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Spatial and Temporal Variation of Physico-chemical Parameters in the Merbok Estuary, Kedah, Malaysia

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Abstrak: Dalam kajian ini, analisis faktor (FA) telah digunakan untuk mendapatkan faktor-faktor tersembunyi yang bertanggungjawab untuk variasi kualiti air dalam kedua-dua musim hujan dan panas. Sampel air diambil dari enam stesen persampelan (St. 1 Sungai Lalang, St. 2 Sungai Semeling, St. 3 Sungai Jagung, St. 4 Sungai Teluk Wang, St. 5 Sungai Gelam dan St. 6 Sungai Derhaka) di muara Merbok, Malaysia dari Januari hingga Disember 2011; sampel telah dianalisis selanjutnya di makmal. Analisis korelasi daripada set data menunjukkan korelasi yang kuat antara parameter. Nutrien seperti nitrat (NO_3^-), nitrit (NO_2^-), ammonia (NH_3) dan fosfat (PO_4^{3-}) menjadi petunjuk penting kualiti air sepanjang tahun. Parameter kualiti air yang mempengaruhi semasa musim hujan ialah kekonduksian, kemasinan, keperluan oksigen biokimia (BOD), oksigen terlarut (DO) dan klorofil *a* (Chl*a*), manakala pepejal terampai total (TSS) dan pH merupakan indikator kualiti air penting pada musim kemarau. Ujian Kruskal-Wallis H menunjukkan bahawa parameter kualiti air berbeza dengan signifikan antara bulan-bulan persampelan dan stesen (p<0.05), dan ujian Mann-Whitney U seterusnya mendedahkan parameter yang berbeza dengan signifikan adalah suhu, pH, DO, TSS, NO_2^- dan BOD (p<0.01), manakala kemasinan, konduktiviti, NO_3^-, PO_4^{3-}, NH_3 dan Chl*a* tidak berbeza secara signifikan (p>0.05). Parameter kualiti air di muara ini bervariasi secara temporal dan spatial, dan keputusan ini dapat berfungsi sebagai maklumat garis asas untuk pengurusan muara, khususnya untuk muara Merbok.

Kata kunci: Analisis Faktor, Perubahan Bermusim, Parameter Fizikokimia, Muara Merbok

Abstract: In this study, factor analysis (FA) was applied to extract the hidden factors responsible for water quality variations during both wet and dry seasons. Water samples were collected from six sampling stations (St. 1 Lalang River, St. 2 Semeling River, St. 3 Jagung River, St. 4 Teluk Wang River, St. 5 Gelam River and St. 6 Derhaka River) in the Merbok estuary, Malaysia from January to December 2011; the samples were further analysed in the laboratory. Correlation analysis of the data sets showed strong correlations between the parameters. Nutrients such as nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_3) and phosphate (PO_4^{3-}) were determined to be critical indicators of water quality throughout the year. Influential water quality parameters during the wet season were conductivity, salinity, biochemical oxygen demand (BOD), dissolved oxygen (DO) and chlorophyll *a* (Chl*a*), whereas total suspended solid (TSS) and pH were critical water quality indicators during the dry season. The Kruskal-Wallis H test showed that water quality parameters were significantly different among the sampling months and stations (p<0.05), and Mann-Whitney U tests further revealed that the significantly different parameters were temperature, pH, DO, TSS, NO_2^- and BOD (p<0.01), whereas salinity,

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conductivity, NO_3^-, PO_4^{3-}, NH_3 and Chl*a* were not significantly different (p>0.05). Water quality parameters in the estuary varied on both temporal and spatial scales and these results may serve as baseline information for estuary management, specifically for the Merbok estuary.

Keywords: Factor Analysis, Seasonal Variation, Physico-chemical Parameters, Merbok Estuary

INTRODUCTION

Estuarine and coastal areas have complex and dynamic aquatic environments (Morris *et al*. 1995). Estuarine ecosystems play an important role in the global economy and biodiversity of the region (Smith & Hollibaugh 1993) as well as act as a transitional zone between land and sea (Bardarudeen *et al*. 1996). A large number of physical and chemical processes occur as the river water mixes with seawater, which may influence water quality (Anitha & Kumar 2013). Water quality within estuaries is deteriorating due to rapid industrialisation and aquaculture practices along the river. Estuaries and coastal areas are essential for domestic, industrial, and agricultural purposes and are also used as a means for waste disposal, transportation, food sources and recreational activities (Boon *et al.* 1992). These areas are facing an increasing number of ecological problems due to the population increase and the resulting rapid economic development. These problems lead to an excess of nutrients from industrial and municipal waste water as well as from forest and agricultural products (Ball 1992). Nutrient loads discharge into the estuaries and cause eutrophication, which affects biological communities (Wang *et al.* 1999). Hydrobiological studies are therefore important to better understand the different trophic levels and food webs of these aquatic systems (Damotharan *et al.* 2010).

Water quality varies both spatially and temporally. River discharge and pollutant concentration in water bodies vary with temporal variations in precipitation, surface runoff, interflow and groundwater flow (Vega *et al.* 1998). Seasonal changes in surface water quality are used to interpret temporal variations in river pollution caused by natural or anthropogenic inputs from point and nonpoint sources (Ouyang *et al.* 2006; Fan *et al.* 2012). Previous water quality monitoring studies focused on the physical and chemical parameters as well as a few key biological parameters, including dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand, suspended solids, pH, conductivity, salinity, temperature, nitrogen in the form of ammonia (NH_3), turbidity, dissolved solids, total solids, nitrates, chloride and phosphates for scoring water quality status (Ouyang *et al.* 2006; Iscen *et al.* 2008; Pejman *et al.* 2009; Varol *et al.* 2012; Mustapha *et al.* 2012; Anitha & Kumar 2013).

Although a number of researchers have studied the physico-chemical characteristics of Malaysian estuaries and seas (Ong *et al.* 1991; Alkarkhi *et al.* 2009; Juahir *et al.* 2011), only a few studies have been conducted at the Merbok estuary to assess its water quality. The present study analyses the seasonal and temporal variations of the physico-chemical variables in the Merbok estuary to answer two central questions: (1) how does water quality vary with respect to seasonal changes and (2) what are the critical parameters that contribute to the seasonal variation of the estuary water quality?

MATERIALS AND METHODS

Study Area and Sampling Stations

The Merbok is a mangrove estuary, located in the northwest Peninsula of Malaysia. It lies between 5° 38´ 2.87´´ and 5° 42´ 13.46´´ N latitude and 100° 20´ 57.33´´ and 100° 30´ 24.56´´ E longitude. It is generally flat and slopes gradually towards the Merbok River with an average elevation of 0.915 m (3.0 feet) [Food and Agriculture Organization (FAO) 1979]. The length of the river is approximately 35 km with a width that ranges from approximately 20 m at the upper reaches to 2 km at the mouth of the estuary and a depth of 3 to 15 m. The tidal range varies from 0 to 2.9 m. During low tide, the water remains in the main channel; when the tidal surge rises, its banks overflow and flood the surrounding mangrove vegetation. However, freshwater discharges and flows into the mangrove estuary in wet tropical locations through a number of estuarine tributaries. The estuary is linked to the Muda River in the south through a channel, and the average discharge rate is approximately 100 m^3 sec^{-1}. The catchment area is approximately 550 km^2 and consists of alluvial deposits overlying an extensive span of ferruginous shale and mudstone (Ong *et al.* 1991; Kaniz *et al.* 2012). Location and description of sampling stations are presented in Figure 1 and Table 1.

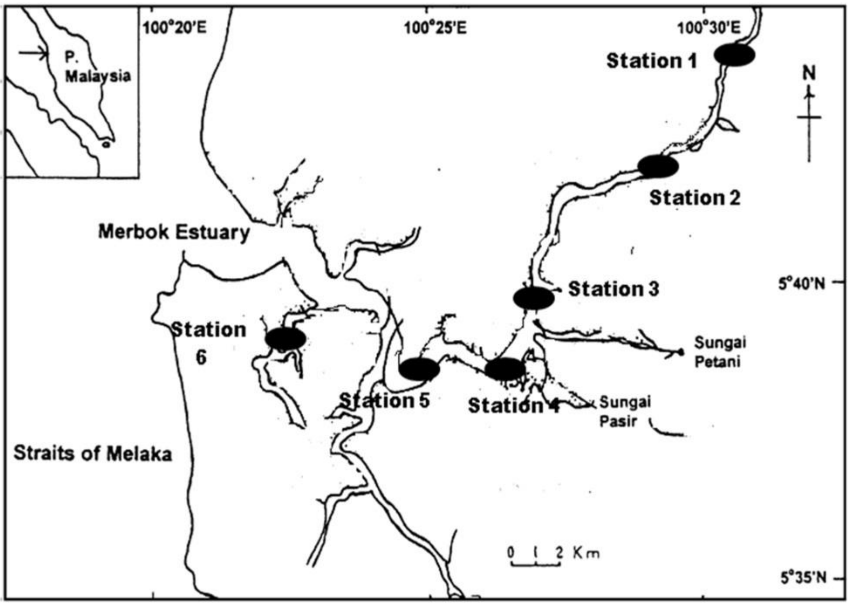


Figure 1: Map showing the sampling stations of the Merbok Estuary (image adapted from Uncles *et al.* 1992).

Table 1: Location and description of sampling sites.

Stream	Sampling stations	Symbol	GPS locations	Description
Upstream	Lalang River	St. 1	05° 41´ 56.63´´ N 100° 30´ 16.94´´ E	Surrounded by mangrove forest, located near a fishing village and residential area. Receives pollutants from surrounding agricultural fields, livestock farms, fish ponds and wastewater discharges.
	Semeling River	St. 2	05° 41´ 13.66´´ N 100° 28´ 32.19´´ E	
Middle stream	Jagung River	St. 3	05° 39´ 27.33´´ N 100° 26´ 58.00´´ E	Surrounded by mangrove forest; receiving polluted water from branches of the Sungai Petani and the Sungai Pasir. In addition, aquaculture is the main activity in these areas.
	Teluk Wang River	St. 4	05° 38´ 2.87´´ N 100° 25´ 57.67´´ E	
Downstream	Gelam River	St. 5	05° 38´ 37.68´´ N 100° 25´ 4.01´´ E	Surrounded by mangrove forests and oil palm plantations, aquaculture activities and land development.
	Derhaka River	St. 6	05° 39´ 26.27´´ N 100° 23´ 3.27´´ E	

Sample Collection and Analytical Methods

Surface and bottom water samples were collected monthly for one year from January to December, 2011 at six sampling stations in the Merbok estuary. Water samples were collected in acid-washed polythene bottles (1.5 litre), and all the samples were kept in the dark at a cool temperature (4°C) before transportation to the Plankton Laboratory, School of Biological Sciences, Universiti Sains Malaysia (USM). All the collected samples were kept in a refrigerator below 4°C to reduce metabolism of the organisms in the water. Rainfall data were obtained from the Meteorological Department of Kedah, Malaysia. Temperature, DO, salinity and electrical conductivity (EC) were measured in situ using HYDROLAB SRV3-DL (Surveyor 3 Data Logger, USA). pH was measured using a pH meter (Eco Testr TM, USA). BOD, Chl*a*, ammonia, nitrite (NO_2^-), nitrate (NO_3^-), phosphate (PO_4^{3-}) and total suspended solids (TSS) were measured following standard methods [Strickland & Parsons 1972; American Public Health Association (APHA) 2005]. According to the Malaysian Meteorological Department (MMD) annual report, rainfall above 200 mm constitutes the wet season and 0–200 mm constitutes the dry season (MMD 2009). This study used rainfall data from MMD (2011) and adopted seasonal classifications used by MMD for grouping the data into dry and wet seasons. The mean annual rainfall at Sungai Petani, Kedah was 2528.05 mm during the study period.

A nonparametric (Kruskal-Wallis H) test was performed to determine the differences in the water quality parameters among the sampling months and stations. Mann-Whitney U tests were performed to observe the effect of seasons on the water quality parameters (Ho 2006). Spearman rank-order correlations (Spearman *R* coefficient) were used to study the correlation structure between variables as datasets showed abnormal distribution of water quality parameters (Wunderlin *et al.* 2001). In this study, temporal variation of estuary water quality parameters was evaluated using a correlation matrix. Factor analysis was conducted to observe variables by a smaller number of factors, and the factors were extracted using the Varimax rotated principal component method (Coakes *et al.* 2006). All mathematical and statistical analyses were carried out using SPSS version 17.00 for MS Windows.

RESULTS AND DISCUSSION

Physico-chemical parameters (mean±SD, range) at different stations within the Merbok estuary are shown in Table 2. The mean water temperature varied from 27.46°C (St. 1) to 29.71°C (St. 3) with a maximum of 30.75°C (St. 3) and a minimum of 27.50°C (St. 3, 4 and 5) (Table 2). Temperature influences the chemical and biological reactions in water and is a critical physical factor; it controls the rate of photosynthesis in aquatic ecosystems. Temperature variation is usually influenced by rainfall. In the present study, the temperature increased slightly during the wet season but decreased in the dry season [Fig. 2(a)]. This difference may be due to the influx of warm water from tributaries and the resulting decrease in salinity and water transparency. In a tropical estuary, temperature is always inversely correlated with salinity and water transparency. Transparency decreased more during the wet season than during the dry season due to flooding from adjacent catchment areas (Simier *et al.* 2006). Mansor *et al.* (2012) also observed an increase in temperature during heavy rains and the reverse effect during the dry season.

Table 2: Physico-chemical parameters at different stations on the Merbok estuary from January to December 2011.

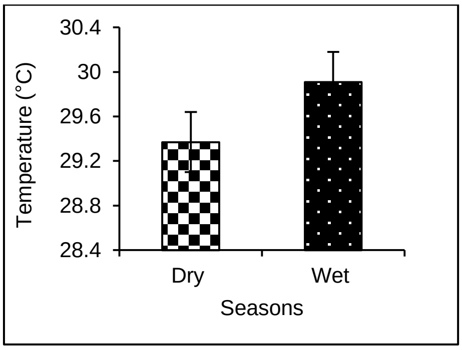
Variables (unit)	St. 1 Mean±SD range	St. 2 Mean±SD range	St. 3 Mean±SD range	St. 4 Mean±SD range	St. 5 Mean±SD range	St. 6 Mean±SD range
Temp. (°C)	29.46±0.92[a] (30.5–27.5)	29.64±0.86[a] (30.6–27.7)	29.71±0.94[a] (30.8–27.5)	29.68±0.90[a] (30.5–27.5)	29.66±0.91[a] (30.6–27.5)	29.68±0.96[a] (30.7–27.8)
pH	6.89±0.45[a] (7.70–6.20)	6.95±0.37[a] (7.80–6.28)	7.01±0.29[a] (7.70–6.63)	7.05±0.35[a] (7.80–6.42)	7.18±0.39[ab] (8.10–6.53)	7.37±0.45[bc] (8.30–6.48)
EC (µS/ cm)	183.67±54.94[a] (260.0–70.0)	263.86±53.94[b] (337.5–155.0)	284.29±62.24[bc] (370.0–165.0)	287.67±57.43[bc] (366.0–183.0)	301.19±56.5[bc] (370.0–175.0)	294.79±49.65[bc] (380.0–197.5)
DO (mg/l)	5.46±3.83[a] (13.65–1.02)	3.38±1.92[b] (7.90–1.00)	3.24±1.44[b] (6.30–1.70)	3.52±1.80[b] (8.02–0.80)	3.67±1.71[b] (7.23–2.15)	4.81±2.07[bc] (7.76–2.66)
Salinity (ppt)	13.74±4.26[a] (22.0–5.5)	20.43±5.55[b] (32.0–12.0)	22.81±8.42[b] (35.0–12.0)	23.49±8.14[bc] (35.0–14.9)	24.66±7.96[bc] (32.0–12.5)	23.35±6.67[bc] (35.0–14.0)
NO_3^- (mg/l)	0.21±0.12[a] (0.41–0.05)	0.15±0.08[bc] (0.29–0.05)	0.09±0.04[ab] (0.14–0.02)	0.07±0.04[b] (0.13–0.02)	0.07±0.03[b] (0.14–0.02)	0.05±0.03[bd] (0.10–0.01)
NO_2^- (mg/l)	0.19±0.06[a] (0.32–0.12)	0.17±0.10[a] (0.40–0.06)	0.14±0.07[b] (0.27–0.03)	0.13±0.08[b] (0.28–0.01)	0.13±0.07[b] (0.27–0.01)	0.10±0.07[bc] (0.23–0.01)

(*continued on next page*)

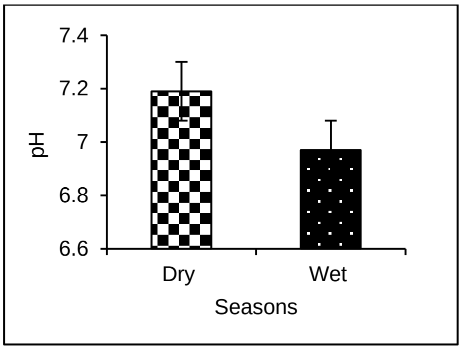
Table 2: (*continued*)

Variables (unit)	St. 1 Mean±SD range	St. 2 Mean±SD range	St. 3 Mean±SD range	St. 4 Mean±SD range	St. 5 Mean±SD range	St. 6 Mean±SD range
NH_3	1.18±0.69[a]	0.30±0.21[bc]	0.17±0.12[b]	0.13±0.10[b]	0.10±0.08[ab]	0.10±0.07[ab]
(mg/l)	(3.41–0.05)	(0.96–0.02)	(0.35–0.02)	(0.30–0.01)	(0.29–0.02)	(0.23–0.02)
TSS	30.28±11.16[a]	36.67±14.19[bc]	41.67±14.24[b]	47.45±17.92[b]	45.00±15.19[b]	65.00±38.25[ab]
(mg/l)	(66.66–20.00)	(80.00–20.00)	(100.00–20.00)	(93.33–26.66)	(86.66–20.00)	(186.60–33.33)
BOD	3.94±3.78[a]	3.00±2.31[a]	2.16±1.67[ab]	1.80±1.69[b]	1.33±1.50[b]	1.55±1.74[bc]
(mg/l)	(12.38–0.06)	(10.51–0.82)	(6.64–0.51)	(6.68–0.30)	(5.85–0.14)	(9.42–0.01)
Chl*a*	1.14±1.31[a]	0.49±0.35[a]	0.46±0.39[ab]	0.48±0.41[ab]	0.45±0.30[a]	1.78±1.66[a]
(µg/l)	(4.27–0.03)	(1.24–0.02)	(1.38–0.01)	(1.38–0.03)	(1.01–0.01)	(13.94–0.80)
PO_4^{3-}	0.08±0.04[a]	0.08±0.03[a]	0.08±0.02[a]	0.07±0.02[b]	0.07±0.02[b]	0.06±0.02[b]
(mg/l)	(0.16–0.02)	(0.12–0.03)	(0.10–0.02)	(0.10–0.02)	(0.09–0.03)	(0.10–0.02)

Notes: Mean±SD in similar row with different superscript letters are significantly different (Kruskal-Wallis H test). Temp. = temperature; numbers in brackets represent variation of water quality parameters within 12 months period.

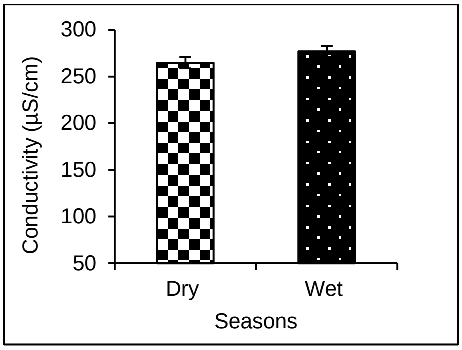


(a)



(b)

Figure 2: Seasonal variations of physico-chemical (mean±SE) parameters of the Merbok estuary from January to December 2011: a) temperature; b) pH; c) conductivity; d) DO; e) salinity; f) NO_3^-; g) NO_2^-; h) NH_3; i) TSS; j) BOD; k) Chl*a*; l) PO_4^{3-} (*continued on next page*).



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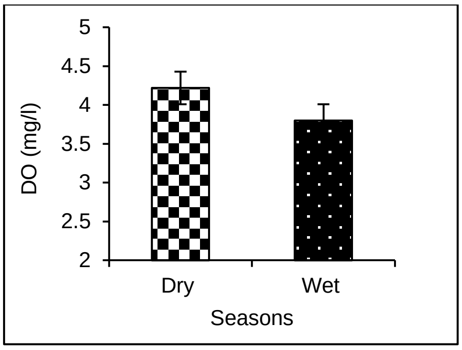

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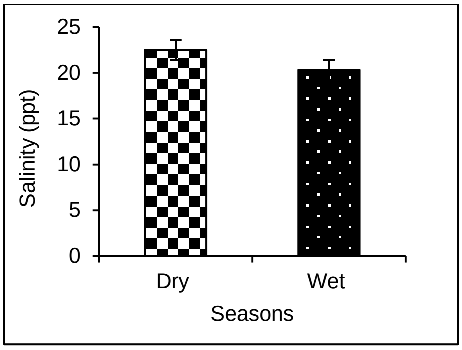

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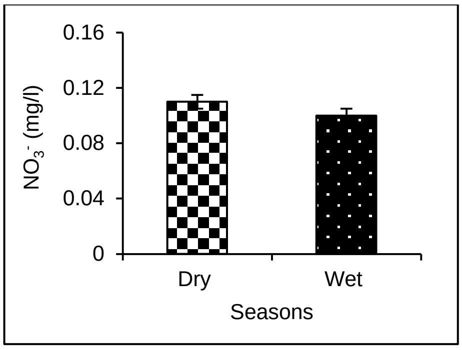

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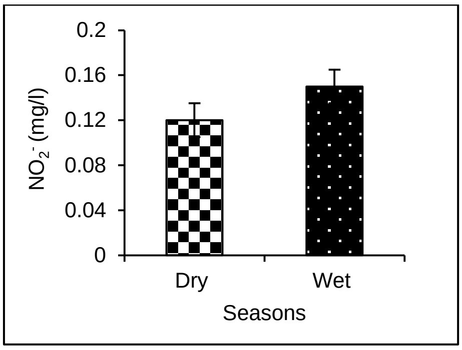

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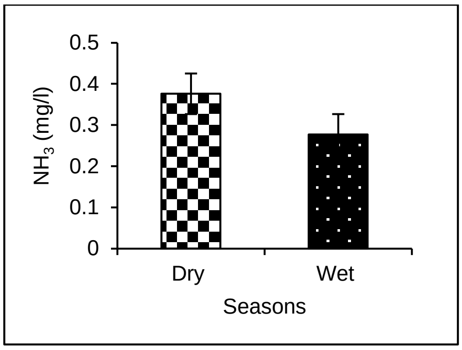

(h)

Figure 2: (*continued on next page*)

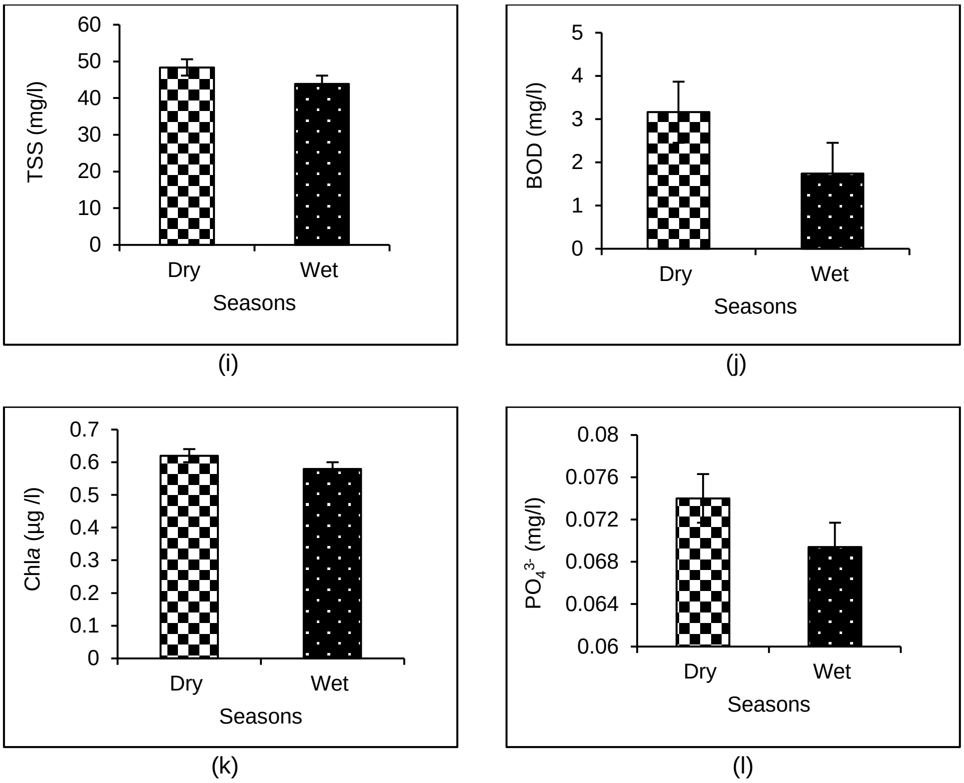

Figure 2: (*continued*)

Mean pH values varied from 6.89 (St. 1) to 7.37 (St. 6) with a maximum pH value of 8.3 (St. 6) in the dry season and a minimum pH value of 6.2 (St. 1) in the wet season [Table 2 and Fig 2(b)]. Streams and rivers transporting large quantities of humic materials containing colloidal suspensions are generally acidic in nature (Reid 1961). Anila Kumary *et al.* (2007) reported that pH values change from acidic to alkaline when colloidal particles mix with seawater and become coagulated. This mixing results in higher pH values downstream. Similar results were recorded in the present study where higher pH values were recorded at the stations located further downstream within the estuary.

The mean EC values ranged from 183.67 µS/cm (St. 1) to 301.19 µS/cm (St. 5) with a high of 380.00 µS/cm (St. 6) and a low of 70.00 µS/cm (St. 1) (Table 2). EC values showed temporal variation where higher values were recorded during the rainy season compared to the dry season [Fig 2(c)]. These variations may be the result of continuous flush-off effluent during the rainy season. Similar findings were also observed by Manikannan *et al*. (2011). Bellos and Sawidis (2005) stated that bodies of water rich in electrolytes have conductivity values between 250 and 1000 µS/cm and are therefore characterised as eutrophic. The mean conductivity recorded in this study was 269.25±55.78 µS/cm; this finding indicates that the estuary is rich in electrolytes and may be characterised as eutrophic.

Average DO concentrations varied from 3.24 (St. 3) to 5.46 (St.1) mg/l with a maximum value of 13.65 mg/l (St. 6) and a minimum value of 0.80 mg/l (St. 4) (Table 2). Mean DO concentrations were higher in the dry season compared to the wet season [Fig 2(d)]. The average DO value was 4.01±2.12 mg/l, which was higher compared to the standard value set for mangrove estuaries and class 2 river mouths located in Malaysia [Department of Environment (DOE) 2011] (Table 3). DO is considered the most important parameter for water quality analysis because it acts as a vital indicator of the physical, chemical and biological activities of the water. Higher DO concentrations recorded during the dry season may be due to the combined effects of higher wind energy and the mixing of heavier rainfall and freshwater. A previous study by Damotharan *et al.* (2010) observed similar results.

Table 3: Comparison of water quality results between Malaysian marine water quality criteria and standard values.

	DO	TSS	NO_3^-	NO_2^-	NH_3	PO_4^{3-}
Reference value (class 2 and class E) (mg/l)	5.00	50.00	0.06	0.055	0.07	0.075
Observed result (mg/l)	4.01	44.35	0.11	0.19	0.33	0.073

The average salinity values ranged from 13.74 ppt (St. 1) to 24.66 ppt (St. 5) with a maximum value of 35.00 ppt (St. 3, 4 and 6) and a minimum value of 5.50 ppt (St. 1) (Table 2). The maximum salinity value was recorded during the dry season [Fig 2(e)], which may be due to the higher degree of evaporation in the study areas. Lower values recorded during the wet season resulted from heavy rainfall and a large inflow of freshwater. Manikannan *et al.* (2011) recorded a maximum salinity value during the summer and lower values during the wet (monsoon) season, which is a result of the heavy rainfall. These results correlate with our findings.

The mean values for nitrate ranged from 0.05 mg/l (St. 6) to 0.21 mg/l (St. 1) with a high of 0.41 mg/l (St. 1) and a low of 0.01 mg/l (St. 6); the mean values for nitrite from 0.10 mg/l (St. 6) to 0.19 mg/l (St. 1) with a high of 0.40 mg/l (St. 2) and a low of 0.01 mg/l (St. 4, 5 and 6) (Table 2). The highest nitrate concentrations were recorded during the dry season and the minimum during the wet season [Fig 2(f)], which is a result of weathering of rocks, fertiliser, domestic and municipal sewage, and freshwater inflow. A previous study by Selvam *et al.* (1994) reported that decomposition of organic matter caused an increase in nitrate values in mangrove waters with an average nitrate value of 0.11±0.06 mg/l. This value was higher compared to the standard value set for mangrove estuaries and river mouths (class 2 and class E) in Malaysia (DOE 2011) (Table 3). The present study findings correlate with the findings of Day *et al.* (1989), which state that nitrate levels can be 10 times higher at the head of the estuary (upstream) in comparison to the mouth (downstream). The maximum nitrite value was recorded during the wet season and the minimum during the dry season [Fig 2(g)]. Variations in phytoplankton excretion, oxidation of ammonia, and reduction of nitrate most likely contributed to this finding, in addition to the recycling of nitrogen and bacterial decomposition from planktonic detritus and denitrification. Prabu *et al.* (2008) observed a similar pattern of results. The mean nitrite value in the present study was 0.19±0.08 mg/l. This value was more than three-fold higher than the typical value observed for mangrove estuaries and river mouths (class 2 and class E) in Malaysia (DOE 2011) (Table 3).

Ammonia values were also measured and ranged from 0.10 mg/l (St. 5 and 6) to 1.18 mg/l (St. 1) with a high of 3.41 mg/l (St. 1) and a low of 0.01 mg/l (St. 4) (Table 2). The highest ammonia concentration was recorded during the dry season [Fig 2(h)], a result stemming from low precipitation. However, dilution of rainwater may be important in reducing the ammonium level in the estuary. A similar pattern of results was observed by Damotharan *et al.* (2010). Altogether, our study recorded a mean ammonium concentration of 0.33±0.21 mg/l. As with our other parameters, the ammonium concentrations gathered from this study were higher than the standard values set for mangrove estuaries and river mouths (class 2 and class E) in Malaysia (DOE 2011) (Table 3).

TSS levels ranged from 30.28 mg/l (St. 1) to 65.00 mg/l (St. 6) with a minimum of 20.00 mg/l (St. 1, 2, 3 and 5) and a maximum of 186.60 mg/l (St. 6) (Table 2). The mean recorded TSS level was 44.35±18.49 mg/l. This value was lower compared to the standard value set for mangrove estuaries and river mouths (class 2) in Malaysia (DOE 2011) (Table 3). Furthermore, TSS levels were higher during the dry season than the wet season [Fig 2(i)]. The TSS level increased at the middle of the estuary and further downstream due to wastewater disposal, an influx of run-off from the upper reaches, and the use of fish feed for caged fish rearing. These findings also correlate with a study conducted by Jonnalagadda and Mhere (2001).

Mean BOD values varied from 1.33 mg/l (St. 5) to 3.94 mg/l (St. 1) with the highest value reaching 12.38 mg/l (St. 1) and the lowest reaching 0.01 mg/l (St. 6) (Table 2). Higher BOD values were observed during the dry season compared to the wet season [Fig 2(j)]. BOD values are indicators of organic pollution in the water. A BOD_5 value accounts for the decomposition of organic material over the span of 5 days, which is directly correlated with burdens of organic materials in streams (Grafny *et al.* 2000). The present study recorded high BOD values at St. 1, and this increase may be due to the influx of organic sewage from anthropogenic activities, wastewater discharges and/or agricultural activities.

The mean Chl*a* content ranged from 0.45 µg/l (St. 5) to 1.78 µg/l (St. 6) with the highest level reaching 13.94 µg/l (St. 6) and the lowest reaching 0.01 µg/l (St. 3 and 5) (Table 2). The maximum was measured during the dry season and the minimum during the wet season [Fig 2(k)], and these values may be a direct result of longer daylight hours during the dry season. Dunn *et al.* (2007) and Prabhahar *et al.* (2011) also reported lower Chl*a* concentrations during the monsoon season and higher levels during the summer.

Average phosphate values ranged from 0.06 mg/l (St. 6) to 0.08 (St. 1, 2 and 3) with a high of 0.16 mg/l (St. 1) (dry season) and a low of 0.02 mg/l (St. 1, 3, 4 and 6) (wet season) [Table 2 and Fig 2(l)]. A previous study by Ajithkumar *et al.* (2006) reported that fertilisers from agricultural fields are a source of phosphates that contribute to the increased phosphate levels. The present study showed that the mean phosphate concentration in the water samples was 0.073±0.02 mg/l, a value slightly lower than that set for mangrove estuaries and river mouths (class 2 and class E) in Malaysia (DOE 2011) (Table 3).

Kruskal-Wallis H tests showed that the water quality parameters were significantly different among the sampling months (p<0.05). Kruskal-Wallis H tests were performed to compare the water quality parameters among the different sampling stations and revealed that except for temperature and Chl*a,* all other parameters were significantly different (p<0.05). Mann-Whitney U tests showed that among the 12 water quality parameters, 6 (temperature, pH, DO, TSS, NO_2^- and BOD) were significantly different between the 2 seasons (p<0.01), whereas the other 6 (salinity, EC, NO_3^-, PO_4^{3-}, NH_3 and Chl*a*) were not significantly different with regard to seasons (p>0.05).

Table 4 provides the correlation matrix of the water quality parameters for both dry and wet seasons, respectively. In both the dry and wet seasons, temperature significantly correlates with the other parameters including pH, DO, salinity, EC, NO_3^-, NH_3, PO_4^{3-}, Chl*a* and BOD (p<0.01). Altın *et al.* (2009) observed that water temperature had a very weak correlation with parameters such as DO, conductivity, NO_3^-, BOD, NH_3, PO_4^{3-} and TDS.

The correlation coefficients between pH and EC, NO_3^- and NH_3 were 0.302, –0.374 and –0.315 during the wet season, respectively. However, during the dry season, correlation coefficients between pH and EC, TSS, NO_2^- and BOD were 0.364, 0.537, –0.391 and 0.371, respectively. DO is correlated with BOD and Chl*a* during the wet season to a significant degree (p<0.01), whereas in the dry season, only DO is correlated with Chl*a* (r=0.439) to a significant degree (p<0.01). Salinity correlated with EC, NO_3^-, NH_3 and NO_2^-, respectively, with correlation coefficients of 0.819, –0.518 and –0.686 in the wet season and 0.814, –0.461, and –0.546 in the dry season. Ouyang *et al.* (2006) reported that pH showed a strong correlation with EC (0.83) and salinity (0.83) during the fall season. However, the correlation between these same parameters was very poor during the spring, summer and winter. The present study also found that EC values were negatively correlated with NO_3^- (r=–0.744), NO_2 (r=–0.509) and NH_3 (r=–0.734) during the wet season, but EC values strongly correlated with TSS (r=0.410), NO_3^- (r=0.521), NO_2^- (r=–0.613) and NH_3 (r=–0.409) during the dry season. TSS values recorded during the dry season correlated with NO_3^- (r=–0.215), NO_2^- (r=–0.469), NH_3 (r=–0.189), and BOD (r=0.295) to a significant degree (p<0.01). In contrast, wet season TSS values were positively (p<0.05) correlated with Chl*a* (r=0.144). Muslim and Jones (2003) studied the seasonal variation of dissolved nutrients, Chl*a*, and suspended sediments. This study found a link between Chl*a* and TSS and Chl*a* and PO_4^{3-} with correlation coefficients of 0.49 and 0.47, respectively. These results are similar to our findings in which PO_4^{3-}, BOD, and Chl*a* correlated to a significant degree (p<0.01) during both the dry and wet seasons. Strong correlations between NO_3^-

and NO_2^- (0.505) and NO_3^- and NH_3 (0.789) occurred during the wet season. However, in the dry season, there was not a strong correlation between NO_3^- and NH_3 (r=0.643), BOD (r=0.422) or NO_2^- (r=0.370). Muduli *et al.* (2011) found that BOD was positively correlated with ammonia levels but that salinity was negatively correlated with nutrient values. These findings are similar to those recorded in the present study.

Principle component analysis (PCA) methods were used to extract key factors. The component loadings are the linear combinations for each principal component, and they express the correlation between the original variables and the newly formed components. The component loadings are used to determine the relative importance of a variable compared to other variables in a principal component. Eigenvalues greater than 1 were used as a cut-off value to determine the number of factors. The first 4 principal components had eigenvalues greater than 1 and explained approximately 73.772% of the total variances in the original dataset for the wet season. For the dry season, the first 3 principal components had eigenvalues greater than 1 and explained approximately 67.457% of the total variances in the original dataset (Table 5). For the wet season, Factor 1 (F1) explained 32.062% of the total variance, showing a strong positive loading for conductivity and salinity but a strong negative loading for NH_3 and NO_3^-. These differences may be due to tidal effects (Tables 5 and 6). Factor 2 (F2) explained 20.597% of the total variance and had a strong positive loading for BOD, DO and Chl*a*, a reflection of the biological interactions among parameters. Factor 3 (F3) explained 12.01% of the total variance and had a moderate positive and negative loading for pH, temperature and PO_4^{3-}, respectively. These results may be due to domestic wastewater discharges from the catchment area. Factor 4 (F4) explained 9.107% of the total variance and had a moderately positive loading for TSS, due to erosion effects, and a negative loading for NO_2^- (Tables 5 and 6). In the dry season, Factor 1 (F1) explained 30.375% of the total variance and had a moderately positive loading for EC, salinity, TSS, pH and BOD and a negative loading for NO_2^-. These results can be attributed to sea water intrusion into the river. Factor 2 (F2) explained 19.686% of the total variance and had a strong positive loading for NO_3^- and moderate loading for both NH_3 and BOD. These parameters were determined to be non-point sources of pollution. Finally, Factor 3 (F3) explained 17.395% of the total variance and had a moderate positive loading for BOD, DO, temperature and Chl*a* (Tables 5 and 6). As with Factor 2, these results may be due to biological interactions among parameters.

According to Pejman *et al.* (2009), water quality parameters, which showed a strong correlation coefficient value (>75%), were considered to be significant parameters for water quality monitoring. The significant water quality parameters that should be used to measure the seasonal variation in water quality of the Merbok estuary are listed in Table 7. NO_3^-, NO_2^-, NH_3 and PO_4^{3-} are the most significant parameters defining water quality for both seasons in the Merbok estuary. These nutrient concentration patterns are the result of both point and nonpoint sources of pollution as well as erosion effects. Point sources of pollution can be attributed to domestic wastewater discharged from upstream human settlements, whereas nonpoint sources of pollution feed into the estuary

Table 4: Correlation matrices of water quality parameters during wet and dry seasons.

	Temp.	pH	DO	Salinity	EC	TSS	NO_3^-	NO_2^-	NH_3	PO_4^{3-}	BOD	Chl*a*
Wet season												
Temp.	1											
pH	.318**	1										
DO	.429**	.222**	1									
Salinity	.299**	.211**	.095	1								
EC	.297**	.302**	.132	.819**	1							
TSS	.035	.056	.007	.073	.116	1						
NO_3^-	–.323**	–.374**	–.223**	–.518**	–.744**	–.084	1					
NO_2^-	.062	–.195**	–.204**	–.270**	–.569**	–.133	.505**	1				
NH_3	–.410**	–.315**	–.132	–.686**	–.734**	–.014	.789**	.168*	1			
PO_4^{3-}	–.099	–.247**	.169*	.062	.204**	.086	–.256**	–.094	–.152*	1		
BOD	.061	.005	.651**	–.235**	–.185**	.088	.012	.075	.075	.326**	1	
Chl*a*	–.024	-.016	.644**	–.110	.000	.144*	–.039	–.139*	.006	.260**	.648**	1
Dry season												
Temp.	1											
pH	–.068	1										
DO	.440**	–.037	1									
Salinity	.273**	.277**	.205**	1								
EC	.389**	.364**	.325**	.814**	1							
TSS	–.076	.537**	.093	.310**	.410**	1						
NO_3^-	–.373**	–.148*	–.204**	–.461**	–.521**	–.215**	1					
NO_2^-	.139*	–.391**	–.219**	–.546**	–.613**	–.469**	.370**	1				
NH_3	–.055	–.038	.163*	–.355**	–.409**	–.189**	.643**	.357**	1			
PO_4^{3-}	.255**	.195**	.280**	.290**	.269**	.029	.197**	.087	.431**	1		
BOD	–.304**	.371**	.173*	–.048	.077	.295**	.422**	–.135*	.338**	.217**	1	
Chl*a*	.277**	–.015	.439**	.053	–.002	–.046	.014	.170*	.259**	.379**	.027	1

Notes: **Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed); Temp. = temperature.

from agricultural and livestock farms (Madramootoo *et al.* 1997; Kaniz *et al.* 2012). BOD, salinity, conductivity, DO and Chl*a*, all with strong factor loadings, were the most important parameters in determining water quality variations during the wet season. These variations likely stem from domestic wastewater discharges that contributed to the degradation of water quality. In contrast, TSS and pH, both with strong positive factor loadings, were additional contributors to the significant water quality variation during the dry season and are likely affected by the upward movement of seawater into the river.

Table 5: Total variance explained before and after Varimax rotation for each season.

Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
Wet									
1	3.847	32.062	32.062	3.847	32.062	32.062	3.595	29.957	29.957
2	2.472	20.597	52.659	2.472	20.597	52.659	2.482	20.681	50.637
3	1.441	12.005	64.664	1.441	12.005	64.664	1.471	12.255	62.892
4	1.093	9.107	73.772	1.093	9.107	73.772	1.306	10.879	73.772
Dry									
1	3.645	30.375	30.375	3.645	30.375	30.375	2.990	24.913	24.913
2	2.362	19.686	50.062	2.362	19.686	50.062	2.730	22.750	47.662
3	2.087	17.395	67.457	2.087	17.395	67.457	2.375	19.794	67.457

Table 6: Principal Component (PC) matrixes (rotated) for wet and dry seasons.

Wet season				
Variables	PC1	PC2	PC3	PC4
EC	0.906			
NH_3	–0.899			
NO_3^-	–0.846			
Salinity	0.828			
BOD		0.883		
DO		0.875		
Chl*a*		0.824		
PO_4^{3-}			–0.746	
pH			0.737	
Temperature			0.528	
NO_2^-				–0.769
TSS				0.572

(*continued on next page*)

Table 6: (*continued*)

Dry season			
Variables	PC1	PC2	PC3
TSS	0.761		
NO_2^-	–0.758		
pH	0.752		
EC	0.689		
Salinity	0.589		
NO_3^-		0.846	
NH_3		0.775	
BOD		0.675	
DO			0.740
PO_4^{3-}			0.705
Chl*a*			0.702
Temperature			0.675

Note: Extraction method (Coakes *et al.* 2006; Ho 2006): Principal Component Analysis; Rotation method: Varimax with Kaiser Normalisation.

Table 7: Most important water quality parameters for each season.

Seasons	Positively influenced parameters	Negatively influenced parameters
Wet	EC, salinity, BOD, DO, Chl*a*	NH_3, NO_3^-, NO_2^-, PO_4^{3-}
Dry	TSS, pH, NO_3^-, NH_3	NO_2^-

CONCLUSION

Physico-chemical parameters in the Merbok estuary showed seasonal fluctuations. DO, nitrate, nitrite, and ammonia concentrations exceeded marine water quality criteria and standard values set for class 2 and class E rivers, which is an indication of the poor water quality status in the Merbok estuary. Statistical analysis results showed evidence of spatial and temporal variations in observed water quality parameters and strong correlations between parameters. Factor analysis revealed that while one parameter might be crucial in determining the fluctuation of water quality for one season, this same parameter might be less crucial for another season. Both correlation and factor analysis confirmed that NO_3^-, NO_2^-, NH_3, and PO_4^{3-} serve as critical parameters of water quality throughout the year. BOD, salinity, conductivity, DO and Chl*a* were the most important parameters for wet season monitoring. In contrast, TSS and pH were the most important water quality parameters for dry season monitoring. Therefore, it is essential that seasonal variations in the physico-chemical parameters may be considered when implementing environmental strategies in the estuary.

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