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Research Article

Spatial and seasonal variations in surface water quality of the Lower Kinabatangan River Catchment, Sabah, Malaysia

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Abstract
Surface water quality was examined to determine spatial and seasonal variations in the Lower Kinabatangan River catchment, Sabah, Malaysia between October 2004 and June 2005, during the weak La Niña event. The study sought to distinguish between the quality in surface waters draining from an oil palm plantation (OP), a secondary forest (SF) and an oxbow lake (OB); and to identify its seasonal variability. A total of 45 samples were collected during fieldwork campaigns that spanned over the inter-monsoonal period, wet and dry seasons. The Water Quality Index (WQI) was calculated and analysed based on the Malaysia Interim National Water Quality Standard (INWQS). Results show that the quality of the river fall into Class II or moderate level. Discriminant analysis (DA) has been employed to classify independent variables into mutually-exclusive groups. Suspended sediment (SS) and chemical oxygen demand (COD) parameters were found higher during the wet season. COD was found dominant in stream located within the oil palm plantation, whilst SS was dominant in oxbow lake. Surface water quality variations could be influenced by weak La Niña event in 2005/2006, as precipitation anomalies have been observed during the sampling campaign.

Keywords: The Lower Kinabatangan River Catchment, Water Quality Index (WQI), Malaysia Interim National Water Quality Standard (INWQS)

Introduction
In tropical regions, wetlands perform a number of globally significant ecosystem functions and are characterised by marked annual cycles in precipitation, rain periods, high solar radiation (Graneli et al., 1998; Hader et al., 1998; Saigusa et al., 2008) and diverse biological communities (Dudgeon, 2003; Junk, 2002). It is characterised as among the most productive landscapes

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due to intermittent enrichment from retention and import of nutrient-rich sediments from the upper streams and lateral sources (Davies et al., 2008). It is also marked by periodic inundation, which is a complex phenomenon caused by different water sources via various pathways (Tockner & Stanford, 2002). The seasonal pattern of flooding is one of the key drivers of productivity in wetlands and rates of primary production generally show a prominent degree of both spatial and temporal variations (Davies et al., 2008). For example, the effects of inundation and water level fluctuations are significant in the diversity and dispersal of floodplain vegetation in Amazon (Ferreira et al., 2010; Parolin et al., 2010).

The Kinabatangan River Catchment is one example of wetlands marked by seasonal inundation. It is the largest and longest river in Sabah, Malaysia (560 km) with a catchment area of 16,800 km^2 (Josephine et al., 2004). The area is frequently inundated and natural floodplain vegetation mainly comprises pristine lowland dipterocarp forest, while riverine and freshwater swamp forests, with some open reed swamp can be found at the estuary (Boonratana, 2000). The Lower Kinabatangan was subjected to commercial logging activities in the early 1950s until 1987 (Boonratana, 2000), and more than 60,000 ha of the lowland rainforest has been developed into cocoa and oil palm plantations (Boonratana, 2000). Approximately 26 % of the Kinabatangan catchment has been developed for oil palm plantations and is permanently cultivated mainly in the floodplain of the Lower Kinabatangan River catchment (Josephine et al., 2004).

The area has a humid tropical climate with mean daily temperatures ranging from 22°C to 32°C and mean annual rainfall varying between 2,500 and 3,000 mm (Boonratana, 2000; Josephine et al., 2004). The heaviest rainfall occurs during the northeast monsoon (between October and March), when the coastal plain and floodplain are widely inundated. Transition periods, defined as the inter-monsoonal season, normally occur in April and October. Under a normal monsoon cycle, Dambul & Jones (2007) observed the lowest rainfall during this period. However, during the El Niño Southern Oscillation (ENSO) years, this synoptic forcing originating from the Pacific Ocean can override normal monsoonal features, which in turn may reverse rainfall distribution (Sirabaha, 1998). For example, there has been a positive correlation observed between Southeast Asia rainfall anomalies (SEAR) and ENSO evolution (Juneng & Tangang, 2005). Therefore, there is a possibility of significant precipitation even during the dry season (Gazzaz et al., 2012; Suhaila et al., 2010).

This paper presents the trends of surface river water quality in the Lower Kinabatangan River Catchment, Sabah, which was conducted during the weak La Niña event and precipitation anomalies were observed. The water quality of streams from three types of land use (oil palm plantation, secondary forest and oxbow lake) are also addressed in this paper. Deforestation and land conversion to agriculture are known to affect riverine system such as nutrients fluxes (Wilson & Xenopolous, 2009). Conversion of rainforest to oil palm and cocoa plantations in Bukit Tekam, Pahang between 1977 and 1986 (Douglas, 1999) and Sabah (Jakobsen et al., 2007) was found to increase stream sediment loads and surface run-off and nutrients such as nitrogen and phosphorus. The objectives of the paper are to distinguish between surface water quality in waters draining from an oil palm plantation (OP), a secondary forest (SF) and an oxbow lake (OB), and to identify seasonal variations of the surface water quality.

Materials and Methods

Sampling and Analysis

Surface water quality were analysed in the downstream reaches of the Kinabatangan River, in Sabah, Malaysia. Sampling stations located in the Sukau area and included sites that were selected based on the three types of land use and their accessibility: Sg. Resang (05°32'906"N, 118°20'230"E) (oil palm plantation: OP), Sg. Lumun (05°32'542"N, 118°18'513"E) (secondary forest: SF) and Danau Kalinanap (05°30'544"N, 118°17'647"E) (Oxbow Lake: OB). Figure 1 illustrates the location of each sampling station at the Lower Kinabatangan River Catchment.

Water quality physico-chemical parameters (turbidity, total dissolved solids (TDS), pH, temperature, dissolved oxygen (DO) and conductivity) were measured *in situ* in October 2004, December 2004, February 2005, June 2005 and August 2005 by using a water quality meter (YSI 6000 model). Within each area, up to 45 samples were collected in 200 ml high-density-polyethylene (HDPE) bottles pre-washed with 10 % hydrochloric (HCl) acid and deionised water. Water samples were filtered immediately after sampling using a pre-combusted glass-fibre filter. Rainfall data for each month was obtained from the Meteorological Department in Kota Kinabalu, Sabah and presented in Figure 2. Rainfall anomalies were observed during the sampling campaign and investigated further by Cobb et al. (2007) in the relationship between large-scale climate variations, precipitation oxygen isotopic composition ($\delta^{18}O$) and cave dripwater $\delta^{18}O$ in northern Borneo.

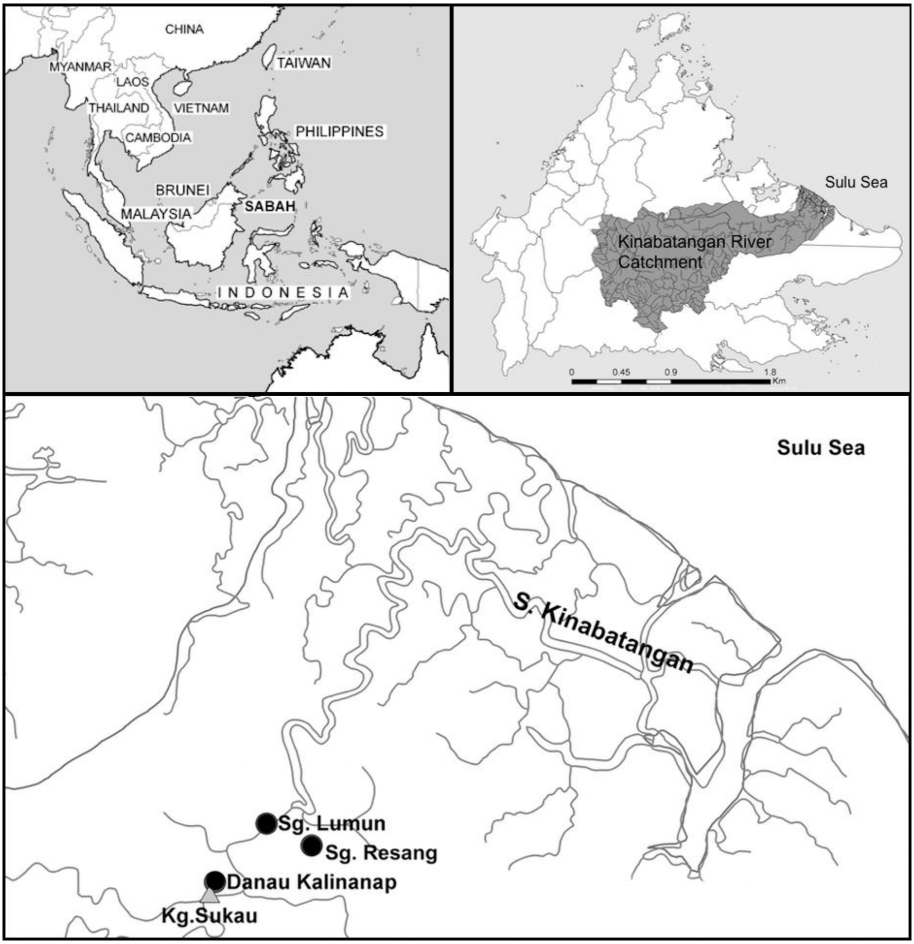

Figure 1. The location of each sampling station (circles) at the Lower Kinabatangan River Catchment.

At each sampling station, water samples were obtained at the surface. Ammonia nitrogen (NH_3^-N) and chemical oxygen demand (COD) were determined by using MERCK photometric test kits (Model Spectroquant NOVA 60). The other physico-chemical parameters such as suspended sediments (SS) and biochemical oxygen demand (BOD) were determined in the laboratory by gravimetric process and Winkler's method respectively.

Parameters for Water Quality Index (WQI) consisting of DO, BOD, COD, ammonia nitrogen, SS and pH were calculated based on a standard formula for each parameter (Department of Environment Malaysia, 2004):

WQI = 0.22(SIDO) + 0.19(SIBOD) + 0.16(SICOD) + 0.15(SIAN) + 0.16(SISS) + 0.12(SIpH)

where,
SIDO = Sub-index DO; SIBOD = Sub-index BOD; SICOD = Sub-index COD;
SIAN = Sub-index NH^{3-}N; SISS = Sub-index SS; and SIpH = Sub-index pH

Statistical Analysis

Multivariate statistical analysis of the surface water samples was employed by using discriminant analysis (DA). DA provides cluster analysis good results as a first explanatory evaluation of spatial and temporal differences, even though details of these differences are not showed (Gazzaz et al., 2012). It is also a multivariate statistical modeling application that can be used for classifying independent variables into mutually-exclusive groups. Discrimination between groups and minimisation of misclassification error rates resulted in linear combinations of the independent variables (Gazzaz et al., 2012; Varol et al., 2012).

Results and Discussion

Surface Water Quality

In general, the pH values for Sg. Resang and Sg. Lumun were low (Department of Environment Malaysia, 2009). This could be associated with the existence of

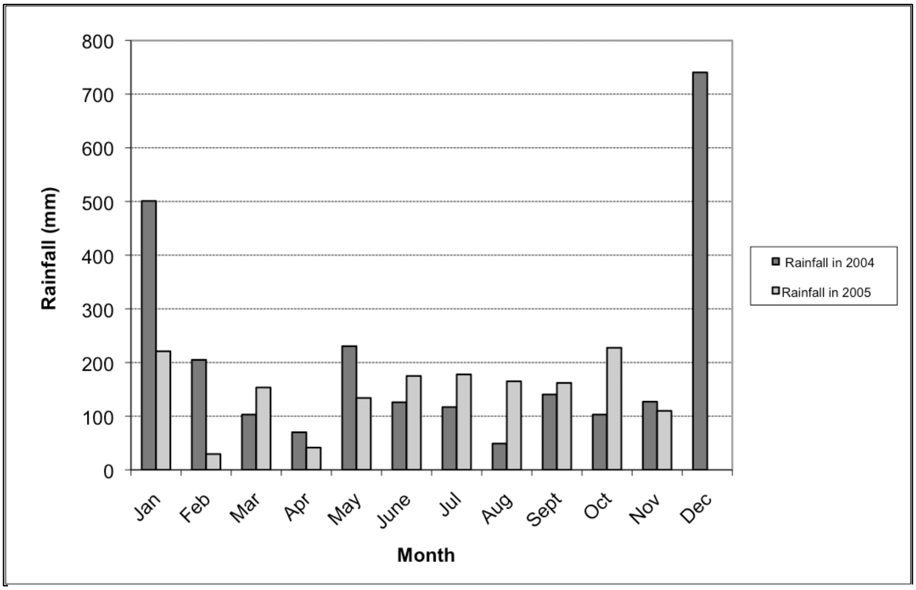

Figure 2. Monthly rainfall at the Kota Kinabatangan during the sampling programme. (Source: Meteorological Department, Kota Kinabalu, Sabah)

oil palm plantations at both sides and upstream of the river. The tendency for the trend of pH to increase with the existence of agricultural activities is partly attributed to runoff from improved grazing farmland that has been limed. Liming can change naturally acidic soils into moderate to high buffering capacity, and the effects of this can last 60 to 100 years (Giller & Malmqvist, 1998).

Figures 3(A-C) exhibit scattergram of DO and SS; BOD_5 and DO; and SS and conductivity. High SS has been found negatively correlated with dissolved oxygen (DO) (Figure 3A), and the results also showed inverse correlation between BOD_5 and DO. It was demonstrated that decreased level of dissolved oxygen in the water column positively correlated with phosphate release from suspended sediments and particles (Best et al., 2007). Surface water quality in Jakara River (Mustapha et al., 2012) and Lake Chad in Nigeria (Gwaski et al., 2013) also showed inverse relationship between BOD_5 and DO.

Spatio-Seasonal Variations

Table 1 presents the summary of the surface water quality data obtained at three sampling stations during the inter-monsoonal, wet and dry seasons. High rainfall has been observed in June and August 2005 during the dry season, while low amount of precipitation occurred in February 2005 (wet season).

In terms of seasonal variations, suspended sediment (SS) concentrations were significantly high at Danau Kalinanap (OB) during the wet season, which could be a result of the export of particulate matter into water bodies from sediment transport and erosion (Mustapha et al., 2012; Viers et al., 2009). Concurrently, high SS concentration at Sg. Lumun (SF) has also been found during the dry season (Table 1).

Interestingly, COD values were consistently high at all sampling stations during the wet season. This could be associated with active land development in this area, which could contribute to high amount of dissolved organic matter (DOM) (Josephine et al., 2004). In previous studies with almost similar setting, higher mean COD concentration during the wet season also was observed in Danjiangkou Reservoir, China (Li et al., 2009) and in the Lake of the Francesa, Brazil (mean: 36.6 mg/l) (Kimura et al., 2011). Inversely, high COD values during the dry season have been observed in other studies: Semarang, Indonesia (Mangimbulude et al., 2009); Pearl River Delta, China (Fan et al., 2012); and upper Ogun River in Nigeria (Adeogun et al., 2011).

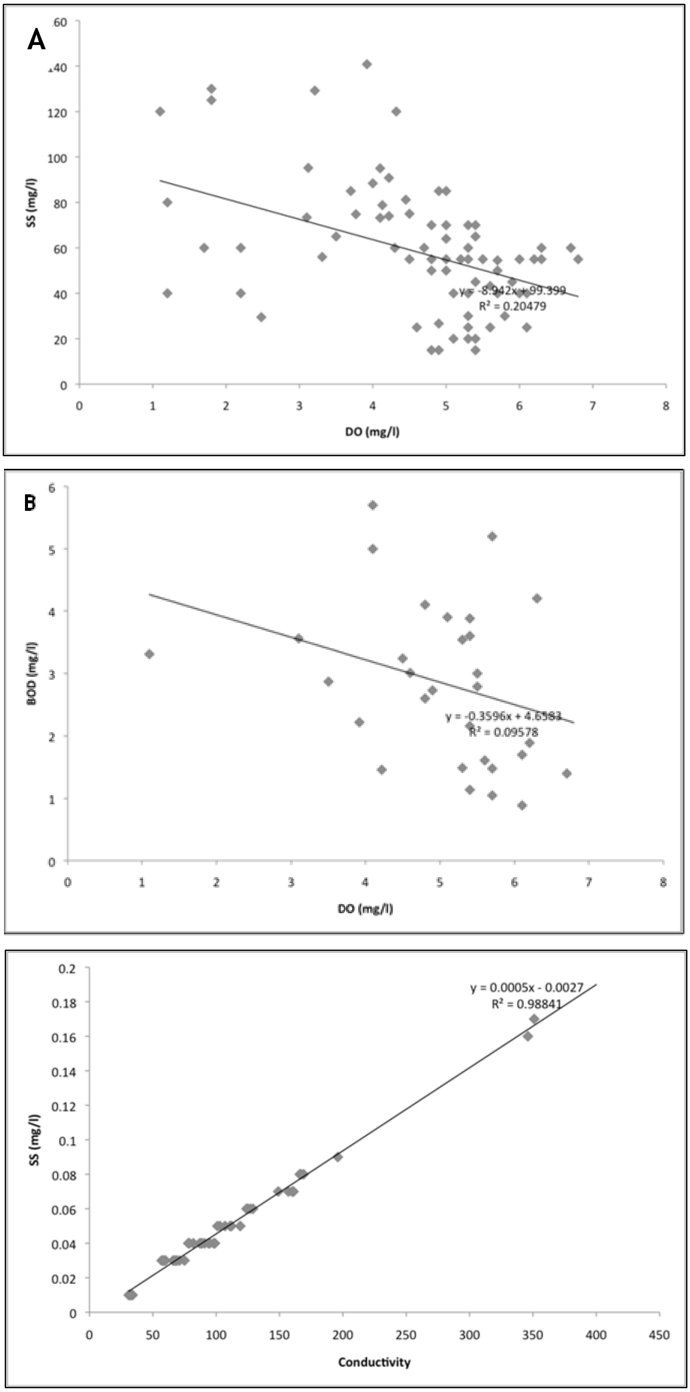

Figure 3. Scattergram. **A** DO and SS. **B** BOD and DO. **C** SS and conductivity.

Table 1. Summary of the surface water quality data in the Lower Kinabatangan River catchment during the inter-monsoonal, wet and dry seasons (standard deviation values in parentheses).

Sampling station	pH	DO (mg/l)	Temperature	TDS (mg/l)	Conductivity	Salinity	SS (mg/l)	AN (mg/l)	BOD (mg/l)	COD (mg/l)
Inter-monsoonal (Oct. 2004)										
Sg. Resang (OP)	5.3 (0.6)	6.1 (0.6)	27.4 (0.2)	134 (53.2)	206.8 (81.4)	0.10 (0.04)	47.0 (22.3)	0.46 (0.01)	**	**
Sg. Lumun (SF)	5.2 (0.1)	5.1 (0.4)	25.6 (0.0)	43 (0.3)	66.2 (0.4)	0.03 (0.0)	50.0 (22.0)	0.10 (0.02)	**	**
Danau Kalinanap (OB)	7.0 (0.1)	1.9 (0.5)	28.8 (0.1)	57 (0.4)	88.0 (0.9)	0.04 (0.0)	60.0 (15.1)	0.13 (0.03)	**	**
Wet season (Dec. 2004 and Feb. 2005)										
Sg. Resang (OP)	5.3 (0.6)	6.2 (0.4)	26.7 (0.5)	69 (6.3)	110.8 (11.8)	0.05 (0.01)	33.0 (13.9)	0.11 (0.06)	2.1 (0.9)	100.0 (8.7)
Sg. Lumun (SF)	5.8 (0.6)	5.6 (0.5)	25.4 (0.5)	34 (14.4)	52.9 (21.6)	0.01 (0.0)	49.0 (12.3)	0.05 (0.02)	3.2 (1.2)	51.4 (14.8)
Danau Kalinanap (OB)	6.7 (0.4)	3.6 (1.5)	27.1 (1.2)	50 (12.0)	76.9 (18.1)	0.03 (0.0)	96.0 (25.0)	0.11 (0.04)	3.1 (1.2)	45.8 (7.3)
Dry season (June and Aug. 2005)										
Sg. Resang (OP)	6.5 (0.1)	4.3 (1.6)	29.2 (0.4)	75 (15.5)	236.5 (124.1)	**	42.0 (16.8)	0.11 (0.04)	1.3 (0.4)	53.8 (21.3)
Sg. Lumun (SF)	6.7 (0.2)	3.5 (0.6)	27.9 (1.1)	60 (2.3)	175.3 (106.5)	**	75.0 (44.8)	0.26 (0.14)	2.9 (1.0)	36.8 (10.8)
Danau Kalinanap (OB)	6.6 (0.1)	4.1 (0.2)	29.0 (0.1)	61 (14.4)	180.9 (111.1)	**	49.0 (33.5)	0.13 (0.05)	3.6 (3.0)	35.1 (16.1)

** - Data not available

BOD values were the highest in OB during the dry season and also found higher in two sampling stations (OP and SF) during the wet season. BOD has been found positively correlated to organic pollution such as domestic sewage (Islam et al., 2012), and thus could indicate microbial activities in the water bodies (Nakamura et al., 2007; Pant & Adholeya, 2007). High level of BOD during dry season was exhibited in Kathmandu Valley, Nepal (Rutkowski et al., 2007), Pearl River Delta, China (Fan et al., 2012) and Chini Lake, Malaysia (Islam et al., 2012).

Conductivity values at all sampling stations were higher during the dry season, compared to the wet and inter-monsoonal season. Prathumratana et al. (2008) and Irvine et al. (2011) observed a similar result of high conductivity values at the lower Mekong River in Cambodia during the dry season. Lower conductivity during the high water period could be related to dilution of dissolved organic material released from the sediment bed (Irvine et al., 2011).

Variations for water quality physico-chemical parameters such as COD, BOD and SS from other studies were possibly affected by incongruent rainfall distribution with monsoons that determine wet and dry seasons. Monsoon and El Niño Southern Oscillation (ENSO) are the most influential forces modulating surface climate (Dambul, 2010). Studies on relationship between rainfall and ENSO variability in Indonesia and Malaysia have been carried out extensively (Aldrian & Susanto, 2003; Chang et al., 2004; Gomyo & Koichiro, 2009; Tangang & Juneng, 2004). Precipitation anomalies in Southeast Asia are found to be highly affected by the irregular ENSO-related sea surface temperature (SST) anomalies (Juneng & Tangang, 2005). For example, a weak La Niña event in 2005/2006 was found associated with precipitation anomalies in Mulu Cave, Sarawak (Cobb et al., 2007). Through these climatic evidences, there is a high possibility that surface water quality in the Lower Kinabatangan has been affected by such irregular events.

Spatial variations in this study presented by discriminant functions (Figure 4) exhibited that COD was dominant in sampling stations located in OP, whilst SS was negatively correlated with DO was dominant in the oxbow lake. This is reflected by high concentrations of suspended sediments in Danau Kalinanap particularly during the wet season. It could also be affected by semi-lotic characteristic of this oxbow lake, which has downstream connectivity (Glinska-Lewczuk, 2009), thus, allowing sediment transportation into the lake system.

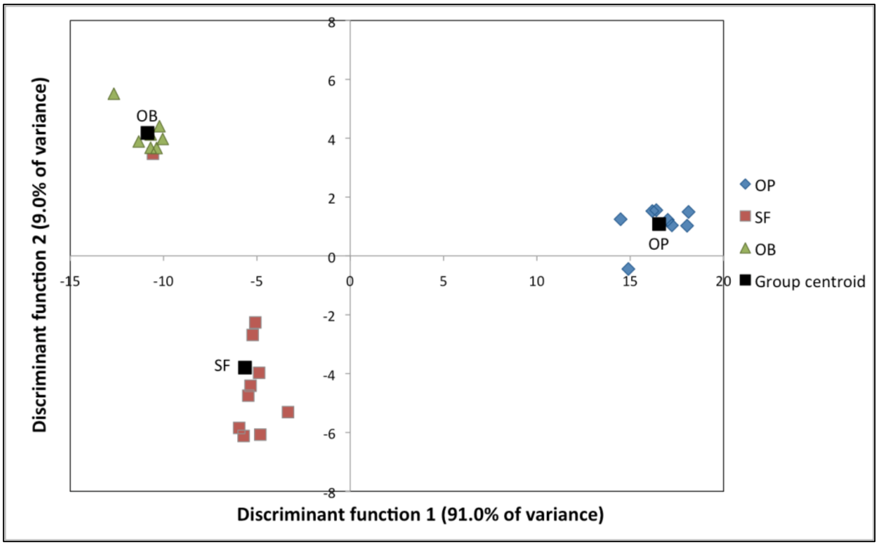

Figure 4. Discriminant analysis functions for each type of land use at the Lower Kinabatangan River catchment.

Water Quality Index (WQI)

The WQI of all sampling stations indicated that the river water quality is under Class II with slight pollution. The index values for each station are as follows: Sg. Resang (81.8), Sg. Lumun (81.9) and Danau Kalinanap (81.7) (Table 2).

Based on the suspended sediment result, the subindex value for all stations indicated that the river was slightly polluted. This is probably due to the existence of logging activities, which were carried out from 1952 to 1986 (Boonratana, 2000; Hutton, 2004). The subindex value for ammonia nitrogen (AN) for all stations reflects the water as slightly polluted. Sewage, fertilizers and agricultural waste have been identified as major sources of high ammonia nitrogen concentration in rivers and streams (Ballance, 1996). Similar results were obtained for Sg. Lumun, Sg. Kinabatangan and Danau Kalinanap where the subindex value for BOD was categorised as slightly polluted. BOD value for untreated palm oil mill effluent (POME) is 25,000 mg/l, which may cause severe effects to the aquatic system if discharged directly into the river (Ma, 1999). Currently, there are four oil palm mills located at the Kinabatangan area where effluents may be directly discharged into the river through man-made channels and to the ground (Department of Environment Malaysia, 2005). Subindex value for SS for stations Sg. Lumun, Sg. Kinabatangan and Danau Kalinanap were categorised as polluted. Basically, logging activities can contribute to the transportation of water and sediment into river systems.

Table 2. Water Quality Index (WQI) for each sampling site.

WQI Subindex	**Sg. Resang (OP)**	**Sg. Lumun (SF)**	**Danau Kalinanap (OB)**
SIDO	100	100	100
SIBOD	91.8	87.0	84.9
SICOD	36.3	50.8	55.9
SISS	77.9	68.2	60.0
SIAN	85.6	85.3	88.0
SIpH	93.2	96.3	98.7
WQI	**81.8**	**81.9**	**81.7**

Deforestation and poor cultivation pratices of catchments, particularly in the upper reaches were identified as main factors leading to the increment of sediment loads within rivers in Malaysia and throughout Southeast Asia (Pringle & Benstead, 2001).

Conclusions

Based on the surface water quality physico-chemical assessment, it is concluded that the quality of all sampling stations at the Lower Kinabatangan River Catchment are at a moderate level. The results suggest that waters draining from oil palm plantation have the highest COD during the wet season. The physico-chemical parameter is possibly influenced by agricultural activities and the sampling period, either in the wet or dry seasons. The weak La Niña event in 2005/2006 could have played a significant factor in determining the surface water quality as this ENSO forcing can override monsoon’s normal features. Further studies are urgently needed to investigate any spatial and seasonal trends in surface water quality in catchments such as the Lower Kinabatangan River Catchment.

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