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Original Research

Influence of Rainfall on the Physicochemical Characteristics of a Tropical River in Sarawak, Malaysia

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Abstract

A rainfall event is an important factor that can greatly affect the water quality of a river, particularly in a tropical country where the seasonal variations of river water quality are mainly dominated by precipitation. Hence, the present study aimed to determine the changes in the physicochemical characteristics of the Batang Baram, a tropical river in Malaysia, due to a rainfall event. Two samplings were conducted in the Baram in Sarawak before and after rain. The results show that the mean velocity and mean depth of the river increased substantially after rain. The high volume of surface runoff coupled with the fast-flowing river significantly increased the dissolved oxygen, oxygen saturation, turbidity, chlorophyll *a*, total sulphide, hydrogen sulphide, and nitrite-nitrogen in the river after rain; whereas the pH, transparency, and organic nitrogen decreased significantly after rain. The water quality index (WQI) in the tributary after rain showed improvement mainly due to an increase in the concentration of dissolved oxygen. On the other hand, the total suspended solids in the main river after rain changed from Class I/II/III to Class III/V due to soil erosion.

Keywords: physicochemical parameters of surface waters, water quality index, Baram River, Borneo Island

Introduction

In recent years, extreme rainfall events and an increase in rainfall variability have been reported in different parts of the world as a result of climate change [1-2]. Such changes in rainfall have a direct impact on water bodies. The rainfall-induced risks on the quality of the water bodies are of more concern in a tropical country where seasonality is primarily governed by precipitation [3]. A rainfall event can greatly affect the physicochemical characteristics of a water body by changing its hydrological conditions, bringing substantial amounts of pollutants

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via rainfall runoff [3-7]. These can cause water pollution and eutrophication and subsequently endanger the living organisms in the water body [8-11].

The Batang Baram ("batang" denotes big river; coordinates: 4°35'5.28"N and 113°58'44.256"E) is the third longest river in Malaysia. It is located on the northern part of Sarawak, where its mouth is approximately 29 km north of the city of Miri. It has been an important source of fisheries products and a major source for drinking water for rural communities. As logging and timber extraction have been carried out in the Upper Baram area [12] and agricultural developments are increasingly important in the watershed, the river water can be seriously impacted by a rainfall event that potentially threatens aquatic organisms and public health.

Hence, the aim of the present study was to investigate the changes in the physicochemical characteristics of the Batang Baram due to a rainfall event. The investigation of the changes due to the effects of rainfall runoff on the river is highly necessary for watershed management. Besides, the impacts of rainfall runoff on river water can be intensified through interactions with different land use such as forestry, agriculture, and residential development in the adjacent area [13-15]. Hence, the impact of land use such as longhouses and logging activities near the river on its water quality is also described in the present study.

Materials and Methods

Study Area

Ten sampling stations were selected along the Batang Baram and its tributaries covering a distance of 32 km (Fig. 1). Five stations were located at the main river of Baram while five stations were located at tributaries, namely Patah, Piping, Jertang, Kesseh, and Nakan. Land use activities near each of the sampling stations are included in Table 1.

Field Study

Two sampling trips were carried out where no rain was recorded for a week prior to the first sampling, while it rained one night before the second sampling. Details of the two samplings carried out in January and March 2016 are included in Table 1. *In situ* parameters including temperature, dissolved oxygen (DO), oxygen saturation (DOsat), pH, conductivity, and turbidity were measured using a multiparamater water quality sonde (YSI6920 V2-2). Transparency, depth, and flow velocity were measured using a secchi disc with a measuring tape, a depth sounder (PS-7, Hondex), and a stream flow meter (Geopacks), respectively. All *in situ* parameters were measured in triplicate except for flow velocity. Mean velocity and mean depth were calculated according to [16]. Water samples were taken for the analyses of chlorophyll *a* (chl *a*), total suspended solids (TSS), five-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total sulphide (TS), total ammonia nitrogen (TAN), nitrite-nitrogen (NO_2^--N), nitrate-nitrogen (NO_3^--N), organic nitrogen (Org-N), and total phosphorus (TP). All sampling bottles were acid-washed, cleaned, and dried before use. Analyses of chl *a*, TSS, BOD_5, NO_2^--N, NO_3^--N, and TS were conducted in the field immediately after sampling. Water samples were acidified to pH<2 for COD, TP, TAN, and Org-N analyses. The samples were placed in an ice box and transported to the laboratory for further analysis [17].

Laboratory Analyses

All the analyses were conducted in triplicate according to the standard methods [17-18]. Chl *a* was determined

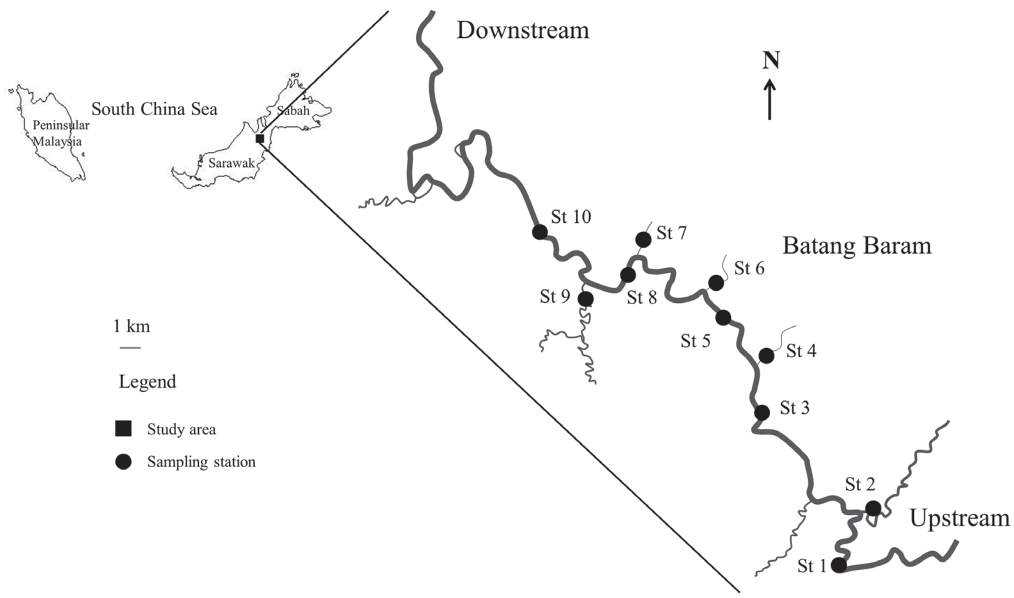

Fig. 1. The study area and location of the sampling stations.

from samples filtered through a 0.7 µm glass microfibre filter (Whatman GF/F) and extracted for 24 h using 90% (v/v) acetone. TSS was calculated as the difference between the initial and final weight of the 1.0 µm glass microfibre filter (Whatman GF/B), after filtration of an adequate sample volume and drying to constant weight at 105ºC. BOD_5 was determined as the difference between the initial and final DO content, after a five-day long incubation of the sample. For the initial DO content, it was measured in the field whereby it was raised by vigorous aeration if the *in situ* DO value was too low. COD was determined by the closed reflux method followed by the titrimetric method. TP was determined by the ascorbic acid method after persulfate digestion of samples. TAN, NO_2^--N, and NO_3^--N were determined by Nessler's method, the diazotization method (low range), and the cadmium reduction method, respectively. Water samples were filtered through a 0.7 µm glass microfibre filter (Whatman GF/F) prior to the analyses of NO_2^--N and NO_3^--N. Org-N was determined by the Macro-Kjeldahl Method where ammonia was removed from the water sample before digestion and distillation, followed by Nessler's method. TS was analyzed using the methylene blue method. H_2S was calculated according to [17] with the following equation:

$$H_2S = \frac{TS}{10^{pH-pK'} + 1}$$

…where H_2S is the unionized hydrogen sulphide, TS is the total sulphide, and pK' is the conditional first dissociation constant of hydrogen sulphide for freshwater.

A calibration curve was constructed for each chemical analysis. Blank and standard solutions were treated in the same 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 with the following equation:

$$WQI = 0.22 \times SI_{DO} + 0.19 \times SI_{BOD} + 0.16 \times \times SI_{COD} + 0.15 \times SI_{AN} + 0.16 \times SI_{SS} + + 0.12 \times SI_{pH}$$

…where SI_{DO} is the subindex for DO (% saturation), SI_{BOD} is the subindex for BOD (mg/L), SI_{COD} is the subindex for COD (mg/L), SI_{AN} is the subindex for AN (mg/L), SI_{SS} is the subindex for SS (mg/L), and SI_{pH} is the subindex for pH [19].

Statistical Analyses

Comparison of water quality parameters between the stations in the Batang Baram was conducted using one-way ANOVA and Tukey's pairwise comparisons with 5% significance level. The Student's *t*-test was used to compare the water quality between the main river and tributary stations. A positive value of mean difference indicated that the parameter studied was higher in the main river of Batang Baram, whereas a negative value indicates that the parameter studied was higher in the tributary.

Table 1. Details of the sampling regime and sampling stations surveyed in the present study.

Station	Trip 1	Trip 2	Remark
Station 1: Batang Baram N03°19'50.8" E114°35'43.1"	13/01/16	14/03/16	Near the Long Na'ah longhouse Presence of logging activities
Station 2: Sungai Patah N03°21'02.9" E114°36'22.3"	13/01/16	14/03/16	Presence of logging activities
Station 3: Batang Baram N03°23'06.6" E114°33'37.3"	13/01/16	14/03/16	Presence of logging activities
Station 4: Sungai Piping N03°24'47.4" E114°33'29.0"	13/01/16	14/03/16	Presence of logging activities
Station 5: Batang Baram N03°25'47.7" E114°32'58.5"	13/01/16	14/03/16	Presence of logging activities
Station 6: Sungai Jertang N03°26'19.3" E114°32'28.3"	13/01/16	13/03/16	Presence of logging activities
Station 7: Sungai Kesseh N03°27'22.5" E114°30'53.3"	14/01/16	13/03/16	Near the Long Kesseh longhouse Presence of logging activities
Station 8: Batang Baram N03°27'16.8" E114°30'34.0"	14/01/16	13/03/16	Near the Long Kesseh longhouse Presence of logging activities
Station 9: Sungai Nakan N03°26'29.6" E114°29'20.6"	14/01/16	13/03/16	Near the Long Nakan longhouse Presence of oil palm plantation Presence of logging activities
Station 10: Batang Baram N03°26'24.7" E114°32'08.2"	14/01/16	13/03/16	Presence of logging activities

The influence of rain on the water quality of the river was determined by comparing the first and second trips using Student's *t*-test. A positive value of mean difference indicated that the parameter studied increased after rain, whereas a negative value indicates a decrease after rain. Pearson's correlation analysis was performed to determine the relationship among all the parameters during each trip. Cluster analysis was used to investigate the grouping of the sampling stations by using the water quality parameters collected in the river. Z-score standardization of the variables and Ward's method using Euclidean distances as a measure of similarity were used. All the statistical analyses were carried out using the Statistical Software for Social Sciences (SPSS Version 22, SPSS Inc. 1995).

Results and Discussion

Physicochemical Characteristics of the Batang Baram and its Tributaries before and after Rain

The present study shows that rainfall has a great impact on the *in situ* parameters of the Batang Baram and its tributaries (Fig. 2). Mean velocity and mean depth of the river were found higher after rain, although it was not significantly different (p value >0.05), as shown in Table 2. The mean flow velocity of the Batang Baram and its tributaries ranged from 0.09 m/s to 0.89 m/s and from 0.06 m/s to 1.79 m/s before and after the rainfall event, respectively. The highest mean velocity was

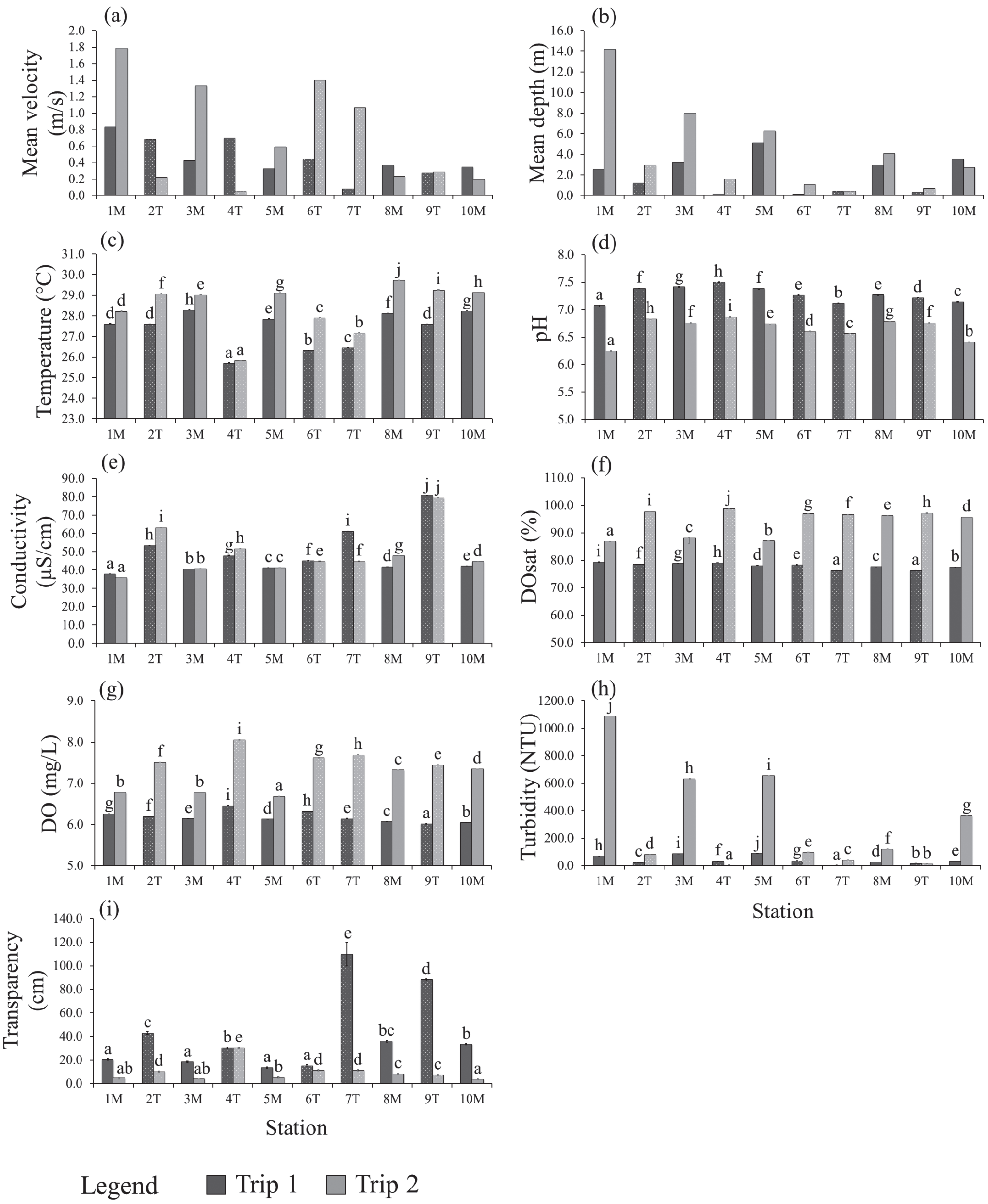

Fig. 2. *In situ* parameters of a) mean velocity, b), mean depth, c) temperature, d) pH, e) conductivity, f) DOsat, g) DO, h) turbidity, and i) transparency collected at the ten sampling stations located along the Batang Baram during two different trips (different letters indicate significant difference at p value≤0.05 during each trip).

Table 2. Mean difference of *in situ* and *ex situ* water quality parameters between the first trip (no rain recorded for a week before sampling) and second trip (rained one night before sampling).

Parameters		Mean Difference	*p* value
In situ	Mean velocity, m/s	+0.3	0.083
	Mean depth, m	+2.2	0.216
	Temperature, ºC	**+1.1**	**0.000**
	pH	**-0.6**	**0.000**
	Conductivity, µS/cm	+0.2	0.926
	DOsat, %	**+16.2**	**0.000**
	DO, mg/L	**+1.1**	**0.000**
	Turbidity, NTU	**+268.8**	**0.036**
	Transparency, cm	**-31.2**	**0.015**
Ex situ	Chl *a*, mg/m^3	**+1.8**	**0.028**
	TSS, mg/L	+322.5	0.057
	BOD_5, mg/L	-1.0	0.053
	COD, mg/L	-1.1	0.940
	TS, mg/L	**+0.46**	**0.018**
	H_2S, mg/L	**+0.37**	**0.019**
	TAN, mg/L	-0.12	0.093
	NO_2^--N, mg/L	**+0.005**	**0.008**
	NO_3^--N, mg/L	+0.007	0.522
	Org-N, mg/L	**-0.31**	**0.000**
	TP, mg/L	-0.17	0.474

The significant difference at *p* value ≤ 0.05 is indicated in bold.

observed at station 1 and it showed a decreasing trend as we move downstream along the main river during both sampling trips. The mean velocity in tributaries also showed a decreasing trend from the upper part of the river to downstream before rain, but higher mean velocity was observed at stations 6 and 7 after rain. The mean depth of the river increased from 2.0 m to 4.2 m after rain and it shows a decreasing trend along the main river and tributaries after rain. There was no significant difference in mean velocity between the main river and tributaries (*p* value>0.05), but the main river was significantly deeper than tributaries both before and after rain (*p* value ≤0.05).

River temperature of the Batang Baram ranged from 25.7ºC to 28.3ºC and from 25.8ºC to 29.3ºC during the first and second trips, respectively. The river temperature was significantly higher (*p* value≤0.05) during the second trip, although it rained one night before the sampling. The results indicated that the rainfall event at the previous night did not have a major influence on the river temperature in the present study. River temperature was found to be significantly lower (*p* value≤0.05) in the tributaries as they were more shady than the main river. This indicates that direct solar radiation might have more influence on river temperature than the rainfall event. Besides, the river temperature was significantly and positively correlated (*p* value≤0.05) with mean velocity of the river before rain (Table 4), and significantly and negatively correlated (*p* value≤0.05) with transparency after rain (Table 5), showing that the elevated suspended solids in the Batang Baram had increased the river water temperature [20].

There was no sign of acidification of the river water as shown by the pH value of more than 7 during the first trip. However, significantly lower pH values were observed at stations 1 and 10 in the main river during both trips (*p* value≤0.05), which were most likely attributed to the domestic discharge from the adjacent longhouse and residential area [21-23]. In addition, the pH values decreased from 7.1 to 6.3 at the two stations after rain. pH values of the Batang Baram and its tributaries were significantly lower (*p* value≤0.05) after rain than before rain (Table 2). After the rainfall event, the mean velocity was significantly and positively correlated (*p* value≤0.05) with BOD_5, TS, and H_2S. The relationships indicate that the increased surface runoff after rain had brought in more organic matter into the river, hence the decrease of the pH value in the river. The conductivity value in the main river increased downstream with the lowest conductivity value being observed at station 1 (≈ 36.9 µS/cm) during both trips and the highest value at station 10 (42.3 µS/cm) and station 8 (48.0 µS/cm) during the first and second trips, respectively. Significantly higher (*p* value≤0.05) conductivity value was observed at station 9 in a tributary. Conductivity of tributaries was significantly higher (*p* value≤0.05) than the main river before rain (Table 3).

The Batang Baram and its tributaries were well oxygenated with a mean DO value of more than 5 mg/L at all stations. Before rain, the DOsat and DO values showed a decreasing trend toward downstream in the main river. However, significantly higher DOsat and DO values (*p* value≤0.05) were observed downstream of the main river after rain. The mean values of DO and DOsat of the river were significantly higher (*p* value≤0.05) after rain, whereby it increased from 6.2 mg/L to 7.3 mg/L and from 78.1% to 94.3%. It was also observed that the rainfall has more influence on the tributaries than the main river, where the DO and DOsat values were significantly higher (*p* value≤0.05) in tributaries after rain with a mean value of 7.7 mg/L and 97.6%, respectively. The DO value was found significantly and negatively correlated with temperature (*p* value≤0.05) before rain, as cooler water holds more oxygen. After the rainfall event, the DOsat and DO values were significantly and negatively correlated with mean velocity (*p* value≤0.05). Besides, the DOsat and DO values were significantly and negatively correlated with turbidity, TSS, COD, TS, and H_2S (*p* value≤0.05), while the DOsat value was significantly and negatively correlated with BOD_5 (*p* value≤0.05).

Table 3. Mean difference of *in situ* and *ex situ* water quality parameters between the main river of the Batang Baram and its tributaries during the first trip (no rain recorded for a week before sampling) and second trip (rained one night before sampling).

Parameters		Before rain		After rain	
		Mean Difference	*p* value	Mean Difference	*p* value
In situ	Mean velocity, m/s	+0.0	0.888	+0.2	0.607
	Mean depth, m	**+3.0**	**0.000**	**+5.7**	**0.023**
	Temperature, ºC	**+1.3**	**0.012**	+1.2	0.116
	pH	+0.0	0.678	-0.1	0.308
	Conductivity, µS/cm	**-17.0**	**0.029**	-14.8	0.065
	DOsat, %	+0.6	0.431	**-6.7**	**0.015**
	DO, mg/L	-0.1	0.265	**-0.7**	**0.005**
	Turbidity, NTU	**+37.4**	**0.035**	**+524.3**	**0.012**
	Transparency, cm	-33.1	0.111	-8.9	0.067
Ex situ	Chl *a*, mg/m^3	+0.2	0.425	+2.1	0.129
	TSS, mg/L	+20.9	0.169	**+625.0**	**0.030**
	BOD_5, mg/L	+0.1	0.838	+0.5	0.407
	COD, mg/L	+1.6	0.923	+22.9	0.232
	TS, mg/L	+0.05	0.439	**+0.75**	**0.016**
	H_2S, mg/L	+0.02	0.321	**+0.57**	**0.022**
	TAN, mg/L	+0.06	0.621	+0.00	0.672
	NO_2^--N, mg/L	+0.000	1.000	**+0.005**	**0.039**
	NO_3^--N, mg/L	-0.005	0.683	-0.032	0.063
	Org-N, mg/L	+0.13	0.178	+0.01	0.899
	TP, mg/L	-0.78	0.101	-0.04	0.861

The significant difference at *p* value ≤ 0.05 is indicated in bold.

These relationships indicate that after the rainfall event, the DOsat and DO contents in the river were mainly regulated by the decomposition of organic matter originating from the increased runoff after rain.

The turbidity values ranged from 3.1 NTU to 88.8 NTU and from 6.0 NTU to 1091.5 NTU during the first and second trips, respectively. Turbidity was significantly higher (*p* value≤0.05) at the upper part of the main river, whereas the lowest turbidity values were observed in tributaries during both trips (Fig. 2). Significantly higher turbidity values were found after rain (*p* value≤0.05) and in the main river (*p* value≤0.05). The turbidity value after rain in the present study was found to be considerably lower than the turbidity value in the Gaoping River, Taiwan after a typhoon-induced extreme rainfall event that reached 57000 NTU. The Batang Baram and its tributaries were significantly less transparent after rain (*p* value≤0.05) due to the high turbidity, where the transparency value in the river decreased from 40.9 cm to 9.7 cm. No significant difference in transparency between the main river and tributaries before and after rain (*p* value>0.05) was observed. The turbidity value in the river was mostly caused by the high suspended solids as proven by the significant positive correlation between turbidity and TSS (*p* value≤0.05). In both sampling trips, the highest TSS occurred at the upper part of the main river where before rain it was observed at station 3 (83.8 mg/L) while after rain it was at station 1 (1363.3 mg/L) (Fig. 3). In addition, after rain TSS in the main river was in a decreasing trend, indicating loading from the main river upstream. The lowest TSS values were found at station 7 (5.0 mg/L) and station 4 (31.1 mg/L), which were located in tributaries during the first and second trips, respectively. TSS value at the Batang Baram increased substantially after rain but was not statistically significant (*p* value = 0.057). However, TSS value in the main river was significantly higher (*p* value≤0.05) than in tributaries after rain.

The results show that the rainfall was transporting large amounts of sediment into the river. Similarly, the highest suspended sediment concentration was reported during the first storm event after an extended drought period in the Enxoé temporary rive in southern Portugal [24]. In general, stations 2, 3, 5, and 6, which were subjected to logging activities, showed high turbidity and substantial suspended solids during both trips, indicating that the logging activities had increased the sedimentation of the area [25]. Similarly, the Baleh River in Sarawak, which was subjected to logging activities, also showed elevated turbidity and TSS values, particularly after rain [26]. In the present study, comparatively, stations that were located near to the longhouse tend to show lower turbidity and suspended solids. However, the highest turbidity and

Table 4. Correlation matrix (*p* value ≤ 0.05) of the *in situ* and *ex situ* parameters collected from the 10 sampling stations during the first trip (no rain recorded for a week before sampling).

	vel	depth	temp	pH	cond	DOsat	DO	turb	trans	chl *a*	TSS	BOD_5	COD	TS	H_2S	TAN	NO_2^--N	NO_3^--N	Org-N	TP
vel			.756					.701												
depth						.861														
temp	.756						-.783													
pH																	.642			
cond						-.732			.829											
DOsat		.861			-.732		.661		-.830		.738									
DO			-.783			.661												.699		
turb	.701								-.739		.855									
trans					.829	-.830		-.739			-.696									
chl *a*																				
TSS						.738		.855	-.696								.699			
BOD_5													.884							
COD												.884					-.669			
TS															.933					
H_2S														.933						
TAN																		-.688	.826	
NO_2^--N				.642							.699		-.669					.747		
NO_3^--N							.699									-.688	.747			
Org-N																.826				
TP																				

Table 5. Correlation matrix (*p* value ≤ 0.05) of the *in situ* and *ex situ* parameters collected from the 10 sampling stations during the second trip (rained one night before sampling).

	vel	depth	temp	pH	cond	DOsat	DO	turb	trans	chl *a*	TSS	BOD_5	COD	TS	H_2S	TAN	NO_2^--N	NO_3^--N	Org-N	TP
vel						-.860	-.795	.948			.958			.913	.873					
depth											.653	.686	.685							
temp									-.829								.662	-.669		
pH														-.757	-.797					
cond																				
DOsat	-.860						.938	-.936			-.955	-.746	-.770	-.820	-.757					
DO	-.795					.938		-.863	.776		-.858		-.752	-.770	-.708			.634		
turb	.948					-.936	-.863				.972		.699	.959	.926					
trans			-.829				.776						-.635							
chl *a*																	.851			
TSS	.958	.653				-.955	-.858	.972				.756	.672	.887	.835					
BOD_5		.686				-.746					.756									
COD		.685				-.770	-.752	.699	-.635		.672									
TS	.913			-.757		-.820	-.770	.959			.887				.992					
H_2S	.873			-.797		-.757	-.708	.926			.835			.992						
TAN																				
NO_2^--N			.662							.851										
NO_3^--N			-.669				.634													
Org-N																				
TP																				

suspended solids were observed at station 1 after rain, which was most probably due to the resuspension of deposited sediment under high flow rates as the highest mean velocity after the rainfall event was recorded there. This is further supported by the significant correlation between turbidity, TSS, and mean velocity (p value ≤ 0.05).

Significantly higher (p value≤0.05) chl a concentration was observed in the Batang Baram and its tributaries after rain, where there was an increase from 0.5 mg/m^3 to 2.3 mg/m^3. The highest and the lowest chl a concentrations were located at station 1 (1.6 mg/m^3) and station 6 (0.2 mg/m^3) before rain, and station 8 (7.7 mg/m^3) and station 7 (0.5 mg/m^3) after rain, respectively (Fig. 3). The highest chl a concentration was found near the longhouses and in the main river, whereas the lowest concentration of chl a was observed in the tributary. However, there was no significant difference (p value>0.05) in chl a concentration between the main river and tributaries. The higher chl a concentration near the longhouses was most probably due to the nutrient availability from domestic wastewater, which favors their growth [27-29]. This is further evidenced by the significant correlation between chl a and NO_2^--N concentrations in the river after rain (p value≤0.05).

BOD_5 and COD concentrations did not differ significantly before and after rain (Table 2, p value>0.05) or between the main river and tributaries (Table 3, p value>0.05). However, the rainfall event might have an influence on the distribution patterns of the BOD_5

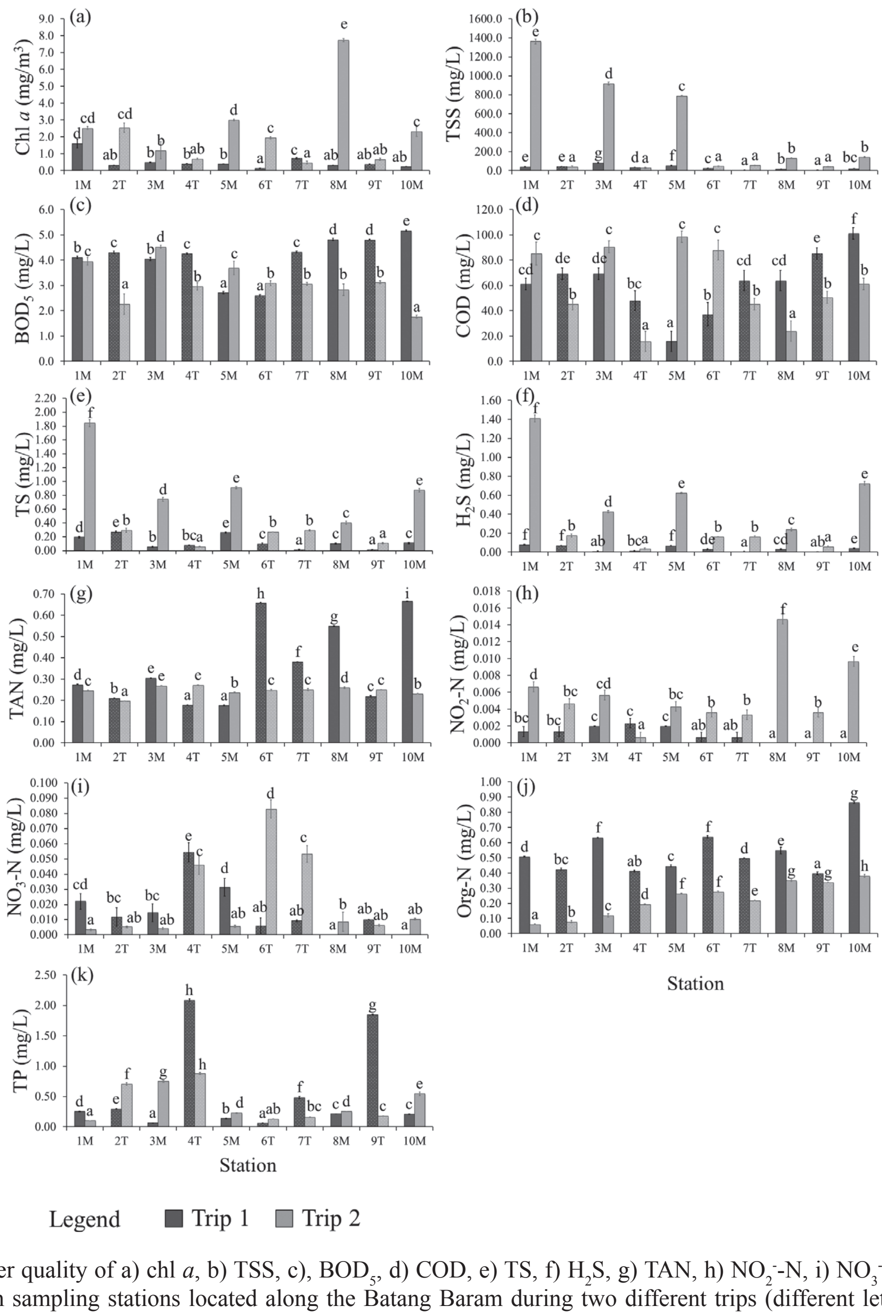

Fig. 3. *Ex situ* water quality of a) chl a, b) TSS, c), BOD_5, d) COD, e) TS, f) H_2S, g) TAN, h) NO_2^--N, i) NO_3^--N, j) Org-N, and k) TP collected at the ten sampling stations located along the Batang Baram during two different trips (different letters indicate significant difference at p value≤0.05 during each trip).

and COD concentrations along the river. Both BOD_5 and COD concentrations were found to be significantly lower (p value≤0.05) at the middle section of the river (stations 5 and 6) than the upper and lower parts of the river during the first trip (Fig. 3). After the rainfall event, significantly higher (p value≤0.05) BOD_5 concentrations were found upstream and it gradually decreased moving downstream, whereas the BOD_5 concentrations remained relatively constant in the tributaries (2.3-3.1 mg/L). The COD concentrations were found significantly higher (p value≤0.05) at the upper part of the main river (stations 1, 3, and 5) and at one of the tributaries (station 6). The higher concentrations of BOD_5 and COD at the upstream area indicated that high organic matter was derived from anthropogenic sources in the upstream. Organic matter in the present study area was most likely attributed to the domestic discharge and runoff as those stations were located near longhouses and logging activities. The decrease of BOD_5 concentration along the river indicates the fast decomposition of the biodegradable organic matter in the river. However, the COD concentration shows that non-biodegradable organic matter remained high in the main river and shows signs of decrease after station 7. The BOD_5 and COD concentrations did not correlate significantly with other *in situ* parameters before rain (p value>0.05). After the rainfall event, the BOD_5 concentration was significantly and positively correlated with mean depth and TSS (p value≤0.05), whereas the COD concentration was significantly and positively correlated with mean depth, turbidity, and TSS (p value≤0.05) – indicating that the organic matter which was attached to the suspended solids increased due to the increased surface runoff after rain [13]. The decomposition of organic matter and respiration of bacteria reduced the dissolved oxygen content in the river as indicated by the significant negative correlation between BOD_5 concentration and DOsat (p value≤0.05), and between COD concentration and DOsat and DO (p value≤0.05).

The TS and H_2S concentrations in the Batang Baram increased significantly (p value≤0.05) after the rainfall event, particularly in the main river as shown by the significantly higher (p value≤0.05) concentrations in the main river after rain. When no rain was recorded during a week before sampling, the TS was significantly higher (p value≤0.05) at stations 1, 2, and 5 (≈ 0.24 mg/L), indicating that the TS originated from the adjacent longhouse and logging activities. After the rainfall event, significantly higher TS (1.84 mg/L) and H_2S (1.41 mg/L) concentrations were observed at station 1 (p value≤0.05). The four other stations located along the main river also contained significantly higher TS (≈ 0.73 mg/L) and H_2S (≈ 0.50 mg/L) concentrations (p value≤0.05). The high volume of surface runoff after rain increased the TS and H_2S concentrations in the river as indicated by their significant correlation (p value ≤ 0.05) with mean velocity after rain. Similar to BOD_5 and COD, TS and H_2S concentrations were also significantly and positively correlated with turbidity and TSS (p value≤0.05), as most of the pollutants are attached to the particles, and negatively correlated with DOsat and DO (p value≤0.05) as the decomposition of organic matter consumes oxygen in the river.

The TAN concentrations ranged from 0.18 mg/L to 0.67 mg/L and from 0.20 mg/L to 0.27 mg/L, when no rain was recorded for a week before sampling and it rained one night before sampling, respectively. No significant difference in TAN concentration (p value>0.05) was observed before rain and after rain, and between the main river and tributaries; but TAN concentrations were significantly higher (p value≤0.05) at stations 6, 7, 8, and 10 when there was no rain, and became relatively consistent along the river after rain. The extremely high concentrations at those stations suggested that the longhouses and logging activities most likely contributed substantial TAN in the area but was diluted by the rain. Ammonium was found to be negatively correlated with rainfall in the Burnt Mill Creek and Smith Creek, USA [13]. The authors hypothesized that rainfall creates better mixing and oxic conditions that enhance nitrification, and cools the water and reduces pH, which may reduce the formation and accumulation of ammonium.

The NO_2^--N exhibited a similar trend with TS and H_2S, where NO_2^--N concentration increased significantly (p value≤0.05) after rain particularly in the main river where the NO_2^--N concentration in the main river was significantly higher (p value≤0.05) than tributaries. When there was no rain recorded for a week before sampling, the NO_2^--N concentrations were found to be decreasing along the main river. In contrast to TS and H_2S, where the highest concentration was observed at station 1, significantly higher concentrations of NO_2^--N (p value≤0.05) were observed at stations 8 and 10 after the rainfall event. This could be due to the abundance of ammonium-oxidizing bacteria that oxidized ammonium to nitrite in the nitrification process, which leads to the higher NO_2^--N concentration at stations 8 and 10, whereas

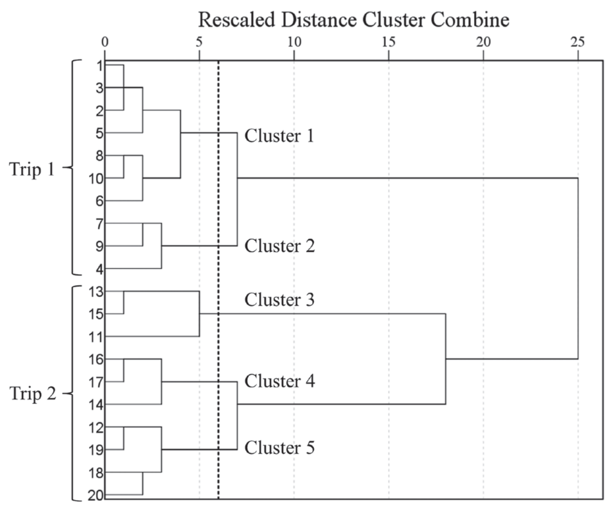

Fig. 4. Clustering of the ten sampling stations during the two sampling trips.

anaerobic bacteria that use sulfate instead of oxygen produces toxic hydrogen sulphide during the decomposition of organic matter at station 1.

The NO_3^--N concentration exhibited different trends of distribution where higher NO_3^--N concentration was observed in the middle of the river studied. There was no significant difference in NO_3^--N concentrations (p value>0.05) before and after rain, and between main river and tributaries. Significantly higher concentrations of NO_3^--N were observed at stations 4 and 5 before rain (p value≤0.05), whereas significantly higher concentrations of NO_3^--N were observed at stations 4, 6, and 7 after the rainfall event (p value≤0.05). The high concentration at those stations could be due to the domestic discharge and surface runoff that contained substantial NO_3^--N concentration. The NO_3^--N concentration was significantly and positively correlated with DO and NO_2^--N concentration but negatively correlated with TAN concentration during the first trip (p value≤0.05); and significantly and positively correlated with DO but negatively correlated with temperature during the second trip (p value≤0.05). These relationships indicate that the high DO content in the river favors the nitrification process that converts the nitrogen into the NO_3^--N form.

The highest concentration of Org-N was observed at station 10 during both trips. The Org-N concentrations in the river ranged from 0.40 mg/L to 0.86 mg/L when there was no rain recorded for a week before the first trip, whereas a noticeable increasing trend was observed along the river after rain, ranging from 0.06 mg/L to 0.38 mg/L. In contrast to NO_2^--N concentration, which increased significantly (p value≤0.05) after rain, Org-N concentration was found to decrease significantly (p value≤0.05) after the rainfall event, indicating the rapid decomposition of organic matter and conversion into inorganic nitrogen form after rain.

There was no significant difference in TP (p value>0.05) before and after rain (Table 2), or between the main river and tributaries (Table 3). Significantly higher TP concentrations were observed at stations 4 and 9 (≈ 1.97 mg/L) before rain (p value≤0.05), and significantly higher TP concentrations were found at stations 2, 3, and 4 (≈ 0.78 mg/L) after rain (p value≤0.05), as illustrated in Fig. 3. The highest concentration of TP was observed at station 4 during both trips. Stations 4 and 9

Table 6. Classification of water quality of the 10 sampling stations according to WQI, when no rain was recorded for a week before sampling (first trip) and it rained one night before sampling (second trip).

Trip	Type	Station	CLASS							Status
			AN	BOD_5	COD	DO	pH	TSS	WQI	
First	Main	1	II	III	IV	II	I	II	III	Slightly polluted
		3	III	III	IV	II	I	III	III	Slightly polluted
		5	II	II	II	II	I	III	II	Clean
		8	III	III	IV	II	I	I	III	Slightly polluted
		10	III	III	V	II	I	I	III	Slightly polluted
	Tributary	2	II	III	IV	II	I	II	III	Slightly polluted
		4	II	III	III	II	I	II	II	Slightly polluted
		6	III	II	III	II	I	II	II	Slightly polluted
		7	III	III	IV	II	I	I	II	Slightly polluted
		9	II	III	IV	II	I	I	III	Slightly polluted
Second	Main	1	II	III	IV	II	II	V	III	Slightly polluted
		3	II	III	IV	II	II	V	III	Slightly polluted
		5	II	III	IV	II	II	V	III	Slightly polluted
		8	II	II	II	I	II	III	II	Slightly polluted
		10	II	II	IV	I	II	III	III	Slightly polluted
	Tributary	2	II	II	III	I	II	II	II	Clean
		4	II	II	II	I	II	II	II	Clean
		6	II	III	IV	I	II	II	II	Slightly polluted
		7	II	III	III	I	II	III	II	Clean
		9	II	III	IV	I	II	II	II	Clean

were located near the logging camp and longhouses, which most likely contributed substantial TP into the river, whereas stations 2 and 3 were subjected to logging activities. The Batang Baleh in Sarawak that was subjected to logging activities also showed significantly higher TP concentration after rain [26].

Cluster Analysis (CA)

Cluster analysis (CA) was applied to detect similarities among the sampling stations using the *in situ* and *ex situ* parameters of the 10 stations collected during two different trips. The dendrogram shows that the 10 sampling stations can be grouped into five clusters (Fig. 4). Clusters 1 and 2 consist of stations studied during the first trip, whereas clusters 3, 4, and 5 consist of stations that were studied during the second trip. This clustering demonstrates that the rainfall event has a great influence on the water quality of the Batang Baram. Before the rain, most of the stations at Batang Baram and its tributaries shared similar characteristics and are grouped together as cluster 1 except for stations 4, 7, and 9, which are the tributaries of Batang Baram. After the rain, the Batang Baram can be differentiated by the upper part of the main river (cluster 3), the tributary (cluster 4), and the downstream of the river, which also included a tributary where station 2 is located (cluster 5). This clustering shows that the main river and tributaries of the Batang Baram shared no similarity after the rain. Besides, the upstream and downstream of the Batang Baram showed different characteristics after rain as shown by clusters 3 and 5. However, one of the tributaries, represented by station 2, shared similar characteristics with the downstream river and is grouped together as cluster 5.

Water Quality Index (WQI)

When no rain was recorded for a week before the sampling, the Batang Baram and its tributaries were classified as Class II or III according to the water quality index (WQI; Table 6). Four out of five stations located in the main river of the Batang Baram and two out of five stations located in the tributary were classified as Class III. Almost all stations were categorized as ‘slightly polluted’ except station 5, which was categorized as ‘clean.’ Among the six parameters, pH and DO were classified as Class I and II, respectively, whereas the AN and BOD_5 were classified as Class II and/or III. The worst classification of the parameter was COD, which was mostly classified as Class IV.

The WQI of the main river of the Batang Baram remained unchanged after rain, where four out of five stations were classified as Class III. However, all stations located in the main river were categorized as ‘slightly polluted’ after rain. The water quality of tributaries improved after rain where all of the stations were classified as Class II and categorized as ‘clean,’ except station 6, which was categorized as ‘slightly polluted.’ The improved parameters included DO and AN, whereas pH and TSS deteriorated after rain. After the rainfall event, the worst classification of the parameter in the river was TSS, where there were three stations classified as Class V. The deterioration in TSS was also reported in the Batang Baleh, where the TSS changed from Class I to Class III and/or IV after rain [26].

Conclusions

The present study shows that a rainfall event has a major impact on the physicochemical characteristics of the Batang Baram and its tributaries. The rainfall event increased the mean velocity of the river. Subsequently, the rainfall runoff and the fast flowing river adversely impacted the water quality in the river, particularly pH, transparency, turbidity, TSS, TS, H_2S, chl *a*, and NO_2^--N. However, the DO content showed an improvement in the river, and Org-N concentration decreased significantly (p value≤0.05) after rain. The WQI of the river was mostly classified as Class II and/or III and categorized as ‘slightly polluted,’ particularly due to the high COD concentration. After the rainfall event, the WQI of the tributaries showed improvement due to the high DO content, although the TSS deteriorated after rain.

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