas, silt ranged from 0.20% to 77.94% (Figure 4.30, Table 4.36). For the sand, station 22 had the highest percentage of sand with 99.31%, whereas, station 16 had the lowest percentage of sand with 8.88%. The mean sand in the sediment of the stations at the Rajang River shows a gradual increasing trend from upstream to downstream except for station 15, 17 and 19. For the clay, station 16 shows the highest percentage of clay with 55.00%. Meanwhile the lowest was recorded at station 22 and 29 with 0.20%. The mean clay in the sediment of the stations at the Rajang River shows a gradual decreasing trend from upstream to downstream except for station 17. For the silt, station 26, 16 and 17 recorded an extremely high percentage of silt compared to the other stations. Station 26 recorded 77.94% of silt, whereas, station 16 recorded 36.12% of silt and station 17 with 34.30% of silt. The mean silt in the sediment of the stations at the Rajang River shows a gradual decreasing trend from upstream to downstream except for station 17. This implies that the silt from tributary at station 16 was being brought to the station 17 at Rajang River. The gradual decreasing trend from upstream to downstream shows that the silt from upstream gradually deposited and accumulated at the river bed.

In terms of texture the particle size analysis of sediment samples in the Rajang River area shows that the sediments ranged from sand, sandy clay loam, clay, sandy loam to silt loam. This finding is similar to the observation of Ezekiel *et al.* (2011) who reported the texture of sediments in Sombreiro River ranging from sand, clay to silt. This study is in correlation with

the study conducted by Ling *et al.* (2016) in upper reaches of the Baleh River where the soil texture of the stream sediments is mostly sand, followed by clay and silt.

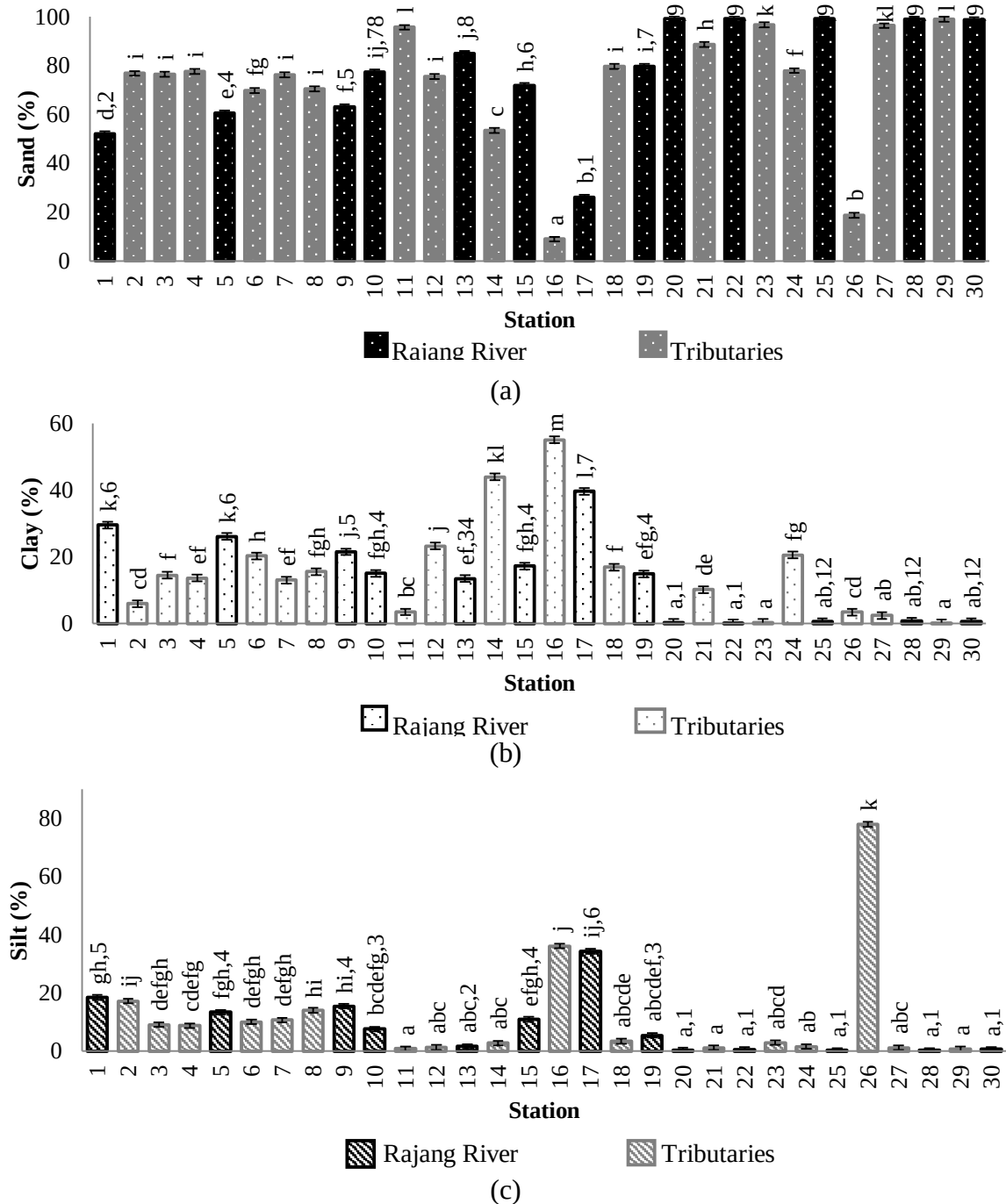


Figure 4.30: The PSA distribution in sediment: (a) sand, (b) silt and (c) clay (%) at all stations from upstream to downstream. Different letters show significant difference among the stations ($p < 0.05$), same numbers indicate no significant difference ($p < 0.05$) among the stations along the main river only.

Table 4.36: The percentage of sand, clay and silt in sediment with their textural class

Station	Sand (%)	Clay (%)	Silt (%)	Textural Class
1	52.04 ± 0.34	29.53 ± 0.34	18.43 ± 0.40	Sandy Clay Loam
2	76.82 ± 0.10	6.02 ± 0.25	17.16 ± 0.03	Sandy Loam
3	76.41 ± 0.11	14.51 ± 0.28	9.08 ± 0.74	Sandy Loam
4	77.66 ± 0.31	13.64 ± 0.28	8.70 ± 0.25	Sandy Loam
5	60.57 ± 0.38	26.08 ± 0.08	13.35 ± 1.39	Sandy Clay Loam
6	69.76 ± 0.19	20.25 ± 0.25	9.98 ± 0.59	Sandy Clay Loam
7	76.25 ± 0.22	13.09 ± 0.91	10.67 ± 0.82	Sandy Loam
8	70.46 ± 0.35	15.54 ± 0.23	14.00 ± 1.50	Sandy Loam
9	63.05 ± 0.37	21.51 ± 0.37	15.45 ± 0.93	Sandy Clay Loam
10	77.35 ± 0.26	15.06 ± 0.06	7.59 ± 0.51	Sandy Loam
11	95.70 ± 0.04	3.52 ± 0.03	0.78 ± 0.06	Sand
12	75.51 ± 0.08	23.21 ± 0.71	1.28 ± 0.11	Sandy Loam
13	84.98 ± 0.14	13.47 ± 0.03	1.55 ± 0.06	Loamy Sand
14	53.37 ± 0.28	43.88 ± 0.08	2.74 ± 0.20	Sandy Clay
15	71.81 ± 0.50	17.26 ± 0.17	10.93 ± 0.14	Sandy Loam
16	8.88 ± 0.03	55.00 ± 0.14	36.12 ± 0.31	Clay
17	26.06 ± 0.45	39.64 ± 0.25	34.30 ± 0.23	Clay Loam
18	79.75 ± 0.39	16.89 ± 0.25	3.37 ± 0.20	Sandy Loam
19	79.68 ± 0.08	14.91 ± 0.00	5.41 ± 0.25	Sandy Loam
20	99.30 ± 0.30	0.40 ± 0.03	0.30 ± 0.03	Sand
21	88.72 ± 0.03	10.17 ± 0.03	1.11 ± 0.03	Loamy Sand
22	99.31 ± 0.13	0.20 ± 0.03	0.49 ± 0.03	Sand
23	96.78 ± 0.31	0.37 ± 0.00	2.85 ± 0.03	Sand
24	77.95 ± 0.27	20.55 ± 0.06	1.50 ± 0.03	Sandy Loam
25	99.15 ± 0.19	0.63 ± 0.03	0.21 ± 0.00	Sand
26	18.62 ± 0.48	3.44 ± 0.08	77.94 ± 0.57	Silt Loam
27	96.41 ± 0.26	2.47 ± 0.37	1.12 ± 0.11	Sand
28	98.99 ± 0.14	0.81 ± 0.03	0.20 ± 0.00	Sand
29	99.10 ± 0.01	0.20 ± 0.03	0.70 ± 0.08	Sand
30	98.81 ± 0.17	0.60 ± 0.06	0.60 ± 0.08	Sand

*Bold indicates the stations along Rajang River

4.2.3 Total Organic Matter (TOC) and Organic Matter (OM)

The TOC and OM of the sediment are shown in Figure 4.31 and Figure 4.32 respectively. The mean TOC ranged from 0.01% to 0.90% whereas mean OM varied from 0.18% to 5.16%. The TOC percentages obtained in this study were below the mean value of 2.51% obtained from Sombreiro River, Nigeria by Ezekiel *et al.* (2011) but higher than the range of percentages (0.15 to 0.25%) found at Baleh River (Ling *et al.*, 2016). Meanwhile, the OM percentages in this study were similar to the range of percentage of OM found at Baleh River which ranged 0.10 to 0.30% except for a total of 4 stations. The highest mean TOC and OM were recorded at station 16 at Rarai River meanwhile the lowest mean were recorded at station 24 at Mela River for TOC and station 27 at Nanga Senuang for OM.

Among the stations at the tributaries, higher amount of TOC percentages was found station 2 at Punan Sama River (0.68%), station 4 at Miah River (0.77%), station 6 at Bah River (0.73%), station 7 at Metah River (0.77%), station 16 at Rarai River (0.89%), station 26 at Cermin River (0.81%) and station 29 at Baleh River (0.85%). Among the stations at the Rajang River, higher amount of TOC percentages was found at station 1 (0.84%), station 5 (0.83%), station 9 (0.85%), station 17 (0.88%) and station 28 (0.83%). These higher amounts of TOC are due to contributions from households as these stations are near to longhouses. Therefore, the discharge of the household and human wastes resulted in the accumulation of organic carbon in the sediment. Manures and urea that entered the river results in an increase of nutrients thus an increase in organic carbon in sediment. The study by Zhao & Cheng (2011) suggests that there was more serious organic pollution in the sewage area sediment. Therefore, the discharge of the household and human wastes resulted in the accumulation of organic carbon in the sediment causes the high TOC in those stations. Manures and urea that

entered the river results in an increase of nutrients thus an increase in organic carbon in sediment. Meanwhile, Davide *et al.* (2003), also supported that high levels of organic carbon mainly comes from anthropogenic inputs which are influenced by human activities.

Based on Ezekiel *et al.* (2011), the level of organic matter decomposition may have contributed to the variation in organic carbon content. Among the stations at the tributaries, higher amount of OM percentages was found station 2 at Punan Sama River (1.88%), station 4 at Miah River (2.19%), station 6 at Bah River (2.05%), station 7 at Metah River (2.17%), station 16 at Rarai River (5.16%), station 26 at Cermin River (2.31%) and station 29 at Baleh River (2.83%). Among the stations at the Rajang River, higher amount of OM percentages was found at station 1 (2.51%), station 5 (2.17%), station 9 (3.23%), station 17 (4.84%) and station 28 (3.26%). The higher organic matter present in the sediments at these stations were due to the discharge of human wastewater and animal wastes from both longhouses and areas with logging activities.

Station 16 and station 17 shows significant higher OM percentage compared to other stations (p value $< \text{value} < 0.05$). This higher OM was influenced by the particle size of the sediment in that particular station. This statement is in correlation with the significantly and highly positive correlation of OM with percentage of clay ($r = +0.453$, p value $< \text{value} < 0.05$, $n=30$) and silt ($r = +0.749$, p value $< \text{value} < 0.05$, $n=30$) but highly and negatively correlated with the percentage of sand ($r = -0.844$, p value $< \text{value} < 0.05$, $n=30$). This can be explained by the smaller size of clay and silt which has bigger surface area to absorb organic matter more efficient compared to bigger particle such as sand (Zhu *et al.*, 2014). Significantly and highly positive correlation of TOC with silt ($r = +0.609$, p value $< \text{value} < 0.05$, $n=30$). This is due to the adsorption capacities of silt which is larger compared to sand (Zhu *et al.*, 2014).

The high OM and TOC in these stations can also be contributed by the soil erosion from the logging operations. This is supported by studies by Salimin *et al.* (2010) and Satrio *et al.* (2009) where carbon storage and OM significantly decreased after logging operation in the peat swamp forest. This is suggesting that the OM and C were lost from the land due to the soil erosion resulting from the logging operation. The soil from the erosion could be end up in the bottom of nearby river which settles as sediment.

In this study, a positive correlation was found between OM and TOC percentage in sediment ($r = +0.923$, p value < 0.05 , $n=30$). The trend of the percentage of both OM and TOC in the sediment at the stations located at the Rajang River is decreasing from upstream to downstream area. However, the percentage of OM and TOC increased significantly from station 25 to station 28 then decreased significantly to station 30. This is probably due the contribution of organic matter from the tributaries upstream of the stations.

Based on the sediment guidelines for the protection and management of aquatic sediment quality in Ontario, the TOC in this present study is below the limit of the lowest effect level (Table 4.37). This indicates that the level of sediment contamination for TOC can be tolerated by most benthic organisms (Persaud *et al.*, 1993).

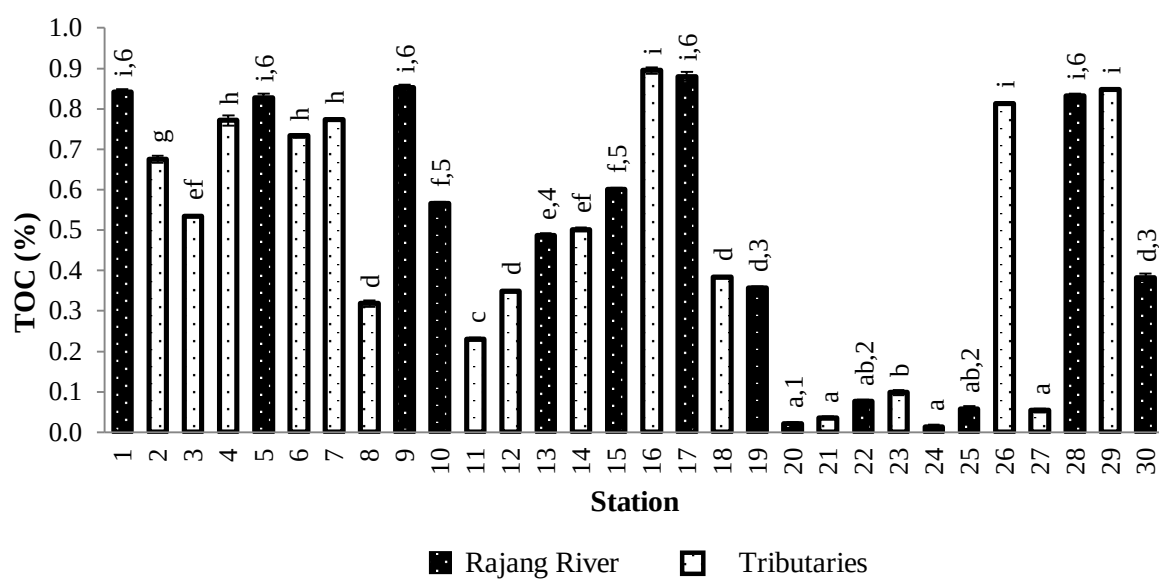


Figure 4.31: The mean TOC in sediment. The same letters indicate no significant difference ($p < 0.05$) among the stations, same numbers indicate no significant difference ($p < 0.05$) among the stations along the main river only.

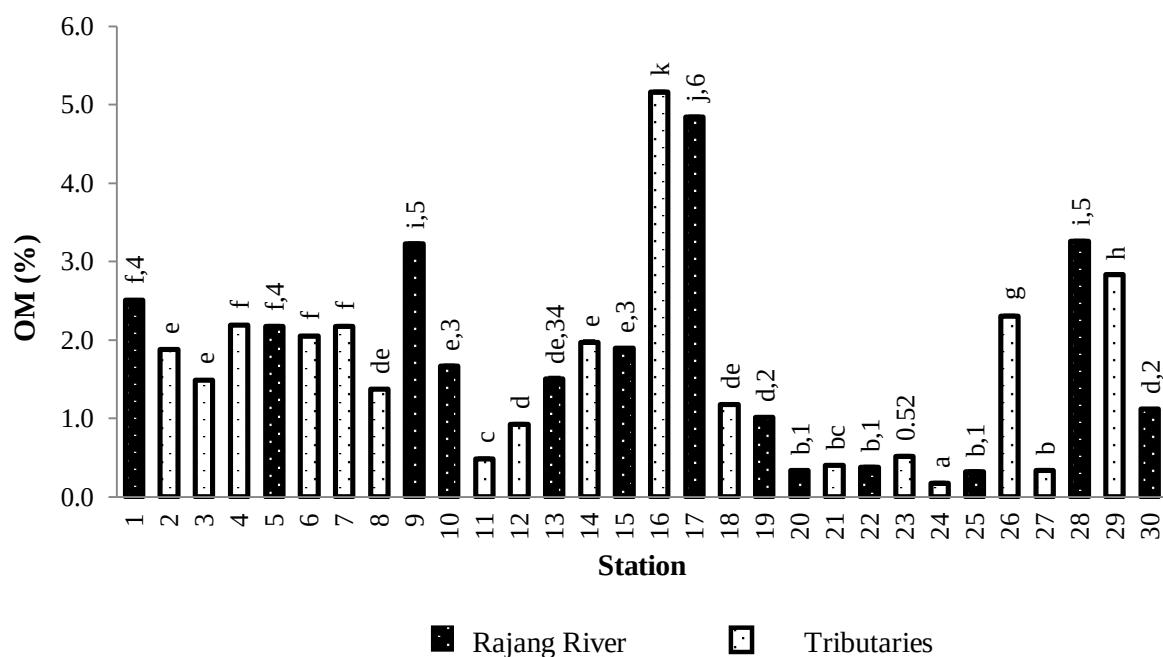


Figure 4.32: The mean OM in sediment. The same letters indicate no significant difference ($p < 0.05$) among the stations, same numbers indicate no significant difference ($p < 0.05$) among the stations along the main river only.

Table 4.37: The classification of TOC, TKN and TP in sediment based on guidelines for contaminated freshwater sediments (Persaud *et al.*, 1993).

Station	TOC (%)	Level effect	TKN (mg/kg)	Level effect	TP (mg/kg)	Level effect
1	0.84	LEL	733.90	>LEL	66.69	LEL
2	0.68	LEL	681.87	>LEL	56.06	LEL
3	0.53	LEL	404.09	LEL	44.70	LEL
4	0.77	LEL	621.65	>LEL	44.43	LEL
5	0.83	LEL	648.64	>LEL	89.10	LEL
6	0.73	LEL	575.26	>LEL	67.43	LEL
7	0.77	LEL	515.20	LEL	54.86	LEL
8	0.32	LEL	645.00	>LEL	55.60	LEL
9	0.85	LEL	863.81	>LEL	77.58	LEL
10	0.57	LEL	671.08	>LEL	57.10	LEL
11	0.23	LEL	198.17	LEL	33.58	LEL
12	0.35	LEL	866.52	>LEL	66.74	LEL
13	0.49	LEL	501.80	LEL	55.83	LEL
14	0.50	LEL	842.57	>LEL	99.50	LEL
15	0.60	LEL	644.41	>LEL	68.08	LEL
16	0.89	LEL	1597.86	>LEL	151.55	LEL
17	0.88	LEL	1368.10	>LEL	120.43	LEL
18	0.38	LEL	672.30	>LEL	77.14	LEL
19	0.36	LEL	387.89	LEL	55.90	LEL
20	0.02	LEL	102.84	LEL	50.20	LEL
21	0.03	LEL	62.19	LEL	70.62	LEL
22	0.08	LEL	109.88	LEL	62.17	LEL
23	0.10	LEL	164.49	LEL	43.62	LEL
24	0.01	LEL	56.51	LEL	110.67	LEL
25	0.06	LEL	85.47	LEL	41.41	LEL
26	0.81	LEL	694.86	>LEL	149.27	LEL
27	0.05	LEL	112.25	LEL	43.10	LEL
28	0.83	LEL	1169.26	>LEL	49.41	LEL
29	0.85	LEL	498.36	LEL	42.98	LEL
30	0.38	LEL	803.41	>LEL	47.92	LEL
No level effect (NLE)	-		-		-	
Lowest level effect (LEL)	1%		550 mg/kg		600 mg/kg	
Severe level effect (SEL)	10%		4800 mg/kg		2000 mg/kg	

*Bold indicates the stations along Rajang River

4.2.4 Nutrients (TKN and TP)

In this study, the TKN in the sediment are shown in Figure 4.33. Based on Figure 4.33, the range of TKN in sediment is 56.51 to 1597.86 mg/kg. Station 5 recorded the lowest value of TKN in sediment with 56.51 mg/kg, whereas, station 16 had the highest TKN value which recorded 1597.86 mg/kg of TKN. Besides, there are other stations that also recorded amount of TKN in sediment higher than 550 mg/kg of the lowest level effect level for the protection and management of aquatic sediment quality (Persaud *et al.*, 1993).

Among the stations located at the tributaries, those high amount of TKN in sediment were recorded at station 2 at Punan Sama River (681.87 mg/kg), station 4 at Miah River (621.65 mg/kg), station 6 at Bah River (575.26 mg/kg) station 8 at Pila River (645.00 mg/kg), station 12 at Buya River (866.52 mg/kg), station 14 at Sama River (842.57 mg/kg), station 16 at Rarai River (1597.86 mg/kg), station 18 at Peraran Besai River (672.86 mg/kg) and station 26 at Cermin River (694.86 mg/kg). Generally, the high mean TKN concentration recorded at those stations was most probably due to the runoff from nearby logging activities, agricultural land, human and animal waste from the longhouses at the upstream area. The logging activities and agricultural land increased nutrients in the river through surface runoff. Additionally, the nutrients entered the river through the disposal of the manure and animal husbandry (Ismail & Ibrahim, 2015). However, high TKN amount in sediment were also recorded at station 12, station 16 and station 18 although they are secondary forest with canopy cover and do not have known logging activities or other man-made sources of nutrient pollution. Those high amounts of TKN in sediment were probably due to accumulation as there was low flow at those stations. The flow at station 12 was only 2.55 m³/s, station 16 was 1.60 m³/s and station 18 was 2.40 m³/s. Those flows were low and thus particulates with

nutrients were easily trapped and accumulated in the sediment. Freshwater flushing time had a great impact on the nitrogen loads in the sediment (Trimmer *et al.*,1998).

Among the stations located at the Rajang River, those high amount of TKN in sediment were recorded at station 1 (733.90 mg/kg), station 5 (648.64 mg/kg), station 9 (863.81 mg/kg), station 10 (671.08 mg/kg), station 15 (644.41 mg/kg), station 17 (1368.10 mg/kg), station 28 (1169.26 mg/kg) and station 30 (803.41 mg/kg). Transports activities near and along the rivers constitute as one of the main sources of water pollution through the petrol spills and the emissions from the internal combustion engines which include the oxide of nitrogen, sulphur and carbon (Mirsal, 2004). For station 17, there is a high significant difference between station 17 compared to stations 15 and 19. This implies that the TKN from tributary where station 16 was located was influencing the TKN at the station 17 at the Rajang River. Other than that, the source of the high mean TKN concentration was most probably the runoff from nearby logging camp and longhouses. This is because discharge from sewage works and logging activities increased nutrients in the river through surface runoff.

The TKN result can be influenced by the particle size of the sediment in that particular station. This statement is in correlation with the significant and highly positive correlation of TKN with percentage of clay ($r = +0.559$, p value < 0.05 , $n=30$) and silt ($r = +0.553$, p value < 0.05 , $n=30$). The finding of Zhu *et al.* (2014), smaller particle like clay and silt had larger specific surface areas and can reach equilibrium more slowly than sand thus can bond with more nutrient as well as organic matter.

Based on the sediment guidelines for protection and management of aquatic sediment quality in Ontario, the TKN in this present study is below the limit of the lowest effect level except for a total of 16 stations (Table 4.37). They are station 1, station 2, station 4, station 5, station

8, station 9, station 10, station 12, station 14, station 15, station 16, station 17, station 18, station 26, station 28 and station 30. The stations that have TKN in sediment below the limit of the lowest effect level indicates that the level of sediment contamination for the TKN can be tolerated by most benthic organisms (Persaud *et al.*, 1993).

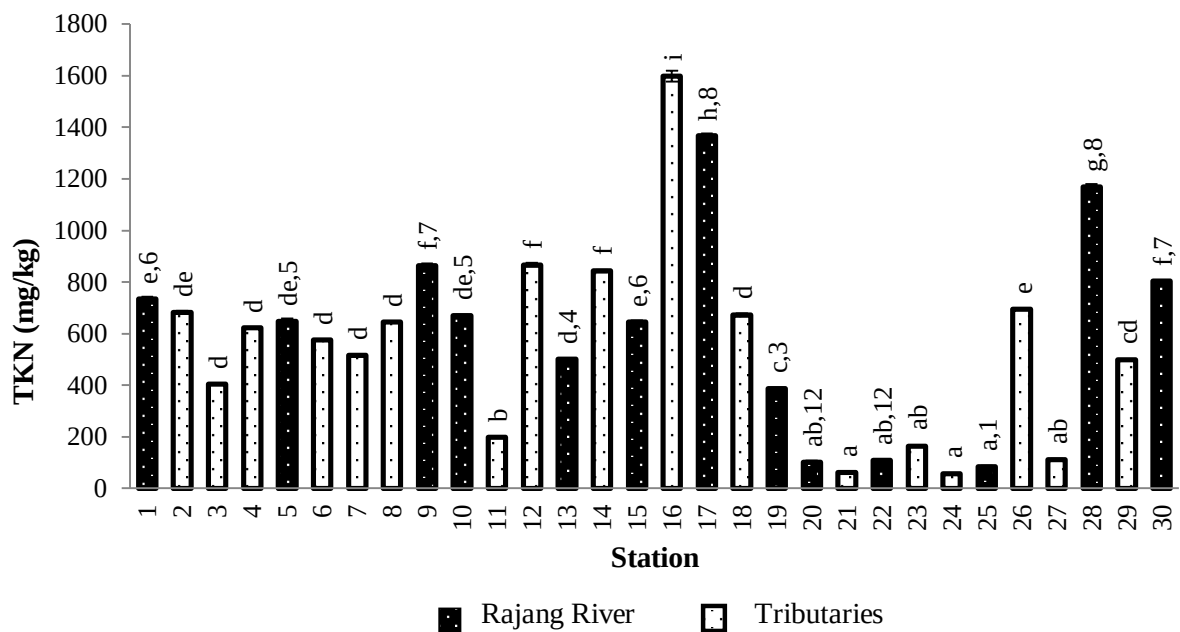


Figure 4.33: The mean TKN in sediment. The same letters indicate no significant difference ($p < 0.05$) among the stations, same numbers indicate no significant difference ($p < 0.05$) among the stations along the main river only

Figure 4.34 illustrate the amount of TP in the sediment of all the stations. It ranged from 41.41 to 151.55 mg/kg. Station 11 had the lowest value of TP in sediment with 41.41 mg/kg, whereas, station 26 at Cermin River had the highest value of TP in sediment with 151.55 mg/kg. Among the stations located at the tributaries, stations 14 at Sama River (99.50 mg/kg), station 16 at Rarai River (151.55 mg/kg), station 24 at Mela River (110.67 mg/kg) and station 26 at Cermin River (149.27 mg/kg) shows significantly higher TP in sediment compared to

other stations. These high TP in sediment are most probably due to the logging activities nearby the river basin. Logs residues from the logging area brought by wind and rainwater most likely ended up in the river. Phosphorus can be derived from the logs residues that decayed and liberated by bacterial communities which resulted in an increase in TP in the upper layer of sediment (Aviles *et al.*, 2006). Additionally, debris that fallen from the trees at the riverbank also could contributed to the high amount of TP in sediment. Other than that, the use of fertiliser in agriculture and plantation in the river basin could cause the nutrient pollutions in the river's sediment through runoff. The nutrients could also be introduced into the river by the soil runoff brought by wind and rainwater. Among the stations located at the Rajang River, the trend of TP in sediment is decreasing from upstream to downstream area but has a significant increase at station 5 with 89.10 mg/kg and station 17 with 120.43 mg/kg. Those high amount of TP in sediment at the station at Rajang River are most probably contributed from the tributaries upstream of those stations.

The TP of sediment is in high and positive correlation OM ($r = +0.401$, p value < 0.05 , $n=30$), TOC ($r = +0.281$, p value < 0.05 , $n=30$). The high amount organic matter in the river settled from the water column to the bottom sediment. Therefore, the decomposition of organic matter increased the phosphorus concentration in the sediment (Walling *et al.*, 2003). A high and positive correlation was also found between sediment silt and sediment TP ($r = +0.749$, p value < 0.05 , $n=30$). Besides, TP is in positive correlation with TKN ($r = +0.553$, p value < 0.05 , $n=30$). This might be related to the difference in size of sand particles compared to the size of clay particle. Clay is smaller in particle compared to sand and had a larger surface area exposed to the surrounding and also pollutants. Thus, the adsorption capacity of

clay particle is larger than the sand particle (Zhu *et al.*, 2014). Therefore, clay particle can adsorb more pollutant from its surrounding system.

Based on the sediment guidelines for the protection and management of aquatic sediment quality in Ontario, the TP in sediment in this present study is below the limit of the lowest effect level (Table 4.37). This indicates that the level of sediment contamination for TP can be tolerated by most benthic organisms (Persaud *et al.*, 1993).

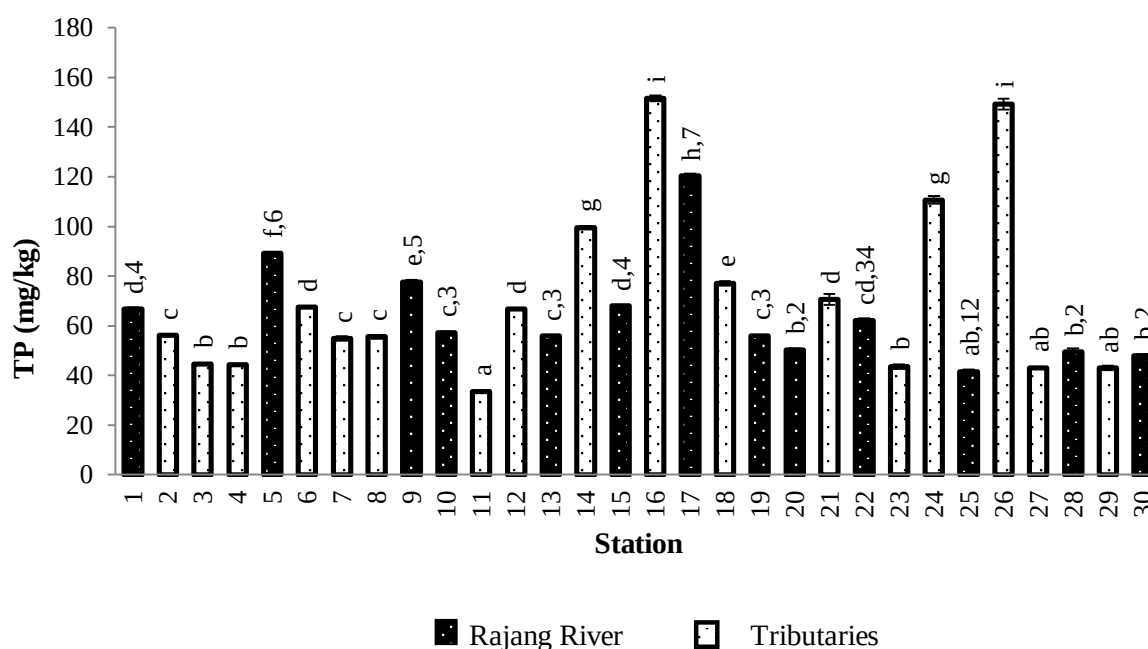


Figure 4.34: The mean TP in sediment. The same letters indicate no significant difference ($p < 0.05$) among the stations, same numbers indicate no significant difference ($p < 0.05$) among the stations along the main river only.

4.2.5 The comparison of sediment characteristics

Table 4.38 shows the comparison of the range and mean range of sediment characteristics between Rajang River and its tributaries. In this present study, the mean range of pH in sediment in stations at Rajang River is lower compared to the station at the tributaries. Meanwhile, the mean range of sand is higher compared to the mean range of sand found at the tributaries. However, the mean range of clay, silt, OM, TOC, TKN and TP were higher at the stations located at the tributaries compared to the stations at Rajang River. This is most likely due to the direct runoff of pollutant from anthropogenic activities occurring nearby the tributaries river basin.

Table 4.38: The comparison of range and mean range of sediment characteristics between the Rajang River and its tributaries

Parameters	Range at Rajang River	Mean range	Range at tributaries	Mean range	<i>p</i> -value
pH	4.50 – 6.3	5.4	4.51 – 6.7	5.6	<i>P</i> <0.05
Sand (%)	26.06 – 99.3	62.7	8.88 – 99.1	54.0	<i>p</i> <0.05
Clay (%)	0.20 – 29.5	14.9	0.37 – 55.0	27.8	<i>P</i> <0.05
Silt (%)	0.20 – 18.4	9.3	0.78 – 36.1	18.5	<i>P</i> <0.05
OM (%)	0.32 – 4.8	2.6	0.34 – 5.2	2.8	<i>P</i> <0.05
TOC (%)	0.02 – 0.9	0.5	0.01 – 0.9	0.5	<i>p</i> <0.05
TKN (mg/kg)	85.47 – 1368.1	726.8	56.51 – 1597.3	826.9	<i>p</i> <0.05
TP (mg/kg)	41.41 – 120.4	80.9	42.98 – 151.6	97.3	<i>p</i> <0.05

4.3 The correlations between water quality and sediment characteristics

Table 4.39 shows the correlations between water quality parameters and sediment characteristics at the Rajang River and its tributaries. River water pH is positively correlated with sediment TP. This shows that the high TP in sediment increases the pH in the river water column as phosphorus is a nutrient required by phytoplankton for photosynthesis. Sediment TP is negatively correlated with water DO. This indicates that TP in the sediment is being released to the water as the concentration of DO decreased. The water temperature is negatively correlated with sediment TKN. This showed that high temperature is favourable for the release of TKN from sediment.

Table 4.39: Correlations between water and sediment parameters (n=30)

	SpH	Sand	Silt	Clay	OM	TOC	STKN	STP
Temperature	.529**	-.251	-.079	-.085	-.320	-.181	-.482**	.174
Conductivity	.240	.049	-.018	.013	-.075	-.111	-.272	.193
pH	.207	-.264	-.113	.198	.019	.229	-.118	.429*
DO	-.409*	.073	.057	.092	.038	.010	.177	-.361*
Turbidity	-.137	-.223	-.160	-.086	-.024	.112	.143	-.052
Transparency	-.184	.237	.473**	.509**	.520**	.204	.308	.286
TSS	.055	-.481**	-.202	-.074	-.080	.225	.118	-.026
BOD	.035	.147	-.047	-.546**	-.426*	-.450*	-.298	-.580**
COD	-.197	-.313	-.321	-.124	.075	.413*	-.069	.360
NO ₂ -N	-.291	.014	-.090	-.231	-.210	-.340	-.056	-.218
NO ₃ -N	-.364*	.156	-.064	-.441*	-.463**	-.582**	-.350	-.515**
NH ₃ -N	-.406*	.559**	.232	-.004	.136	-.214	.184	-.242
Org-N	.101	.021	-.196	-.502**	-.479**	-.494**	-.438*	-.362*

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

S is indicated for sediment.

CHAPTER 5

CONCLUSION AND RECOMENDATIONS

5.1 Conclusion

The present study found that the Rajang River and its tributaries shows sign of pollution as indicated by high concentrations of TSS, BOD, COD, and nutrients in the river which exceeded Class II according to NWQS for Malaysia. The parameter that was consistently classified under Class I according to NWQS for all the studied stations were conductivity, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$. Meanwhile, pH and $\text{NH}_3\text{-N}$ most of the stations was classified as Class I and II, whereas DO was classified as Class I, II and III. The BOD was classified as Class II and III, while, the COD was classified as Class II, III, and IV. The TSS was falls in Class I, II, III, IV, and V according to NWQS. Besides, the turbidity at almost of all stations in this study exceeded Class II limit of NWQS indicating that extensive conventional treatment is required for drinking purposes and the water is not suitable for sensitive aquatic species Thus, soil erosions needs to be controlled to reduce the value of turbidity.

The BOD was higher than 3 mg/L (Class II limit) at most of the stations at Rajang River at upstream sections but not at the midstream section at the time of sampling. The means of conductivity, turbidity, transparency, TSS, pH, DO and $\text{NH}_3\text{-N}$ of the tributaries have significantly higher concentrations compared to the main river stations along the Rajang River, thus, influencing the water quality of Rajang River. The WQI also indicated that all the studied stations are classified as Class I or II whereas the status of stations are considered clean or slightly polluted. Man-made Pollution was shown to come from residential

wastewater and logging activities. Therefore, the anthropogenic activities that lead to exposed land and erosion along the river should be monitored.

The comparison of water quality of Rajang River at downstream section of Pelagus Area in three difference discharges was determined. During the high river discharge in March 2016, the pH, turbidity and TSS were deteriorates. However, other parameters such as conductivity, temperature, DO, COD, BOD and N improved. During the low river discharge in July 2015, the turbidity and TSS was lowest, while pH increases nearer to the neutral value. However, there were rising in temperature, conductivity and N concentrations. This is because of the low water levels which means no dilution of river water occurred.

In this study, Bakun Hydroelectric Dam plays a significant role in regulating the downstream water quality, thus, influencing the water quality variation at the stations in the Rajang River. The amount of water discharged from the spillway of the Bakun Hydroelectric Dam is influencing the DO, BOD and COD values at the stations in Rajang River. The DO values at Rajang River deteriorated due the no water discharges from the spillway at the time of sampling in January 2016. Thus, increasing amount of BOD and COD were observed among the stations at Rajang River. It is also important to maintain the fully oxygenated conditions in order to prevent any ammonia from becoming a problem to fish in the river system. Thus, it is recommended for the Bakun Hydroelectric Dam upstream to maintain the level of water flows from spillway high, so that DO in the river will not be too low.

This study was also carried out to determine the sediment characteristics of Rajang River and its tributaries at Pelagus Area. In this study, the textural class of sediments in Rajang River area ranged from sand, sandy clay loam, sandy loam, clay to silt. In particle size analysis, sand ranged from 18.62% to 99.31%, clay varied from 0.20% to 43.88% and silt from 0.20 to

77.94%. Meanwhile, the river sediment pH values were all below 7 across the stations. Comparatively, the mean pH of sediment is more acidic (6.18) than water (6.90). Additionally, sediment TOC ranged from 0.013% to 0.895% whereas the sediment OM ranged from 0.175% to 5.163%. TKN in sediment ranged from 69.48 to 3427.14 mg/kg while the value of TP sediment was from 1.51 to 225.51 mg/kg. Based on the sediment guidelines for protection and management of aquatic sediment quality in Ontario, the TOC and TP in this present study is classified under lowest level effect level. Meanwhile, 14 stations were recorded value below the limit of the lowest effect level for TKN in sediment, whereas, the other 16 stations were recorded TKN amount more than 550 mg/kg. This indicates that the level of sediment contamination for TOC, TP and TKN at the 14 stations can be tolerated by most benthic organisms (Persaud *et al.*, 1993). There are significant correlations between water and sediment parameters particularly river water pH with sediment TP, sediment TP with water DO and temperature with sediment TKN.

Overall, the DO, pH, BOD and COD were influenced by the discharge from turbine and spillway from Bakun Dam. The land use such as logging and plantation activities, domestic and household waste water and Bakun Dam have influenced the water quality parameters. TSS, turbidity and transparency were influenced by the logging and plantation activities, while, NO₂-N, NO₃-N, NH₃-N and TN were influenced by the domestic and household waste water. This study shows that the water and sediment parameters of the Rajang River were influenced by the discharge from the tributaries particularly water turbidity and TSS, and sediment silt, TP and TKN. The spillway and turbine discharge from Bakun Dam changes the water quality significantly.

5.2 Recommendations

In this study, there are a few recommendations for the further studies. Firstly, it is recommended that the sample for the whole stretch of the studied river to be taken on the same day instead of different days or time periods. This is to avoid the effect of the difference in natural condition such as rainfall event or solar radiation exposure event. Secondly, it is suggested that further studies about the effect of discharge from the dams upstream to the downstream rivers be conducted. Thirdly, longer river coverage should be covered. For example, starting from the falls of Bakun Hydroelectric Dam, to Belaga, followed by Kapit, then Song and lastly to Sibul. Fourthly, proper wastewater management should be implemented at the residential area along the Rajang River. Lastly, water treatment should be done to improve the water quality of the Rajang River for daily consumption.

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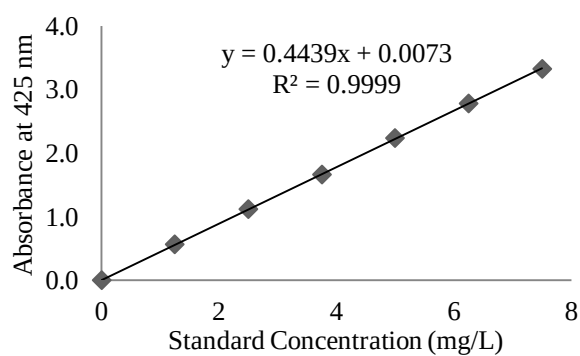
APPENDICES

Appendix 1: Information on standard calibration curves

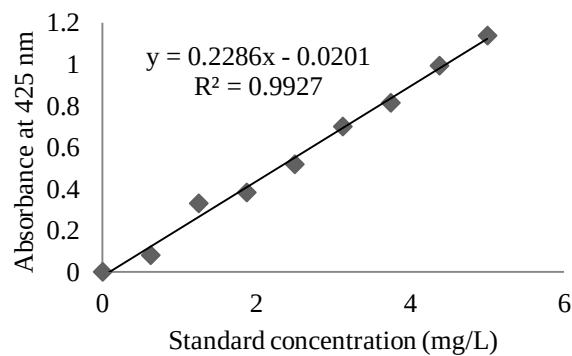
1. Calibration curves for NH₃-N in water

Appendix 1-A: The standard concentration and absorbance reading for NH₃-N in water

DR2800		UV-VIS Spectrophotometer	
Standard Concentration (mg/L)	Absorbance at 425 nm	Standard Concentration (mg/L)	Absorbance at 425 nm
0	0	0.00	0.00
1.25	0.554	0.63	0.08
2.50	1.123	1.25	0.33
3.75	1.699	1.88	0.38
5.00	2.225	2.50	0.52
		3.13	0.70
		3.75	0.81



(a) DR2800



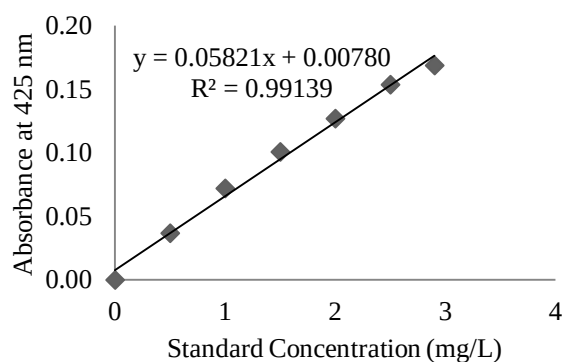
(b) UV 4 Spectrophotometer

Appendix 1-B: Calibration curves for NH₃-N in water

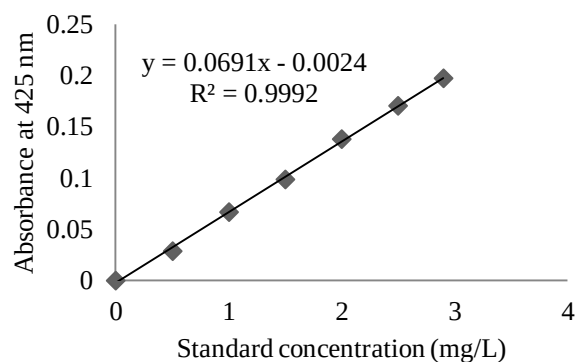
2. Calibration curves for Org-N in water

Appendix 1-C: The standard concentration and absorbance reading for Org-N in water

Hach DR2800		UV-VIS Spectrophotometer	
Standard Concentration (mg/L)	Absorbance at 425 nm	Standard Concentration (mg/L)	Absorbance at 425 nm
0	0	0.0	0.000
0.5	0.037	0.5	0.029
1.0	0.072	1.0	0.067
1.5	0.101	1.5	0.099
2.0	0.127	2.0	0.138
2.5	0.154	2.5	0.171
2.9	0.169	2.9	0.198



(a) Hach DR2800



(b) UV-VIS Spectrophotometer

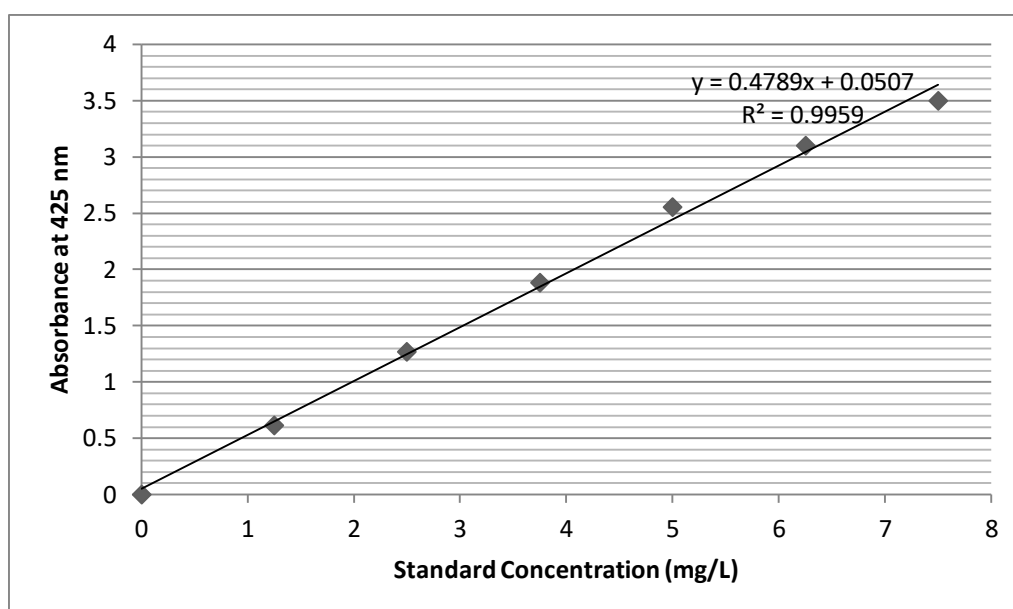
Appendix 1-D: Calibration curves for Org-N in water

3. Calibration curves for TKN in sediment

Instrument used: DR3900

Appendix 1-E: The standard concentration and absorbance reading for TKN in sediment

Standard Concentration (mg/L)	Absorbance at 425 nm
0	0
1.25	0.616
2.50	1.268
3.75	1.884
5.00	2.554
6.25	3.103
7.50	3.5



Appendix 1-F: Calibration curves for TKN in sediment

The sample concentration, C, can be calculated using the equation below:

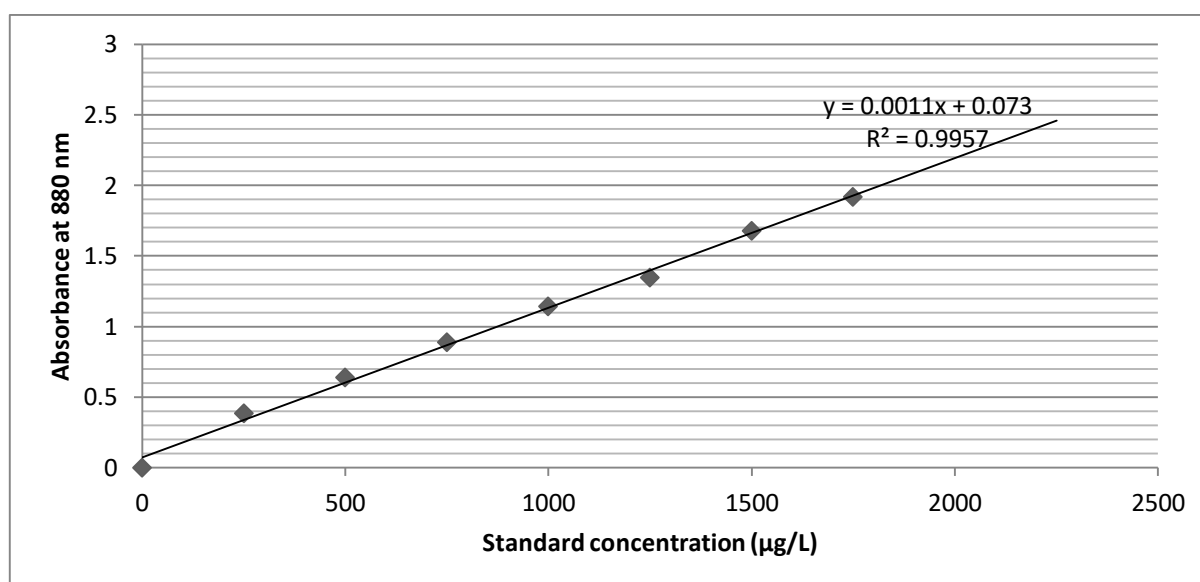
$$C = (\text{Abs} + 0.4789) / 0.0507$$

4. Calibration curves for TP in sediment

Instrument used: DR3900

Appendix 1-G: The standard concentration and absorbance reading for TP in sediment

Standard Concentration (mg/L)	Absorbance at 425 nm
0	0
0.65	0.386
1.18	0.641
1.62	0.891
2.1	1.143
2.48	1.346
2.77	1.678



Appendix 1-H: Calibration curves for TP in sediment

Appendix 2: Water quality classification Tables

Appendix 1-I: National Water Quality Standards for Malaysia

PARAMETER	UNIT	CLASS				
		I	IIA/IIB	III	IV	V
Ammoniacal Nitrogen	mg/L	0.1	0.3	0.9	2.7	>2.7
Biochemical Oxygen Demand	mg/L	1	3	6	12	>12
Chemical Oxygen Demand	mg/L	10	25	50	100	>100
Dissolved Oxygen	mg/L	7	5 - 7	3 - 5	<3	<1
pH	-	6.5 - 8.5	6 - 9	5 - 9	5 - 9	-
Electrical Conductivity	S/cm	1000	1000	-	6000	-
Total Suspended Solid	mg/L	25	50	-	-	-
Temperature	°C	-	Normal +2°C	Normal +2°C	-	-
Turbidity	NTU	5	50	-	-	-
NO ₃	mg/L	-	0.4	0.4(0.03)	-	-
NO ₂	mg/L	-	7	-	5	>5

Source: (DOE, 2014)

Appendix 1-J: Water Classes and Uses

Class	Uses
Class I	Conservation of natural environment. Water Supply 1 – practically no treatment necessary. Fishery 1 – very sensitive aquatic species.
Class IIA	Water Supply II – conventional treatment required. Fishery II – sensitive aquatic species.
Class IIB	Recreational use with body contact.
Class III	Water Supply III – extensive treatment required. Fishery III – common, of economic value and tolerant species; livestock drinking.
Class IV	Irrigation.
Class V	None of the above.

Source: (DOE, 2014)

Appendix 1-K: DOE Water Quality Classification Based on Water Quality Index

Sub index & water quality index	Index range		
	Clean	Slightly polluted	Polluted
Biochemical Oxygen Demand	91-100	80-90	0-79
Ammoniacal Nitrogen (NH ₃ N)	92-100	71-91	0-70
Suspended Solids(SS)	76-100	70-75	0-69
Water Quality Index	81-100	60-80	0-59

Source: (DOE, 2014)

Appendix 3: Sediment guidelines

Appendix 1-L: Review of criteria and guidelines for contaminated freshwater sediments

Compound name	Unit	Guidelines for the protection and management of aquatic sediment quality in Ontario (Persaud <i>et al.</i> , 1993)			Guidelines for the pollutional classification of harbour sediment (EPA, 1977)		
		No effect level	Lowest effect level	Severe effect level	Non polluted	Moderately polluted	Heavily polluted
Total Phosphorous	mg/kg	-	600	2000	<420	420-650	>650
Ammonia	mg/kg	-	100	-	<75	75-200	>200
Total Organic Carbon	%	-	1	10	-	-	-
Total Kjeldahl Nitrogen	mg/kg	-	550	4800	<1000	1000-2000	>2000

Source: Compiled by Washington State Department of Ecology (1995)