Sains Malaysiana 45(4)(2016): 551–558

Seasonal and Spatial Variability of Selected Surface Water Quality Parameters in Setiu Wetland, Terengganu, Malaysia

(Kevariabelan Musim dan Reruang pada Paremeter Kualiti Permukaan Air Terpilih di Tanah Bencah Setiu, Terengganu, Malaysia)

S. SURATMAN*, A.N.A.R. HUSSEIN, N. MOHD TAHIR, M.T. LATIF,
R. MOSTAPA & K. WESTON

ABSTRACT

This paper presents the results for surface water quality parameters measured in the Setiu Wetland, on the east coast of Malaysia, which feeds into the southern part of the South China Sea. There are no previous studies dealing with the seasonal and spatial variation of water quality in this area, despite numerous anthropogenic inputs into this ecologically and economically important wetland. The parameters measured were salinity, temperature, dissolved oxygen (DO), pH, biological oxygen demand (BOD) and total suspended solids (TSS). These parameters were sampled monthly from October 2009 to September 2010, during both the wet and dry seasons, at ten sampling stations distributed throughout the area. The physical water quality parameters were measured in situ *whilst TSS and BOD were determined using the standard methods. A deterioration of water quality in the Setiu Wetland was observed in areas near agriculture and aquaculture activities. This was expected to be as a result of the use of fertilisers, waste from fish farm food and the waste products of aquaculture. The parameters measured showed lower mean values of surface salinity, temperature, DO, pH and TSS during the wet season relative to the dry season. In contrast, the concentration of BOD was high during the wet season and lowest in the dry season. Results obtained from this study clearly showed the surface physical water quality for the Setiu Wetland was highly influenced by anthropogenic activities and seasonal variation. Therefore, both factors must be considered to move towards proper management of this wetland.*

Keywords: Anthropogenic activities; seasonal and spatial variability; Setiu Wetland; surface water; wet and dry seasons

ABSTRAK

Kertas ini melaporkan keputusan kajian mengenai parameter kualiti air permukaan yang diukur di Tanah Bencah Setiu, di Pantai Timur Semenanjung Malaysia yang mengalir ke bahagian selatan Laut China Selatan. Tiada kajian dijalankan sebelum ini berkaitan parameter bermusim dan reruang pada kualiti air di kawasan ini yang diketahui mempunyai kepentingan ekonomi dan ekologi, walaupun ia menerima kesan daripada input antropogen. Parameter yang diukur ialah saliniti, suhu, keterlarutan oksigen (DO), pH, permintaan oksigen biologi (BOD) dan jumlah pepejal terampai (TSS). Pensampelan untuk parameter tersebut dilakukan setiap bulan semasa musim kering dan basah di sepuluh stesen pensampelan merangkumi seluruh kawasan ini. Parameter fizikal diukur secara in situ *manakala TSS dan BOD ditentukan menggunakan kaedah piawai. Kemerosotan kualiti air di Tanah Bencah Setiu diperhatikan di kawasan berdekatan aktiviti pertanian dan akuakultur. Kesan ini adalah hasil daripada penggunaan baja, baki daripada makanan ikan dan hasil buangan akuakultur. Parameter yang diukur menunjukkan purata nilai yang rendah untuk saliniti, suhu, DO, pH dan TSS semasa musim basah berbanding dengan musim kering. Sebaliknya, kepekatan BOD adalah tinggi semasa musim basah dan rendah pada musim kering. Keputusan kajian ini menunjukkan kualiti air fizikal permukaan untuk Tanah Bencah Setiu banyak dipengaruhi oleh aktiviti antropogen dan perubahan musim. Oleh itu, kedua-dua faktor perlu dipertimbangkan ke arah pengurusan berkesan untuk tanah bencah ini.*

Kata kunci: Aktiviti antropogen; kevariabelan bermusim dan reruang; musim kering dan basah; permukaan air; Tanah Bencah Setiu

INTRODUCTION

The rapid growth in human population, industrial development, urbanisation, intensifying land use and aquaculture and agriculture in coastal areas globally has led to increased stress on the natural environment from numerous sources (Kitsiou & Karydis 2011; Schaffelke et al. 2012). For example, the waste products from anthropogenic activities may enter into the aquatic environment without any prior treatment. The aquatic environment can be disturbed directly or indirectly by both organic and inorganic pollutants, as pollutants often enter into river systems and are ultimately transported to the marine environment (Suratman et al. 2008). This pollution can have many negative impacts on the marine aquatic environment, such as eutrophication (Herbeck et al. 2013; Wang et al. 2011). As a result of the recognition of these environmental issues, there have been many studies focussing on the monitoring and interpretation of water quality, especially with respect to understanding the thresholds that impact significantly on the environment. Some examples related to this study include the Sungai Langat, Peninsular Malaysia (Azrina et al. 2006), Daya Bay, South China Sea (Wu et al. 2009) and the Great Barrier Reef lagoon, Australia (Schaffelke et al. 2012).

The present study was carried out in the Setiu Wetland (Figure 1). This area is located north of Kuala Terengganu, Malaysia. It is generally fairly hot and humid all year round, averaging from 28ºC to 33ºC in the daytime and slightly cooler after sunset (Suratman et al. 2005). It is subject annually to the northeast monsoon between November and March (wet season) and southwest monsoon from May to September (dry season). The Setiu Wetland receives fresh water inputs from the Sungai Setiu that flows into the wetland from the southeast. It also receives freshwater inputs from a nearby natural lake (Berambak Lake) which is connected to the wetland via the Sungai Ular (Suratman et al. 2005). The wetland covers an area of 23, 000 ha and the water column within the wetland is shallow and well mixed. It is a unique and important habitat in Malaysia, consisting of riparian forests lining the riverbanks, freshwater swamps, peat swamps, mangroves, brackish water lagoon with vegetated sand islands, sea grass beds and sandy beaches (WWF 2008). However, a number of major developments are planned in this area, such as fish and shrimp aquaculture, palm oil plantations and light industry, which have the potential to impact the water quality of this significant wetland. Numerous studies have been conducted in order to establish a water quality baseline to support the development of sustainable aquaculture and to monitor the effect of the potential pollutants such as hydrocarbons, heavy metals, pesticides and organic matter (Law et al. 2006; Mohd Tahir et al. 2006; Suratman et al. 2005). According to the Malaysian Department of Fisheries (2009) there is an increasing number of brackish water cage culture and oyster farming activities in the Setiu Wetland. For example, the number of units involved in brackish water cage culture was 2717 in 2009, compared to 2191 in 2008. The aquaculture production in this area rose from 1443.68 metric tonnes in 2008 to 1834.48 metric tonnes in 2009 and is predicted to reach 3000 metric tonnes by 2012. It is predicted that the expansion of aquaculture farming in the Setiu Wetland will result in the deterioration of water quality due to the input of wastes from uneaten fish food associated with aquaculture and the excretory by-products of fish and shrimp aquaculture. These inputs may be critical in the Setiu Wetland as the wetland is an almost 'closed' system with a small opening to the sea, especially during low water, resulting in a high residence time of the water within the wetland.

In this study, the seasonal and spatial variations of the selected surface physical water quality parameters in the Setiu Wetland were determined, i.e. the salinity, temperature, dissolved oxygen (DO), pH, biological oxygen demand (BOD) and total suspended solids (TSS). The purpose of this study was to understand the seasonal cycle of these parameters and to use them to support the management of water quality of this economically and environmentally important area.

Materials and Methods

Monthly field sampling was conducted from October 2009 to September 2010 at high tide. Surface water was collected at ten sampling stations (Figure 1) which were chosen in order to represent the range of activities within the study area (Table 1). Water samples were collected from surface water (~ 0.5 m depth) into acid-washed 1 L high density polyethylene (HDPE) bottles. Samples were stored at 4ºC prior to transfer to the laboratory for further analysis. Samples for BOD determination were stored in 250 mL dark BOD bottles at 4ºC. Precautions were taken to eliminate any bubbles in the bottles which can disturb the analysis. The physical water quality parameters (salinity, temperature, DO and pH) were measured *in situ* using an YSI multi parameter data logger (model 6600, YSI, United States) and calibrated according to the manufacturer's recommendations before field sampling.

The BOD and TSS samples were analysed according to APHA (1998). BOD incubations were started within 4 h of sampling at various dilutions and values obtained by measuring the differences in DO values after a five-day incubation period in the dark at 20ºC. Water samples for TSS were filtered through GF/F filters (0.7 μm pore size) using a vacuum pump. The filters were weighed both before and after filtration and dried in an oven at temperatures of 103ºC- 105ºC until a constant weight was obtained.

Results and Discussion

Spatial Distribution

In the present study, salinity ranged between 0 and 37 ppt (Table 2). Based on a two-factor without replication ANOVA test, there was a significant difference ($p < 0.05$) between sampling stations and also between dates of sampling. Table 2 shows the mean values of salinity for each station, which were in the range of 4 to 30 ppt. Generally, lower mean values were recorded at two stations, S1 (4 ± 4 ppt) and S9 (16 ± 7 ppt). This is due to their location near the Sungai Setiu dan Sungai Ular, which contribute more freshwater. Thus, their mean values were much lower compared to other stations due to the mixing process between the freshwater and seawater. In contrast, other stations recorded high mean salinity values in the range of 27 ± 4 ppt to 30 ± 3 ppt, suggesting the major influence of seawater in these areas.

The range of water temperatures during the present study was between 27 and 35ºC (Table 2). Based on a

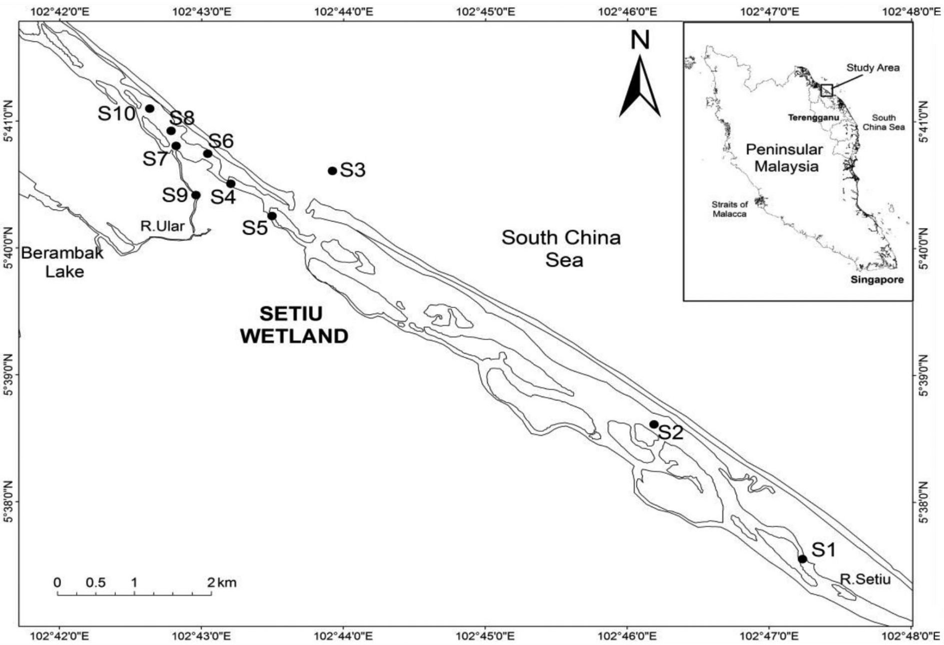

FIGURE 1. The locations of the sampling stations in the Setiu Wetland

TABLE 1. Description/Justification of the sampling stations

Station	Coordinate		Description/ Justification
	Longitude	Latitude	
S1	102º47.20'	05º37.53'	Located at downstream of the Sungai Setiu. It is important as this station provides the information on the input of nutrients from freshwater to the wetland area
S2	102º47.20'	05º37.53'	Located within the wetland but there is no major anthropogenic activity around this station
S3	102º44.00'	05º40.63'	Located in the coastal sea waters ~200 m from the wetland. This station provides the baseline of nutrient concentrations i.e. without any anthropogenic activities
S4	102º43.28'	05º40.53'	Located at the main activities in the wetland such as aquaculture (brackish water cage culture, pond culture, pen culture and oyster farming) and activities involving seafood-based food production (fermented fish sauce, fish crackers, dried anchovies and belacan)
S5	102º43.57'	05º40.28'	
S6	102º43.28'	05º40.53'	
S7	102º42.90'	05º40.83'	
S8	102º42.86'	05º40.95'	
S10	102º03.80'	05º40.28'	
S9	102º42.71'	05º41.13'	Located at downstream of Sungai Ular connects Berambak Lake and the wetland area. This station was chosen as the main activities nearby are agricultural activities which are mainly the palm oil plantation

two-factor without replication ANOVA test, there was a significant difference ($p < 0.05$) both between sampling stations and between the dates of sampling. Table 2 shows the mean values of temperature for each station was in the range of 30 to 32ºC. There was no general trend of high or low temperature values at the different stations, with temperature similar throughout the sampling period for all stations. The range of temperatures seen in the present study was probably due to the heating effect of the sun, which is dependent on the time of sampling. Suratman et al. (2005, 1999) also reported that the small temperature variation observed in their study was most probably due to the time of day of sampling, which in turn depended on the tide.

DO concentrations ranged from 3.1 to 7.6 mg/L (Table 2). The ANOVA test showed that the DO concentrations were significantly different ($p < 0.05$) between sampling stations and also between dates of sampling. The mean values of DO for each station were in the range of 4.6 to 6.3 mg/L. The highest mean concentration of DO was at S4 (6.3 ±

TABLE 2. Mean values/concentrations of selected surface water quality parameters for each sampling station

Stations	Salinity (ppt)	Temperature (ºC)	DO (mg/L)	pH	BOD (mg/L)	TSS (mg/L)
S1	4±4	30±2	5.1±0.7	6.5±0.7	1.2±0.4	33±21
	(0-14)	(27-33)	(3.4-6.0)	(5.3-7.7)	(0.8-2.3)	(5-76)
S2	27±4	30±2	5.5±0.7	6.8±1.0	1.3±0.4	48±42
	(21-32)	(28-34)	(4.2-6.3)	(5.6-8.3)	(0.92-1.90)	(7-114)
S3	30±3	30±2	6.0±0.5	7.9±0.4	1.2±0.4	39±27
	(23-35)	(28-32)	(4.5-6.5)	(7.1-8.4)	(0.78-2.27)	(15-85)
S4	30±2	31±2	6.3±0.6	7.8±0.7	1.2±0.4	105±88
	(28-32)	(28-33)	(5.1-7.6)	(6.1-8.7)	(0.64-1.78)	(8-218)
S5	30±2	30±2	6.1±0.6	8.0±0.2	1.2±0.4	94±90
	(26-32)	(27-32)	(4.9-7.6)	(7.6-8.4)	(0.59-2.10)	(3-224)
S6	29±3	31±2	5.6±0.8	7.9±0.3	1.4±0.4	106±89
	(22-32)	(28-34)	(4.3-6.9)	(7.6-8.4)	(0.68-1.92)	(9-244)
S7	29±3	31±2	5.2±0.8	7.6±0.6	1.5±0.5	101±88
	(25-32)	(29-34)	(3.5-6.1)	(5.9-8.1)	(0.92-2.19)	(7-219)
S8	29±3	32±2	5.2±1.0	7.3±0.8	1.6±0.8	94±79
	(24-37)	(29-35)	(3.1-6.7)	(6.0-8.0)	(0.57-2.88)	(5-198)
S9	16±7	31±2	4.6±0.6	6.6±0.9	1.5±0.5	62±74
	(6-30)	(28-34)	(3.7-5.4)	(5.3-7.7)	(0.62-2.25)	(2-222)
S10	28±3	31±2	5.1±0.9	7.1±1.1	1.4±0.7	92±79
	(25-33)	(28-34)	(3.5-6.4)	(5.2-8.0)	(0.75-2.82)	(2-187)

(   ) range of values/concentrations

0.6 mg/L) and the lowest mean DO concentration was at S9 (4.6 ± 0.6 mg/L). The lower mean DO concentration at S9 was probably due to the location of the station, which is in an area with large scale palm oil plantation activity, upstream of the Sungai Ular. The use of fertilisers at this plantation increased the runoff of nutrients such as phosphates and nitrates into the adjacent wetland areas. This increases the phytoplankton growth and subsequent decomposition processes when the phytoplankton die, resulting in low DO in the water column (Sullivan et al. 2010). Stations S1, S7, S8 and S10 also showed low mean DO concentrations. The low DO concentration at S1 was probably caused by the input of domestic wastes from the town of Penarik located upstream. This is in agreement with other studies, which recorded low DO in the water column due to domestic wastes. For example, Suratman et al. (2006) suggested that low DO concentration recorded at the Sungai Besut basin, Terengganu was as a result of domestic waste input from the town of Jertih. Azrina et al. (2006) also observed that lower water quality downstream of the Sungai Langat, Malaysia could be attributable to several anthropogenic activities such as urban run-off into surface river water due to direct or unregulated discharges passing through populated regions. The lower mean concentrations of DO at S7, S8 and S10 were probably due to the aquaculture activities such as brackish water cage culture, pond culture, pen culture and oyster farming in the area. These activities can result in a decrease of the DO concentration as a result of the respiration of the farm fish and other aquatic organisms inside the caged area of the water column (Sidik et al. 2008). In addition, excess fish food increases the organic discharge to the water column and associated benthos. The decomposition of this organic matter can cause decreases of DO and increases of CO_2 in the water column. Tovar et al. (2000) have shown that the main cause of the reduction of DO in the water around fish farming activities is the extensive use of oxygen by the farmed fish and the decomposition of organic matter from fish excretion.

The range of pH recorded in the present study was 5.2 to 8.7 (Table 2). Based on a two-factor without replication ANOVA test, there was a significant difference ($p < 0.05$) between dates of sampling but no significant difference ($p > 0.05$) between sampling stations. Table 2 shows the mean values of pH for each station was in the range of 6.5 – 8.0. Generally, lower mean values of pH were recorded at S1 (6.5 ± 0.7) and S9 (6.6 ± 0.9). Their lower mean values may be due to their location on the Sungai Setiu dan Sungai Ular, where high freshwater input results in a low pH characteristic of surface water. According to Suratman et al. (2005), the mixing process between the freshwater and seawater results in increased pH values in wetland areas relative to the freshwater input. As shown in Table 2, lower mean pH values were also recorded at S2, S7, S8 and S10, ranging from 6.8 ± 1.0 to 7.6 ± 0.6. For these stations, the pH value was probably influenced by the anthropogenic inputs from aquaculture nearby, which is also consistent with the observed reduction of DO at these stations. The waste production from these anthropogenic activities was discharged into the wetland and may increase the production of dissolved CO_2 gases through the decomposition of organic matter. Thus, the pH of the water column becomes more acidic (Millero et al. 2009; Moran & Stottrup 2011; Tovar et al. 2000).

In the present study, the concentrations of BOD were in the range of 0.57 to 2.88 mg/L (Table 2). The ANOVA test showed that the BOD concentrations were significantly different ($p < 0.05$) between sampling stations and that there was no significant difference ($p > 0.05$) between dates of sampling. In general, the highest mean concentrations of BOD were recorded at S7, S8, S9 and S10. The mean concentrations in these stations ranged from 1.4 ± 0.7 to 1.6 ± 0.8 mg/L. The BOD values were inversely correlated with DO values, suggesting that the decomposition of organic material by microorganisms has occurred. These results can be clearly observed in this study, particularly at stations S7 to S10 which recorded low values of DO but high values of BOD. Oxygen consumed in the decomposition process caused increased competition between aquatic organisms to get the oxygen that they need to live.

The ranges of TSS concentrations during the present study were 2 to 244 mg/L (Table 2). The ANOVA test showed that the TSS concentrations were significantly different ($p < 0.05$) between sampling stations and also between dates of sampling. The lowest mean TSS value was recorded at S1 (33 ± 21 mg/L), probably due to the absence of major anthropogenic activities around this station. The low levels of TSS are also associated with freshwater input from the Sungai Setiu. The low mean TSS concentration at S3 (39 ± 27 mg/L) was, in contrast to S1, due to its location which is on the coast away from the wetland. The highest mean values of TSS concentrations were recorded at stations S4, S5, S6, S7, S8 and S10, ranging from 92 ± 79 to 106 ± 89 mg/L. These higher concentrations were probably caused by waste, such as organic and particulate materials, from anthropogenic activities such as aquaculture and activities involving seafood-based food production. In addition, the resuspension of sediments by strong currents during the high tide period when sampling took place also increased the TSS concentrations. The Setiu Wetland is almost a ‘closed’ system with a small opening to the sea. This may have caused the high concentration of suspended substances as water movement and exchange flow within the lagoon area are restricted.

SEASONAL VARIABILITY

The variation of mean values of the parameters measured was plotted against the respective monthly rainfall (Figure 2). There was no general trend of high or low salinity values with different months. Low salinity was expected during the heavy rainfall period associated with the wet season due to the dilution factor and high salinity during the dry season (Markou et al. 2007; Ouyang et al. 2006). However, this was not observed in this study area.

In general, lower mean temperature values were recorded during the heavy rainfall period i.e. the wet season (October – December). Values ranged from 28 to 29ºC. In contrast, higher mean values (29 – 33ºC) were recorded during the dry season (January – September). This occurred because during the wet season, the meteorological conditions are usually cloudy and rainy (Suratman et al. 2006), resulting in cooler temperatures because of the absence of direct sunlight. This trend also occurred in the Sungai Besut basin (Suratman et al. 2006), the Daya Bay, South China Sea (Wu et al. 2009) and the Jinshui River, China (Bu et al. 2010).

In general, lower mean DO concentrations were recorded during the heavy rainfall in wet season (October – December), ranging from 4.7 to 5.0 mg/L. In contrast, higher mean concentrations (5.2 – 6.1 mg/L) were recorded during the dry season (January – September). Similar observations, that low and high oxygen concentrations were recorded during heavy and light rainfall, respectively, were also reported in Port of Genoa, Italy (Ruggieri et al. 2011), Daya Bay, South China Sea (Wu & Wang 2007; Wu et al. 2009) and the Sungai Besut basin, Terengganu (Suratman et al. 2006). The relationship is expected to be due to the flushing of organic matter and pollutants from land during the heavy rainfall periods associated with the wet season. The subsequent decomposition of this organic matter then results in low water column DO (Ruggieri et al. 2011; Wu et al. 2009). This effect will be more critical in the Setiu Wetland as this wetland is almost a ‘closed’ system, where high organic matter inputs are possible due to its location surrounded by palm oil plantation and aquaculture producing shrimp and fish. Increased water currents associated with the wet monsoon, especially from the Sungai Setiu dan Sungai Ular, will also lead to high levels of suspended solids in the study area. Studies have shown that suspended solids have their own oxygen demand and therefore will reduce the DO concentration of the water column (Brewer et al. 1977; Suratman et al. 1996). The concentration of DO in the water column was seen to decrease with the increasing TSS. This suggests that the resuspension of sediments associated with the high tide led to a severe reduction in DO content of the water column. This observation is similar to the Sungai Selangor estuary where DO distribution was strongly influenced by the level of TSS that arose due to the resuspension of bottom sediments during the spring tide (Suratman et al. 1996). In the present study, the TSS concentrations at S6, S7, S8 and S10 showed an inverse correlation with DO concentrations. This is consistent with the observation that the reduction in DO in a particular area is due to the uptake and consumption of DO by the TSS content within that area. Thus, it is hypothesised that TSS plays an important role in controlling the oxygen content of the water column in the Setiu Wetland. The DO concentrations increased again after the wet season because there was light rainfall resulting in slower water currents in the river and the wetland areas. Consequently, the input of pollutants from the land into the wetland was reduced and with low TSS concentrations in the water column, the DO concentrations will increase again.

In general, the lower mean pH levels were recorded during the heavy rainfall periods, especially the wet season. The lowest means were observed in November 2009 (7.0

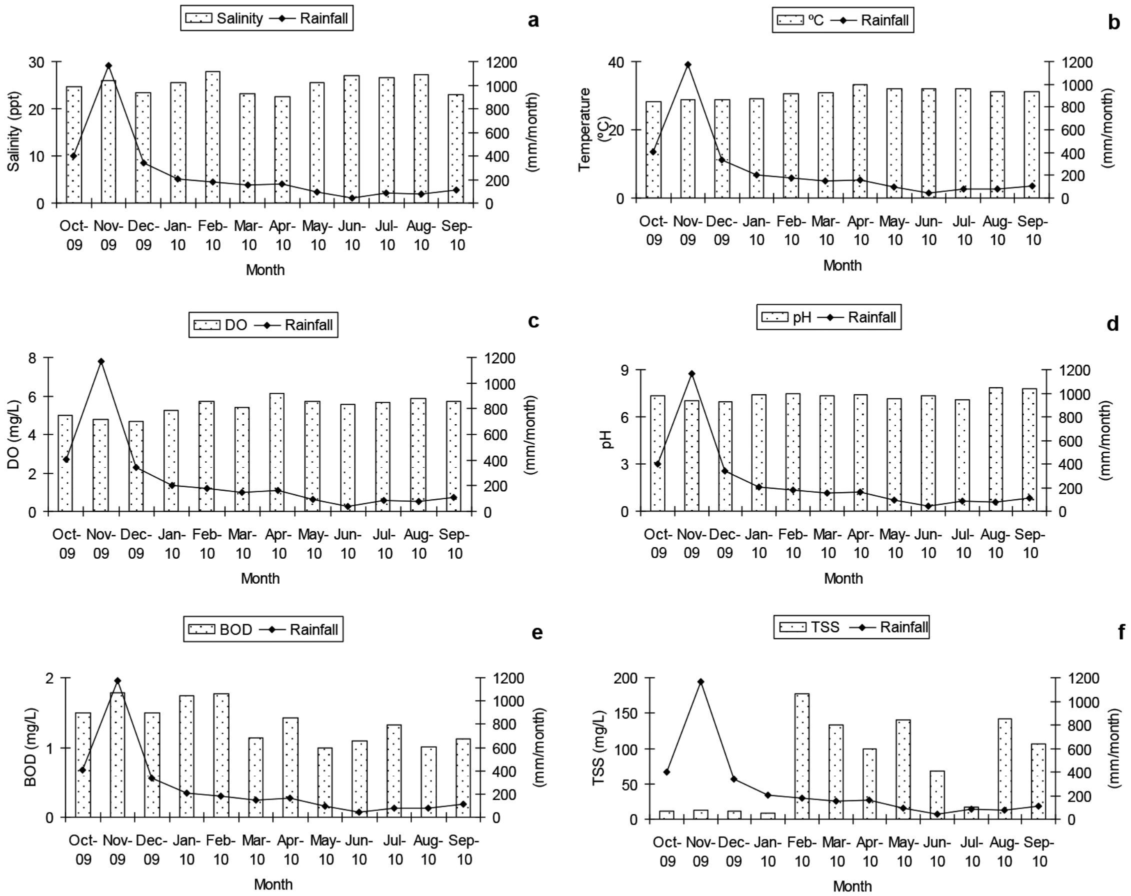

FIGURE. 2. Variation of mean salinity, temperature, DO, pH, BOD and TSS values/concentrations with monthly rainfall

± 1.3) and December 2009 (7.0 ± 1.1). The lowest mean pH value was highly influenced by the deposition and accumulation of substances such as livestock wastes, fertilisers, municipal landfill waste and agriculture runoff from the soil and these will be discharged into the wetland during the wet season. As an almost ‘closed’ system, the overload of nutrients and organic wastes in this wetland will occur as movement and flow are restricted within the lagoon area. This will lead to an increase of CO_2 production due to the decomposition process. As a result, the pH values of the water column will be decreased. The low pH is correlated with low DO concentration and high values of BOD, suggesting that the decomposition of organic materials in water is a major factor contributing to the reduction of pH in the study area. This observation is similar to those obtained at other study areas such as East Asia (Park et al. 2011) and the Sungai Besut basin (Suratman et al. 2006), where the pH values were low during the monsoon season. These studies found that during the wet season, heavy rains will bring a lot of acidic substances from the land into the aquatic environment. In contrast, other months recorded high mean pH values ranging from 7.1 ± 0.7 to 7.9 ± 0.3. These samples were taken during the dry season with low rainfall. Thus, there is low input of wastes from the land.

The highest mean BOD concentrations were recorded during the heavy rainfall in November 2009 (1.78 ± 0.7 mg/L) and also in January 2010 (1.74 ± 0.4 mg/L) and February 2010 (1.76 ± 0.3 mg/L). Again, the high levels of BOD recorded within the wet season were probably due to the rainfall washing out organic materials from the land and discharging them into the wetland. As noted earlier, the wetland is an almost ‘closed’ ecosystem, thus all the organic materials will have restricted movement and flow within the lagoon area. Consequently, it will increase the oxygen demand. This observation is similar to the study undertaken at the Sungai Besut basin, Terengganu where the BOD concentration was high during the wet season (Suratman et al. 2006). Conversely, during the dry season, lower mean concentrations of BOD, ranging from 0.99 ± 0.3 mg/L to 1.43 ± 0.3 mg/L, were recorded, suggesting that with little rainfall, the amounts of organic matter introduced to the water column were also low.

It is assumed that during heavy rainfall, especially the wet season (October – December), the TSS concentrations will be higher due to the run-off from land into the wetland (Park et al. 2011; Suratman et al. 2006). For example, Suratman et al. (2006) have reported high concentrations of TSS in the Sungai Besut basin, Terengganu during the wet season. Their results showed the role played by the heavy rain in bringing solid waste from the land into the river. In addition, with fast-flow currents in the river during the monsoon, the structure of the soil river bank and the surrounding areas becomes loose and enters the river, leading to increased TSS concentrations. Park et al. (2011), during their study at Phnom Penh, Cambodia and Kota Kinabalu, Malaysia, have shown that the amount (%) that the monsoon influences TSS concentrations increased during the wet period to about 70% and decreased during the dry period (23%). Again, they suggested that soil erosion influenced the TSS concentration when rainfall was heavy. However, in this present study in the Setiu Wetland, the inverse result was obtained. The lowest mean TSS concentrations (9 – 13 mg/L) were recorded during the wet season October 2009 to January 2010. In contrast, with an exception of a low TSS concentration recorded in July 2010, high mean TSS concentrations were observed during the dry season. It is suggested that the dilution effect by the heavy rainfall probably reduced the concentration of TSS in this study. This phenomenon was similar to the one seen in the studies at Kota Kinabalu in 2006 and Phnom Penh in 2007-2008 (Park et al. 2011).

CONCLUSION

The results from the analysis of surface water collected from the Setiu Wetland showed that the water quality was impacted mostly by aquaculture and agriculture. Lower concentrations of DO and pH, which correspond to high BOD and TSS values, were found at stations located close to these activities. In addition, attention must also be paid to the effects of seasonal variation on the parameters measured, especially during the wet season where low DO, low pH and low TSS levels, but high BOD levels, were observed in the wetland. This was thought to be due to the high run-off from the land. Future management should therefore consider long term monitoring of this wetland as seasonal conditions will also influence the parameters measured.

ACKNOWLEDGEMENTS

The authors would like to thank the Ministry of Science, Technology and Innovation, Malaysia for supporting the present study (Grant No. 04-01-12-SF0085). Thanks to Dr. Rose Norman for assistance with proof reading of the manuscript.

REFERENCES

APHA 1998. *Standard Methods for the Examination of Water and Wastewater*. 20th ed. New York: American Public Health Association, American Water Works Association and Water Environment Federation.

Azrina, M.Z., Yap, C.K., Rahim Ismail, A. & Tan, S.G. 2006. Anthropogenic impacts on the distribution and biodiversity of benthic macroinvertebrates and water quality of the Langat River, Peninsular Malaysia. *Ecotox. Environ. Safe* 64: 337-347.

Brewer, W.S., Abernathy, A.R. & Paynter, M.J.B. 1977. Oxygen consumption by freshwater sediments. *Wat. Res*. 11: 471-473.

Bu, H., Tan, X., Li, S. & Zhang, Q. 2010. Temporal and spatial variations of water quality in the Jinshui River of the South Qinling Mts., China. *Ecotox. Environ. Safe* 73: 907-913.

Department of Fisheries. 2009. A list of aquaculture fisherman in Terengganu for the year 2008 and 2009. SMPP 23/92. Amendment 12/93 (in Malay). Department of Fisheries, Malaysia.

Herbeck, L.S., Unger, D., Wu, Y. & Jennerjahn, T.C. 2013. Effluent, nutrient and organic matter export from shrimp and fish ponds causing eutrophication in coastal and back-reef waters of NE Hainan, tropical China. *Cont. Shelf Res*. 57: 92-104.

Kitsiou, D. & Karydis, M. 2011. Coastal marine eutrophication assessment: A review on data analysis. *Environ. Inter.* 37: 778-801.

Law, A.T., Chuah, L.F., Chung, W.N. & Khaili, K.N. 2006. Nitrogen and phosphorus distribution in Setiu Lagoon, Terengganu, South China Sea. *Proceedings of Estuarine Ecosystem of South China Sea (NSESCS)*. pp. 1-38.

Markou, D.A., Sylaios, G.K., Tsihrintzis, V.A., Gikas, G.D. & Haralambidou, K. 2007. Water quality of Vistonis Lagoon, Northern, Greece: Seasonal variation and impact of bottom sediments. *Desalination* 210: 83-97.

Millero, F.J., DiTrolio, B., Suarez, A.F. & Londo, G. 2009. Spectroscopic measurement of the pH in NaCl brines. *Geochim. Cosmochim. Acta* 73: 3109-3114.

Mohd Tahir, N., Rahim, H.M.A., Abas, M.R. & Rashid, M.K.A. 2006. Distribution and characterization of hydrocarbons in sediments of Setiu Wetland, Terengganu: A preliminary study. *Malays. J. Anal. Sci*. 10: 177-184.

Moran, D. & Støttrup, J.G. 2011. The effect of carbon dioxide on growth of juvenile Atlantic cod *Gadus morhua* L. *Atlantic Tox*. 102: 24-30.

Ouyang, Y., Nkedi-kizza, P., Wu, Q.T., Shinde, D. & Huang, C.H. 2006. Assessment of seasonal variations in surface water quality. *Wat. Res*. 40: 3800-3810.

Park, J.H., Inam, E., Abdullah, M.H., Agustiyani, D., Duan, L., Hoang, T.T., Kim, K.W., Kim, S.D., Nguyen, M.H., Pekthong, T., Sao, V., Sarjiya, A., Savathvong, S., Sthiannopkao, S., Syers, J.K. & Wirojanagud, W. 2011. Implication of rainfall variability for seasonality and climate-induced risks concerning surface water quality in East Asia. *J. Hydrol*. 400: 323-332.

Ruggieri, N., Castellano, M., Capello, M., Maggi, S. & Povero, P. 2011. Seasonal and spatial variability of water quality parameters in the Port of Genoa, Italy, from 2000 to 2007. *Mar. Pollut. Bull*. 62: 340-349.

Schaffelke, B., Carleton, J., Skuza, M., Zagorskis, I. & Furnas, M.J. 2012. Water quality in the inshore Great Barrier Reef lagoon: Implications for long-term monitoring and management. *Mar. Pollut. Bull*. 65: 249-260.

Sidik, M.J., Un-Nabi, M.R. & Hoque, M.A. 2008. Distribution of phytoplankton community in relation to environmental parameters in cage culture area of Sepanggar Bay, Sabah, Malaysia. *Estuar. Coast. Shelf Sci*. 80: 251-260.

Sullivan, A.B., Snyder, D.M. & Rounds, S.A. 2010. Controls on biochemical oxygen demand in the upper Klamath River, Oregon. *Chem. Geol*. 269: 12-21.

Suratman, S., Jickells, T., Weston, K. & Fernand, L. 2008. Seasonal variability of inorganic and organic nitrogen in the North Sea. *Hydrobiologia* 610: 83-98.

Suratman, S., Mohd Tahir, N., Lee, C.Y. & Abdul Rashid, S.R. 2006. Monsoon effects on water quality at Besut River basin, Terengganu (in Malay). *Malays. J. Anal. Sci*. 10: 143-148.

Suratman, S., Mohd Tahir, N., Jusoh, S.R. & Mohd Ariffin, M. 2005. Assessment of anthropogenic effects on water quality at Setiu lagoon, Terengganu (in Malay). *Sains Malaysiana* 34: 87-92.

Suratman, S., Mohd Tahir, N. & Tong, S.L. 1999. Physico-chemical observations during the neap-spring tidal cycle in the Selangor River estuary. *Malays. J. Anal. Sci.* 5: 1-7.

Suratman, S., Mohd Tahir, N. & Tong, S.L. 1996. Tidal variation of physico-chemical and nutrient parameters in Selangor River Estuary, Malaysia. *Malays. J. Anal. Sci.* 2: 317-326.

Tovar, A., Moreno, C., Manuel-Vez, M.P. & Garcia-Vargas, M. 2000. Environmental implications of intensive marine aquaculture in earthen ponds. *Mar. Pollut. Bull.* 40: 981-988.

Wang, Z.H., Mu, D.H., Li, Y.F. & Zhang, Y.J. 2011 Recent eutrophication and human disturbance in Daya Bay, the South China Sea: Dinoflagellate cyst and geochemical evidence. *Estuar. Coast. Shelf Sci.* 92: 403-414.

Wu, M.L., Wang, Y.S., Sun, C.C., Wang, H., Dong, J.D. & Han, S.H. 2009. Identification of anthropogenic effects and seasonality on water quality in Daya Bay, South China Sea. *J. Environ. Manage.* 90: 3082-3090.

Wu, M.L. & Wang, Y.S. 2007. Using chemometrics to evaluate anthropogenic effects in Daya Bay, China. *Estuar. Coast. Shelf Sci.* 72: 732-742.

WWF 2008. Sustainable Management of Setiu Wetlands. Available at: http://www.wwf.org.my. Accessed in October 2011.

S. Suratman*, A.N.A.R. Hussein & N. Mohd Tahir
Institute of Oceanography and Environment
Universiti Malaysia Terengganu
21030 Kuala Terengganu, Terengganu Darul Iman
Malaysia

N. Mohd Tahir
School of Marine Science and Environment
Universiti Malaysia Terengganu
21030 Kuala Terengganu, Terengganu Darul Iman
Malaysia

M.T. Latif
School of Environmental and Natural Resource Sciences
Faculty of Science and Technology
Universiti Kebangsaan Malaysia
43600 Bangi, Selangor Darul Ehsan
Malaysia

R. Mostapa
Environmental Tracer Application Group (ETAG)
Malaysian Nuclear Agency Bangi
43000 Kajang Selangor Darul Ehsan
Malaysia

K. Weston
Centre for Environment
Fisheries and Aquaculture Science
Lowestoft, Suffolk, NR33 0HT
United Kingdom

*Corresponding author; email: miman@umt.edu.my

Received: 20 November 2014
Accepted: 6 October 2015