Jurnal
Teknologi

Full Paper

TROPICAL REHABILITATION FOREST CONTROL ON WATER CHEMISTRY PATTERN IN BINTULU SARAWAK MALAYSIA

Noraini Rosli[a], Geoffery James Gerusu[a,b], Roland Kueh Jui Heng[a,b]

[a]Department of Forestry Science, Faculty of Agricultural Science and Forestry, Universiti Putra Malaysia Bintulu Sarawak Campus, Jalan Nyabau, 97008 Bintulu, Sarawak, Malaysia
[b]Institut Ekosains Borneo, Universiti Putra Malaysia Bintulu Sarawak Campus, Jalan Nyabau, 97008 Bintulu, Sarawak, Malaysia

Article history
Received
29 May 2021
Received in revised form
7 October 2021
Accepted
7 October 2021
Published Online
20 December 2021

*Corresponding author
geoffery@upm.edu.my

Abstract

With rapid development in South East Asian countries, there is a risk of serious degradation of stream water quality in areas adjacent to developing city areas, where basic information on toxic heavy metals and acidic compounds (NO3- and SO4^{2-}) concentrations and spatiotemporal variation is still unknown in these areas. The concentrations of water quality parameters, major ions, and heavy metals were examined from selected stream in a rehabilitation forest near a developing city having petroleum refinery facility in Bintulu, Sarawak, Malaysia. The concentrations of water quality parameters, major ions, and heavy metals were examined from twelve stream locations in a rehabilitation forest near a developing city with a petroleum refinery facility. Analyses suggested that there is no clear tendency that is detected in heavy metals and basic water properties (EC, DO, BOD, COD, alkalinity and pH) except for turbidity, total suspended solids, and major ion which were high during rainy seasons. Annual means of SO4^{2-}, NO3- and NH$_4^+$ concentrations were 6.34, 1.05 and 0.24 mg/L. The concentration in K$^+$, Mg^{2+}, Na$^+$ and Ca^{2+} were 0.61, 1.21, 2.82 and 1.12 mg/L during hot and rainy season. The mean concentration in almost all heavy metals (Mn, Fe, Cu, Zn) were less than 0.01 mg/L. The concentrations of water quality variables in all samples collected across the seasons except for turbidity found within the permissible limit by the WHO and NWQS for Malaysia. Rehabilitation forest might give a positive impact in preserving water quality especially for COD and major ions except SO4^{2-}.

Keywords: Water chemistry, water-catchment, heavy metals, acidic compounds, sulphur

Abstrak

Dengan pembangunan yang pesat berlaku di negara-negara Asia Tenggara, risiko kemerosotan kualiti air sungai yang serius mungkin berlaku di kawasan yang berdekatan dengan kawasan bandar yang pesat membangun. Walau bagaimanapun, maklumat asas kepekatan dan variasi spatio-temporal pada logam berat toksik dan sebatian berasid (NO3- dan SO4^{2-}) masih belum diketahui di kawasan ini. Kepekatan ion utama, unsur logam berat di sungai yang dipilih di hutan pemulihan Bintulu Sarawak Malaysia yang berdekatan dengan bandar membangun yang memiliki kilang penapisan minyak gas asli. Analisis menunjukkan bahawa tidak ada kecenderungan yang jelas yang dapat dikesan pada logam surih dan sifat asas air (EC, DO, BOD, COD, alkalinity dan pH) kecuali kekeruhan, jumlah pepejal terampai dan ion utama yang didapati tinggi pada musim hujan. Kadar tahunan kepekatan SO4^{2-}, NO3-, dan NH$_4^+$ adalah 6.34, 1.05 and 0.24 mg/L. Purata kepekatan K$^+$, Mg^{2+}, Na$^+$ dan Ca^{+2} adalah 0.61, 1.21, 2.82 and 1.12 mg/L pada musim panas dan hujan. Purata dalam hampir semua logam surih (Mn, Fe, Cu, Zn) adalah kurang daripada 0.01 mg/L. Kepekatan pemboleh ubah kualiti air dalam semua sampel yang dikumpulkan sepanjang musim berada dalam had yang dibenarkan kecuali kekeruhan oleh WHO dan NWQS Malaysia. Hutan pemulihan memberikan kesan positif dalam menjaga kualiti air terutama COD dan ion utama kecuali SO4^{2-}.

Kata kunci: Kimia air, tadahan air, logam berat, sebatian berasid, sulfur

1.0 INTRODUCTION

The tropical forest state in Malaysian Sarawak is one of the world's biodiversity centers (Arthur, 2013; Jason and Shozo, 2013; FAO, 2010) [2, 20, 11]. Majority of the forest in Malaysia especially in Sarawak state has been selectively logged resulting in reduced of biodiversity. Furthermore, the loss of these forest is mainly due to exploitation of forest by human activities through deforestation, land clearance, irrigation, agricultural,

84:1 (2022) 57–75 | https://journals.utm.my/jurnalteknologi | eISSN 2180–3722 | DOI: https://doi.org/10.11113/jurnalteknologi.v84.17102 |

plantation, mining, logging and conversion of land for urban development (Gaveau *et al*., 2014; Abram *et al*., 2013; Bryan *et al*., 2013; Carlson *et al*., 2012; Berry *et al*., 2010) [13,1, 6, 7, 4]. The major concern is the conversion of forested land to developed areas replaces a storm water and pollutant sink with a storm water and pollutant source. Excessive sediment, nutrients, temperature and chemicals affects water chemistry and cause aquatic habitats degradation (US EPA, 2021) [33]. Thus, the rapid destruction to forest in Sarawak may cause serious threat to the water resources. However, the current status of the degradation of chemical properties in river water is still unknown in the area.

Meanwhile, rehabilitation of degraded forest due to forest deforestation, land development and shifting cultivation has been successful implemented in Sarawak. The chemical properties in stream water of rehabilitation forest might be good indicator for the effect of forest rehabilitation programme on the recovering of the water quality. Water quality refers to the physical, chemical and biological attributes of water that affects its ability to sustain environmental values. Water quality is important to assess the health of a forested watershed and the management decisions to control current and future pollution of receiving water bodies affected by a wide range of natural and human activities (US EPA, 2021) [33]. The objectives of this study were 1) to quantify the physiochemical, major ions and heavy metals properties of water quality under tropical rehabilitation forest 2) to evaluate the effect of tropical rehabilitated forest on controlling the water chemistry pattern and 3) to compare the findings with other forest canopies elsewhere.

2.0 STUDY LOCATION

This study was conducted at water catchment of rehabilitated forest of Universiti Putra Malaysia Bintulu Sarawak Campus (RF UPMKB) (latitude 03°12'N and longitude 13°02'E). This site is located at Bukit Nyabau - Phase 1 UPM-Mitsubishi rehabilitated forest of UPMKB. RF UPMKB located in the middle of Bintulu town. Bintulu is an industrial town, located near the Malaysia Liquefied Natural Gas (MLNG) and one of the major liquefied natural gas production facility in the world (Figure 1; Table 1). It is also part of the Sarawak Corridor of Renewable Energy (SCORE). The prevalent climatic condition in the area is marked by two main regimes: the rainy and the dry seasons; where hot season is between March to September and rainy season during October to February (Sarawak Meteorological Department, 2019) [27]. These area experiences an annual rainfall 4000 mm. The rehabilitated forest covers an area of 47.5 hectares. There were 128 species of trees have been planted, and the dominant species are from *Dipterocarpacea* such as *Shorea ovata, Shorea parvifolia, Shorea mecistopteryx, Shorea dasyphylla, Shorea leprosula* and others.

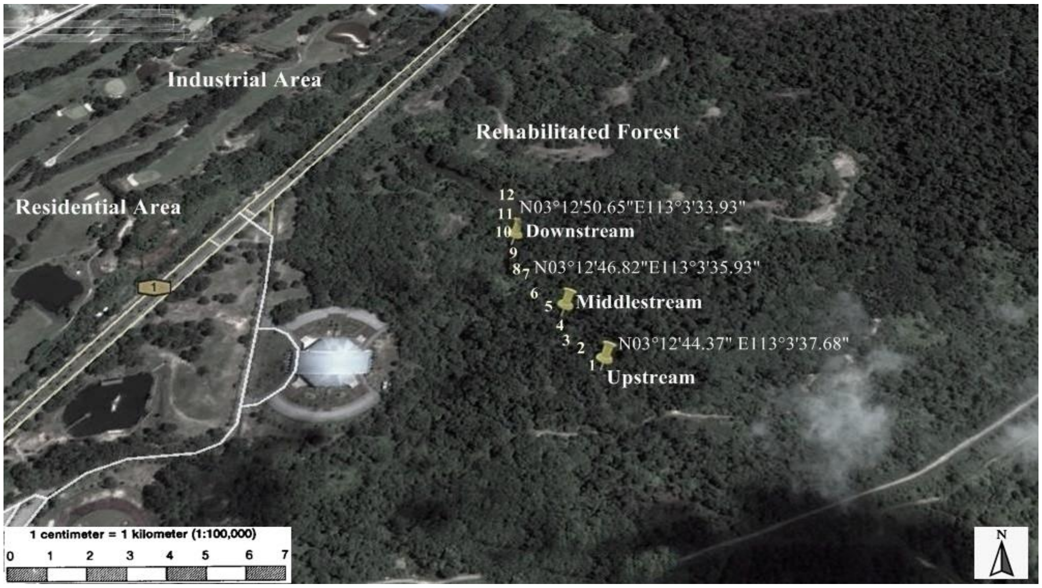

Figure 1 Landsat Image, Rehabilitated Forest UPMKB Sarawak, Malaysia

Table 1 GPS Coordinates Rehabilitated Forest UPMKB Sarawak, Malaysia

Sampling Station	Coordinates	
Upstream 1,2,3,4	N03°12'44.37"	E113°3'37.68"
Middle stream 5,6,7,8	N03°12'46.82"	E113°3'35.93"
Downstream 9,10,11, 12	N03°12'50.65"	E113°3'33.93"

3.0 MATERIALS AND METHODS

3.1 Sampling Design

For sampling design, 12 stations were chosen at the river; four stations at upstream, four stations at middle stream and four stations at downstream. The distances between sampling stations 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 were 100 meters. Three replications were taken for each station and water samples were taken monthly during hot and rainy season from January until December within two years sampling bringing the total of water sampling and analyses are 648 times. Due to other research commitments at the time, data was missing in the first year of this study in February, April, May, July, September, and November. The second year involves collecting complete data on a monthly basis. Water samples were collected from surface water and kept in High-Density Polyethylene (HDPE) and biochemical oxygen demand (BOD) bottles. The water sample for physico-chemical analysis were kept in ice during the data collection and then was immediately transferred into refrigerator at a temperature below APHA 2320-B use to measure alkalinity (A_T), APHA 2540-C gives the method for total dissolved solids (TDS) dried at 180°C, APHA 4500-SO_4 use to measure the sulphur isotope ratio in the powdered ($BASO_4$) and analyzed by using the Elemental Analyzer-Mass Spectrometer (EA IsoLink™ IRMS System) to discriminate origin of sulphur whether atmospheric or biological origin (Sase *et al*. 2012) [28]. APHA 3110 analyzed using Atomic Absorption Spectrophotometer (AAS) (Analyst 800, Perkin Elmer, Norwalk, CT, USA) to measure heavy metals (Mn, Fe, Cu, Zn) and Ion chromatography (ICP-MS 7700x, Agilent Technologies, Inc.) and AAS used to measure the major ion includes K^+, Ca^{2+}, Mg^{2+}, Na^+, NO_3-, Cl^- NH_4^+ and SO_4^{2-}. Standard Methods by APHA are standards and internationally accepted procedures for analysis of water quality measurement. All analyses were tested in three replications. Unit of all water quality variables tested were in milligram/litre (mg/l), except for pH, electrical conductivity (µS/cm), turbidity (NTU), salinity (%) and water temperature (°C). All statistical analysis of data was performed using SPSS software applications version 25 to analyze qualitative and quantitative data. Correlation analysis identify the most significant parameter of water quality and its correlation with other parameters.

4.0 RESULT

The water quality variables concentration of the areas are summarized in Table 2 and illustrated in Figure 2 until Figure 23. The water quality variables such as pH, BOD, COD, DO, EC, TDS, A_T and salinity in this stream showed consistent results during both hot and rainy seasons where hot season is between March to September and rainy season during October to February. No clear seasonal trend found and no significance differences on water quality variables mentioned above; where overall were found in good condition and low concentration during both season (Table 2). Meanwhile, TSS and turbidity showed strong seasonal variations. TSS and turbidity found high during rainy seasons from month of October to February. The effects of rainy season and runoff affect and control the variation in TSS and turbidity. The strong correlations between TSS and turbidity, (Figure 24) indicated these variables could possibly be caused by leaching when surface runoff transports sediments from the soil to the stream and most of the sediments transported during the monsoon months.

Rainfall in rainy season resulted in a change to several major ion concentrations where rainfall from October to December leads to increase in major ion concentration. Major ion concentrations in water were found in the following order: SO_4^{-2} > Cl- > Na^+ > Mg^{2+} > Ca^{2+} > NO_3- > K^+ > NH_4^+ The concentration variations of Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl-, NO_3-, and SO_4^{2-} corresponded to rainy and dry seasons, but the concentration variations of NH_4^+ did not. Only the concentrations of Ca^{2+}, Mg^{2+}, Na^+, K^+ Cl-, NO_3-, and SO_4^{2-} had increased obviously in rainy seasons during two years investigations, and the concentrations of the rest ions (NH_4^+) could not be judged.

The level of heavy metals in water exhibited a unique seasonal pattern in seasonal variations. The values obtained for all elements in the hot season were markedly higher than those of the rainy season. Hot season results in a change to heavy metals concentrations where hot season from month of January to September leads to increase in overall metals concentration. Hot climate cause rises in temperature and water evaporation; and finally increases heavy metals concentration in water bodies. In other words, the average concentration of metals in water during rainy season is lower than that in the hot seasons. These amounts rise again when hot season starts.

Parametric tests use for running data through Pearson correlation. Parametric tests are chosen over non-parametric tests because they are more powerful and can analyze multiple variables and their interactions. Pearson's correlation matrix between various physico-chemical variables are shown in Table 3 and Table 4. Significant positive correlations were also observed among major cations and $SO4^{2-}$. pH was significantly correlated with TDS which was correlated with K, Mg^{2+}, SO_4^{2-} Mn, Fe and Zn. This was affected by rapid increase in those properties in July and August.The analysis of the correlation matrix shows strong correlations between the variables of total suspended solids and turbidity.

Table 2 Summary of the water quality variables concentrations in stream water during two years in water catchment rehabilitated forest UPM Bintulu Sarawak, Malaysia

Water Quality Parameters	Unit	Min	Max	Median	SD	Mean N:648	WHO Permissible Limits	NWQS Malaysia Acceptable Value
Physicochemical Properties								
Water temperature	°C	24.6	27.0	26.2	0.63	26.0	20-33	Normal +2°C
pH	mg/L	4.99	8.76	5.98	0.79	6.03	6.5-9.2	6-9
Dissolved oxygen (DO)	mg/L	4.6	8.24	6.99	0.88	7.15	4-7	5 - 7
Alkalinity (A_T)	mg/L	0.52	1.51	0.62	0.29	0.76	200	-
Ammonia nitrogen (NH_3-N)	mg/L	0.01	0.8	0.08	0.20	0.13	<0.2	0.3
Biochemical oxygen demand (BOD)	mg/L	0.47	0.97	0.8	0.15	0.76	3	3
Chemical oxygen demand (COD)	mg/L	0.1	6.33	0.69	0.595	2.24	10	25
Total dissolved solids (TDS)	mg/L	0	0.17	0.1	0.006	0.045	1200	1000
Total suspended solids (TSS)	mg/L	0.1	70.41	25.81	05.12	27.86	300	50
Salinity (SAL)	%	0	0	0	0	0	<0.5	1
Turbidity (Turb)	NTU	6.92	92.11	65.19	54.65	33.13	<10	50
Electrical conductivity (EC)	µS/cm	0.88	2.07	1.53	0.335	1.4	400	1000
Macro elements (Major Ions)								
Sodium (Na^+)	mg/L	0.46	20.75	1.64	0.54	2.82	200	-
Potassium (K^+)	mg/L	0.12	1.52	0.43	0.38	0.61	-	-
Calcium (Ca^{2+})	mg/L	0.20	3.89	0.84	0.87	1.12	200	-
Magnesium (Mg^{2+})	mg/L	0.19	4.43	0.79	0.09	1.21	150	-
Ammonium (NH_4^+)	mg/L	0.02	3.11	0.06	0.592	0.238	0.5	0.3
Chloride (Cl-)	mg/L	0.43	36.96	4.97	0.268	4.294	1000	200
Nitrate (NO_3-)	mg/L	0.08	5.34	0.74	1.21	1.05	0.3	7
Sulphate (SO_4^{2-})	mg/L	1.03	32.31	3.46	0.361	6.34	200	250
Micro elements (Heavy metals)								
Copper (Cu)	mg/L	0	0.009	0.01	0.002	0.005	0.05	0.02
Iron (Fe)	mg/L	0	0.034	0.01	0.01	0.006	0.3	1
Manganese (Mn)	mg/L	0	0.059	0.01	0.015	0.005	0.1	0.1
Zinc (Zn)	mg/L	0	0.0021	0.01	0.0006	0.0002	5.0	5.0

Notes: 'N' : represents the total number of observations in the sample
NWQS: National Water Quality Stand for Malaysia
WHO: World Health Organization

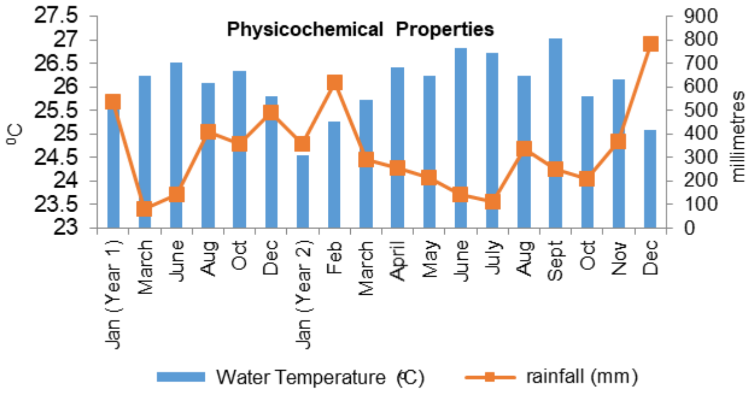

Figure 2 Water temperature concentration

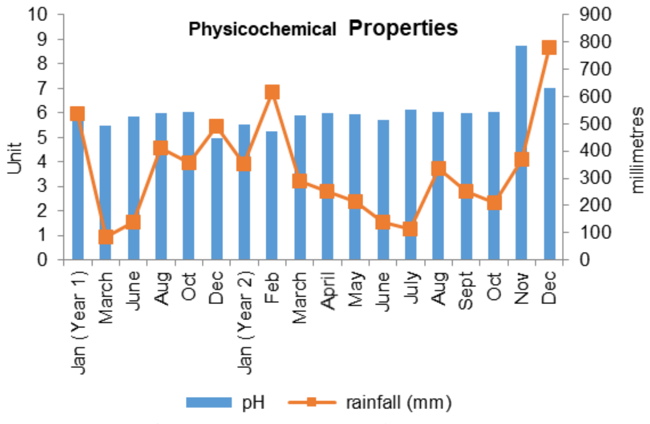

Figure 3 pH concentration

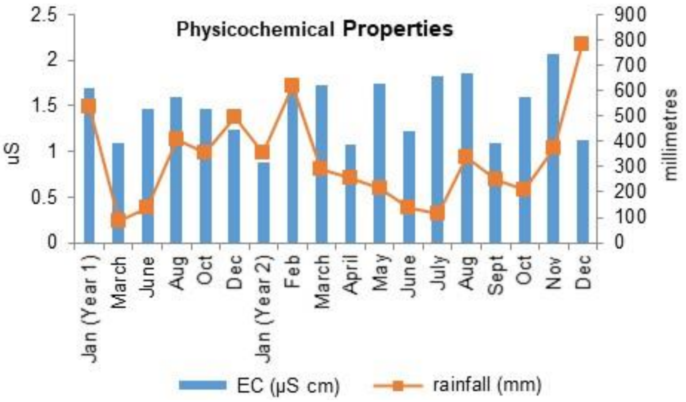

Figure 4 Electrical conductivity (EC) concentration

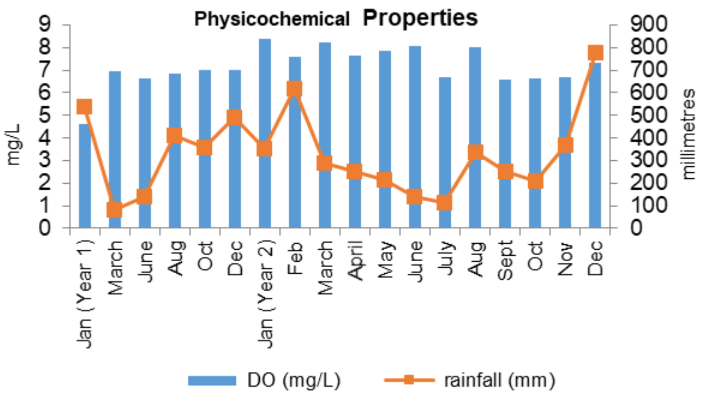

Figure 5 Dissolved oxygen (DO) concentration

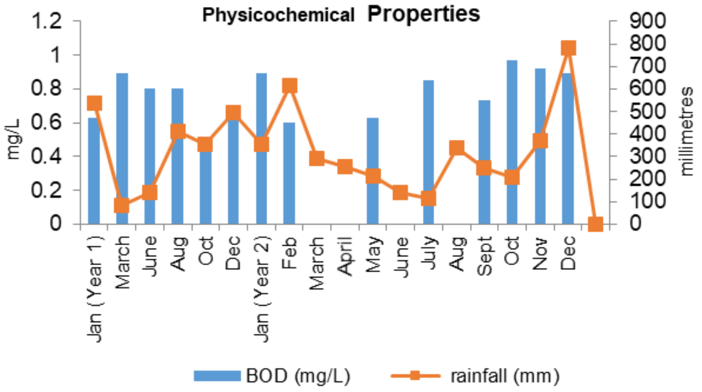

Figure 6 Biochemical oxygen demand (BOO) concentration

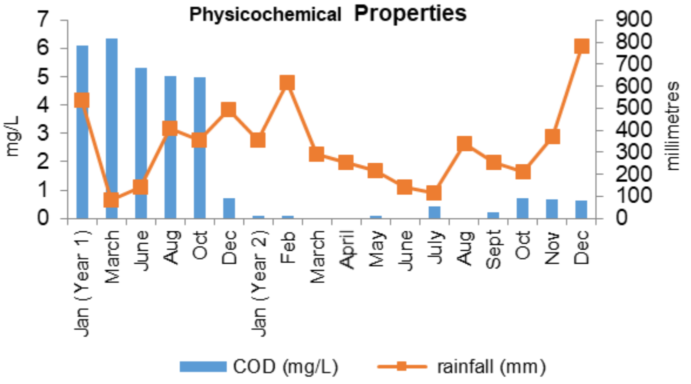

Figure 7 Chemical oxygen demand (COO) concentration

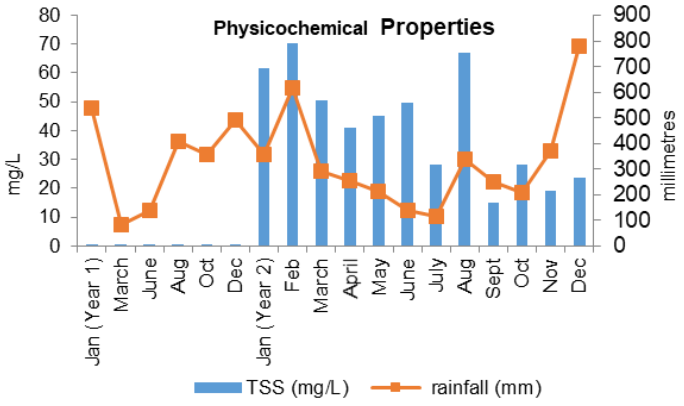

Figure 8 Total suspended solids (TSS) concentration

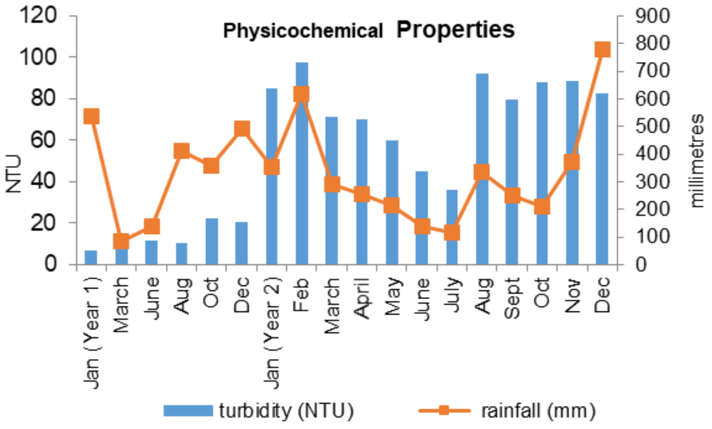

Figure 9 Turbidity concentration

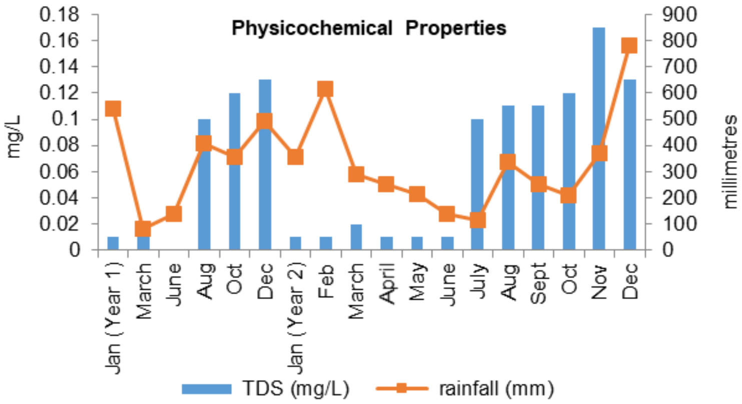

Figure 10 Total dissolved solids (TDS) concentration

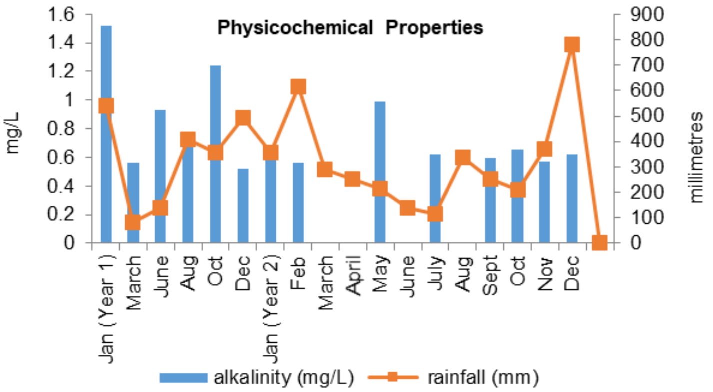

Figure 11 Alkalinity (A_T) concentration

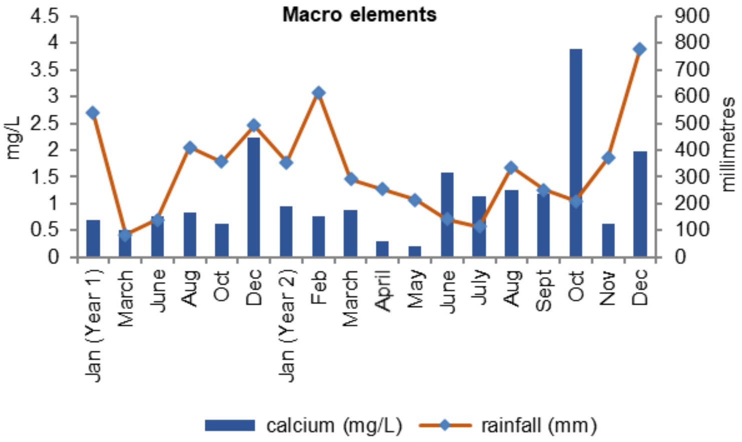

Figure 12 Calcium (Ca^{2+}) concentration

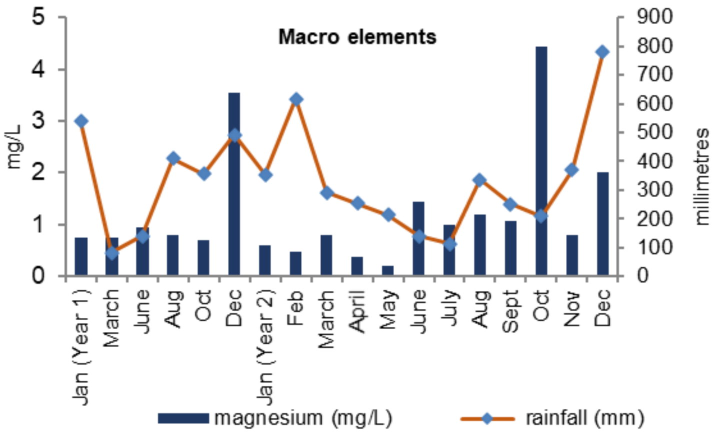

Figure 13 Magnesium (Mg^{2+}) concentration

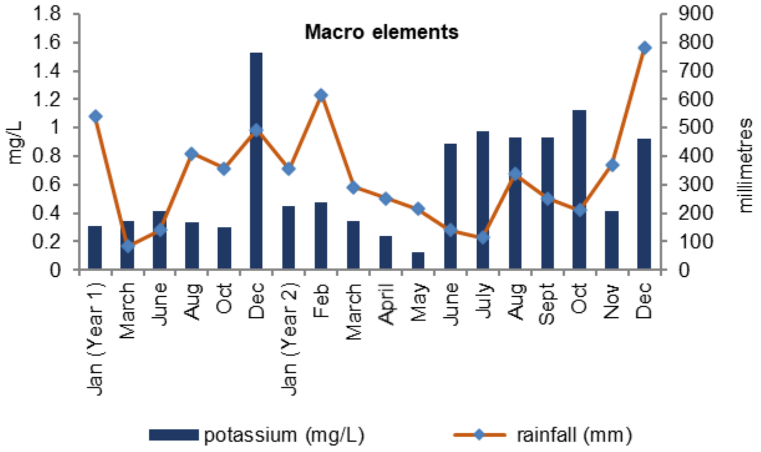

Figure 14 Potassium (K^{+}) concentration

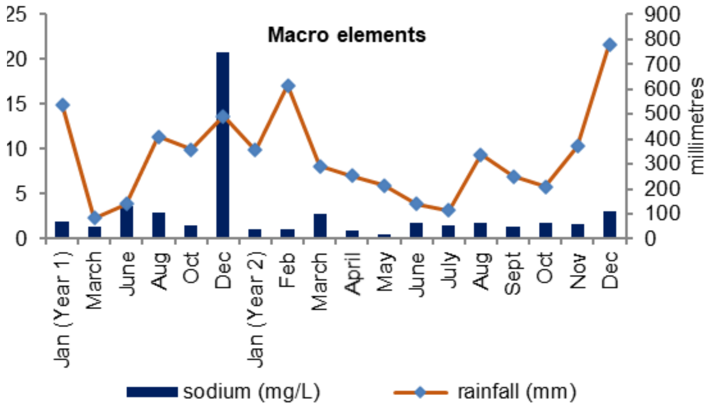

Figure 15 Sodium (Na^{+}) concentration

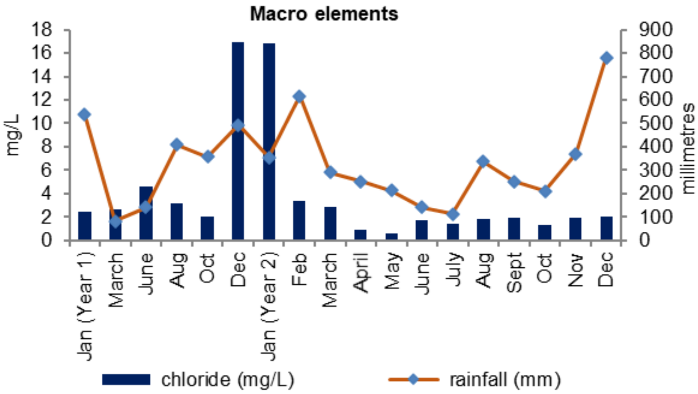

Figure 16 Chloride (Cl-) concentration

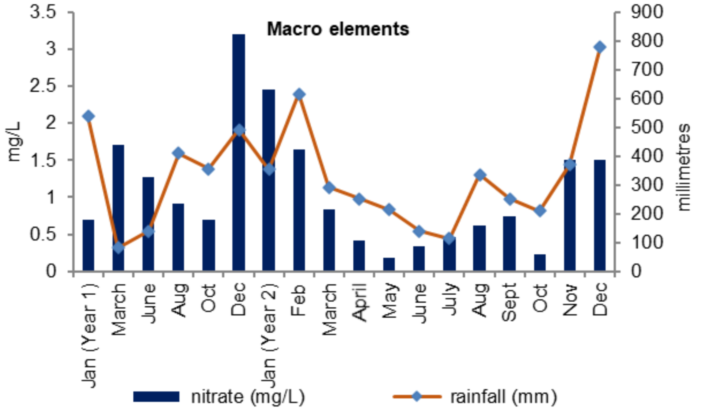

Figure 17 Nitrate (NO_3-) concentration

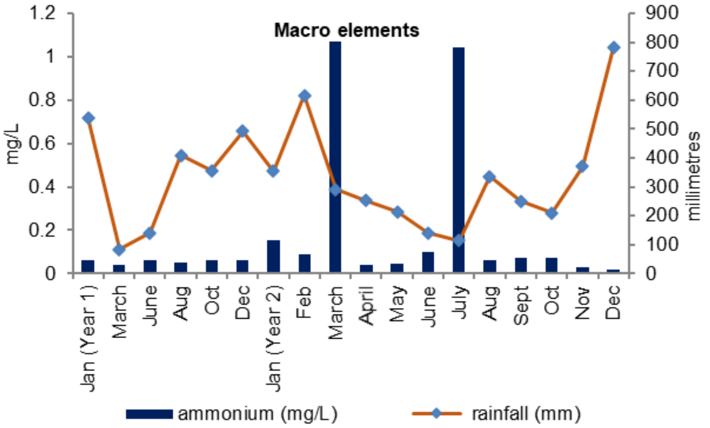

Figure 18 Ammonium (NH_4^+) concentration

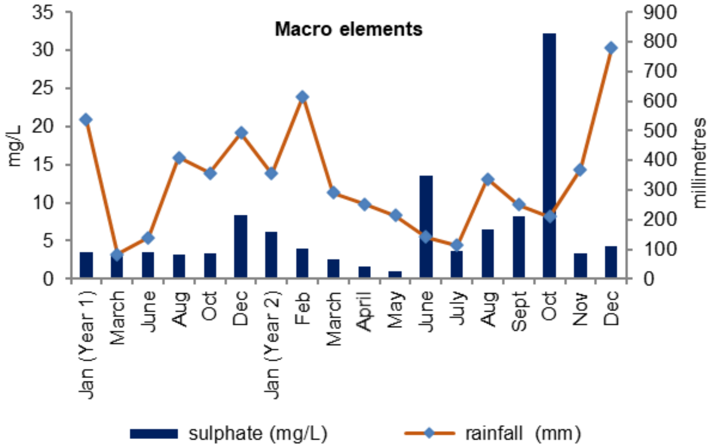

Figure 19 Sulphate (SO_4^{-2}) concentration

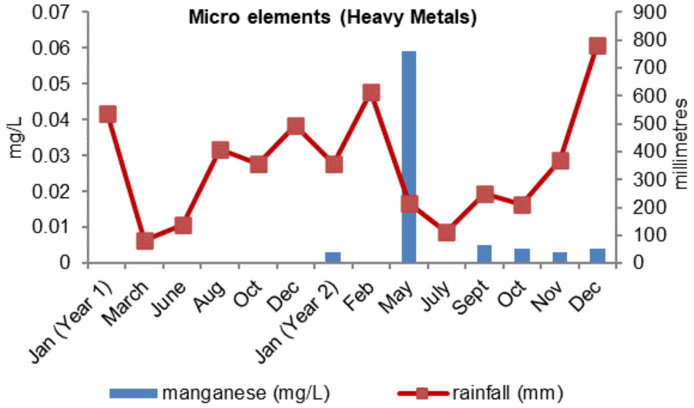

Figure 20 Manganese (Mn) concentration

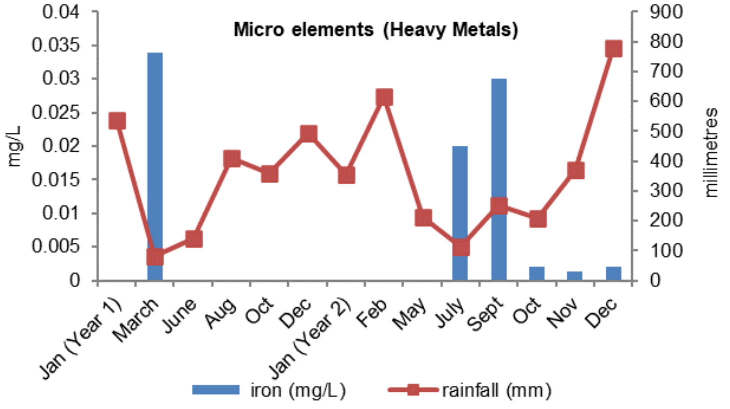

Figure 21 Iron (Fe) concentration

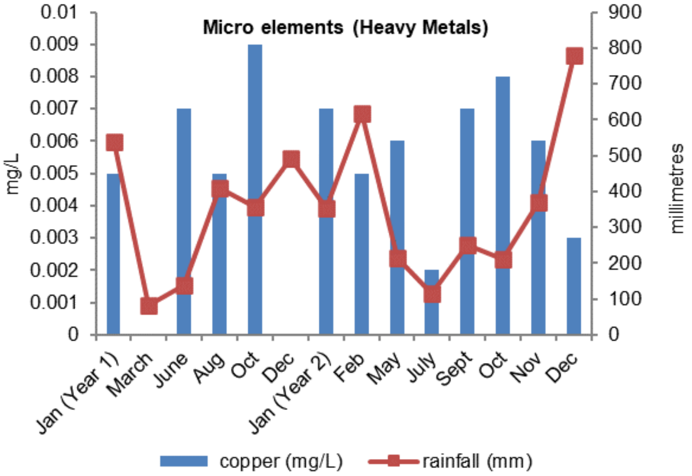

Figure 22 Copper (Cu) concentration

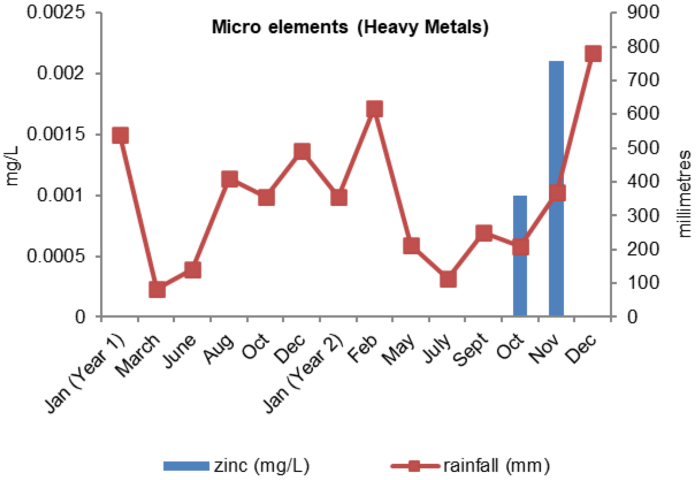

Figure 23 Zinc (Zn) concentration

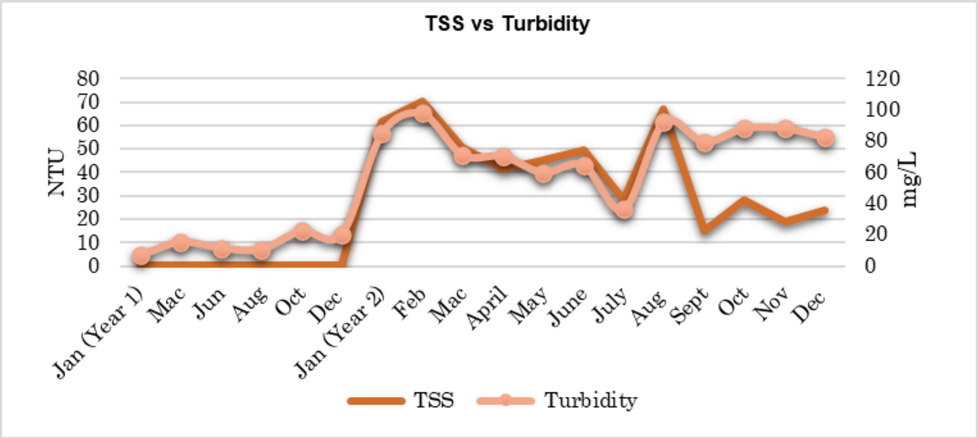

Figure 24 Correlation between TSS and turbidity

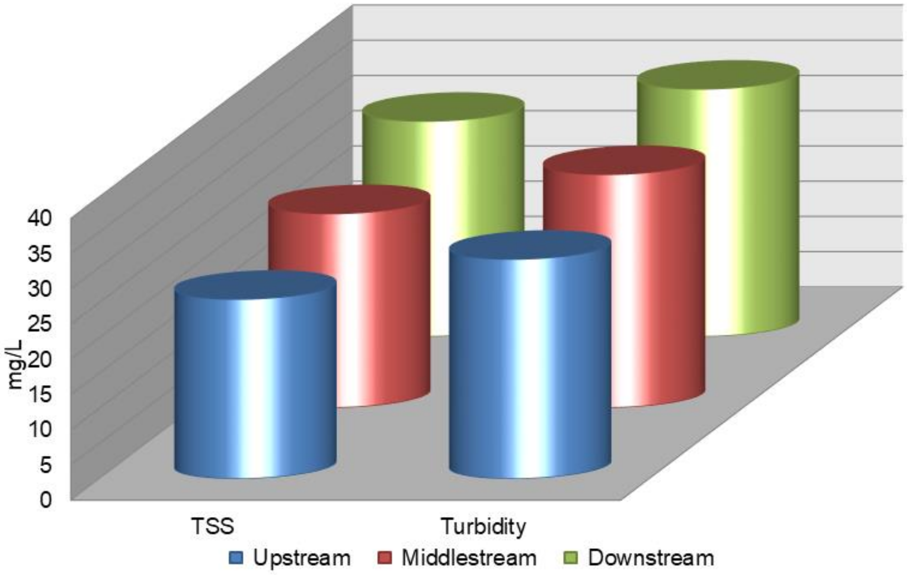

Figure 25 Mean comparison of water quality variables by area (sampling point), rehabilitated forest, UPMKB

In view of the comparatively upstream area contribute the content of downstream waters, generally downstream have larger effects on mean-annual in response to major changes in the land use or channel properties in upstream (water catchments). Results obtained from this study showed that there were interconnections between water quality from upstream, middle stream and downstream of the river. Significant amount of suspended and sediment was brought through the river from the upper to middle stream and finally into downstream areas during the rainy period. The accumulation factor of TSS and turbidity clearly indicated higher values of downstream compared to the upstream. The increasing level of suspended and sediment from the upstream to the downstream indicated progressive pressure in the downstream areas (Nepal *et al*. 2014) [25]. Hence, any upstream alteration in river concentration directly affects concentrations in downstream. The results generally follow existing literature showing the large effects of upstream contributions of pollution to downstream sites (Figure 25).

Pearson Correlation Analysis

Correlation among Various Water Quality Variables

The relationship of water quality characteristics in the samples of water studied was found by calculating correlation coefficients using Pearson's correlation coefficient (r). The association between physicochemical characteristics in water was examined using Pearson's correlation coefficient (r). The correlation matrix is used to determine the Pearson's correlation coefficient (r) value, which is used to detect highly associated and interrelated water quality parameters. When the Pearson correlation is near to 1, the two water quality indicators have a significant association. It also suggests that changes in one variable were linked to changes in the other. Pearson's correlation results between water quality measures at the study location, for example, reveal values that are very near to 1. As a result, it is found that the water quality variables have a strong relationship.

There is a modest correlation between the two variables when r Pearson is close to 0. It also implies that changes in one variable are accompanied by changes in the other two variables. If r Pearson is less than 0.01, the variables are unlikely to be significantly associated. When Pearson r is positive (+), it signifies that as the value of one variable rises, the value of the other rises as well. Similarly, if one variable is affected, both variables are affected. This is called a positive correlation. For example, Pearson r value of 0.931 is positive. A positive value known as SPSS does not put a negative sign in front of it. When Pearson is positive, it can be concluded that when the first number of variables increases, both variables will also increase.

As Pearson r is negative (-), when the value of one variable increases, the value of the other variables decreases, and this is known as negative correlation. When SPSS generates negative Pearson r values, the number of the first variable increases, implying that the second variable will decrease. The Sig (2-tailed) value indicates that the two variables are statistically related. For example, the value of Sig (2-tailed) was 0.002. If the Sig (2-tailed) is greater than 05, it can be stated that the two variables do not have a significant relationship. This means that an increase or decrease in one variable has no bearing on the increase or decrease in the second. If the sig (2-tailed) is less than or equal to 0.05, the two variables are statistically significant. This suggests that an increase or decrease in one variable is strongly linked to an increase or decrease in the second. The correlation analysis was used to determine the link between the concentrations of water quality variables. To investigate the nature of variation and major patterns among these variables, a correlation was calculated and defined. Pearson's correlation coefficient (r) indicates the potential for biophysical variables to be related.

There is a significant correlation found between TDS and most of chemical properties, manganese between pH; COD between NH_4^+ and A_T between K, NO_3^- and NH_4^+. Results of correlation analysis suggested that physicochemical variables interact in complicated ways reflecting the complex processes occurring in the natural environment. It can be concluded that the correlation studies of the water quality variables have great significance in the water resources (Table 3 and 4).

Table 3 Pearson's correlation matrix

	TDS	NH_3	BOD	COD	TSS	Ca^{2+}	SO_4^{2-}	NO_3^-	Cl-	NH_4^+	Na^+	K^+
Turbidity	0.529 0.0236 18	0.152 0.594 14	0.169 0.552 14	-0.71 0.00388 14	0.846 0.0000002 14	0.257 0.297 18	0.289 0.254 17	-0.255 0.316 17	-0.331 0.189 17	0.262 0.302 17	-0.34 0.164 18	0.348 0.153 18
TDS		0.418 0.134 14	0.556 0.0373 14	-0.202 0.472 14	0.259 0.364 14	0.402 0.0962 18	0.534 0.0266 17	-0.073 0.773 17	-0.122 0.632 17	0.137 0.592 17	0.101 0.686 18	0.525 0.0248 18
NH_3			0.385 0.167 14	-0.0989 0.727 14	-0.0813 0.773 14	0.473 0.0841 14	0.566 0.0414 13	0.247 0.403 13	0.181 0.541 13	0.104 0.723 13	0.389 0.162 14	0.349 0.212 14
BOD				0.222 0.435 14	0.00659 0.976 14	0.134 0.637 14	0.291 0.323 13	0.121 0.682 13	-0.044 0.878 13	-0.0824 0.778 13	0.196 0.492 14	0.24 0.399 14
COD					-0.859 0.0000002 14	-0.2 0.482 14	-0.165 0.578 13	0.22 0.458 13	0.5 0.0776 13	-0.346 0.236 13	0.569 0.0322 14	-0.257 0.364 14
TSS						0.182 0.521 14	0.121 0.682 13	-0.341 0.244 13	-0.626 0.0207 13	0.313 0.286 13	-0.56 0.0355 14	0.266 0.348 14
Ca^{2+}							0.892 0.0000002 17	-0.115 0.652 17	0.167 0.515 17	0.801 0.0000002 17	0.523 0.0255 18	0.872 0.0000002 18
SO_4^{2-}								-0.0907 0.722 17	0.1 0.694 17	0.662 0.00365 17	0.414 0.0955 17	0.863 0.0000002 17
NO_3^-									0.618 0.00811 17	0.211 0.409 17	0.191 0.454 17	0.162 0.527 17
Cl-										0.243	0.752	0.181

	TDS	NH_3	BOD	COD	TSS	Ca^{2+}	SO_4^{2-}	NO_3^-	Cl-	NH_4^+	Na^+	K^+
										0.341	0.000189	0.478
										17	17	17
NH_4^+											0.238	0.87
											0.351	0.0000002
											17	17
												0.337
												0.167
												18
K^+												

Table 3 *(continue)*

	EC	DO	Turb	TDS	BOD	COD	TSS	Na	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	NO_3^-	Cl-	NH_4^+	A_T	Mn	Fe	Zn	Cu
pH	0.18	0.251	0.284	0.747	0.103	-0.44	0.103	0.042	0.15	0.096	0.255	0.132	-0.23	-0.11	-0.27	0.064	0.617	0.383	0.516	0.038
	0.466	0.309	0.248	1E-04	0.715	0.168	0.715	0.863	0.546	0.699	0.301	0.605	0.377	0.659	0.288	0.82	0.018	0.167	0.056	0.892
	18	18	18	18	14	11	14	18	18	18	18	17	17	17	17	14	14	14	14	14
EC		-0.2	-0.14	0.058	-0.49	-0.18	0.101	0.006	-0.17	-0.3	-0.21	-0.16	0.066	0.087	-0.15	0.227	-0.24	-0.26	0.321	0.101
		0.416	0.58	0.811	0.072	0.575	0.715	0.974	0.497	0.217	0.407	0.54	0.795	0.73	0.553	0.425	0.399	0.356	0.251	0.715
		18	18	18	14	11	14	18	18	18	18	17	17	17	17	14	14	14	14	14
DO			0.224	0.356	0.051	-0.28	0.165	0.197	0.307	0.34	0.439	0.267	-0.18	0.056	0.26	-0.01	0.49	0.283	0.065	-0.26
			0.365	0.143	0.856	0.384	0.562	0.426	0.211	0.164	0.067	0.293	0.484	0.824	0.307	0.976	0.072	0.316	0.82	0.356
			18	18	14	11	14	18	18	18	18	17	17	17	17	14	14	14	14	14
Turb				0.509	0.2	-0.79	0.82	-0.27	0.377	0.344	0.119	0.35	-0.3	-0.29	0.316	-0.4	0.561	0.071	0.4	0.32
				0.031	0.482	0.002	2E-07	0.27	0.12	0.159	0.632	0.163	0.242	0.246	0.211	0.152	0.036	0.797	0.148	0.258
				18	14	11	14	18	18	18	18	17	17	17	17	14	14	14	14	14
TDS					0.33	-0.46	0.254	0.066	0.562	0.434	0.563	0.561	-0.13	-0.13	0.149	-0.16	0.588	0.67	0.702	0.199
					0.238	0.149	0.373	0.786	0.015	0.07	0.015	0.019	0.625	0.612	0.559	0.573	0.026	0.008	0.005	0.482
					14	11	14	18	18	18	18	17	17	17	17	14	14	14	14	14
BOD						0.4	0.121	0.007	0.068	0.068	0.178	0.181	0.055	-0.12	-0.19	-0.03	0.331	0.329	0.447	0.12

	EC	DO	Turb	TDS	BOD	COD	TSS	Na	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	NO_3^-	Cl-	NH_4^+	A_T	Mn	Fe	Zn	Cu
						0.21	0.67	0.976	0.808	0.808	0.532	0.541	0.849	0.682	0.516	0.904	0.238	0.244	0.105	0.67
						11	14	14	14	14	14	13	13	13	13	14	14	14	14	14
COD							-0.88	0.373	-0.66	-0.48	-0.25	-0.52	0.248	0.382	-0.66	0.464	-0.38	-0.16	-0.08	-0.03
							2E-07	0.245	0.026	0.124	0.45	0.116	0.468	0.258	0.033	0.141	0.233	0.614	0.797	0.903
							11	11	11	11	11	10	10	10	10	11	11	11	11	11
TSS								-0.68	0.13	0.042	-0.32	0.005	-0.39	-0.72	0.17	-0.1	0.48	0.073	0.144	0.298
								0.006	0.648	0.88	0.251	0.978	0.179	0.005	0.565	0.715	0.078	0.797	0.615	0.293
								14	14	14	14	13	13	13	13	14	14	14	14	14
Na^+									0.337	0.523	0.699	0.414	0.191	0.752	0.238	0.125	-0.31	-0.13	0.097	-0.17
									0.167	0.026	0.001	0.096	0.454	2E-04	0.351	0.659	0.279	0.637	0.727	0.542
									18	18	18	17	17	17	17	14	14	14	14	14
K^+										0.872	0.812	0.863	0.162	0.181	0.87	-0.6	0.088	0.395	0.177	-0.2
										2E-07	2E-07	2E-07	0.527	0.478	2E-07	0.024	0.762	0.157	0.532	0.492
										18	18	17	17	17	17	14	14	14	14	14
Ca^{2+}											0.87	0.892	-0.12	0.167	0.801	-0.27	0.132	0.205	0.061	-0.04
											2E-07	2E-07	0.652	0.515	2E-07	0.34	0.648	0.472	0.832	0.88
											18	17	17	17	17	14	14	14	14	14
Mg^{2+}												0.875	-0.03	0.311	0.571	-0.18	0.134	0.453	0.332	-0.11
												2E-07	0.913	0.218	0.016	0.521	0.637	0.098	0.238	0.693
												17	17	17	17	14	14	14	14	14
SO_4^{2-}													-0.09	0.1	0.662	-0.29	0.204	0.332	0.376	0.162
													0.722	0.694	0.004	0.323	0.493	0.261	0.199	0.591
													17	17	17	13	13	13	13	13
NO_3^-														0.618	0.211	-0.68	-0.42	0.044	-0.07	-0.52
														0.008	0.409	0.01	0.148	0.878	0.806	0.067
														17	17	13	13	13	13	13
Cl-															0.243	-0.24	-0.61	-0.24	-0.14	-0.48

	EC	DO	Turb	TDS	BOD	COD	TSS	Na	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	NO_3^-	Cl-	NH_4^+	A_T	Mn	Fe	Zn	Cu
															0.341	0.414	0.024	0.414	0.643	0.093
															17	13	13	13	13	13
NH_4^+																-0.65	-0.24	0.072	-0.19	-0.22
																0.016	0.424	0.806	0.516	0.458
																13	13	13	13	13
A_T																	0.046	-0.35	-0.12	0.464
																	0.868	0.212	0.67	0.091
																	14	14	14	14
Mn																		0.297	0.358	0.367
																		0.293	0.201	0.189
																		14	14	14
Fe																			0.246	-0.22
																			0.39	0.444
																			14	14
Zn																				0.315
																				0.264
																				14
Cu																				

*Notes:
Significant correlation
TDS vs. many chemical properties
Mn vs. pH
COD vs NH_4^+
A_T vs K, NO_3, NH_4^+

Table 4 Pearson's correlation between water quality variables (rehabilitated forest, Bintulu)

		Water Temp	pH	DO	A_T	NH_3N	BOD	COD	Salt	Turb	EC	TDS	TSS	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cu	Fe	Mn
Rehabilitated forest (Bintulu Sarawak Malaysia)	pH	0.105																		
	DO	-.519**	0.033																	
	A_T	.461**	-0.005	-0.139																
	NH_3N	.297**	0.047	-.251**	.201*															
	BOD	-.214*	0.049	0.023	-0.031	0.030														
	COD	-0.079	-0.005	-.215*	.303**	0.063	0.158													
	Salt	.^{c}	.^{c}	.^{c}	.^{c}	.^{c}	.^{c}	.^{c}	.^{c}											
	Turb	-.224*	0.024	.327**	-.456**	-0.145	-0.047	-.743**	.^{c}											
	EC	.453**	.190*	-.333**	.339**	0.145	-0.169	0.180	.^{c}	-.353**										
	TDS	0.006	-0.054	0.073	-0.131	0.083	0.000	-.284**	.^{c}	.357**	-0.075									
	TSS	-.756**	-0.067	.611**	-.461**	-.265**	0.137	-.397**	.^{c}	.758**	-.531**	.234*								
	Na^+	0.135	.263**	-0.084	0.100	0.062	-0.083	-0.044	.^{c}	-0.003	.734**	0.036	-0.098							
	K^+	.343**	0.154	-0.152	0.029	0.150	-.285**	-.256**	.^{c}	0.158	.548**	.294**	-0.131	.406**						
	Ca^{2+}	.375**	.201*	-0.175	0.185	0.086	-.196*	-0.106	.^{c}	0.009	.692**	0.041	-.253**	.318**	.655**					
	Mg^{2+}	.265**	0.128	-0.030	0.015	0.042	-.190*	-.357**	.^{c}	.340**	.634**	0.170	0.030	.447**	.622**	.806**				
	Cu	.283**	0.154	-.243*	0.142	0.010	-0.139	0.134	.^{c}	-.337**	.394**	-.226*	-.414**	0.169	.305**	.358**	0.177			
	Fe	.759**	0.144	-.434**	.616**	.222*	-0.096	.333**	.^{c}	-.590**	.449**	-0.142	-.812**	0.061	0.139	.292**	0.002	.312**		
	Mn	.349**	-0.027	-.255**	.277**	0.019	0.182	0.039	.^{c}	-.214*	0.112	-0.085	-.377**	-0.010	0.061	0.055	-0.051	.305**	.432**	
	Zn	.503**	0.033	-.438**	.380**	.206*	-0.078	.347**	.^{c}	-.484**	.248**	-0.113	-.593**	-0.085	0.070	0.100	-0.075	.360**	.583**	0.074

Notes: ** Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

The mutual link between two variables known as correlation. When the value of one variable increase or decreases, the value of another variable also increases or decreases. This is known as direct correlation. The correlation of physico-chemical variables of river water revealed that all of the variables were more or less connected with one another with particularly strong correlations between the variables. In the present study, the correlation of physico-chemical variables of river water revealed that all the variables were correlated with one another, especially strong correlations observed between the group listed. The dendrogram showed four different cluster groups (Group A = 5 variables (water temperature, pH, DO, turbidity, TSS); Group B = 7 variables (EC, Na^+, salinity, Mn, TDS, Fe, Zn); Group C = 3 variables (BOD, COD, NH^3N), Group D = 5 variables (Ca^{2+}, Mg^{2+}, K^+, Cu, A_T) and with the biggest cluster of seven variables (Figure 26).

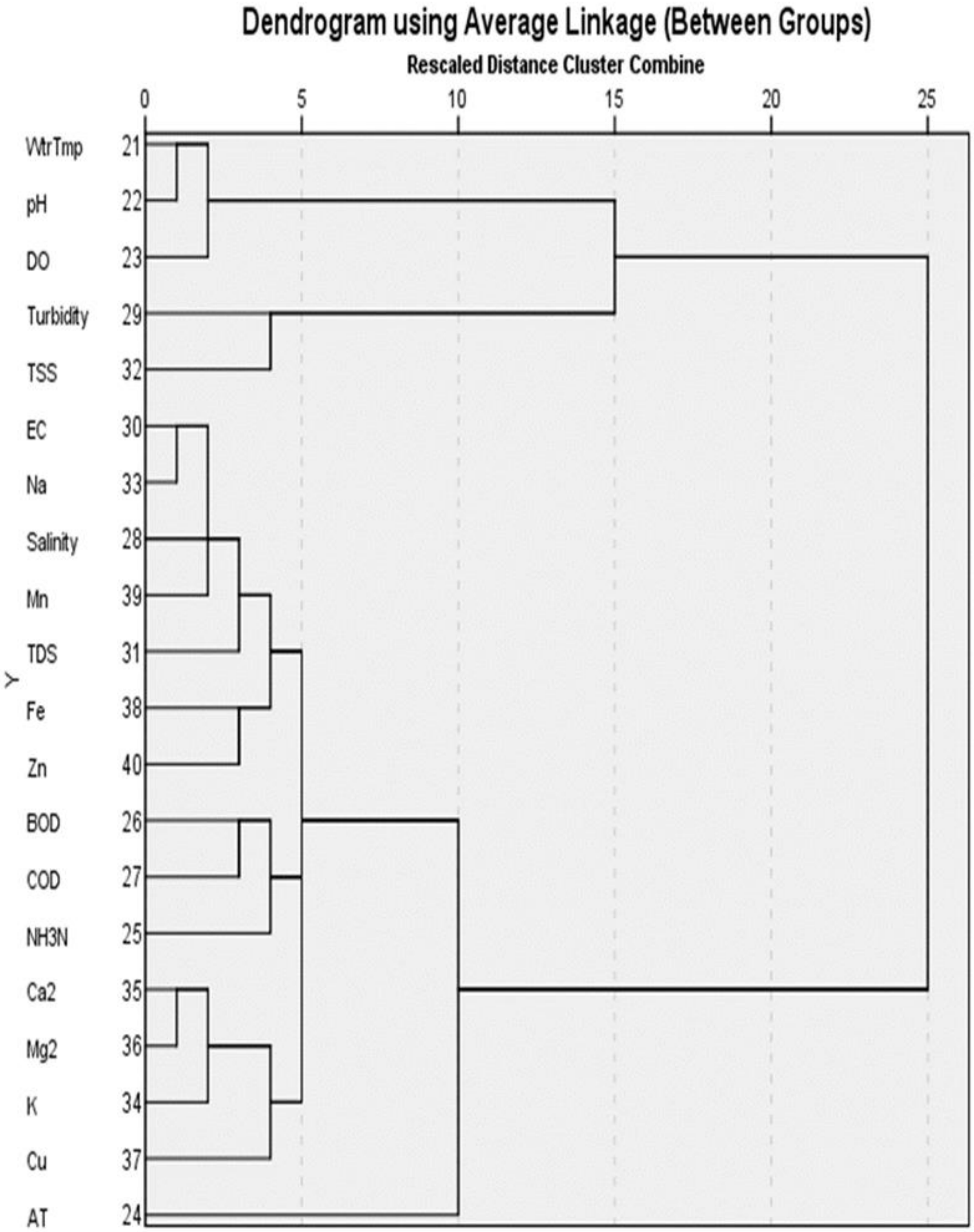

Figure 26 Dendrogram of similarity and dissimilarity clusters showing similar physicochemical of water quality variables (rehabilitated forest, Bintulu Sarawak Malaysia)

5.0 DISCUSSION

5.1 Seasonal Variation in Chemical Properties

The concentrations of total ions showed increasing trends obviously in the rainy seasons (October to February). According to this study, the major ions (Ca^{2+}, Mg^{2+}, Na^+, K^+ Cl-, NO_3-, and SO_4^{2-}) found have sensitivity to rainfall. The differentiation of temporal variation of water quality during hot and rainy seasons are results of sediments loading by rainwater and high evaporation particularly during hot seasons (WIREs Water, 2018) [36]. In addition, the atmosphere transfers pollutants onto land and water *via* atmospheric deposition and into the air if incinerated. The natural entry of pollutants into water bodies takes place *via* rain and reacts with particles from atmosphere by dry deposition and these reactions result in the rainwater gaining major ion includes dissolved SO_4^{2-} fall down directly onto the water bodies (Gupta, 2004) [14]. Previous study reported by Hilmi *et al*., (2013) [16] found that the annual deposition of SO_4^{-2} in rainwater at same site of study area was 802.4; Ca^{2+} (1704); Mg^{2+} (4.9); Na^+ (207.3); NO_3-, (218); NH_4^+ (899.5); Cu (1.7) and Zn (0.1) mg m^{-2} $year^{-1.}$ This indicated that the atmospheric deposition of major ion and metals from atmosphere *via* rainwater and its deposition into the stream at the study site could give significant impacts on its stream water quality.

The strong positive correlation between TSS and turbidity also indicated the strong role of the rainfall. The eroded soil particles, disturbance of a land surface and sediment can be carried by storm water to surface water onto the middle and downstream of the river that causes high concentration of its suspended solids (Danielle, 2019) [9]. In general; during the wet season, the bulk of the annual water discharge and sediment discharge may occur in a few days of high river flow (Julie *et al*. 2013) [21]. The concentration of suspended solids is an important water quality variable used to know the ecological productivity, transport of pollutants and linked to evaluation and assessment of water management (Hermann, 2013) [15]. Thus, in this study the heavy rain events leads to the turbidity *via* surface water which leads to soil erosion. Meanwhile, this did not directly affect the variation in major ions concentrations.

As for heavy metal experimental results, concentrations of heavy metals in water are significantly lower than acceptable concentration limit of toxic concentration set by World Health Association (WHO) and National Water Quality Standard (NWQS) Malaysia during both hot and rainy seasons. However, it can be clearly stated that the concentrations of heavy metals in the dry season were higher than those in the rainy season when the rainfall was comparatively low. These results showed the effect of hot seasons increased the heavy metals concentration. The seasonal variations of heavy metals in water were reported by different researchers at different water bodies. These were similar to results of different researchers in different countries which found that hot seasons affect the accumulation of heavy metals in water. In the rainy season, the concentration was low because of heavy rainfall dilution by upstream water parts due to seasonal and heavy rainfall in the area that disperses and dilutes the pollutant load, cause by variations in flow and other runoff processes (Shafei, 2015; Saeed *et al*. 2014; Ibrahim and Omar, 2013; Shabalala *et al*. 2013; Kaonga *et al*. 2008; Mohamed, 2005) [29; 30; 18; 31; 22; 24].

5.2 Comparison with Other Studies

Annual mean of chemical properties in this stream was compared to the values in other rivers on city area all around the world, oil palm and agricultural area in addition to the water quality in dam and natural forest. As a result, COD, major cations and nitrate in this stream were significantly lower than the river in oil palm, agricultural and town area in other area whereas other water properties and SO_4^{2-} concentrations were not so different from the river on other land use. Stream water chemistry varied according to land use change. In addition, was higher in disturbed sites. Several studies in tropical watersheds evaluated the impact of urbanization, industrialization and agricultural practices on water quality.

Streams located in disturbed sites showed high concentration for COD and major ions except SO_4^{2-}. Poor water quality can be the result of natural processes of stream water in tropical forest; but is more often affect by anthropogenic activities and closely linked to land use change and development activities occurred at the area. Pollutants discharged particularly waste from agricultural, industrialization and urbanization into water bodies in the forest severely affects the tropical forest water quality. The impacts includes water acidification, increasing level of BOD, COD, NH_3N, SO_4^{2-}, alkalinity, TDS, and TSS as found by different researchers at different area particularly; land use change for development of paddy field, oil palm plantation, dam, agricultural, industrial and residential area (disturbed forest) compared to stream water of rehabilitated forest and forest reserve (undisturbed forest) that still having a good water quality status (Table 5).

The relationship between forests and water is an important issue, which should be a priority. Forests serve as a water catchment and almost all water sources come from streams and lakes from forest-derived water tables and give an influence on catchment hydrology, which can affect water quality. Healthy and managed forests capable to store and serve high quality freshwater resources in streams, lakes, and wetlands (Baillie and Neary, 2015); Blumenfeld *et al*., 2009; USDA, 2008; Wilk, 2000). [3, 5, 34, 35]

The availability and quality of water threatened by overuse, misuse and pollution factors disposed into water bodies and it is strongly influence by the forests. Stream water affected by several processes in the watershed includes anthropogenic activities which resulting in changes in water quality as well as in the functioning of these stream ecosystems. Climate change forest's role in regulating water flows and influences the availability of water (Marthe *et al*., 2015; Daniela *et al*., 2012; IUFRO, 2007) [23, 8,19]. The removal and destruction of natural ecosystems are among the greatest causes degradation on sustainability of natural water resources. Forested watersheds generally offer higher-quality water because it is generally low in nutrients compared to water draining from other land uses. Anthropogenic activities may increase annual water yields and disrupt the natural cycling of nutrients, which leading to changes in infiltration and runoff patterns as well to pollution (FAO, 2017; Scott, 2015) [12; 32].

Forests planted in agricultural, industrial and urban areas can reduce pollutants (Evans, 2009) [10]. Managed forests usually have low input of nutrients, pesticides, chemicals and other pollutants compared to intensive area with variety of land uses development (Hjalmar *et al*. 2010; Robin *et al*. 2010) [17; 26]. Land use comparisons proved that natural forests, planted forest, well-managed forest or rehabilitated forest as found in this study could protect and provide a sustainable source of well-maintained and high-quality water supplies.

6.0 CONCLUSION

Normal water temperature, neutral pH, Low EC, TDS, NH_3-N, salinity, A_T, BOD and COD; safe concentration of major ion (K^+, Ca_2^+, Mg^{2+}, Na^+, NO_3, Cl-, NH_4^+) and heavy metals (Mn, Fe, Cu, Zn) concentration found in this study. All cations in this stream are found within the permissible level recommended by WHO. Hence, major ions (particularly NO_{3-}) found in this study area are not hazard to human, plant and aquatic organism. Moreover COD, major cations and nitrate concentration in this stream were significantly lower than the river in oil palm, agricultural and town area SO_4^{2-} concentrations were relativity high, which might be due to relativity high atmospheric deposition in this area (Table 5). Rehabilitation of degraded forest through reforestation might give a positive impact in maintaining and preserving environmental quality particularly on its forest water resources. Although the results obtained from the rehabilitated forest of UPMKB stream water does not show any form of danger posed to water quality from this stream; but the possibility of adverse effects after long period cannot be ruled out. Therefore, the need for continual assessment and further investigation should be carried out to confirm the trends and as a precautionary measure. Forest restoration and rehabilitation is necessary and important to re-establish its function, for protection and restoration of critical habitat, riparian areas, watersheds and many other attributes in order to achieve sustainable development and for effective environmental conservation and management.

Acknowledgement

Sincerely thanks to staff of Universiti Putra Malaysia Bintulu Sarawak Campus for their help during fieldwork and laboratory experiment. Special thanks to Sarawak Meteorological Department for their cooperation.

Table 5 Comparison of water quality of river or lake in tropical, urban and forest area by different researchers

References	**Preeti et. al 2009**	**Sujaul et. al 2012**	**Norhaziqah et. al 2013**	**Sangamner et. al 2013**	**Kim Irvin et. al 2013**	**Seca et. al 2014**	**Harlina et. al 2014**	**Ahmad et. al 2014**
Country	India	Malaysia	Malaysia	India	Malaysia	Malaysia	Malaysia	Malaysia
Site	Kerwa	Pahang	Bintulu	Maharashtra	Selangor	Lawas	Penang	Sabah
Land use	**Dam**	**Forest reserve**	**Oil palm, industrial, residential**	**Agricultural, industrial**	**Agricultural**	**Oil palm plantation**	**Paddy field**	**Town area**
Water Tmp	29	31.3	29.12	ND	27.3	28.51	ND	28.78
pH	7.4	57.14	7.22	8.9	3.63	7.12	5.19	7.23
DO	ND	6.93	7.47	ND	0.31	5.5	0.76	5.05
BOD	4	2.34	2.89	ND	ND	1.163	6	0.87

NH_3-N	ND	0.580	0.60	ND	<0.5	ND	02.4	0.04
A_T	140	ND	ND	ND	ND	17.6	ND	ND
NH_4^+	ND	ND	ND	ND	ND	ND	ND	ND
COD	22	18.66	16.80	ND	ND	14.03	160	11.45
TDS	170	35.90	2.45	4038	ND	20.71	ND	0.22
TSS	ND	37.75	12.1	ND	ND	61.5	219	21.21
Turb	2.5	44.70	177.49	ND	1.2	233.67	ND	26.71
Na^+	ND	ND	ND	522	ND	233.92	ND	14.35
K^+	ND	ND	ND	2.8	ND	5.36	ND	3.232
Ca^{2+}	36	ND	ND	723	ND	18.53	ND	5.453
Mg^{2+}	12	ND	ND	870	ND	28.66	ND	9.038
Cl^-	22	ND	ND	2490	ND	ND	ND	ND
NO_3-	30	ND	1.18	92	ND	ND	ND	ND
SO_4^{2-}	5.4	5	ND	184	ND	ND	ND	ND
Cu	ND	ND	ND	ND	ND	0.05	ND	ND
Fe	ND	ND	ND	-0.05	ND	0.09	ND	ND
Mn	ND	ND	ND	0.88	ND	0.03	ND	ND
Zn	ND	ND	ND	ND	ND	0.14	ND	ND

Notes: all variables are in mg/L except for pH and turbidity (NTU), ND: Not Determined

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