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Research Article

Evaluation of Spatial and Seasonal Variations of Dissolved Organic Matter in Maliau Basin, Sabah, Malaysia

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Abstract
The characteristics dissolved organic matter (DOM) and surface water quality in Maliau Basin, Sabah, Malaysia, were determined from December 2014 to September 2015. The objectives of this study were: (i). to distinguish the surface water quality of rivers which consisted of different types of land use: primary forest (PF), secondary forest (SF), main river (MR) and altered habitat (AH); (ii). to assess seasonal variations of the water quality. A total of 36 water samples were collected during the fieldwork campaign that extended over high and low rainfall periods. The water quality physico-chemical parameters such as water temperature, pH, dissolved oxygen (DO), conductivity, and salinity were measured *in-situ* with the YSI-multiparameter instrument, while dissolved organic carbon (DOC) concentration was evaluated using Shimadzu TOC-V-SCH analyzer with auto-sampler TOC-ASI-V equipped. Dissolved organic matter (DOM) was determined optically in the laboratory at 254 (a_{254}), 340 (a_{340}) and 410 (a_{410}). Discriminant analysis (DA) was employed to organize independent variables into mutually-exclusive groups. The outcome of DA indicated that water temperature, total suspended solid (TSS), and conductivity were dominant at AH, whilst a_{340} was dominant at MR in March 2015. Our results also showed seasonal variations for water quality parameters. The highest mean concentrations of pH and a_{340} were found during the dry period (March 2015) and dissolved oxygen (DO) during the wet season (December 2014), suggesting spatio-seasonal variations of DOM and water quality parameters were determined by environmental factors such as precipitation, water velocity and discharge amount. UV-vis absorptions a_{254} and a_{340} show significant positive correlation with dissolved organic carbon (DOC), suggesting that it could be a suitable proxy for DOC concentration for tropical flowing water.

Keywords: Water quality, dissolved organic matter (DOM), Maliau Basin.

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Introduction

Tropical river systems are mainly characterized by marked annual cycles in precipitation, rain periods and high solar radiation (Saigusa et al., 2008) and also low in aquatic primary production and nutrients (Davies et al., 2008). These streams or rivers occur in complex variety with seasonal differences in velocity of flow, water chemistry, and metabolic rates. Spatial and seasonal variations of tropical rivers biogeochemistry are mostly driven by local topography that surround the river (Allan, 2004) and it can also be altered by anthropogenic activities such as logging and road construction (Dudgeon, 2012). Forest canopy coverage also was found to play an essential role in determining the turbidity and total suspended solids in the fluvial system (Singh & Mishra, 2014). The presence of vegetation can stabilize riverbanks to prevent erosion, filter nutrients and sediments, moderate water temperature by governing light availability and provide various other ecological services (Iwata et al., 2013).

Several studies had demonstrated that the spatial and seasonal variations of river water chemistry, for instance, Zakeyuddin et al. (2016) found that the concentration of dissolved oxygen, water temperature, electrical conductivity, and total dissolved solids in Bukit Merah Reservoir, Malaysia displayed variations from December 2012 until January 2014. Udoh et al. (2013) revealed seasonal variation in several physico-chemical parameters, more specifically between the wet and dry seasons. Furthermore, da Costa et al. (2015) reported that the water temperature, salinity, and pH were higher during the long dry season. In addition, Harun et al. (2016) suggested that there were significant seasonal and spatial variations in dissolved organic matter (DOM) in the tropical catchment of North Borneo, and the concentration of DOM was mainly determined by the types of land use and precipitation rate.

Dissolved organic matters (DOM) are an important source of energy in the aquatic environment; the quality and quantity of DOM can determine the productivity of the local fluvial ecosystem (Carlson, 2002; del Giorgio & Davis, 2003). From a catchment perspective, streams at the upper area which receive more terrestrial-derived DOM tend to have higher dissolved organic carbon (DOC) concentrations (Dalzell et al., 2009; Mayorga et al., 2005). DOC is the carbon component of DOM; therefore, determining the DOM flux is essential for a better understanding of the aquatic ecosystem (Hopkinson & Vallino, 2005). There are numerous techniques in evaluating the quality and quantity of DOM (Coble, 2007), while the optical parameters method is currently increasingly used in water quality related research due to its lower application costs and lower operational knowledge (Hansen et al., 2016). The absorption coefficient at 340 nm was considered as an effective proxy for dissolved organic matter concentration for natural water (Allpike et al., 2005), while the spectral slope can be used to reveal the molecular weight and aromaticity of the DOM (Helms et al., 2008). In freshwater, DOM mainly derived from leaf litter, plants and soil organic matter (allochthonous) and in-situ heterotrophic production (autochthonous) (Pagano et al., 2014). In tropical regions, DOM plays a crucial role in surface water quality to indicate anthropogenic and land use activities that influence stream water DOM concentrations (Harun et al., 2016; Holbrook et al., 2006; Williams et al., 2010; Yamashita et al., 2011; Lu et al., 2013; Burrows et al., 2013). Consequently, DOM has been shown to vary seasonally in the tropical river catchment of Kinabatangan, Sabah, Malaysia (Harun et al., 2016), undisturbed rainforest sub-catchment in Australia (Bass et al., 2011) and sub-tropical bay in Florida, USA (Maie et al., 2012).

In tropical forest stream ecosystems, very little work is published on the characterization of water quality and dissolved organic matter (DOM) according to spatial and seasonal variations. Maliau Basin Conservation Area (MBCA) is a pristine tropical forest situated in Sabah, Malaysian Borneo. The basin is drained by Maliau River, which flows and joins Kuamut River at the southeastern part of the basin, and eventually joins the largest waterway in Sabah: Kinabatangan River (Hazebroek, 2004; YS, 2014). The objectives of this study were twofold: (i). to distinguish the surface water quality of rivers which consisted of different types of land use: primary forest (PF), secondary forest (SF), main river (MR) and altered habitat (AH); and (ii). to assess seasonal variations of the water quality. To-date, only four water quality assessments have been carried out at the MBCA within a period of two decades: Mykura, 1989; Anton & Alexander, 1998; Mokhtar et al., 2009; Harun et al., 2010. The data regarding to river water quality in this area has not been updated since 2006 (Mokhtar et al. 2009). Therefore, we would like to provide the latest data on the water quality status of the rivers.

Methodology

Study Site

Maliau Basin is located in Sabah in the northeastern part of Borneo Island (Figure 1). It occupies an area of about 390 km^2 and is surrounded by a formidable ridge reaching over 1,675 m above sea level (Webb & Ali, 2002). The area is a Class I (Protection) Forest Reserve which means it is totally protected and not for logging activities. The area is also covered entirely by an evergreen tropical rainforest, which consists of a mixture of tree species with at least 12 distinct forest types (Hazebroek et al., 2004). The basin is a huge water catchment drained by the main river: Maliau River (MR). Figure 1 illustrates the location of each sampling station at the Maliau Basin. Four streams consisting of four types of land use were investigated in this study: altered habitat (AH), Maliau River (MR), secondary forest (SF) and primary forest (PF). PF is situated within the core area of the forest reserve which is supposed to receive minimal disturbance, while SF is located in the buffer zone of MBCA which consists of lowland mixed dipterocarp forest. MR could be regarded as a high order river, as it is a single massive water catchment area that is connected and drained by a set of radiating tributaries. It drains the heath forest which attributes to the tea-colouration of the river water (Mykura, 1989). Stream at AH may have been subject to deterioration as there was a road construction project adjacent to the AH stream during the sampling periods. It was perceived that logging activities in the 1970s and mid-1990s (Ewers et al., 2011) would disturb the natural habitats of SF, MR and AH, as these three streams are located in the buffer zone area of Maliau Basin.

The area is influenced by monsoon winds (YS, 2014) and typically record heaviest rainfall from August to September (Maral, 2002; Hazebroek et al., 2004). The sampling campaign was conducted from December 2014 to September 2015. Two periods corresponded to the wet season (WS): December 2014 and March 2015; and another two corresponded to the dry season (DS): May 2015 and September 2015.

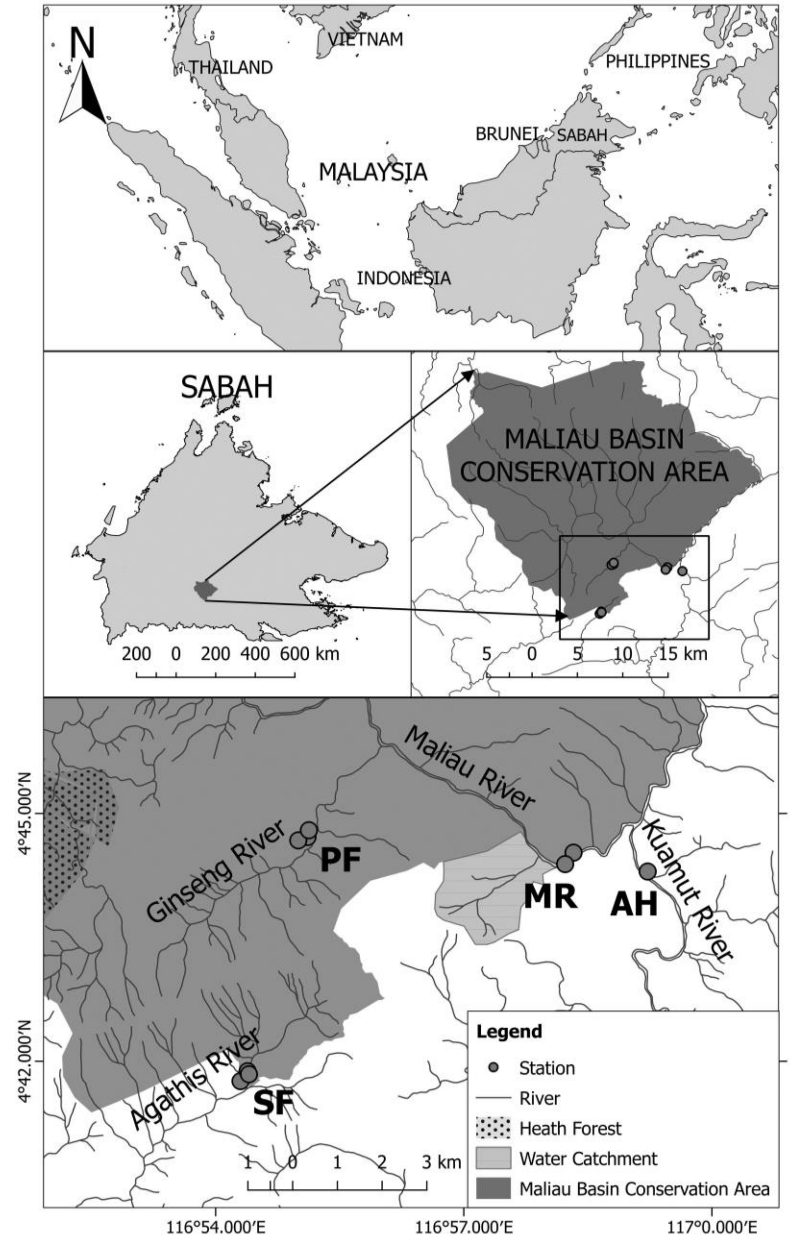

Figure 1. The locations of sampling stations at Maliau Basin, Sabah.

Surface Water Analysis

Physico-chemical parameters such as pH, water temperature, conductivity, total dissolved solids (TDS), and dissolved oxygen (DO) were recorded *in-situ* by using YSI Profesional Plus (ProPlus) (Model 6026 S/N Y5173) multiparameter. To analyze total suspended solids (TSS) and optical parameters (a_{254}, a_{340}, $a_{410,}$ and $S_{275-295}$), water samples were randomly collected from each stream into 250 mL high-density polyethylene (HDPE) bottles. Sampling bottles were pre-washed with 10 % hydrochloric acid (HCl) and rinsed with deionized water to avoid contamination from metal and non-metal ions (Perera et al., 2016). During the water sample collection, the water bottles were rinsed with river water three times before the samples were collected (Perera et al., 2016). Water samples were immediately filtered after sampling using Whatman GF/F filters (pore size 0.7 µm). The Whatman GF/F filters were used as these can achieve higher particle retention efficiency when filtering large volumes of less turbid water and provide a more accurate measurement of the TSS for less turbid water like those at Maliau rivers. Filtered samples were kept in a dark area and stored at 4°C for further analysis at Universiti Malaysia Sabah (UMS).

Spectral Measurement and DOC

Several studies demonstrated the applicability of using the absorption coefficients in determining the DOM concentration (Baker et al., 2008; Peacock et al., 2014). A study carried out by Peacock et al. (2014) elucidated that absorbance in the Ultraviolet or visible spectrum can act as a proxy for the DOM concentration in stream water. In addition, several UV-Vis spectrums were used as a proxy for DOM concentration, for example, absorbance coefficient at wavelength 254 nm (Allpike et al., 2005; Baker et al., 2008; Burrows et al., 2013), 340 nm (Baker & Spencer, 2004; Baker et al., 2008), and 410 nm (Baker et al., 2008).

The optical properties of the stream water were identified by UV-Visible spectroscopy technique performed with Agilent Cary 60-Vis Spectrophotometer (Agilent Technologies, California, United States) and referenced to deionized water. Two hours prior to analysis, the filtered water samples were taken out from the cooler to ensure the water samples were restored to room temperature (Loginova et al., 2016). The water samples were then transferred into 1 cm quartz cuvettes with 2 mL volume. The water samples were scanned with a spectrophotometer with a wavelength range of 200 nm to 800 nm, at one nm intervals (Cooper et al., 2016). The absorbance for each water sample was recorded and used for the calculation of absorption coefficients and spectral slopes. The absorbance spectra for these three wavelengths were converted to Napierian absorption coefficients using the following equation (Helms et al., 2008):

$$a = 2.303 \bullet A / l$$

where a is Napierian absorption coefficient, A is the absorbance provided by a spectrophotometer, and l is the path length of the cuvette in meters. The spectral slope for the interval of 275 to 295 nm ($S_{275-295}$) was calculated by linear regression of the log-transformed a spectra (Helms et al., 2008).
Dissolved organic carbon (DOC) was acquired by high-temperature catalytic combustion method using Shimadzu TOC-VCSH analyzer with auto-sampler TOC-ASI-V (Zigah et al., 2012). Samples were acidified with hydrochloric acid (HCl) after the filtration processes. Two hours prior to lab analysis, the water samples were taken out from the refrigerator, and allowed to warm to room temperature (Loginova et al., 2016). Samples were acidified to pH ~2 and then sparged for 8 minutes at 75 or 100 mL/min with ultra-pure oxygen to remove all inorganic carbon from samples prior to measurement (Zigah et al., 2012). Due to equipment and technical constraints, only one sample set (September 2015) was used for DOC analysis in this study.

Statistical Analysis
Discriminant analysis is a multivariate statistical modeling technique, which can be used as a tool for pattern recognition. Objects can be classified into mutually-exclusive groups according to a set of independent variables (Gazzaz et al., 2012). Discriminant analysis has been employed using the statistical software of SPSS (Version 20) to discriminate the water quality data in different habitat types where the water samples were collected, as well as the seasonal variations of the stream water quality into mutually-exclusive clusters. To increase the ability to identify important parameters, water quality parameters that covaried strongly ($r > 0.7$) were removed, retaining those with most direct ecological interpretation. For instance, salinity and TDS were removed as they covaried strongly with conductivity while absorption coefficients, a_{254} and a_{410} were also not included in this analysis. The standardized coefficient represents the partial contribution of the variable and ranks the importance of each variable to the discriminant function. Wilks' Lambda test is to test which variables contribute significantly to the function. The closer Wilks' Lambda is to 0, the more the variable contributes to the function. The significance of Wilks' Lambda is tested by the Chi-Square

statistic. The corresponding function explains the group membership well if the *p*-value is less than 0.05.

Results and Discussion

Suitability of UV-Vis absorption coefficients as proxy for DOM concentrations

In many aquatic systems, particularly in freshwater systems, UV-vis absorbance values have been showed to positively correlate with dissolved organic carbon (DOC) (Baker et al., 2008; del Vecchio & Blough, 2004) and estimate DOC concentrations (Cook et al., 2017). The spectral reading from the wavelength absorption is a good substitute in identifying the concentration of the DOC (Cook et al., 2017; Kwak et al., 2013). Figure 2 exhibits scattergram of optical parameters (a_{254}, a_{340}, and a_{410}) and dissolved organic carbon (DOC) concentrations. UV-vis absorption coefficients at 254 and 410 nm also showed positive correlations with DOC. Highest correlations were found between a_{254} and DOC, followed by a_{340} and DOC, and the lowest were found between a_{410} and DOC. This result suggests that the absorption coefficient at 254 nm and 340 nm is suitable to act as the proxy for DOM concentration for tropical flowing water. These two wavelengths are also commonly used in the water treatment industry (Allpike et al., 2005) and natural water studies (Baker et al., 2008; Hernes & Benner, 2003; Tipping et al., 2009).

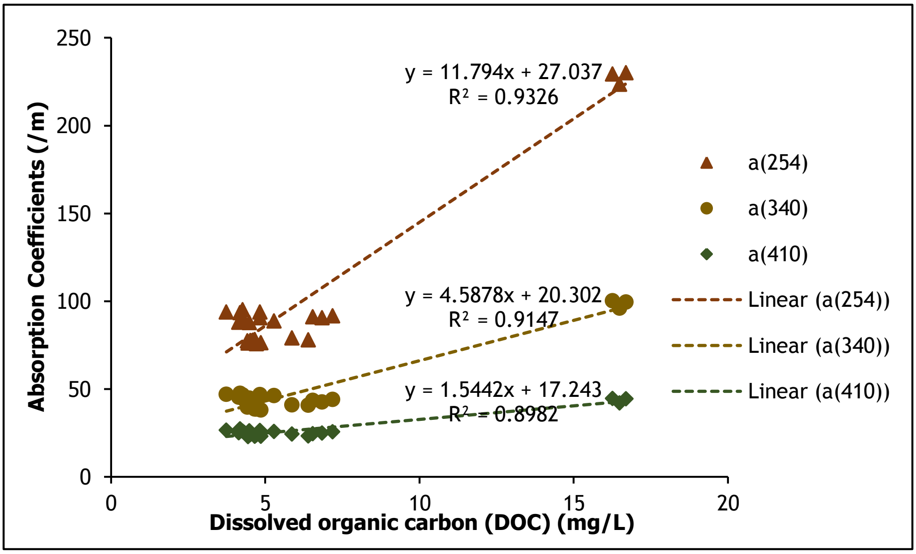

Figure 3. UV-vis absorption coefficients at 254 nm, 340nm and 410 nm (a_{254}, a_{340}, and a_{410}) against dissolved organic carbon (DOC) concentration.

Spatial Variations of Water Quality

Physico-chemical and optical properties of the four streams in Maliau Basin showed significant variations (Table 1). The ordination plot of discriminant analysis (DA) for water quality data set based on land use type is demonstrated in Figure 4a. Based on the DA plot, sampling stations at the primary forest (PF) and secondary forest (SF) both indicated higher resemblance in their physical and chemical characteristics. However, segregation of altered habitat (AH) and main river (MR) revealed that these two streams differed distinctively from other streams in their water quality properties. It has been found that water temperature, total suspended solids (TSS), and conductivity were higher in AH, while dissolved organic matter concentrations (a_{340}) were higher in MR (Figure 4a; Table 2). Spatial variations of water quality are determined by several local environmental conditions such as solar radiation, ambient temperature, water velocity and discharge amount (Qadir et al., 2008), and influenced and enhanced by the seasonal precipitation rate.

The varied water temperature at different sampling locations can be attributed to riparian vegetation shading, topographic variable of elevation, shape of the channel (i.e. wide and shallow channels more easily heated and cooled) (Poole et al., 2001), and river water circulation that is influenced by heat exchange on the earth's surface (Mokhtar et al., 2009). Higher water temperature was recorded at AH and MR (27.07 ± 1.408 °C and 24.28 ± 1.229°C respectively), characterized by a wider channel which increased the surface area exposed to solar radiation that consequently resulted in higher water temperature.

The suspended-sediment loads in tropical streams are highly variable with soil type, local precipitation rates, topography, riparian vegetation and human activities (Jacobsen, 2008). Even without the presence of anthropogenic disturbances at the upper stream, a heavy flow can give rise to higher TSS levels (Jacobsen, 2008). In addition, it has been reported that increment of sediment loads at Maliau River during flood flow was due to constant erosion of soft mudstone at steep valley slopes in the upstream area (Mykura, 1989). These processes could take part during the study period as well, as indicated by high sediment concentrations at MR during high rainfall periods. The constant erosion possibly provided sediment input to the Maliau River, however, this assumption needs further confirmation through geological analysis on soil properties and the erosion rate needs further confirmation. Moreover, road construction at Maliau Basin was suspected to be the causative factor that resulted in a high value of TSS in AH.

Results from this study show that lower conductivity was observed at PF (33.73 ± 13.42 μS/cm) and SF (46.32 ± 14.427 μS/cm). On the other hand, a comparatively higher conductivity (99.04 ± 27.149 μS/cm) was determined at Kuamut River (termed AH), where the earthwork operation for road construction adjacent to the river may cause high conductivity values as recorded in this study. Anthropogenic activities like logging and agricultural activities were reported to cause remarkable disruption to the nutrient cycle (i.e. calcium fixation) in the natural habitat. Nutrient leaching followed by the interruption of forest activities and land clearing can result in higher river water conductivity in the affected regions (Singh & Mishra, 2014). Meanwhile, lower river water conductivity, in general, is associated with riparian forests characterized by higher vegetation densities (de Souza et al., 2013), the low conductivity and TDS at MR (21.69 μS/cm and 13.38 mg/L, respectively) could be caused by the acidity of the water and this is because the water conductivity is highly dependent on the ionic concentration of the water bodies (Balance, 1996). Apart from that, blackwater rivers typically have lower dissolved solids and exhibit low values for conductivity (Duncan & Fernandes, 2010), for instance, the Negro River in Amazon Basin recorded a mean conductivity of 14.4 μS/cm.

DOM concentrations were the highest at Maliau River (MR), the main river of Maliau Basin, and lower DOM concentrations were observed at forest habitats (for both PF and SF). Aiken et al. (2011) revealed that DOM concentrations were lower in pristine forest habitats. This could be due to the root mat of pristine/undisturbed forests that provides efficient service in recycling plant nutrients and non-humic substances into the living biomass, and at the same time retaining organic matters that are released from the litter layer before entering the groundwater and draining into the river system (Foster & Bhatti, 2006; Tank et al., 2010). The nutrients recycling and organic matter retention abilities of pristine forest were believed to reduce the amount of organic matter leaching into the fluvial ecosystem, thus we observed a relatively low DOM concentration within the rivers located at PF and SF. The existence of heath forest vegetation at the upstream of Maliau River was believed to result in high DOM concentration of water samples from MR (the downstream of Maliau River). This could be due to the heath forest vegetation being less efficient compared to the dipterocarp forest in trapping humic compound (Mykura, 1989).

Table 1. Mean ± SE of physico-chemical and optical parameters in the four tropical streams of Maliau Basin.

	Altered Habitat (AH)	Main River (MR)	Secondary Forest (SF)	Primary Forest (PF)
Physico-Chemical Parameters				
PH	7.2 ± 0.6	5.8 ± 1.4	7.1 ± 0.4	7.2 ± 0.5
Temperature (°C)	27.1 ± 1.4	24.3 ± 1.2	23.5 ± 0.3	22.5 ± 0.4
Conductivity (μS/cm)	99.0 ± 27.2	21.7 ± 2.0	46.3 ± 14.8	33.7 ± 13.4
DO (mg/L)	7.6 ± 1.6	8.4 ± 1.8	7.0 ± 0.4	8.4 ± 2.8
TDS (mg/L)	60.1 ± 20.0	13.4 ± 2.2	27.5 ± 11.4	20.4 ± 10.4
TSS (mg/L)	48.1 ± 61.4	72.2 ± 113.1	11.3 ± 5.2	9.1 ± 4.9
Optical Parameters				
a_{254} (/m)	72.1 ± 7.8	167.8 ± 49.8	82.4 ± 21.6	95.8 ± 32.2
a_{340} (/m)	36.4 ± 4.2	76.4 ± 17.6	42.2 ± 10.2	46.7 ± 13.5
a_{410} (/m)	22.3 ± 2.1	35.6 ± 5.9	24.1 ± 3.7	25.6 ± 4.9
$S_{275-295}$ (10^{-3}/nm)	8.7 ± 0.4	9.3 ± 1.0	8.1 ± 0.1	8.7 ± 0.6

Seasonal Variations of Water Quality

Rainfall data for each month were obtained from the Meteorological Department of Maliau Basin Studies Centre, Sabah (Figure 3). The second sampling occasion (March 2015) recorded the lowest rainfall, while the rest of the sampling occasions recorded rainfall above the mean monthly rainfall. In terms of seasonal variations, water samples collected in December 2014 were discriminated from other sampling months (Figure 4b; Table 2); water samples collected during this period was characterized by a higher dissolved oxygen (DO) concentrations (10.29 ± 2.244 mg/L). Water temperature plays an important role in determining the DO concentration by influencing the solubility of oxygen in water (Rajwa-Kuligiewicz et al., 2015). Several studies have shown that higher DO was observed in association with lower water temperature (Zaidi et al., 2015; Dienye & Woke, 2015). Discriminant analysis performed in this study indicated a negative correlation between DO concentration and water temperature. The lowest mean water temperature observed in December 2014 at all sampling sites (23.56 ± 1.226 °C) possibly increased the solubility of oxygen in the water bodies (Hosseini et al., 2017).

Water samples from the month with the lowest rainfall (March 2015) were discriminated from other sampling occasions with higher pH values and DOM concentrations (Figure 4b; Table 2). The seasonal variations of pH were mainly contributed by the water samples from the main river (MR), as other sampling stations exhibited relative consistency in pH values throughout the study period. Notably, pH in MR was as low as 5.79 indicating MR as having acidic river water characteristics (Table 1). The acidity of river water at Maliau Basin has been reported in previous studies carried out at Maliau River (Mykura, 1989), Eucalyptus River (Mokhtar et al., 2009), Giluk River and Takob-Akob River (Harun et al., 2010). The acidic river water recorded in this study could be caused by humic substances leached from vegetation in the heath forest zone as indicated in Figure 1 (Mykura, 1989; Hazebroek et al., 2004). Besides that, the main river (MR) was found to be associated with high values of a_{340}. UV-vis absorption coefficient at 340 nm was positively correlated with dissolved organic carbon (DOC), thus could indicate high dissolved organic matter (DOM) concentration (Figure 2). Consequently, the high concentration of DOM probably caused the acidity of river water at MR due to the acidic properties of most DOM (i.e. humic and fulvic acids found in organic contents) (Findlay & Sinsabaugh, 2003). Therefore, neutral pH values observed at MR during the low rainfall month (March 2015) could be due to low input of dissolved organic matter.

UV-vis absorption coefficients at 340 nm (a_{340}) displayed seasonal variations and the fluctuations patterns vary among sampling locations. Highest mean DOM concentrations were determined at both primary and secondary forests (PF and SF respectively) during the dry month (March 2015), while the lowest mean for DOM concentration was observed at altered habitat (AH) and the main river (MR) during the sampling occasion performed in the same month (Table 1). The result from this study indicated a higher concentration of DOM at PF and SF during the low rainfall month possibly due to the condensation process by evaporation. Research carried out by Aiken et al. (2011) revealed that a higher DOM concentration was associated with the dry month, primarily due to the evaporation of surface water, and lower concentration was commonly observed during the period of higher rainfall caused by dilution by rain water. Inversely, lower DOM concentration observed at AH and MR during the dry month may reflect low in-situ production of DOM (both allochthonous and autochthonous). Wantzen et al. (2008) stated that the primary source of organic matter in streams/rivers is plant litter from the riparian zone and the retentiveness capacity of leaf litter influences the organic decomposition rate. However, leaf litter data was not collected in this study, thus, we are not able to evaluate whether the density of leaf litter influenced the DOM concentration for both AH and MR. On the other hand, flow/discharge rate that determines the transportation of DOM from one locality to another might also influence the DOM concentration in the fluvial system (Larsen et al., 2010). Meanwhile, the flow and discharge rates are governed by liquid precipitation, canals, and groundwater discharge rates (Njogu & Kitheka, 2017). During the period with lower rainfall rate, the export of DOM might be reduced thus resulting in a lower concentration of DOM at both AH and MR during the dry month.

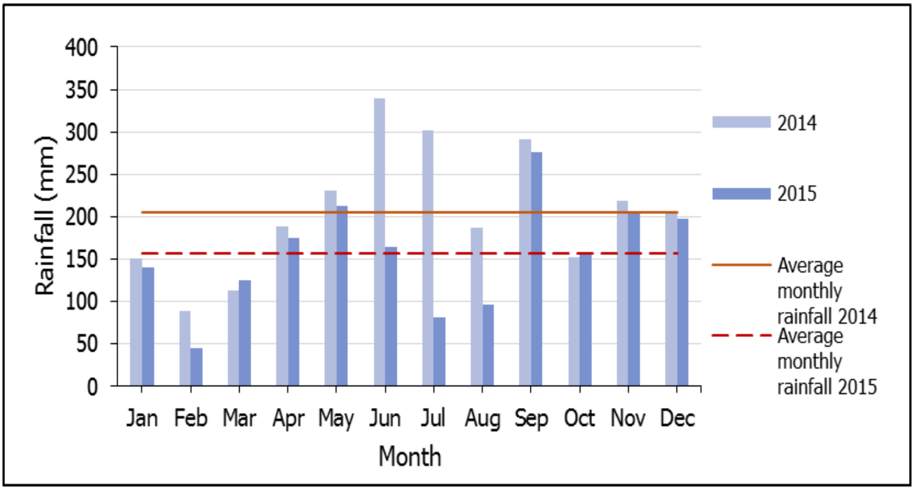

Figure 3. Monthly rainfall data recorded at the Maliau Basin from January 2014 to December 2015. (Source: Meteorological Centre of Maliau Basin Studies Centre, Sabah).

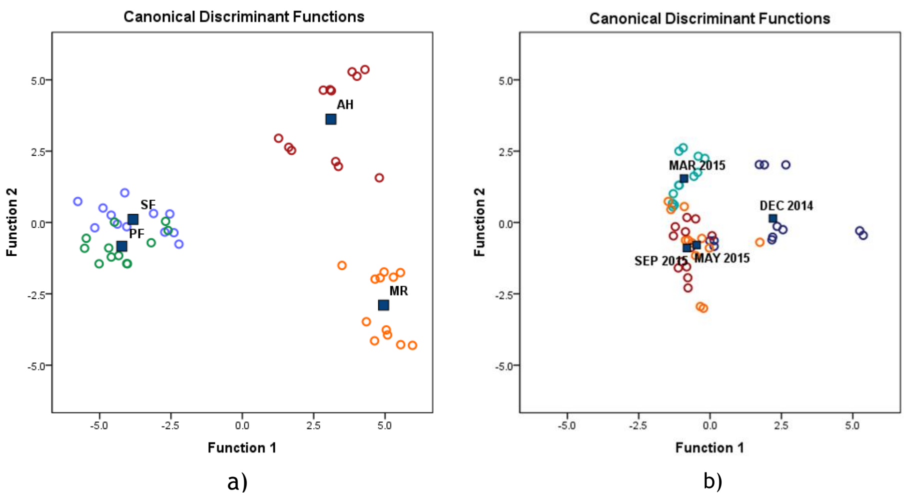

Figure 4. (a) Discriminant analysis functions for each type of land use at the Maliau Basin (PF - Primary forest, SF - Secondary forest, MR - Main river, and AH - Altered habitat). (b) Discriminant analysis functions for each sampling month (December 2014, March 2015, May 2015, and September 2015).

Table 2. Standardized canonical discriminant function coefficients, eigenvalue, cumulative percent of the variance, and Wilk's Lambda from the discriminant analysis that employed to examine the spatial and seasonal variations of water quality at Maliau Basin.

Variables	Spatial Variations		Seasonal Variations	
	DF1	**DF2**	**DF1**	**DF2**
pH	0.126	-0.004	-0.280	**1.200**
Temperature	**2.309**	-0.002	-0.546	-0.038
Conductivity	-0.729	**1.002**	0.558	0.469
Dissolved Oxygen (DO)	**1.038**	0.150	**1.065**	0.077
Total Suspended Solids (TSS)	**1.417**	0.237	-0.065	-0.127
a_{340}	**1.339**	-0.620	-0.210	**1.178**
$S_{275-295}$	0.033	-0.097	-0.213	-0.082
Eigenvalue	18.160	6.056	1.790	1.042
Cumulative % of Variance	74.3	99.1	46.7	73.9
Wilk's Lambda	0.006	0.117	0.088	0.244
(Sig. p)	(0.00)	(0.00)	(0.00)	(0.00)

Conclusions

Based on the surface water quality physico-chemical and optical assessment, we concluded that the water quality from all sampling stations at Maliau Basin was clean as indicated by most parameters, in accordance with the Interim National Water Quality Standards for Malaysia (INWQS). The water quality at PF and SF were categorized as Class I, thus suitable for conservation of the natural environment. However, our findings showed that the rivers located in the buffer zone of Maliau Basin (such as AH) are likely subjected to water quality deterioration. Both the physico-chemical and optical parameters demonstrated spatial and seasonal variations, where UV-vis absorbance a_{340} was dominant at the main river (MR), followed by primary forest (PF), secondary forest (SF) and altered habitat. Seasonally, the respective UV-vis absorbance was dominant during sampling in December 2014 and the least in March 2015. This also suggests that the quality of dissolved organic matter (DOM) varies in different types of land use, and is also altered by the monsoonal cycle. Significant positive correlation of UV-vis absorption coefficients at 254 and 340 nm with dissolved organic carbon (DOC) suggests its suitability as a proxy for DOC concentration in tropical regions. Consequently, further studies are needed to investigate the spatial and seasonal trends in surface water quality in catchments at Maliau Basin for a better understanding of this precious natural capital.

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