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Assessing the Bottom Water Quality of a Ramsar Site Subjected to Anthropogenic Disturbances: A Case Study in Kuching Wetland National Park, Sarawak, Malaysia

(Penilaian Kualiti Air Bahagian Dasar Tapak Ramsar Disebabkan Gangguan Antropogenik: Suatu Kajian di Taman Negara Tanah Bencah Kuching, Sarawak, Malaysia)

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ABSTRACT

Recently the interest of public and stakeholders were focus on the environmental status of Kuching Wetland National Park (KWNP) due to the increase of urbanization processes and anthropogenic activities. A field sampling which covered 10 stations was conducted at the outer and inner boundary of KWNP in August 2011 during high tide. Physico-chemical water parameters were recorded. Triplicate of near bottom water samples were collected using 2.5 L Van don water sampler (Wildco®) for further analyses of nutrient, chlorophyll a *(chl* a*), biological oxygen demand (BOD) and total suspended solids (TSS). The aimed of the study were to assess the water quality of KWNP and to determine the distribution pattern of physico-chemical components and its relationship to the phytoplankton chlorophyll* a *concentrations in water between the outer and inner part of KWNP. One-way analyses of similarity indicated that all the study sites were significantly different between stations (*p*-value < 0.05) and boundaries (*p*-value < 0.05). Water temperature, pH, ammonium nitrogen (NH4–N) and inorganic phosphorous (Inorg–P) were known affecting the abundance of phytoplankton communities. The concentrations of nitrate nitrogen (NO_3–N) at the outer and inner boundaries of KWNP were over-ranged as compared to Malaysia marine standards.*

Keywords: Anthropogenic; chlorophyll a*; Malaysia; nutrients; Ramsar; water quality*

ABSTRAK

Kebelakangan ini perhatian orang awam serta pihak berkepentingan tertumpu kepada status alam sekitar di kawasan Taman Negara Tanah Bencah Kuching (TNTBK). Ini disebabkan oleh peningkatan proses perbandaran dan aktiviti antropogenik di kawasan tersebut. Kerja lapangan merangkumi 10 stesen telah dijalankan pada waktu air pasang di bahagian luar dan dalam TNTBK pada 11 Ogos 2011. Komponen fiziko-kimia air telah direkodkan. Tiga botol sampel air berdekatan bahagian dasar telah diambil dengan menggunakan penyampel air Van don (Wildco®) untuk analisis nutrien, klorofil a *(chl* a*), permintaan oksigen biokimia (BOD) dan jumlah pepejal terampai (TSS). Tujuan kajian ini ialah untuk menilai kualiti air dan menentukan hubungan antara corak taburan komponen fiziko-kimia air dengan kepekatan klorofil* a *fitoplankton pada bahagian luar dan dalam TNTBK. Analisis kesamaan satu hala menunjukkan bahawa terdapat perbezaan signifikan (nilai-*p*<0.05) antara stesen bagi semua tempat kajian. Suhu air, pH, ammonium nitrogen (NH4-N) dan fosforus bukan organik (Inorg-P) didapati telah menjejaskan komuniti fitoplankton. Kepekatan nitrogen nitrat (NO_3-N) di sempadan luar dan dalam TNTBK didapati telah melebihi paras yang dibenarkan oleh Piawai Marin Malaysia.*

Kata kunci: Antropogenik; klorofil a*; kualiti air; nutrien; Ramsar; Malaysia*

INTRODUCTION

Estuarine had been well known by their high biological productivity, presence of economically value, and intensive human activities (Boyes & Elliott 2006; Braga et al. 2000). For decades, lots of studies had determined the impacts of anthropogenic activities such as urbanization (Rodrigues et al. 2009; Wang et al. 2007), reclamation (Martin et al. 2008), aquaculture (Bui et al. 2012; Xie et al. 2004), deforestation (Khan & Ansari 2005; Meng et al. 2008) and runoff (Brodie et al. 2012; Whitall et al. 2010) on the estuarine and coastal systems. Bottom water is known to have a direct influence on the community structure of the benthic organisms which direct/indirectly contribute to the changes in food-web structure and functioning over time. A preliminary survey carried out by Chen et al. (2012) in ten Sarawak estuaries had suggested the importance of water qualities on the community structure of meiobenthos. In most of the cases, poorly flushed waters where the anthropogenic nutrient inputs can lead to algal blooms and hypoxia or anoxia in the bottom water due to the increase of organic matter (Cloern 2003; Xu et al. 2011).

The Kuching Wetland National Park (KWNP) is located inside a much larger area known as Sarawak Mangrove Forest Reserve (SMRF) which was gazetted in 1924 to control the harvesting of mangroves. It covers an area of 17153 ha and had been gazatted as a totally protected area (TPA) in 2002 which is also known as the present KWNP. In 2005, KWNP was listed as the first RAMSAR wetland in

Sarawak (5th in Malaysia). Basically, KWNP consists of two main rivers: Salak River (eastern boundary) and Sibu River (western boundary). These two rivers are interconnected at several locations and almost the entire lengths of the two rivers are brackish. KWNP is mostly covered with mangrove and the remaining parts are nipah palms. The tidal range in the area is relatively high (up to 5 m) (IBEC 2010). Several villages such as Kampung Semariang, Kampung Salak, Kampung Sibu and Kampung Telaga Air are located at the boundary of KWNP (Figure 1). An ongoing highway construction project is located at the boundary of KWNP together with a flood diversion channel that constructed through KWNP into Salak River. Moreover, a 3000 acres of the KWNP located near to Salak River had been used as waste/dredged soil dumping site (IBEC 2010). The intensive ongoing anthropogenic activities have attracted the concern of the government agencies, researchers and local communities regarding the disturbances that potentially contributed to KWNP.

The aims of the present study were to assess the water quality of KWNP; determine the distribution pattern of physicochemical components in water between the outer and inner part of KWNP; indicate the changes of phytoplankton chlorophyll *a* (chl *a*) concentrations subjected to physicochemical components in water and quantify the environment status of both outer and inner of KWNP.

Materials and Methods

Field Sampling and Laboratory Analyses

A field sampling which covered 10 stations was conducted at the outer and inner boundary of KWNP in August 2011 during high tide (Figure 1). The location of the study stations was recorded using the global positioning system (GPSMAP®76CSx, Garmin). Depth of each study station was determined using the depth finder (PS-7, Hondex). Secchi disc was used to measure the transparency level of the study stations. Measurement of pH, salinity, temperature and dissolved oxygen (DO) were done using Eutech multiprobe (PCD650). Triplicate of near bottom water samples were collected using 2.5 L Van don water sampler (Wildco®) for further analyses of nutrient, chlorophyll *a* (chl *a*), biological oxygen demand (BOD) and total suspended solids (TSS). Water samples were kept in acid cleaned and pre-rinsed polythene bottle. The water samples were preserved in cooler boxes filled with ices which later were taken to the laboratory.

BOD_5 were conducted in the dark where the initial DO had been recorded and the samples were kept in the dark (20°C) for 5 days prior to the second reading. TSS were determined by filtering adequate seawater through pre-weighed GF/C glass microfiber filters (Whatman) using a vacuum pump prior to oven dry. Phytoplankton chl *a* was determined using spectrophotometric method where the water samples were filtered through a Whatman GF/C glass micro- fiber and extraction in 90% aqueous acetone for 24 h at 4°C in the dark prior to the reading of absorbance. The filtered water samples were used to determine the dissolved nutrients (NH_4-N, NO_2–N, NO_3–N, Org –N, Inorg – P and Org –P) using the spectrophotometric methods described in APHA, AWWA and WEF (1998). All the absorbance of the sample was measured by using spectrophotometer (UV-160, SHIMADZU). A five-point calibration curve was constructed for each element. Blank and standard solutions were treated in a similar way as sample.

Data Analysis

The data were analyzed in order to compare the physciochemical component of the water between both stations and boundaries; cluster the study stations according to the similarities in water quality and determine the environmental factors that affected the phytoplankton chl *a* concentration of the studied stations.

Two tests of one-way analysis of similarity were conducted on the environment parameters (between stations and boundaries) with the resemblance on Euclidean distance (Clarke & Gorley 2006) which is defined as:

$$D = \sqrt{\sum_i \left(y_{y1} - y_{i2}\right)}.$$

All the environmental variables were subjected to normalization prior to the resemblance. The results of the analysis were subjected to the acceptance or rejection of the H_o at the significant level of $p = 0.05$. The purpose of conducting these tests was to determine whether the environment condition differed significantly between both stations and boundaries.

All the physicochemical components (Table 1 and Figure 2) were obtained and analyzed using principal component analysis (PCA) in order to gain knowledge on the distribution of environmental variables by detecting similarities and differences between data (Clarke & Warwick 2001). PC1 is the axis which maximises the variance points projected perpendicularly to it; PC2 is constrained to be perpendicular to PC1, but chosen as the direction in which the variance of points projected perpendicularly onto it is maximised; and PC3 is the axis perpendicular to both PC1 and PC2. The total of the variances along all PC axes is equal to the total variance of points projected successively onto each of the original axes (Clarke & Warwick 2001). BioEnv had been conducted using the physicochemical (*in situ* and *ex situ*) and the concentration of chl *a* using Spearman rank correlation (Clarke & Gorley 2006):

$$\rho^s = 1 - \frac{6}{n\left(n^2 - 1\right)} \sum_j \left(r_{1j} - r_{2j}\right)^2,$$

to determine the best pairing or combination of the environment variables contributed to the chl *a* concentration.

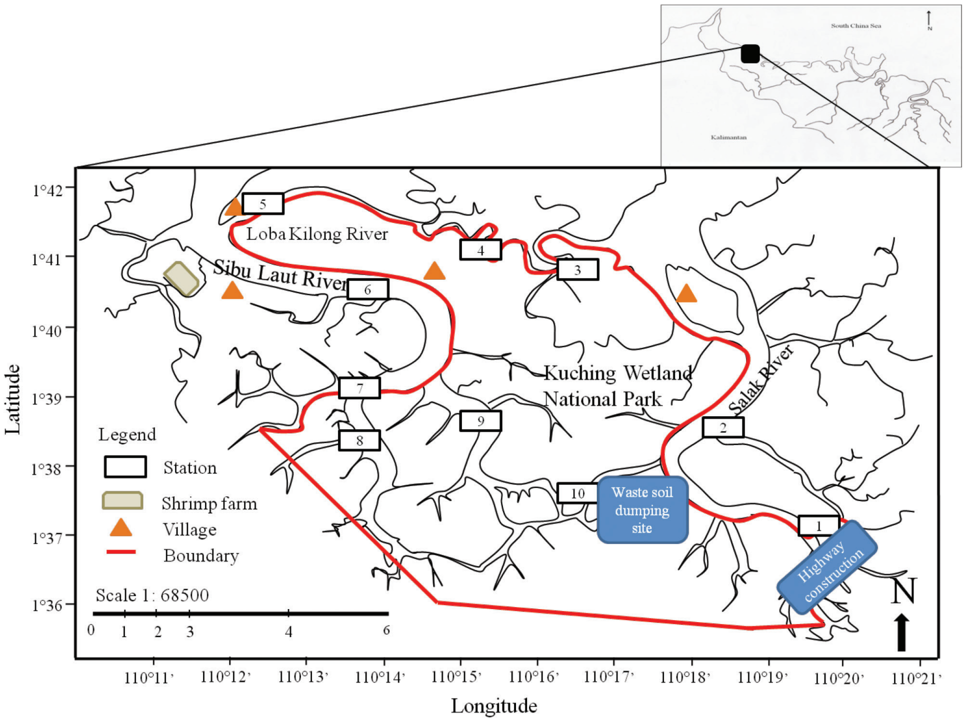

FIGURE 1. The location of the 10 sampling stations

RESULTS

PHYSICOCHEMICAL PARAMETERS

Results of the one-way analyses of similarity indicated that all the study sites were significantly different between stations (r = 0.995; p-value < 0.05) and boundaries (r = 0.177; p-value < 0.05). We analyzed the recent status of water quality with the values of average and standard deviation such as depth, transparency, salinity, pH, temperature, DO, turbidity, chl a, TSS, NH_4 -N, NO_2 –N, NO_3 –N, Org –N, Inorg –P and Org –P of ten study stations which located at the outer and inner boundary of KWNP (Table 1 and Figure 2). Low levels of visibility were observed in station 1, 2, 3 and 5 (0.49 - 0.73 m) compared with the stations that located in KWNP (0.9 - 2.35 m). Upper stream station (station 1) was recorded with the lowest salinity (25 ± 0.0 PSU). The pH of the study stations were within the range of 7.45-8.68. High concentrations of DO were recorded in the river mouth stations (station 3, 5 and 6) within the range of 6.45–7.63 mg/L. The highest turbidity reading was recorded in station 5 followed by station 2 and 1 (17.38±1.94 mg/L; 12.21±0.23 mg/L; 11.08±1.23 mg/L, respectively).

Stations 1, 3, 5 and 8 were recorded with high concentration of NH_4 –N (Figure 2(a)) while the highest was recorded in station 1 (0.097±0.027 mg/L). A total of

TABLE 1. Results of the *in situ* physico-chemical parameters (mean ± standard deviation)

Station	Location	Depth (m)	Transparency (m)	Salinity (PSU)	pH	Temperature (°C)	DO (mg/L)	Turbidity (NTU)
S1	Boundary	2.00 ± 0.10	0.50 ± 0.00	25.00 ± 0.00	7.58 ± 0.00	29.70 ± 0.00	5.24 ± 0.03	11.08 ± 1.25
S2	Boundary	1.23 ± 0.06	0.63 ± 0.00	28.00 ± 0.00	7.82 ± 0.01	30.40 ± 0.10	5.93 ± 0.04	12.21 ± 0.23
S3	Boundary	1.87 ± 0.15	0.73 ± 0.00	29.00 ± 0.00	8.13 ± 0.02	30.77 ± 0.06	6.54 ± 0.01	9.54 ± 0.11
S4	KWNP	1.87 ± 0.06	0.90 ± 0.00	30.00 ± 0.00	7.70 ± 0.00	29.20 ± 0.00	4.91 ± 0.03	9.13 ± 0.23
S5	Boundary	2.30 ± 0.10	0.49 ± 0.00	33.00 ± 0.00	8.66 ± 0.00	30.10 ± 0.00	6.45 ± 0.04	17.38 ± 1.94
S6	Boundary	3.73 ± 0.06	2.13 ± 0.00	33.33 ± 0.57	8.68 ± 0.00	30.33 ± 0.06	7.63 ± 0.03	6.92 ± 0.27
S7	Boundary	9.93 ± 0.06	1.46 ± 0.00	28.33 ± 0.57	7.91 ± 0.00	30.13 ± 0.06	5.14 ± 0.02	5.25 ± 0.08
S8	KWNP	4.60 ± 0.30	2.35 ± 0.00	31.00 ± 1.00	8.00 ± 0.00	29.80 ± 0.00	5.74 ± 0.03	4.95 ± 0.39
S9	KWNP	6.83 ± 0.15	1.30 ± 0.00	31.00 ± 0.00	7.75 ± 0.01	30.30 ± 0.00	4.80 ± 0.04	6.18 ± 0.48
S10	KWNP	1.97 ± 0.06	1.10 ± 0.00	30.00 ± 0.00	7.45 ± 0.01	29.60 ± 0.00	4.75 ± 0.02	3.74 ± 0.52

* TDS – Total dissolved solids; DO – dissolved oxygen

0.02±0.001 mg/L of NO_2 –N was recorded in station 2 compared to stations 6, 7 and 9 (Figure 2(b)). Overall, high NO_3 –N concentration was recorded in all the study stations (0.35 - 0.53 mg/L). Most of the stations' Org –N were observed within the range of 0.30 – 0.46 mg/L except station 3 (1.91±0.03 mg/L). In contrast, low concentrations of phosphorus (P) were recorded during the study compared to nitrogen (N). Dissolved Inorg –P (DIP) was recorded highest in station 10 with a total of 0.007±0.000 mg/L followed by station 5 and 2 (Figure 2(e)). Higher Org –P was observed in the samples compared to DIP. Station 8 recorded with 0.023 ± 0.001 mg/L of Org –P followed by stations 10 and 3 (Figure 2(f)). Stations located in Salak River (station 1, 2 and 3) were recorded with high organic matter compared to the others (Figure 2(g)). The organic matters in both Loba Kilong River and Sibu River were recorded within the range of 0.83–1.18 mg/L. Stations 2 and 5 were noted with high TSS contents (67.4±14.6 mg/L; 75.1±6.4 mg/L, respectively) while the lowest was observed in station 8 (23.57±1.2 mg/L). The highest chl *a* concentration was recorded in station 1 (2.16 mg/m^3) (Figure 2(i)). Most of the remained stations were having chl *a* concentration ranged between 1.00 and 1.52 mg/m^3 except stations 4 and 10.

Figure 3 shows the distribution pattern of physicochemical variables between the study stations. A 3D PCA with a cumulative variation of 72.1% had been generated from the results of *in situ* and *ex situ* physic-chemical parameters (Figure 3). The results of the analysis indicated only 31.7% of variation in principle component 1 followed by a cumulative of 58.6% in principle component 2. Generally, result of the average cluster analysis (Figure 4) indicated that the study stations could be grouped into three main groups (represent by the ellipse in Figure 3). Stations 1, 2 and 3 which located along Salak River had been clustered as a group indicated similarities in higher organic matter, NH_4 –N, and NO_2 –N, concentrations compared to the others. Station 5 which independently categorized as a group was recorded with the highest turbidity reading and TSS while remain stations (4, 6, 7, 8, 9, 10) were all pooled as group three. The results indicated that stations 4, 6, 7, 8, 9 and 10 had similarities in lower turbidity, organic matter, NO_2 –N, and TSS compared to the others. In addition, group three could be sub-divided into two groups (represented in the dashed ellipses in Figure 3). In comparison, station 4, 8, and 10 were found to have higher concentrations of NH_4 –N, NO_2 –N, Inorg –P and Org –P compared to Station 6, 7 and 9.

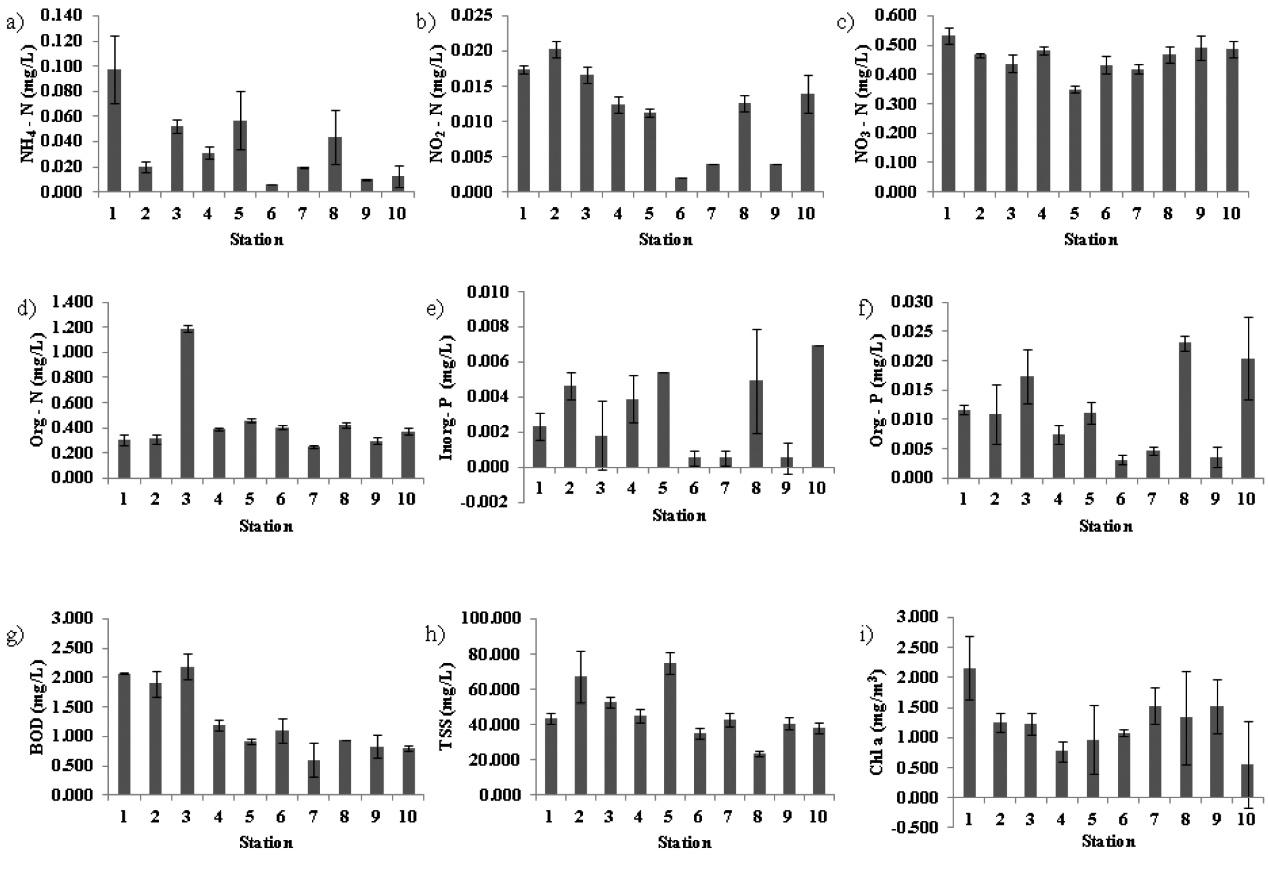

FIGURE 2. Results of environment parameters: NH_4 –N, NO_2 –N, NO_3 –N, Org –N, Inorg –P, Org –P, BOD, TSS and Chl *a* (mean ± standard deviation) in each study station

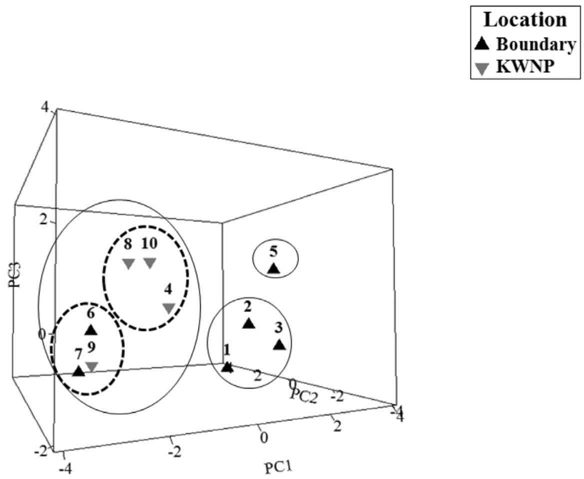

FIGURE 3. Principal component analysis derived from the environment parameters in each study site. PC 1, 2 and 3 accounted for 72.1% of the total variation present

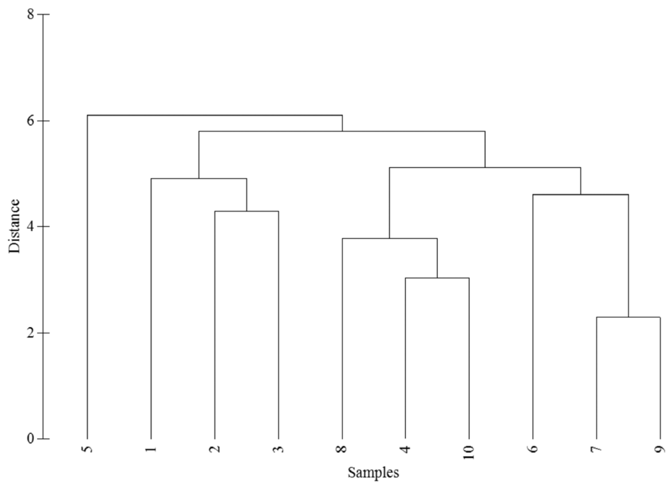

FIGURE 4. Dendogram produced by cluster analysis showing the similarity between the 10 study stations

CORRELATIONS

Stations located at the boundary of KWNP indicated that depth was positively correlated with transparency and pH but negatively correlated with turbidity, BOD, NO_2 –N, NO_3- N, Inorg –P, Org –P and TSS. Temperature was found positively correlated to transparency (correlation = 0.46). The pH of water was positively correlated with depth and salinity (correlation = 0.46; 0.96, respectively). Positive correlation was recorded between temperature and transparency (Table 2). Salinity, pH, temperature and Org –N were all positively correlated with DO. Oppositely, turbidity and BOD were negatively correlated with depth, transparency, salinity and pH (Table 2). NH_4 –N was negatively correlated to most of the parameters except turbidity and BOD, NO_2 –N and Org –P. In addition, NO_2 –N had shown high negative correlation with depth, transparency, salinity and pH (-0.91; -0.64). Generally, most of the nutrients (both N and P) were negatively correlated with *in situ* parameters except turbidity. The Org –N was recorded to be positively correlation with salinity, temperature, pH and DO. Lastly, TSS was positively correlated with turbidity, NO_2 –N, Inorg –P and Org –P (0.74, 0.59, 0.81 and 0.65, respectively) except for transparency and depth.

In comparison, stations located at KWNP had a distinctive pattern of correlation compared with the boundary stations where depth, transparency, salinity, pH and temperature were positively correlated between each other (Table 3). Meanwhile, DO was found positively correlated with pH, BOD, NH_4 –N and Org –N (Table 3). Turbidity showed a negative correlation with both organic and inorganic P yet positively correlated with BOD and TSS. An increasing of depth and temperature indicated a decreasing of BOD (Table 3). NH_4 –N was positively correlated with DO, BOD and Org –N while NO_2 –N was negatively correlated with depth, salinity and temperature. Negative correlation was indicated between NO_3- N and NH_4 –N. Both organic and inorganic P was positively

TABLE 2. Correlation matrix of water quality parameters - boundary

	Depth	Transparency	Salinity	pH	Temperature	DO	Turbidity	BOD	NH_4 -N	NO_2 -N	NO_3- N	Org -N	Inorg -P	Org -P	TSS
Depth	1.00														
Transparency	0.45*	1.00													
Salinity	0.38	0.25	1.00												
pH	0.46*	0.37	0.96**	1.00											
Temperature	-0.33	0.46*	0.37	0.36	1.00										
DO	-0.08	0.25	0.73**	0.76**	0.59**	1.00									
Turbidity	-0.57**	-0.89**	-0.04	-0.15	-0.22	0.07	1.00								
BOD	-0.77**	-0.23	-0.40*	-0.43*	0.25	0.15	0.29	1.00							
NH_4 -N	-0.31	-0.75**	-0.40	-0.42*	-0.46*	-0.32	0.53*	0.40*	1.00						
NO_2 -N	-0.91**	-0.57**	-0.64**	-0.73**	0.09	-0.27	0.53*	0.68**	0.43*	1.00					
NO_3- N	-0.50*	0.00	-0.70**	-0.71**	-0.11	-0.30	-0.05	0.56**	0.19	0.55**	1.00				
Org -N	-0.27	-0.16	0.58**	0.58**	0.51*	0.794**	0.34	0.32	0.14	-0.02	-0.39	1.00			
Inorg -P	-0.57**	-0.78**	-0.04	-0.20	-0.12	-0.05	0.82**	0.16	0.34	0.61**	0.01	0.19	1.00		
Org -P	-0.68**	-0.55**	-0.30	-0.36	0.22	-0.02	0.49*	0.52*	0.64**	0.69**	0.27	0.36	0.49*	1.00	
TSS	-0.57**	-0.72**	-0.03	-0.14	0.13	-0.07	0.74**	0.11	0.39	0.59**	-0.21	0.32	0.81**	0.65**	1.00

**. Correlation is significant at the 0.01 level
*. Correlation is significant at the 0.05 level

TABLE 3. Correlation matrix of water quality parameters - KWNP

	Depth	Transparency	Salinity	pH	Temperature	DO	Turbidity	BOD	NH_4 -N	NO_2 -N	NO_3- N	Org -N	Inorg -P	Org -P	TSS
Depth	1.00														
Transparency	0.76**	1.00													
Salinity	0.80**	0.70**	1.00												
pH	0.61*	0.79**	0.69**	1.00											
Temperature	0.96**	0.80**	0.78**	0.59*	1.00										
DO	-0.02	0.36	0.27	0.66*	-0.06	1.00									
Turbidity	-0.11	-0.39	0.02	0.20	-0.19	0.33	1.00								
BOD	-0.58*	-0.39	-0.23	0.06	-0.59*	0.53*	0.60*	1.00							
NH_4 -N	-0.34	0.09	-0.06	0.42	-0.28	0.73**	0.26	0.59*	1.00						
NO_2 -N	-0.58*	-0.20	-0.66**	-0.26	-0.57*	-0.02	-0.34	0.20	0.21	1.00					
NO_3- N	0.09	-0.12	0.13	-0.22	-0.02	-0.14	0.01	-0.16	-0.54*	0.04	1.00				
Org -N	-0.42	0.15	-0.26	0.18	-0.39	0.65*	-0.17	0.30	0.63*	0.39	-0.37	1.00			
Inorg -P	-0.56*	-0.14	-0.62*	-0.45	-0.49	-0.13	-0.63*	-0.06	0.14	0.79**	-0.03	0.42	1.00		
Org -P	-0.34	0.26	-0.28	-0.05	-0.26	0.32	-0.66**	0.04	0.35	0.59*	-0.17	0.77**	0.74**	1.00	
TSS	-0.32	-0.73**	-0.24	-0.40	-0.35	-0.31	0.65*	0.48	-0.13	-0.24	-0.06	-0.44	-0.44	-0.63*	1.00

**. Correlation is significant at the 0.01 level
*. Correlation is significant at the 0.05 level

correlated with NO_2 –N (Table 3). TSS showed negative correlation to most of the parameters except for turbidity (0.65).

Besides that, the results of the BioEnv using Spearman correlation subjected to Euclidean distance noted that several physicochemical parameters were influencing the growth of the phytoplankton (indicating using chl *a* concentration). Water temperature, pH, NH_4 –N and Inorg –P were known to affect the abundance of phytoplankton (correlation: 0.522; *p*-value: 0.03).

Discussion

THE MAGNITUDE OF NUTRIENTS IN WATER

Expectedly, *in situ* and *ex situ* physicochemical parameters were different between stations. At the western boundary of KWNP, station 1 (upper river) which located near to Semariang Village and the highway construction site (Fig. 1) was recorded with low transparency and salinity but having high concentration of turbidity, chl *a* and nutrients (ammonium, nitrite, nitrate and organic matter). Low visibility is suspected due to the high turbidity which probably contributed by the urbanization (highway construction) nearby. The erosion of the soil subjected to the deforestation and also the re-suspension of the bottom sediments potentially increases the turbid condition of the water. An increasing of human activities associated with the population expansion and urbanization such as deforestation and soil erosion shown negative impacts to the river system and coastal environments (Meng et al. 2008). Besides that, high chl *a* concentration was recorded in station 1 indicated high abundance of phytoplankton. The increase of the phytoplankton production (chl *a* concentration) also potentially decrease the transparency level of water (Yusoff et al. 2002).

In wastewater, nutrients are abundant as phosphates, nitrates, and ammonium or combined organic nitrogen (Khan & Ansari 2005). High organic matters were recorded along Salak River (stations 1, 2 and 3). Treated and untreated municipal wastes (i.e excess food and household wastewater) are often dumped directly into the nearby river-system directly influent the water quality (Wang et al. 2007). The highest readings of nitrite had been recorded in station 2 which located outside the soil dumping site. In comparison to the other two stations that located along Salak River, station 2 had the highest concentration of DIP, TSS and turbidity but lowest concentration of ammonium. The highest turbidity and TSS of station 2 probably indicated the direct impact of soil erosion from the soil dumping site nearby. High organic matter and organic nitrogen were detected in the river mouth station (station 3 - mangrove forest) with a small village nearby. The statistical results in Table 2 suggested that organic matter was positively correlated to the nutrients. Both domestic discharges together with the tidal influence potentially increased the organic matter and nutrients. The mangrove ecosystem is more dynamic, fragile, unique and complex where the plant and environmental factors interact in the process of energy fixation, accumulation of biomass, decomposition of dead organic matter and in nutrient recycling (Islam et al. 2004). Generally, high organic matter, both suspended and dissolved, resulting in high biological oxygen demand (BOD). The hydrodynamic forces during the tidal phenomenon were suspect not only aerates the water but also accumulated the organic matter and nutrients from the upper river during low tide. In a study carried out by Prahl et al. (1997), it was indicated that organic matter contribution from the ocean was minor compared to the river. DO was found closely correlated with salinity, pH, temperature and dissolved organic nitrogen (DON). The increase of pH and salinity potentially indicated the geographical location of the sampling station (river mouth) therefore, expose to greater hydrodynamic forces. Station 5 which located near to the river mouth was recorded with the highest turbidity and TSS potentially due to the disturbances caused by the daily activities of the villagers nearby together with the influence of the tidal events. Most of the stations along Sibu River showed high transparency and low turbidity. Anthropogenic activities such as fishing and transportation along Loba Kilong River probably increased the re-suspension rate of the bottom sediments into the water column which directly increased the turbid condition of the station. During the survey, stations 4, 6, 7, 8, 9 and 10 were all determined to have low level of nutrient contents (except nitrates).

THE RELATIONSHIP BETWEEN PARAMETERS OF WATER QUALITY AND CHL *A* CONCENTRATION

The results indicated that the combination of water temperature, pH, NH_4 –N, and DIP were correlated with the chl *a* concentration in the studied stations. Generally speaking, the autotrophy algae blooming in water composes its bioplasm by sunlight energy and inorganic substances through photosynthesis (detail refers to Yang et al. 2008). Water temperature is an important factor to induce algae bloom. From the conception of ecology, drastic change of temperature may cause the disturbances in biological communities, therefore leading to algal bloom when other environment conditions are adequate (Wang et al. 1996). Algae bloom may not occur in water high in TN and TP if other condition such as temperature is not suitable (Yang et al. 2008).

Changes on physicochemical parameters such as pH directly related to the availability and absorption of nutrients from solution where high pH values promote the growth of phytoplankton (Yang et al. 2008). In an open water system such as rivers, the increase of photosynthesis rate (high chl *a* concentration) which consumed CO_2 increases the pH of the water bodies. Since microalgae are able to metabolize the CO_2 in water, there is an equilibrium trend for the pH to increase. It is well documented that the dense of phytoplankton can raise the pH of the nature water by actively removing the CO_2 from the water through photosynthesis (Round 1981; Yung et al. 1999). In an experimental study carried out by Rocha et al. (2003), it was indicated the importance of pH on the growth of certain species of marine microalgae. Nevertheless, the relationship between pH and phytoplankton community in KWNP needs further investigation.

High nitrate contents had been observed in the samples taken back from the study stations yet only ammonium was found closely correlated with the growth of phytoplankton. Ammonium is always known to be the dominant nitrogen source utilized by phytoplankton compared to nitrate which is energetically more difficult to absorb (Harrison et al. 1996; Sunda & Hardison 2007). In nature, phytoplankton communities typically prefer in up taking the reduced form of NH_4^+ rather than the oxidized form of NO_2^- and NO_3^- (Twomey et al. 2005). Study carried out by Smith Jr. et al. (1997) reported that the uptake rate of phytoplankton on ammonium was low initially, but increased markedly during the middle of summer compare to the results of the present study where the ammonium was not the singular factor that influence the phytoplankton communities yet subjected to the co-existence of other parameters such as temperature, pH and DIP.

Different algal species have various nutrient requirements. Nitrogen and phosphorus are known to be the limiting factor affecting the growth of microalgae subjected to the concentration levels of each element in water column. High total nitrogen was recorded during the survey indicating the presence of phosphorus as limiting factor for the growth of the phytoplankton in KWNP. The results from Kinniburgh and Barnett (2009) which successfully reduced the DIP loadings to the river apparently reduced the chl *a* concentrations. Besides that, DIP also noted to be the potential nutrient that limits the primary production in Sepetiba Bay, SE-Brazil (Rodrigues et al. 2009). Furthermore, it is believed that the increase of nutrients such as orthophosphate and nitrate potentially altered the inhibitory effects of ammonium on phytoplankton (Livingston et al. 2002) suggests the importance of orthophosphate to phytoplankton growth.

ENVIRONMENT STATUS (BOUNDARY *VS.* KWNP)

Statistically speaking, differences had been observed between the stations located at the outer and inner boundary of KWNP. Environmental variables were known to be significantly different between boundaries (r = 0.177; p-value < 0.05). The results in Figure 3 had obviously noted that the environmental status of the present study could be divided into four categories (Disturbed – stations 1, 2 and 3; Semi-disturbed – station 5; slightly disturbed – stations 4, 8 and 10; Undisturbed – stations 6, 7 and 9). Surprisingly, high phosphorus contents were recorded in KWNP stations (especially station 8 and 10) where station 10 was located beside the soil dumping site. In general, two main paths will contribute to the increase of phosphorus in nature water environment: erosion of phosphate rocks (naturally or deforestation) and anthropogenic sources such as detergents and fertilizers (Khan & Ansari 2005). It is believed that the conversion of a part of KWNP into soil dumping site is expected to cause significant changes in wetland function by altering the litter input and phosphorus loads.

Most of the water quality statuses in all the 10 stations were below the Malaysia marine water quality criteria and standard except nitrate. The nitrate concentrations of the present study were way too high (≥ 350 μg/L) compared with the marine standards (55 μg/L) (Table 4). Similar condition has been reported by Sanders et al. (1997) in Humber estuary, where water column nitrate concentration of 500 μg/L, while the others were recorded < 120 μg/L (Devi et al. 1991; Yung et al. 1999). Nitrate concentrations were recorded high in station 1 with a generally decreasing trend towards the river mouth stations (stations 3 and 5). A similar study which has been carried out by Babu et al. (2010) on the water quality between monsoon seasons in Ashtamudi estuary (Ramsar site) indicated high mean nitrate concentrations during both seasons. The nitrate concentrations of the present survey (350 -530 μg/L) which were collected during the non-monsoon season (August 2011) paralleled with Babu et al. (2010) that reported a minimum of nitrate at 309 μg/L during non-monsoon season. The surface runoff was suspected to be the main supplier of nitrates. Some other anthropogenic impact, such as fertilizer usage and/or nitrification in the river channel, might have been responsible for the relatively similar and high nitrate (Rodrigues et al. 2009). Fortunately, low phosphorus had been recorded during the survey which acts as the limiting factor that controls the growth of phytoplankton preventing eutrophication. Further monitoring needs to be carried out to investigate the point source of the pollutants which potentially contributed by the anthropogenic activities that disturbs the environment status of KWNP.

CONCLUSION

In conclusion, different environmental status had been observed between the inner and outer boundary of KWNP. Water temperature, pH, ammonium nitrogen (NH4–N) and inorganic phosphorous (Inorg–P) were known affecting the abundance of phytoplankton communities. All study stations had reported with over-ranged NO_3 –N concentrations as compared with Malaysia marine standards. Anthropogenic activities such as urbanization, deforestation, soil dumping and household activities are suspected to be responsible for the present phenomenon. However, further studies needed to be carried out to allocate the point source of pollutants in order to mitigate the disturbances on KWNP in the near future. The results of the present study only provides a foundation that can be expanded upon which can be used for subsequent analyses to produce a generic model for pollution studies, thus in strengthening the subsequent conservation decisions in the coming future.

TABLE 4. Malaysia marine water quality criteria and standard and interim national water quality standards for Malaysia (DEO 2012)

	Malaysia Marine Water Quality Criteria and Standard Class E
Beneficial uses	Mangroves, estuarine & 00River-mouth water
Temperature (°C)	≤ 2°C increase over maximum ambient
Dissolved oxygen (mg/L)	4
Total suspended solid (mg/L)	100 mg/L or ≤ 30% increase in seasonal average, whichever is lower
Ammonia (unionized) (μg/L)	70
Nitrite (NO_2) (μg/L)	55
Nitrate (NO_3) (μg/L)	60
P (μg/L)	75 (Phosphate)

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