Sains Malaysiana 46(3)(2017): 401–411
http://dx.doi.org/10.17576/jsm-2017-4603-07

Assessment of Water Quality of Batang Rajang at Pelagus Area, Sarawak, Malaysia

(Penilaian Kualiti Air Batang Rajang di Kawasan Pelagus, Sarawak, Malaysia)

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ABSTRACT

This study was carried out to examine the water quality of Batang Rajang at Pelagus area, Sarawak, Malaysia. Water quality was determined at 12 stations along Batang Rajang and its tributaries in terms of in-situ *and* ex-situ *water quality parameters. The results showed that most stations at main river were categorized as slightly polluted while most tributaries were clean according to the Water Quality Index. The river is suffering from organic pollution where almost all stations along the river contained high chemical oxygen demand (≈ 43.1 mg/L) and total ammonia nitrogen (≈ 0.520 mg/L) and were classified as Class III and IV at most of the stations. High suspended solids (218.3 mg/L) and low dissolved oxygen (4.6 mg/L) were observed at the main river. The low dissolved oxygen content from the Bakun dam upstream of the study area has an impact on the river particularly during dry season where DO dropped below the minimum required for sensitive aquatic organisms. As seven tributaries are within Class II indicating healthy freshwater ecosystems, they should be conserved as habitats for sensitive aquatic organisms. Conversely, proper management need to be initiated in particular, Sungai Merit tributary and the main river where DO were below the minimum required for sensitive aquatic organisms.*

Keywords: Hydroelectric dam; longhouses; Pelagus rapids; regulated river; water quality index

ABSTRAK

Penyelidikan ini dijalankan untuk mengkaji kualiti air Batang Rajang di kawasan Pelagus, Sarawak, Malaysia. Kualiti air telah ditentukan di 12 stesen sepanjang Batang Rajang dan anak sungainya daripada segi parameter kualiti air secara in-situ *dan* ex-situ. *Hasil kajian menunjukkan bahawa kebanyakan stesen di sungai utama dikategorikan sebagai sedikit tercemar manakala kebanyakan anak sungai adalah bersih mengikut Indeks Kualiti Air. Batang Rajang mengalami pencemaran organik dengan hampir semua stesen di sepanjang sungai mengandungi permintaan oksigen kimia (≈ 43.1 mg/L) dan jumlah nitrogen ammonia (≈ 0.520 mg/L) yang tinggi dan diklasifikasikan sebagai Kelas III dan IV di kebanyakan stesen. Pepejal terampai yang tinggi (218.3 mg/L) dan oksigen terlarut (DO) yang rendah (4.6 mg/L) diperhatikan di sungai utama. Kandungan oksigen terlarut yang rendah dari empangan Bakun di hulu kawasan kajian mempunyai kesan ke atas sungai terutamanya semasa musim kering dengan DO jatuh di bawah tahap minimum yang diperlukan untuk organisma akuatik sensitif. Memandangkan tujuh anak sungai berada dalam Kelas II yang merupakan ekosistem air tawar yang sihat, mereka harus dipelihara sebagai habitat untuk organisma akuatik yang sensitif. Sebaliknya, pengurusan yang betul perlu dimulakan terutamanya di anak sungai Merit dan sungai utama dengan DO adalah di bawah tahap minimum yang diperlukan untuk organisma akuatik sensitif.*

Kata kunci: Empangan hidroelektrik; indeks kualiti air; jeram Pelagus; rumah panjang; sungai terkawal

INTRODUCTION

The whole area of Sarawak is dominated by river systems which play a significant part in its socio-economic development as it provides Sarawak with a steady water supply, hydroelectric power, irrigation and rich soil. Batang Rajang ('Batang' denotes big river) together with its main tributaries, has a length of 560 km and it is the largest river in Malaysia. Some of the important tributaries of Batang Rajang include Sungai Balui ('Sungai' denotes river) and Batang Baleh. These rivers flow through the Kapit Division and then to the South China Sea. The largest and tallest Bakun hydroelectric dam project (160 m) is located on the narrow Bakun Fall of Sungai Balui. There are 534 longhouses located along the major rivers and tributaries of Batang Rajang. These rivers also serve as the main means of transportation in the division. The heavy usage of the river and human activities in the watershed make it vulnerable to water quality degradation.

According to the Department of Environment, Malaysia, the river water quality in terms of Water Quality Index (WQI) had shown a decrease in year 2014 and the percentage of clean rivers has decreased from 58% to 52%; however, the percentage of polluted river has increased from 5% to 9% in the same year (Department of Environment 2015). In addition it was reported that in Sarawak, most of the part of Batang Rajang is categorized as slightly polluted and classified as Class II and/or Class III according to WQI. Water quality deterioration is often caused by human activities such as domestic waste disposal, logging activities and agricultural runoff. Longhouses located along Batang Rajang and its tributaries usually do not have a proper domestic sewage effluent treatment system; the direct discharge of this untreated or partially treated waste into the river can contribute to the river pollution (Braga et al. 2000; Huang et al. 2003; Ling et al. 2010a, 2010b; Pierson et al. 2001). Timber harvesting often results in degradation of water quality which includes an increase of temperature, sedimentation and nutrient enrichment (Dahlgren 1998; Ensign & Mallin 2001; Gokbulak et al. 2008; Schelker et al. 2012). Besides, agricultural runoff is associated with increased nutrient loading in receiving water which can accelerate eutrophication in the river (Hart et al. 2004; Jarvie et al. 2006; Kim et al. 2007; Neal et al. 2000; Pierson et al. 2001).

In addition to the Malaysia's largest and tallest Bakun hydroelectric dam and the newly filled Murum hydroelectric dam, a new hydroelectric project has been proposed at the Pelagus area of Batang Rajang with the Pelagus Rapids which is cascading approximately 180 km from the Bakun hydroelectric dam. The study area is also surrounded by longhouses, agricultural and recreational activities. Other than the potential influence of the Bakun and Murum hydroelectric dams on the study area (Beck et al. 2012; Cunha & Ferreira 2012; Guo et al. 2012; Kondolf 1997; Li et al. 2010; Lin 2011; Preece 2004; Wang et al. 2012; Wei et al. 2009; Wildi 2010; Yi et al. 2010), future developments may cause environmental degradation and water quality deterioration (Davis & Koop 2006; Hadibarata et al. 2012; Ham et al. 2009; Whitall et al. 2010). Due to the environmental concerns from different anthropogenic activities associated with Batang Rajang, this study was aimed at assessing its water quality the results of which would serve as baseline data for future evaluations of the impacts of increased anthropogenic activities.

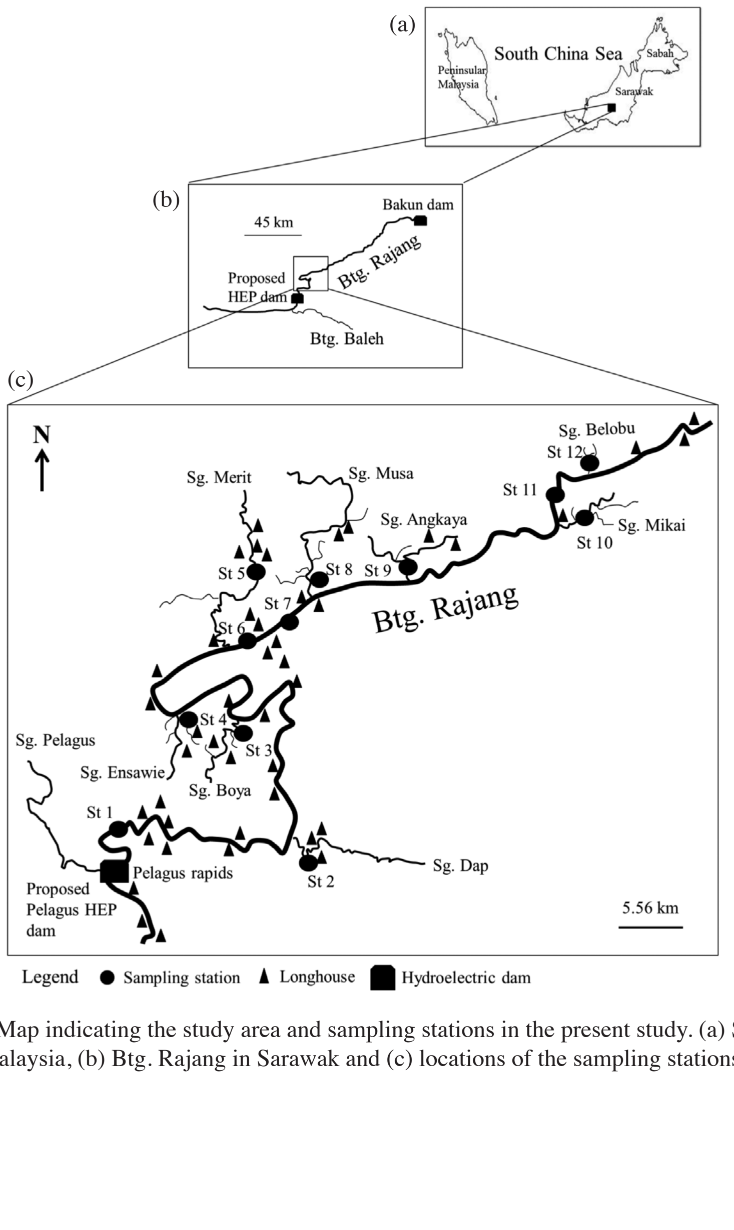

FIGURE 1. Map indicating the study area and sampling stations in the present study. (a) Sarawak, Malaysia, (b) Btg. Rajang in Sarawak and (c) locations of the sampling stations

Materials and Methods

Study Area and Sampling Stations

The present study was conducted at Pelagus area of Batang (Btg.) Rajang and its tributaries in Sarawak, Malaysia. The stations stretched from Sungai (Sg.) Pelagus in upstream direction to Sg. Belobu at the Punan Bah area, a distance of 63 km (Figure 1). Sg. Belobu tributary is approximately 114 km from the Bakun hydroelectric dam. A total of twelve stations were selected along the river whereby four stations were located at the main river while eight stations were located at the tributaries of Btg. Rajang.

Station 1 was located at the main river of Btg. Rajang upstream to the Sg. Pelagus. Stations 2, 3, 4 and 5 were located at the tributaries, namely, Sg. Dap, Sg. Boya, Sg. Ensawie, and Sg. Merit, respectively. Stations 6 and 7 were located at the main river while stations 8 and 9 were located at the tributaries, namely, Sg. Musa and Sg. Angkaya, respectively. Station 11 was located at the main river whereas station 10 and station 12 were located at the tributaries, namely, Sg. Mikai and Sg. Belobu, respectively. All stations were surrounded by longhouses and subjected to land use activities such as paddy field and oil palm plantation. The study area has also been subjected to commercial timber harvesting previously.

The first six stations were studied in August 2014 while stations 7 to 12 were studied in January 2015 (Table 1). Annual rainfall as measured at Kapit (approximately 27 km from station 1) is among the highest found in Sarawak which exceeds 5000 mm in most years. There is usually an average of 250 days per year of measureable precipitation. Temperature is high throughout the year with a mean annual daily maximum temperature of 33°C (Dykstra & Elias 2003). The first and second samplings were conducted in dry and wet season in Sarawak, respectively. However, in August 2014 trip, prior to sampling there was heavy rain. According to the rainfall data acquired from the Malaysian Meteorological Department (Sarawak Branch), records of daily ½ hour heaviest rainfall amount from 22nd to 28th August 2014 were 6.4, 0.0, 0.2, 3.8, 24, 7.4 and 2.6 mm, respectively, whereas rainfall from 9th to 15th January 2015 were 10.2, 30.0, 11.2, 0.4, 3.2, 1.6 and 75.6 mm, respectively, where 75.6 mm rainfall was the extreme for the month.

Field Collection and Laboratory Analysis

In-situ parameters including temperature, pH, dissolved oxygen (DO), conductivity, turbidity, depth and flow

TABLE 1. The details of the sampling location and sampling regime in the present study

Station	Coordinate	Date and time	Weather Condition
St 1-Btg. Rajang	N 02° 11’ 58.1” E 113° 04’ 26.7”	28/8/14 1.20 pm	Heavy rain the previous night Light rain in the morning Sunny during sampling
St 2-Sg. Dap	N 02° 11’ 04.9” E 113° 09’ 51.5”	28/8/14 11.15 am	Heavy rain the previous night Light rain in the morning Sunny during sampling
St 3-Sg. Boya	N 02° 14’ 58.8” E 113° 07’ 32.0”	28/8/14 9.33 am	Heavy rain the previous night Light rain in the morning Sunny during sampling
St 4-Sg. Ensawie	N 02° 15’ 12.0” E 113° 05’ 36.7”	27/8/14 4.02 pm	Heavy rain the previous night Cloudy during sampling
St 5-Sg. Merit	N 02° 19’ 46.4” E 113° 07’ 57.9”	27/8/14 1.12 pm	Heavy rain the previous night Slightly sunny during sampling
St 6-Btg. Rajang	N 02° 17’ 19.2” E 113° 07’ 50.6”	27/8/14 11.19 am	Heavy rain the previous night Light rain during sampling
St 7-Btg. Rajang	N 02° 17’ 27.6” E 113° 08’ 16.0”	14/1/15 9.10 am	Rain the previous night Cloudy during sampling
St 8-Sg. Musa	N 02° 18’ 37.3” E 113° 09’ 56.8”	14/1/15 10.07 am	Rain the previous night Cloudy during sampling
St 9-Sg. Angkaya	N 02° 19’ 13.4” E 113° 13’ 10.3”	14/1/15 12.36 pm	Rain the previous night Sunny during sampling
St 10-Sg. Mikai	N 02° 20’ 43.6” E 113° 18’ 05.2”	14/1/15 2.18 pm	Rain the previous night Sunny during sampling
St 11-Btg. Rajang	N 02° 21’ 34.3” E 113° 17’ 58.2”	14/1/15 3.19 pm	Rain the previous night Raining during sampling
St 12-Sg. Belobu	N 02° 22’ 29.7” E 113° 19’ 23.6”	15/1/15 2.26 pm	Sunny the previous night and during sampling

were measured using a microprocessor pH meter with temperature probe (TI9000, Walklab), a DO meter (DO600-K, Extech), a conductivity meter (HI 9033/9034, Hanna), a turbidity meter (Mi415, Milwaukee), a depth sounder (PS-7, Hondex) and a flowmeter (Geopacks), respectively. Triplicate water samples were taken for the analysis of total suspended solids (TSS), five-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total ammonia nitrogen (TAN), nitrite-nitrogen (NO_2^--N), nitrate-nitrogen (NO_3^--N), total phosphorus (TP) and soluble reactive phosphorus (SRP). All sampling bottles were acid-washed, rinsed and dried before use. Water samples (acidified to pH < 2) were placed in an ice box and transported to the laboratory for further analysis (Jenkins et al. 2005).

For water analysis, the triplicate water samples were composited prior to analyses. All water analysis were performed according to standard procedures in triplicate (Hach 2015; Jenkins et al. 2005). TSS were assayed as the difference between initial and final weight of the 1.2 µm retention glass fiber filter (Sartorius Stedim MGC), after filtration of an adequate sample volume and drying at 105°C. BOD_5 was determined as the difference between initial and five-day DO content, after incubation of the sample in the dark at 20°C. COD was determined by closed reflux titrimetric method (Jenkins et al. 2005). TAN was determined by Nessler's method (Hach 2015). NO_2^--N and NO_3^--N were determined by diazotization method (low range) and cadmium reduction method, respectively (Hach 2015) after filtered through a 0.7 µm glass fiber filter (Advantec GA55). TP was determined by ascorbic acid method after persulfate digestion of samples (Jenkins et al. 2005). SRP was determined by the colorimetric ascorbic acid method (Hach 2015) after filtering through 0.45 µm cellulose acetate membrane filter (Sartorius Stedim). Calibration curve was constructed for each chemical analysis. Blank and standard solutions were treated in a similar way as the sample.

WATER QUALITY INDEX (WQI)

Water quality index (WQI) which combines the six variables of DO, BOD, COD, TSS, AN, and pH was calculated according to (1).

$$\text{WQI} = 0.22*SI_{DO} + 0.19*SI_{BOD} + 0.16*SI_{COD} + 0.15*SI_{AN} + 0.16*SI_{SS} + 0.12*SI_{pH} \quad (1)$$

where SI_{DO} is the sub-index for DO (% saturation); SI_{BOD} is the sub-index for BOD (mg/L); SI_{COD} is the sub-index for COD (mg/L); SI_{AN} is the sub-index for AN (mg/L); SI_{SS} is the sub-index for SS (mg/L); and SI_{pH} is the sub-index for pH (Department of Environment 2015).

STATISTICAL ANALYSIS

All data were tested for normality and equal variance with Shapiro-Wilk test and Levene's test, respectively. Non-parametric tests were used in the subsequent statistical analyses due to the violation of the normal distribution and equal variance assumptions of the parametric tests. The Kruskal-Wallis test was carried out to determine the significant differences among the twelve sampling stations. The Mann-Whitney U test was used to determine the significant difference between the two sampling trips which were conducted in dry and wet season. Cluster analysis (CA) was used to investigate the grouping of the sampling stations using the water quality parameters collected at the study area. Z-score standardization of the variables and Ward's method using Euclidean distances as a measure of similarity was used. All the statistical analyses were carried out using the Statistical Software for Social Sciences (SPSS Version 22, SPSS Inc. 1995).

RESULTS AND DISCUSSION

IN-SITU PARAMETERS

Btg. Rajang was around 4.1 m deep and flowed up to 1.1 m/s whereas the tributaries ranged from 0.2 to 1.3 m deep and flowed from 0.05 to 1.35 m/s in the present study (Figure 2). Stations 7 and 11 which were studied during wet season show deeper water during sampling than stations 1 and 6 which were studied during dry season. The velocity at station 5 (1.35 m/s) was extremely high although Station 5 was located at the tributary. Temperature of the Btg. Rajang and its tributaries ranged from 25.0 ± 0.1°C to 30.6 ± 0.1°C as illustrated in Figure 3. The range of temperature value is typical for tropical rivers and lie within the range of the Sungai Langat basin (Juahir et al. 2011) and the Lower Sungai Kinabatangan catchment (Harun et al. 2014) in Malaysia. Dissolved oxygen in Btg. Rajang (≈ 4.6 mg/L) is lower than the tributaries (≈ 6.6 mg/L) in the present study especially during dry season indicating the impact of the Bakun dam water whereby dam release has low DO level (Ling et al. 2016a) coupled with little dilution from the big tributaries such as Sungai Belaga upstream. During wet season, in spite of the larger amount of rain water and dilution, station 11, which is downstream of Bakun dam, still showed DO of less than 5 mg/L. From stations 11 to 7, with the tributaries inflow, DO increased from 4.6 to 5.6 mg/L. Nevertheless, DO value of the tributaries in the present study area (6.0 - 7.5 mg/L) is also low when compared to the rivers that flows into the Bakun hydroelectric dam reservoir (7.2 - 9.1 mg/L) (Ling et al. 2015) but similar to the upstream tributaries of Batang Baleh (6.3 - 7.6 mg/L) (Ling et al. 2016b). According to the WQI, DO was classified as Class II and III in the main river and Class I and II in the tributaries (Table 2). In addition to the influence of Bakun dam, the low DO may also be associated with the high suspended solids and organic matter content in the study area. The high suspended solids which limit the light penetration have major impacts on the growth of phytoplankton. The decomposition of high organic matter can lead to the depletion of oxygen in the river (Bilotta & Brazier 2008). Hence, the high suspended

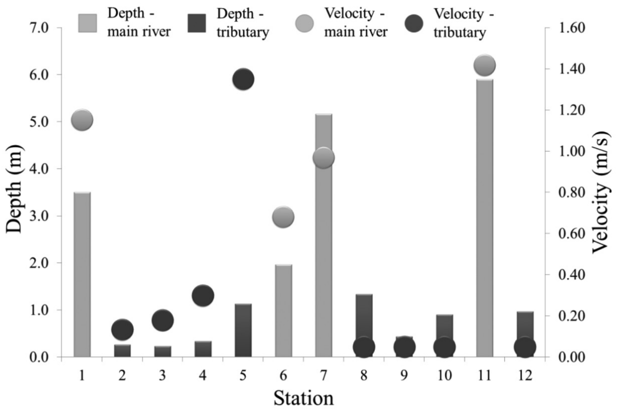

FIGURE 2. The depth and velocity along the Btg. Rajang and its tributaries

solids and organic matter content lead to the lower DO content in the present study area.

The pH value of Btg. Rajang is lower during the dry season (stations 1 and 6) compared to the wet season (stations 7 and 11) with the lowest pH value of 6.1 at Station 1 and up to pH value of 7.1 at station 11. The pH value of Btg. Rajang and its tributaries are considered within acceptable range and classified as Class I and II according to WQI (Table 2). However, the pH value in the present study area is relatively lower than the tributaries at the upper part of Btg. Rajang which flows into the Bakun hydroelectric dam reservoir (6.8 - 7.8) (Ling et al. 2015) and the upstream tributaries of Batang Baleh (7.0 - 7.7) (Ling et al. 2016b). The pH value of Btg. Rajang at stations 7 and 11 (≈ 7.0), as part of a regulated river by Bakun dam, is similar to the pH value of the Bakun dam above 10 m (> 6.9) where the water is released to the river (Ling et al. 2016a). Other than the impact of dam water with low pH (Ling et al. 2016a), the lower pH value at the downstream could be due to the anthropogenic activities. In the present study, Btg. Rajang and its tributaries are surrounded by longhouses, paddy field and oil palm plantation indicating that the low pH is most likely due to the nitrogen pollution from domestic wastewater and the nitrogen fertilizer application. This is supported by the higher total ammonia nitrogen value in the lower part of the river (Figure 4) which is in contrary to the pH value. Nitrogen fertilization, particularly, ammonium increases soil acidity as H^+ is released during root uptake and nitrification process (Johnson et al. 2013). Thus, it decreases river pH during surface runoff. Besides, Btg. Rajang is the main means of transportation in the division. The burning of fossil fuels from boats releases nitrogen oxides into the atmosphere, which contributes to the formation of smog and acid rain, subsequently lowering the pH of the river (Caldeira & Wickett 2003). The conductivity value follows similar distribution of pH where the value increased from 22.9 ± 0.1 µS cm^{-1} at station 1 to 31.9 ± 0.1 µS cm^{-1} at station 11. The conductivity value at station 11 is similar to the conductivity value of 15 m depth in the reservoir near the dam intake (Ling et al. 2016a). However, the conductivity value in some tributaries showed values as high as the main river while some showed lower values. Similarly, the conductivity value in the present study is lower than the upstream of Batang Baleh which ranged from 25.9 - 49.1 µS/cm (Ling et al. 2016b).

High turbidity from anthropogenic sources limits light availability for photosynthesis and has significant negative impacts on aquatic fauna (Baoligao et al. 2016; Gonzalez-Ortegon et al. 2010; Hasenbein et al. 2013; Kimbell & Morrell 2015; Madhu et al. 2010). In the present study, turbidity was high at stations 1, 5, 6 and 7 (Figure 3). The highest value was recorded at station 6 which is up to 500 FTU. Turbidity values at these four stations were significantly higher than stations 3, 4 and 9 which are less than 10 FTU (p-value ≤ 0.05). Turbidity value at station 1 (487.3 FTU) located near to the Pelagus rapids in the present study is higher than the Sg. Belepeh (Ling et al. 2015) and upstream tributaries of Batang Baleh (Ling et al. 2016b) where the authors attributed the high turbidity value to the logging activities in the watershed. In the present study, the high turbidity value is most likely due to the suspended solids originating from the runoff of anthropogenic activities and re-suspension of settled inorganic solids which is supported by the high flow rate at those stations. The day before the first sampling during dry season, there was heavy rain and that resulted in high turbidity in stations 1, 5 and 6.

EX-SITU PARAMETERS

Figure 4 illustrates that BOD_5 ranged from 1.3 ± 0.5 to 3.1 ± 0.2 mg/L and classified as Class II at all stations except station 7 (Class III) in the present study. The lowest and the highest BOD_5 concentrations were found at stations 4 and 7, respectively. The highest value of COD was recorded at station 1 (72.3 ± 15.4 mg/L) while the lowest at station 7 (10.7 ± 2.3 mg/L). The concentration of COD showed wide variations reflecting lower values at the upper part of Btg. Rajang during wet season compared with the lower part of the river during dry season though there was no such trend for BOD_5. Mann-Whitney U test also showed that COD collected during wet season is significantly lower

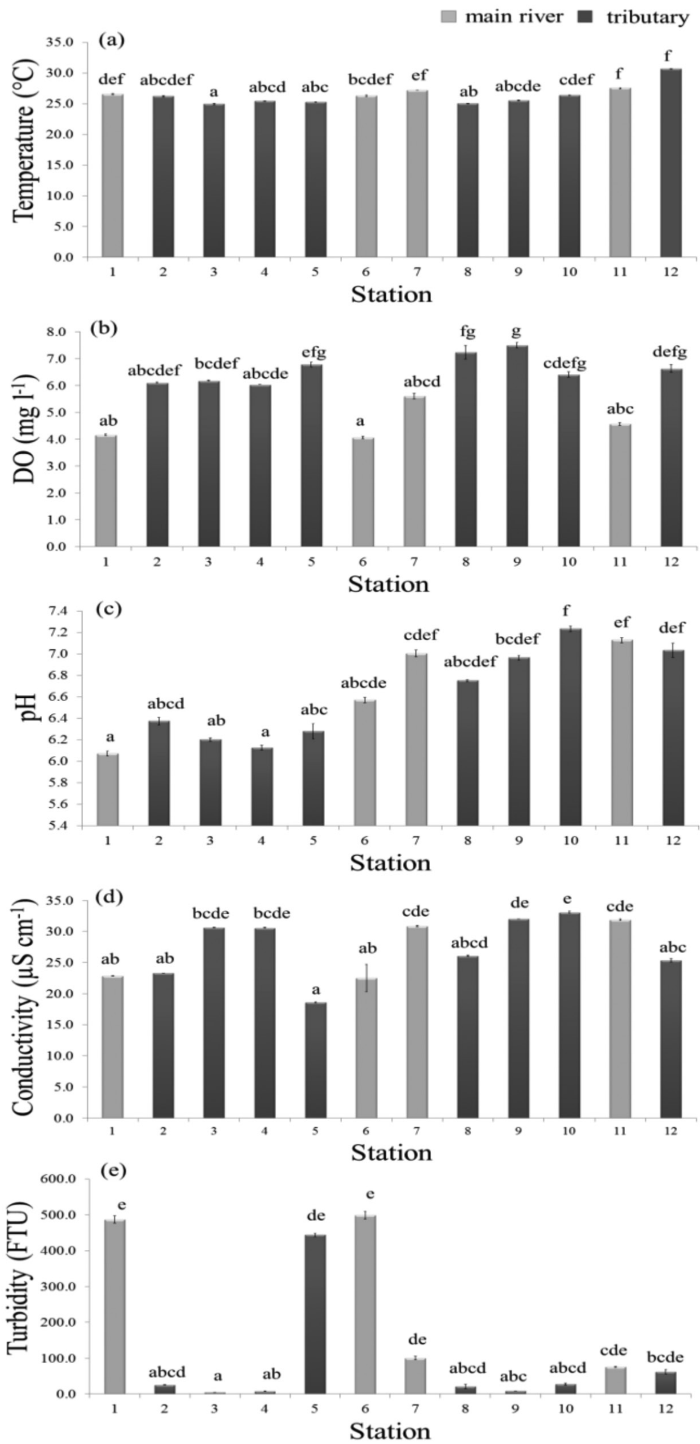

FIGURE 3. *In-situ* parameters include (a) temperature, (b) DO, (c) pH, (d) conductivity and (e) turbidity along the Btg. Rajang and its tributaries (N = 3). The same letter indicated no significant difference between the stations at p-value ≤ 0.05

than dry season (p-value ≤ 0.05). This shows that during wet season, COD is diluted substantially along the river. According to WQI, stations 1, 2, 5 and 6 were classified as Class IV while stations 3, 4, 8, 9, 10 and 12 were classified as Class III. The lowest concentration of COD at station 7 was classified as Class II (Department of Environment 2015). The organic pollution in Btg. Rajang as indicated by the high BOD_5 and COD values most likely originates from the domestic wastewater and runoff from adjacent area. The water released from Bakun dam has minimal influence on the COD values at Btg. Rajang as (Ling et al. 2016a) reported the COD value in the proximity of the dam is 6.7 mg/L at a depth of 15 m. The COD value in the present study is similar to the upstream tributaries of Batang Baleh which ranged from 22.2 to 72.1 mg/L (Ling et al. 2016b).

TABLE 2. Classification of water quality of the twelve sampling stations located along the Btg. Rajang and its tributaries according to WQI

Station	CLASS							Status
	DO	BOD	COD	AN	SS	pH	WQI	
1	III	II	IV	III	IV	II	III	slightly polluted
2	II	II	IV	III	I	II	II	clean
3	II	II	III	III	I	II	II	clean
4	II	II	III	III	I	II	II	clean
5	II	II	IV	IV	IV	II	III	slightly polluted
6	III	II	IV	III	V	II	III	slightly polluted
7	II	III	II	III	III	I	II	clean
8	I	II	III	II	I	II	II	clean
9	I	II	III	III	I	I	II	clean
10	II	II	III	III	II	I	II	clean
11	III	II	III	III	IV	I	III	slightly polluted
12	II	II	III	III	II	I	II	clean

TABLE 3. Mean difference of *in-situ* and *ex-situ* water quality parameters between dry season and wet season which conducted in August 2014 and January 2015, respectively ($n = 6$)

	Parameter	Sampling 1	Sampling 2	Mean difference	p-value
In-situ	Temperature	25.8	27.1	**-1.3**	**0.019**
	DO	5.6	6.3	**-0.8**	**0.019**
	pH	6.3	7.0	**-0.7**	**0.000**
	Conductivity	24.7	29.9	**-5.1**	**0.000**
	Turbidity	244.8	49.4	+195.4	0.569
Ex-situ	TSS	138.4	58.1	+80.3	1.000
	BOD_5	2.0	2.3	-0.3	0.141
	COD	54.9	31.3	**+23.6**	**0.001**
	TAN	0.7	0.4	**+0.326**	**0.000**
	NO_2^--N	0.0	0.0	-0.001	0.059
	NO_3^--N	0.0	0.0	+0.012	0.272
	SRP	28.7	179.8	**-151.1**	**0.000**
	TP	151.6	660.8	**-509.2**	**0.000**

Positive value of mean difference indicates parameter studied is higher at sampling trip 1 (dry season) whereas negative value indicates parameter studied is higher at sampling trip 2 (wet season).

Total phosphorus and soluble reactive phosphorus were significantly higher at the upper part of the river which is studied during wet season (p-value ≤ 0.05). The lowest and the highest TP were located at station 2 (96.6 ± 3.8 μg l^{-1}) and station 10 (1148.0 ± 71.6 μg l^{-1}), respectively whereas the lowest and the highest SRP were located at station 4 (14.2 ± 1.8 μg l^{-1}) and station 12 (460.1 ± 17.7 μg l^{-1}), respectively. According to the National Water Quality Standards (NWQS) for Malaysia (Department of Environment 2015), SRP was classified as Class I at all stations except stations 7, 9 and 12. TP at stations 1 to 6 were classified as Class I and/or Class IIA/IIB whereas TP at the upper part of the river exceeded the guideline value of NWQS. The highest TP and SRP values were both observed at upstream tributaries. The high phosphorus in the present study is most likely due to the domestic wastewater discharge that is loaded with high phosphorus (Ling et al. 2010b) and fertilizer applied in the paddy filed and oil palm plantation in the study area (Hart et al. 2004; Neal et al. 2000). The intensity of the impacts increased substantially during the wet season as more phosphorus is washed down into the river. The present mean values of SRP (120.4 μg/L) and TP (406.2 μg/L) are higher than the SRP (11.3 μg/L) and TP (87.8 μg/L) at the upstream tributaries of Batang Baleh (Ling et al. 2016b).

NO_2^--N concentration was generally low along the river. The highest value of NO_2^--N was observed at station 7 (0.004 ± 0.000 mg/L) while NO_2^--N concentration at stations 4 and 6 were below detection limit. The mean NO_2^--N concentration in Btg. Rajang and its tributaries (0.002 mg/L) is even lower than the upstream tributary of Batang Baleh (0.008 mg/L) (Ling et al. 2016b). Similarly, NO_3^--N concentration was generally low along the river except station 4 which exhibited a peak of 0.080 ± 0.020 mg/L. The peak value of NO_3^--N in the present study is higher than the highest value reported in upstream tributaries of Batang Baleh (0.035 mg/L) although their mean values (0.018 and 0.017 mg/L) are relatively similar (Ling et al.

2016b). Both mean value of NO_2^--N (0.002 mg/L) and NO_3^--N (0.018 mg/L) in the main river of Btg. Rajang are similar to the NO_2^--N (0.001 mg/L) and NO_3^--N (0.023 mg/L) in the Bakun reservoir near to the dam at a depth of 15 m (Ling et al. 2016a). Comparisons of the results with NWQS indicated that NO_2^--N and NO_3^--N in Btg. Rajang and its tributaries complied with the guideline values set by the Department of Environment, Malaysia. All the NO_2^--N and NO_3^--N concentrations observed in the present study were classified as Class I. TAN exhibited a reverse distribution pattern from TP and SRP where significantly higher TAN concentration was found at the lower part of the river which was studied during the dry season (p-value ≤ 0.05). The highest value was recorded at station 5 (1.049 ± 0.012 mg/L) while the lowest at station 8 (0.215 ± 0.005 mg/L). TAN was classified as Class III at all stations except station 5 (Class IV) and station 8 (Class II). The high TAN in the main river of Btg. Rajang (0.54 mg/L) is predominantly from the domestic wastewater and runoff from adjacent area as the tributaries showed higher TAN than main river. This is in addition to the influence of the water released from Bakun dam as Ling et al. (2016a) reported the TAN value in the proximity of the dam is 0.14 mg/L at a depth of 15 m. Similar to the NO_3^--N, the peak value of TAN in the present study is higher than the highest value reported in upstream tributaries of Batang Baleh (0.687 mg/L) although their mean values (0.520 and 0.504 mg/L) are relatively similar (Ling et al. 2016b).

Total suspended solids were found higher at the main river compared to the tributaries in the present study (Figure 4). The mean value of TSS at the main river was 218.3 mg/L compared to the tributaries of 38.3 mg/L. The highest TSS value was found at station 6 (380.0 ± 3.3 mg/L) at the main river and classified as Class V (Table 2). Station 6 was significantly higher than stations 2, 3, 4, 8, 9 and 10 (p-value ≤ 0.05). TSS was low at stations 2, 3, 4, 8 and 9 (< 25 mg/L) at the tributaries and classified as Class I. The present study area contained higher TSS when compared to the TSS (1.17 - 16.3 mg/L) at the upstream tributaries of Batang Baleh (Ling et al. 2016b).

Among the tributaries, station 5 was found to show the highest five-day biochemical oxygen demand, chemical oxygen demand, total ammonia nitrogen, turbidity and TSS indicating the effect of anthropogenic activities on the water quality. There are longhouses upstream, household solid waste were observed and the water was turbid due to soils erosion. Household wastewater contained high oxygen demand and nutrients (Ling et al. 2010). Hence, when the household wastewater is directly dicharged into the river, it contributes substantially to the oxygen demand and nutrients in the river. Besides, as it rained the night before, the turbulence brought up the sediment to the

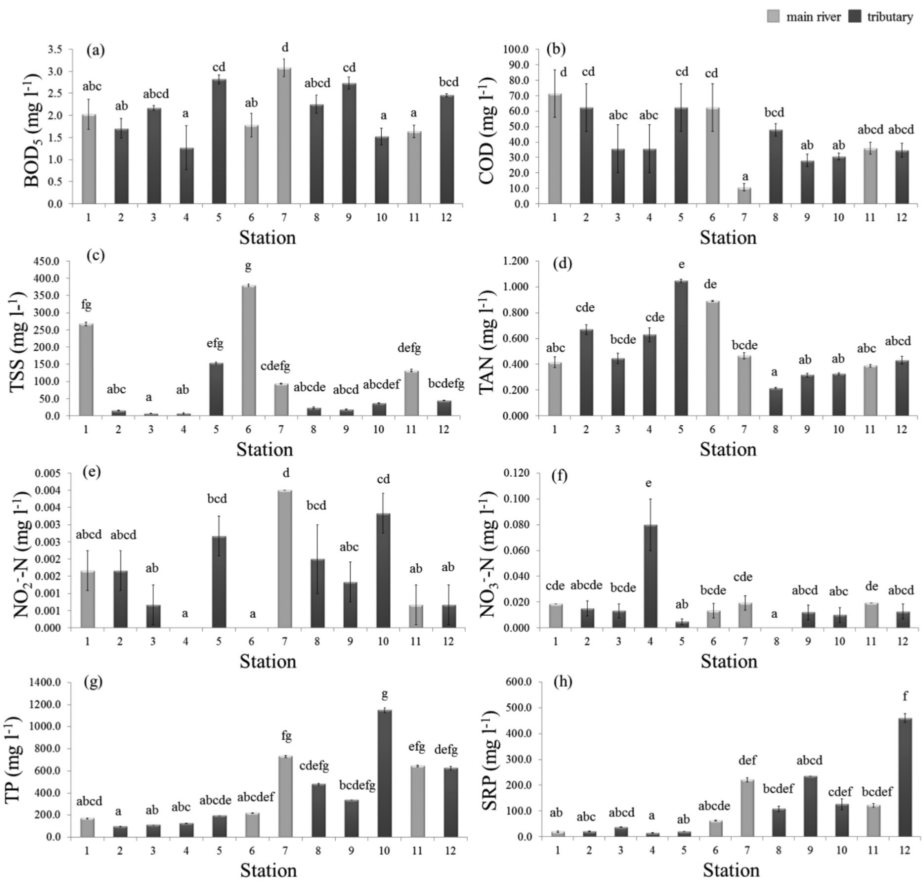

FIGURE 4. Water quality parameters include (a) BOD_5, (b) COD, (c) TSS, (d) TAN, (e) NO_2^--N, (f) NO_3^--N, (g) TP and (h) SRP along the Btg. Rajang and its tributaries ($n = 3$). The same letter indicated no significant difference between the stations

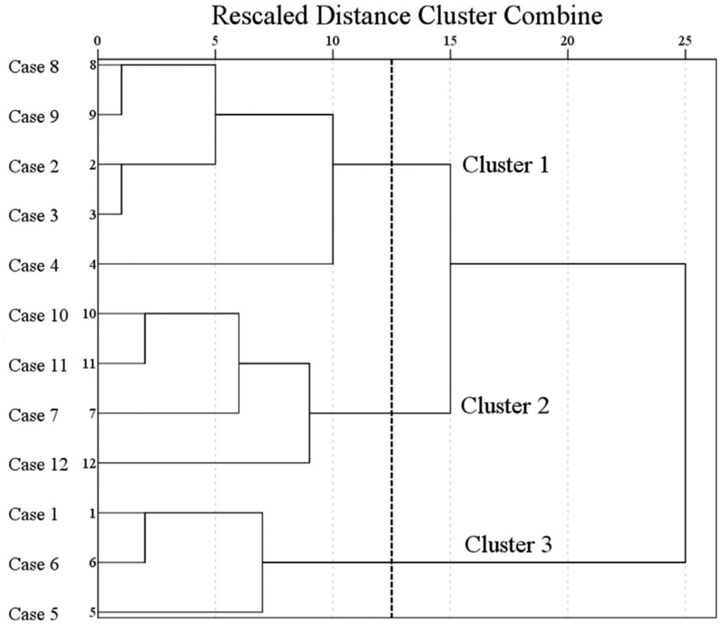

FIGURE 5. Clusters of the twelve sampling stations located along the Btg. Rajang and its tributaries

subsurface thus showing high value of turbidity and TSS despite dilution.

Overall, the WQI's of tributary stations 2, 3, 4, 8, 9, 10 and 12 were classified as Class II which are considered clean and can be used as water supply after conventional treatment. Among them, stations 2, 3, 4, 8 and 9 were also grouped together as cluster 1 in cluster analysis (Figure 5). Station 7 is the only station located at the main river of Btg. Rajang that was classified as Class II and categorized as cluster 2 together with stations 10, 11 and 12. However, all the other stations which are stations 1, 5, 6 and 11 were classified as Class III which is slightly polluted. In contrary to station 7, station 5 is the only tributary that was classified as Class III. Figure 5 shows that stations 10, 11 and 12 which are located at the upper part of the river were grouped as cluster 2 while stations 1, 5 and 6 were grouped as cluster 3. The dry and wet seasons may also influence the water quality characteristic in the river. Clusters 2 and 3 are stations that were studied during wet and dry season, respectively.

CONCLUSION

The present study showed that Btg. Rajang suffers from organic pollution and suspended solids with high COD, TAN, turbidity and TSS. BOD_5, TP and SRP were also high in the study area except NO_2^--N and NO_3^--N which were low along the river. Stations located at the upper part of the river are high in TP and SRP whereas COD and TAN are high at the lower part of the river. The high suspended solids and nutrients indicate anthropogenic activities in the surrounding area. Besides, the higher concentration of nutrients could be due to the increased runoff during wet season. The Bakun dam located upstream of the present study has an impact on water quality of Btg. Rajang particularly DO and pH. Since seven out of eight stations located in the tributaries along Btg. Rajang complied with Class II, those tributaries should be conserved for healthy aquatic organisms. On the other hand, slightly polluted stations require proper management, in particular, station 5 in the tributaries and the main river where DO were below the minimum required for sensitive aquatic organisms during dry season.

ACKNOWLEDGEMENTS

The authors appreciate the financial support provided by the Sarawak Energy Berhad through GL(F07)/SEB/4C/2013(26), and the facilities provided by Universiti Malaysia Sarawak.

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Received: 15 April 2016
Accepted: 28 June 2016