Tropical Life Sciences Research, 24(1), 19–34, 2013

Status of Water Quality Subject to Sand Mining in the Kelantan River, Kelantan

[1]Tan Peck Yen* and [2]Rohasliney H

[1]School of Health Sciences, Universiti Sains Malaysia, 16150 Kubang Kerian, Kelantan, Malaysia
[2]Faculty of Environmental Studies, Department of Environmental Management, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia

Abstrak: Pensampelan kualiti air di sepanjang Sungai Kelantan telah dijalankan pada November 2010 hingga Feberuari 2011 di lima stesen yang dipilih. Pensampelan ini bertujuan untuk menggambarkan tentang keadaan status kualiti air di Sungai Kelantan. Analisis fizikal seperti konduktiviti, oksigen terlarut (DO), pH, jumlah pepejal terlarut (TDS), jumlah pepejal terampai (TSS) dan kekeruhan telah dijalankan. Kajian juga melibatkan analisis kimia nutrien nitrogen seperti ammonia, nitrat dan nitrit. Hasil kajian mendapati TSS, kekeruhan dan kandungan nitrat melebihi piawaian kualiti air kebangsaan (INWQS) dan terdapat perbezaan antara Stesen 1 (KK) dan Stesen 3 (TM). Variasi nilai kandungan TDS, kekeruhan dan nutrien nitrogen di Stesen 1 secara keseluruhan adalah besar kerana faktor perlombongan pasir di sepanjang sungai dan aktiviti pembalakan di kawasan hulu sungai. Kandungan TSS yang sangat tinggi dan kekeruhan telah mewujudkan keadaan yang tidak memuaskan dan memberi tekanan untuk hidupan akuatik di Sungai Kelantan.

Kata kunci: Parameter Fizikal, Parameter Kimia, Kualiti Air, Perlombongan Pasir, Sungai Kelantan

Abstract: This paper aimed to describe the effects of sand mining on the Kelantan River with respect to physical and chemical parameter analyses. Three replicates of water samples were collected from five stations along the Kelantan River (November 2010 until February 2011). The physical parameters included water temperature, water conductivity, dissolved oxygen (DO), pH, total dissolved solids (TDS), total suspended solids (TSS) and turbidity, whereas the chemical parameters included the concentration of nitrogen nutrients such as ammonia, nitrate and nitrite. The Kelantan River case study revealed that TSS, turbidity and nitrate contents exceed the Malaysian Interim National Water Quality Standard (INWQS) range and are significantly different between Station 1 (KK) and Station 3 (TM). Station 1 has the largest variation of TDS, TSS, turbidity and nitrogen nutrients because of sand mining and upstream logging activities. The extremely high content of TSS and the turbidity have caused poor and stressful conditions for the aquatic life in the Kelantan River.

Keywords: Physical Parameters, Chemical Parameters, Water Quality, Sand Mining, Kelantan River

*Corresponding author: peckyen84@yahoo.com

INTRODUCTION

Kelantan is located in the north-eastern part of Peninsular Malaysia. The Kelantan River (also known as Sungai Kelantan in the Malay language) is the largest river in the Kelantan State. It is fed by more than 180 streams and drains a catchment area of approximately 11900 km^2 (Ahmad *et al.* 2009). The Kelantan River is considered to be a middle lowland stream flowing toward the river mouth. Annual rainfall in the Kelantan River area ranges from 0–1750 mm throughout the year. The river flows northward, passing through important towns such as Kuala Krai, Tanah Merah, Pasir Mas and Kota Bharu, the state capital, before discharging into the South China Sea (Ambak *et al.* 2010). The Kelantan River is formed from the combination of the Galas River (Sungai Galas) and the Lebir River (Sungai Lebir) near Kuala Krai. The Kelantan River has been used heavily by the local people for domestic uses, transportation, agriculture, plantation irrigation, small scale fishing industries and also sand mining activities. The Kelantan River's water has been turbid since the early 1990s because of the high amount of suspended solids and siltation. These were caused by logging activities in the upstream areas (Lojing Highlands) (DOE 2009a; Ambak & Zakaria 2010) and sand mining activities. There are approximately 128 sand mining operations along the Kelantan River from Kuala Krai to Tumpat (Ambak *et al.* 2010). The volume of sand mining activity along the Kelantan River increases each year because of the high demand of sand for industry and construction.

There are two types of sources that sand is mined from, terrestrial and marine deposits. The most common terrestrial sources are river channel deposits, floodplain alluvial deposits and residual soil deposits; the marine sources are the shore and offshore deposits (Phua *et al.* 2004). In Malaysia, the main source of sand is from in-stream mining. This type of mining is a common practice because mining locations are usually near the "market" or along a transportation route, which can reduce transportation costs (MNR & DID 2009). Sand mining is an activity within a state's capability and is supported by the federal government. The sand mining permits are provided by the Department of Irrigation and Drainage (DID), whereas the approval of the permits is decided by the District and Land Office (Kelantan). To date, there is no illegal set up of sand mining along the Kelantan River, except for few companies that are operating with expired sand mining permits. Overall, the Kelantan government still manages to control the number of sand mining operations along the Kelantan River. The Department of Mines, under the Ministry of Primary Industry, is the main federal agency that administers the provisions on environmental protection measures prescribed in the Mining Enactment. However, the enforcement by the Department of Irrigation and Drainage of the river sand mining guidelines and monitoring still must be strengthened. In recent years, the sand mining activities in Malaysian rivers have created several environmental problems, such as the deterioration of river water quality, bank erosion, river bed degradation and buffer zone encroachment. All of these are results of excessive sand extraction along the river. Heavy rainfall and soil erosion have resulted in severe sedimentation of Malaysian rivers. Rapid developments, such as land clearing for urban housing, logging and agriculture, have caused erosion and sedimentation in the rivers.

The Effects of Sand Mining on the River System

River sand mining causes the destruction of aquatic habitats by bed degradation, lower water levels and channel degradation (Lawal 2011). The processes associated with channel degradation are as follows: (a) large-scale removal of river sediments, (b) digging below the existing riverbed and (c) changing the channel bed form and shape (ECD 2001). All of these cause soil erosion and sedimentation in the water bodies, which reduce water quality.

The physical disturbance of the sediment while dredging the sand affects the suspended solids and increases the turbidity of the water. Turbidity occurs when there are particles in the water that absorb light and cause backscattering (Supriharyono 2004). Hitchcock and Drucker (1996) noted that very fine sand that is dispersed by dredging may be carried up to 11 km from the dredging site, fine sand may be carried up to 5 km, medium sand may be carried up to 1 km and coarse sand may be carried less than 50 m (Gubbay 2003). The turbidity-degraded water quality and the reduced light penetration within the river affect the photosynthesis rates and the primary production rates of the river. Turbidity also affects the fish populations in the river. Siltation, which causes high turbidity in the water, has depleted fish populations and caused the extinction of certain local species (Ambak & Zakaria 2010). The silt becomes clogged in the fishes' gills (Phua *et al.* 2004), causing physiological stress on the fishes (Ambak & Zakaria 2010). Clogging can lead to infections and the death of the fishes. High turbidity levels also reduce the visibility of certain fish that rely on vision to feed. Changes in light composition decrease the success rate of fish to catch prey (Phua *et al.* 2004). Siltation also affects the spawning beds and egg hatching (Ambak & Zakaria 2010). The initial findings of Ambak *et al*. (2010) indicated that river siltation may lead to the local extinction of certain species and may affect the diversity of fish. Other water quality contamination includes oil spills or leakage from excavation machinery and transportation vehicles (ECD 2001) and water pollution problems (Phua *et al.* 2004).

River sand mining affects the river ecology from the food chain-aquatic plants-to benthic communities and also affects higher order fish and mammals (ECD 2001). Benthic habitats can be destructed by sand dredging. Suspension feeders, such as sponges, bryozoans and hydrozoans, may become clogged by the suspended sediment or stressed by the effects of sediment passing through the feeding and respiratory systems. The settlement of certain species, such as barnacles, could be affected by sedimentation. The deposition of fine sediment could affect the reproductive success of fish eggs because the sediment may reduce the buoyancy of the fish eggs. The loss of benthic organisms affects the food chains in the river ecosystem because benthic organisms provide food for commercial fish (Gubbay 2003).

Sand mining had been in operation along the Kelantan River for years. It is the main cause of high turbidity water in the river (Fig. 1). High turbidity in the river is caused by the high content of fine sediment and organic particles. This can indirectly affect the aquatic ecosystem. When the turbidity content exceeds the natural variation of turbidity and sedimentation in the area, it begins to block the light, decreasing the water transparency. The reduction of light penetration then affects the primary production of the ecosystem. The changes in production will then affect the food chain and the composition of phytoplankton (Supriharyono 2004). The total suspended solids [TSS (which includes silt and clay)] shows an identical pattern. An increase in suspended contents may affect the zooplankton by reducing the food particles that are captured and by clogging the feeding system. Previous preliminary studies between the Kelantan River and the Pengkalan Chepa River (a tributary of the Kelantan River) show that the diversity and abundance of zooplankton in the Kelantan River were far lower than in the tributary (Peck Yen *et al.* 2010). This may be one of the effects of turbidity and TSS on zooplankton. High solid content, such as turbidity and TSS, also cause silt to clog fish gills (Phua *et al.* 2004). A study by Ambak and Zakaria (2010) discovered that the turbidity contents in the Kelantan River have seriously affected the diversity of fishes in the river.

(a) Original picture showing brownish colour of the water.

(b) Edited picture showing the enhancement of brownish colour of the water.

Figure 1: The turbidity and brownish colour of the Kelantan River due to sand mining activities (taken during sampling from November 2010 to February 2011).

Kelantan River Water Quality Status

The Department of the Environment (DOE) [Kelantan] was responsible for monitoring the water quality for the Kelantan River. The Department of the Environment detected changes of the Kelantan River's water quality and identified the pollution sources of the river. The Water Quality Index (WQI) was used by the Department of the Environment for a baseline assessment of the watercourse in relation to pollution load categorisation and the designation of classes of beneficial use, as stipulated in the Malaysian Interim National Water Quality Standards (INWQS). The WQI was derived by using dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonia nitrogen (NH_3-N), suspended solids (SS) and pH (DOE 2009b). Figure 2 shows the status of the Kelantan River's water quality from 1998 to 2009 using the WQI. Overall, the Kelantan River was classified as a clean river because the WQI was above 80. For the last 5 years, the WQI value for the Kelantan River increased from 84 (2005) to 85 (2007 to 2009). This indicates that the water quality of the Kelantan River is improving; the higher the WQI value, the cleaner the river. The latest baseline studied by Ahmad *et al*. (2009) indicated that the Kelantan River has good water quality and the river was classified as class I –

class III based on the INWQS criteria (Table 1). Most of the parameters, such as suspended solids and turbidity contents of the river, were still within the range of the INWQS criteria (Table 2).

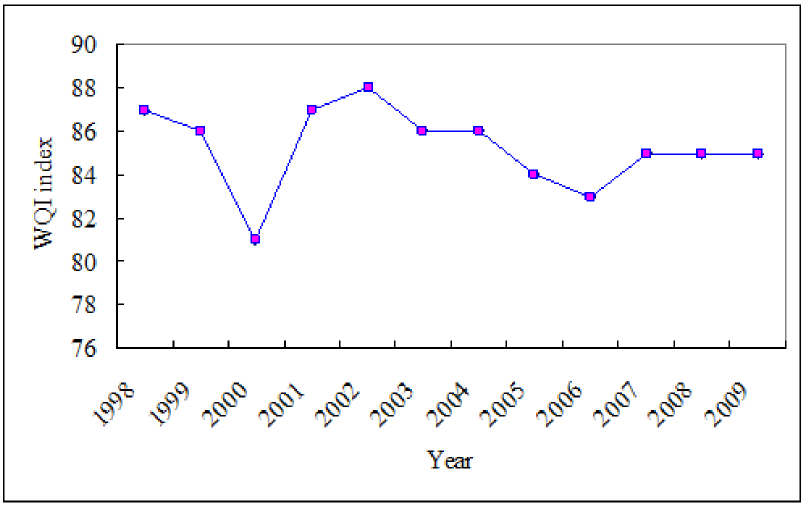


Figure 2: WQI for the Kelantan River from 1998 to 2009.
Source: DOE (2009a, b)
Note: DOE water quality classification based on the WQI.

Parameter	Index range				
	Clean		Slightly polluted		Polluted
WQI	81–100		60–80		0–59
	Class				
	I	II	III	IV	V
WQI	>92.7	76.5–92.7	51.9–76.5	31.0–51.9	<31.0

MATERIALS AND METHODS

Case Study of the Kelantan River Water Quality Analysis

Sampling locations

Water quality analysis was conducted in the Kelantan River during the monsoon season (from November 2010 to February 2011). Five stations were selected as sampling stations: Station 1 (KK), Station 2 (TG), Station 3 (TM), Station 4 (PM) and Station 5 (KB). Figure 3 shows the location of the five sampling stations in the Kelantan River. Samples were collected monthly from November 2010 until February 2011 (N = 45 samples per stream). The surface water samples were collected in plastic bottles, stored at 4°C and transferred to the laboratory within 48 hours for further analysis.

Table 1: Physical and chemical parameter analysis of the Kelantan River from a previous study (Ahmad *et al.* 2009).

Parameters	Units	Values
Temperature	°C	–
Conductivity	µS/cm	587±33
DO	mg/l	7.2±0.40
TDS	g/l	–
TSS	mg/l	36.6±13.52
pH	–	6.4±0.41
Turbidity	NTU/FTU	44.0±17.0
Nitrogen ammonia	mg/l	0.08±0.02
Nitrate	mg/l	0.62±0.24
Nitrite	mg/l	0.06±0.01

Note: Sampling period: January 1993

Sampling methods

Analytical analysis

The physical parameters, such as water temperature (°C), water conductivity (µS/cm), total dissolved solids (TDS) (g/l), DO (mg/l) and pH were measured in situ with a YSI Model 556 (Yellow Springs, OH, USA). The turbidity level [nephelometric turbidity unit (NTU)] was read with an HACH portable Turbidimeter model 2100P (Loveland, CO, USA). The TSS and the chemical parameters (nutrients) were determined using the HACH DR/890 Colorimeter (Loveland, CO, USA): TSS (photometric method), nitrogen ammonia (salicylate method), nitrate (cadmium reduction method), nitrite (diazotisation method).

Statistical analysis

The results of the water parameters of the river are presented as the mean ± the standard deviation (mean±SD). The physico-chemical parameters were compared among the stations in the Kelantan River. Significant differences among the stations were investigated with Tukey's HSD (Honestly Significant Difference) test at 5% level.

RESULTS AND DISCUSSION

Table 3 summarises the mean±SD of the physical and chemical parameters from the five sampling stations along the Kelantan River. The water temperature is the most important ecological factor because it controls the physiological behaviour and distribution of organisms (Krishnamoorthi *et al.* 2011). The water temperature of the Kelantan River ranged from 25.29°C to 25.98°C. The water conductivity of the surface water varied from 0.125 to 0.135 µS/cm. The mean water conductivity for the Kelantan River was 0.130 µS/cm. The DO levels of the Kelantan River varied from 5.60 to 6.57 mg/L, which is within the INWQS limit (Table 2). The maximum value of DO was detected at site KB and the lowest value was detected at site KK. The low DO value may be because of high organic matter content and the low flow of water. High organic matter limits primary production, and the senescence of phytoplankton increases microbial respiration that leads to the depletion of dissolved oxygen (Mandal *et al.* 2011; Prasanna & Ranjan 2010; Parr & Mason 2004). The distribution of low DO may be controlled by circulation in the water body (Yin *et al*. 2004; Radwan *et al*. 2003; Guasch *et al.* 1998). Higher flowing water has higher DO levels because of the water movement at the air-water interface (Radwan *et al*. 2003).

Table 2: Malaysian Interim National Water Quality Standards (INWQS).

Parameters	Units	Classes					
		I	IIA	IIB	III	IV	V
Ammonical nitrogen	mg/l	0.1	0.3	0.3	0.9	2.7	>2
BOD	mg/l	1	3	3	6	12	>12
COD	mg/l	10	25	25	50	100	>100
DO	mg/l	7	5–7	5–7	3-5	<3	<1
pH		6.5–8.5	6.5–9.5	6–9	5–9	5–9	
TDS	mg/l	500	1000	–	–	–	–
TSS	mg/l	25	50	50	150	300	>300
Temperature	°C	–	Normal+2	–	Normal+2	–	–
Turbidity	NTU	5	50	50	–	–	–
Nitrate	mg/l	–	0.4	0.4 (0.03)	–		–
Nitrite	mg/l	–	7	–	5	–	–

Notes:

Class	Uses
I	Conservation of the natural environment
	Water supply I - practically no treatment is necessary (except disinfection by boiling only)
	Fishery I - very sensitive aquatic species
IIA	Water supply II - conventional treatment required
	Fishery II - sensitive aquatic species
IIB	Recreational use with body contact
III	Water supply III - extensive treatment required
	Fishery III - common, of economic value and tolerant species
IV	Irrigation
V	None of the above

Source: DOE (2009)

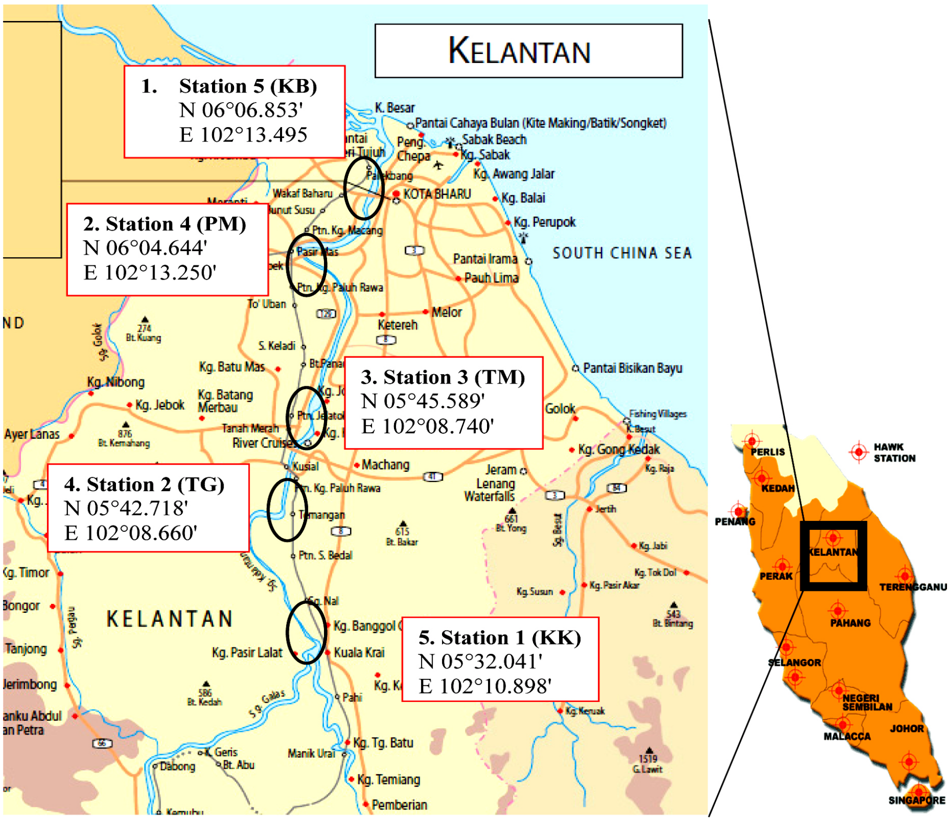


Figure 3: Location of the sampling sites along the Kelantan River, Kelantan, Malaysia.
Source: Wonderful Malaysia (2007)

The TDS of the surface water ranged from 0.081 to 0.084 g/l. The pH of the surface water was alkaline and fluctuated between 7.28 and 7.54. It was well within the limits (the most suitable pH for diverse aquatic ecosystems range from 7 to 8) [Maun & Moulton 1991] of the INWQS. The pH is one of the most important factors and serves as index for pollution. A pH between 7.3 and 8.4 is suitable for fish growth (Krishnamoorthi *et al.* 2011).

The TSS included silts and clays, which cause the brownish colour of the river system. The TSS in the Kelantan River ranged from 190.17 mg/l to 424.58 mg/l, which exceeds the INWQS limit (Table 2). The TSS value was greatest at site KK (424.58±305.40 mg/l) and smallest at site TM (190.17±88.16 mg/l). The TSS for the Kelantan River was significantly different between site KK and site TM. A TSS content between 80–400 mg/l has previously indicated the poor condition of aquatic ecosystems (Maun & Moulton 1991). The high value of TSS during the monsoon season occurred because of the floating fine silt and detritus that was carried by the rainwater from the catchment (Prasanna & Ranjan 2010). Deforestation activities upstream (Lojing Highlands) and sand mining activities caused an increase in silt and detritus at site KK.

Table 3: Mean value±SD and Tukey test results for the physical and chemical parameters of the five sampling stations along the Kelantan River that were sampled from November 2010 to February 2011.

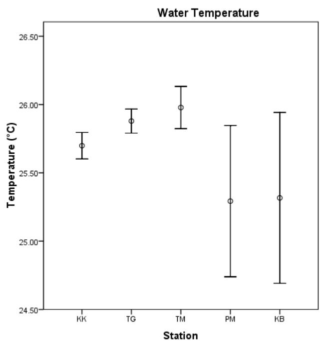
Parameters	Units	Stations				
		KK	TG	TM	PM	KB
Temperature	°C	25.70±0.17	25.88±0.15	25.98±0.27	25.29±1.01	25.32±1.08
Conductivity	µS/cm	0.131±0.007	0.135±0.011	0.132±0.009	0.125±0.007	0.125±0.009
DO	mg/l	5.60±0.62	6.03±0.73	6.01±0.60	6.34±0.53	6.57±0.87
TDS	g/l	0.084±0.005	0.085±0.005	0.084±0.005	0.081±0.003	0.081±0.005
TSS	mg/l	424.58±305.40[a]	237.50±124.16	190.17±88.16[a]	300.11±65.93	283.50±90.92
pH	–	7.52±0.21	7.29±0.23	7.28±0.32	7.54±0.21	7.43±0.32
Turbidity	NTU/FTU	672±481.12[a]	330.68±180.57	264.98±142.63[a]	453.04±103.18	437.42±126.30
Ammonia	mg/l	0.41±0.26	0.32±0.16	0.26±0.12	0.41±0.10	0.38±0.07
Nitrate	mg/l	17.6±12.9	15.4±8.9	13.3±8.8	20.7±9.0	21.7±11.3
Nitrite	mg/l	0.183±0.122[a]	0.108±0.029	0.098±0.030[a]	0.127±0.032	0.116±0.010

Notes: [a] Indicates that the station's values are significantly different from those of every other station ($\alpha<0.05$)

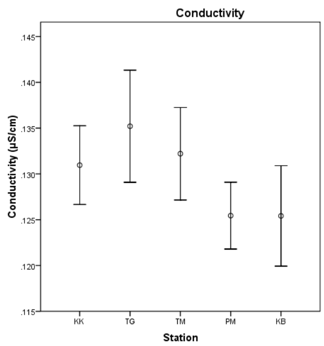
Rapid changes and extremely high TSS values are stressful to fish and other aquatic organisms. The turbidity is because of the dispersion of suspended particles. It is caused by fine sediment and organic particles. The turbidity values of the Kelantan River varied from 264.98 to 672.01 NTU, which exceeded the INWQS limit (Table 2). A significant difference was found between the sites KK and TM. The highest turbidity value was observed at site KK (672±481.12 NTU) and the lowest turbidity value was observed at site TM (264.98±142.63 NTU). Abnormal values of turbidity are because of the discharge of water with floating sediments that are carried by the river from catchment areas (Prasanna & Ranjan 2010). High turbidity decreases the ability of water to transmit light. Primary productivity in the river may be reduced because of high turbidity (Krishnamoorthi *et al.* 2011). A previous study by Ambak and Zakaria (2010) discovered that the turbidity in the Kelantan River has seriously affected the fish population in the river.

The nitrate concentration of the Kelantan River ranged from 13.3 to 21.7 mg/l, exceeding the INWQS limit (Table 2). The maximum nitrate concentration was observed at site KB and the minimum nitrate concentration was observed at site TM. The presence of nitrates in the river could be because of anthropogenic sources, such as domestic sewage, agricultural run-off and other waste effluents which contain nitrogenous compounds (Prasanna & Ranjan 2010). The high value of nitrate concentration at site KB was because of the agricultural runoff resulting from a few agricultural sites along site KB. The nitrogen ammonia concentration varied from 0.26 to 0.41 mg/l. The ammonia concentration was lower than the nitrate concentration. This indicates a minimal influence from industrial effluents on the Kelantan River ecosystem. The nitrite concentration varied from 0.098 to 0.183 mg/l. A significant difference in nitrite concentration was found between sites KK and TM. The highest value of nitrite concentration was observed at site KK (0.183±0.122 mg/l) and lowest value was observed at site TM (0.098±0.030 mg/l).

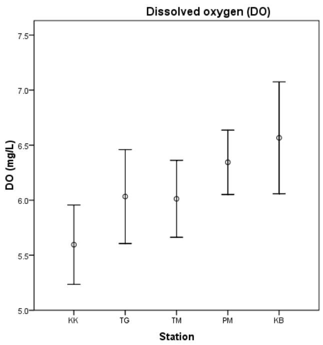
Figure 4 (a–j) shows box plots of water temperature, conductivity, DO, pH, TSS, TDS, turbidity, nitrogen ammonia, nitrate and nitrite concentrations. There was a considerable increase in DO from site KK to site KB. The box plots for TDS, TSS and turbidity show an identical pattern of considerable decrease from site KK to site KB. The high organic contents (such as TDS, TSS and turbidity) at site KK depleted the oxygen in the water (Prasanna & Ranjan 2010). The high amount of sediment from sand dredging decreased the oxygen levels in the water by disturbing the layers of anaerobic sediment, therefore reducing the oxygen exchange in the sediments (Gubbay 2003). The box plots also show that site KK had the greatest variation in terms of TDS, TSS, turbidity, nitrogen ammonia, nitrate and nitrite compared to other sampling sites. The upstream logging (Lojing Highlands) activities, such as sand mining operations and heavy use of the local jetty, has caused site KK to vary largely in physico-chemical and nutrient parameters. Water quality is crucial for the survival and distribution of aquatic life. If certain parameters exceed the optimum or reach harmful limits, it will affect the survival and general heath of the aquatic organisms. Sedimentation and soil erosion not only lead to short term changes in the community structure of the river but also have long term implications. When the environment of the river has been changed by dredging or sand mining, it also changes the biota in the river because the biota adjust to adapt to the poor environment rather than recover from their poor condition (Gubbay 2003). Therefore, proper management must occur to prevent various parameters in the river from exceeding their limit.



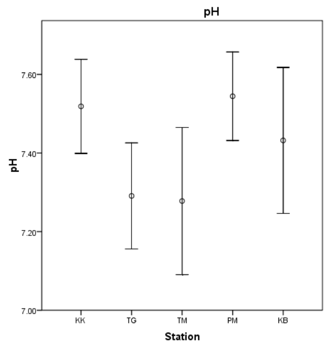
(a)



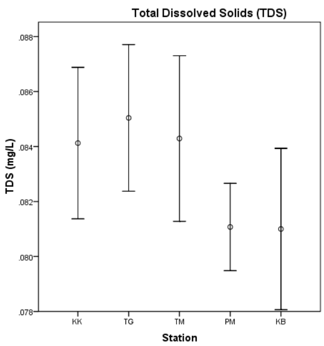
(b)



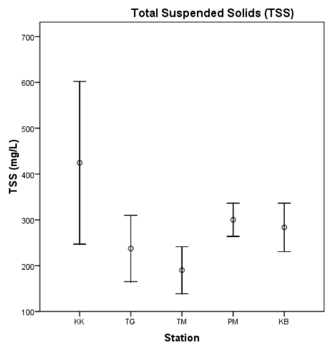
(c)



(d)



(e)



(f)

Figure 4: Mean and SD in the form of box-plots: (a) water temperature, (b) water conductivity, (c) DO, (d) pH, (e) TDS, (f) TSS, (g) turbidity, (h) nitrogen ammonia, (i) nitrate and (j) nitrite, from the five stations along the Kelantan River (November 2010–February 2011) (*continued on next page*).

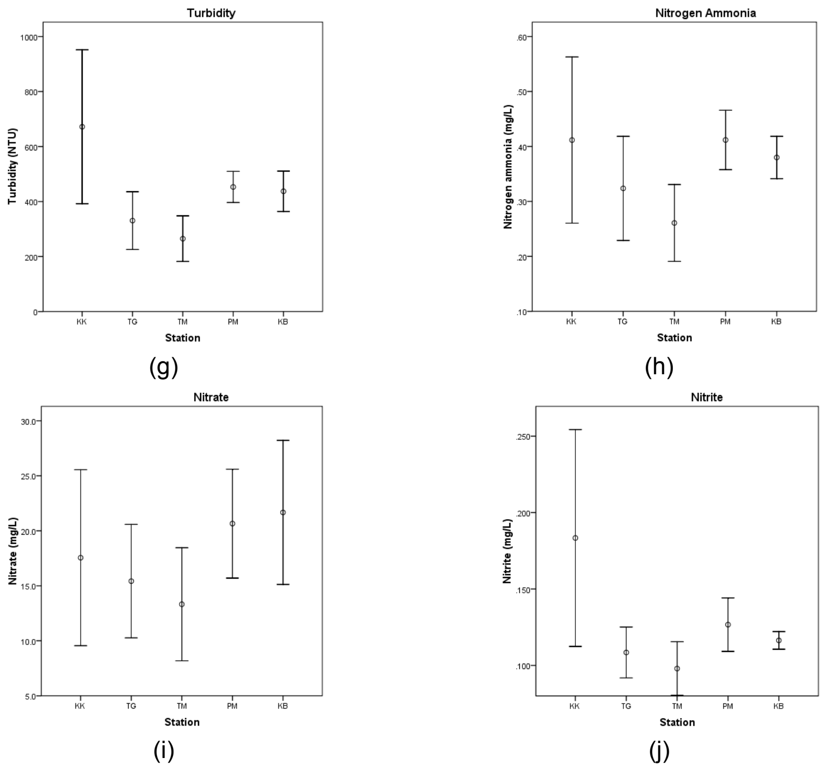


Figure 4: (*continued*)

Figure 5 depicts the TSS (mg/l), plotted against discharge (m^3/s). A linear relationship exists between the TSS and the discharge (Fig. 4) as described by the equation $y = 0.085x + 132.6$ ($R^2 = 0.340$). There is an increase of TSS when the measured discharge in the Kelantan River increases. The maximum TSS, ranging from 115.56 to 248.78 mg/l, occurred between discharges ranging from 209.95 to 958.44 m^3/s in the Kelantan River. Figure 6 shows the average monthly rainfall data. The monsoon season occurs during November and December, with almost double the rainfall volume of the dry season. In the monsoon period, the TSS value was high because of floating materials, such as fine silt and detritus that were carried by rainwater from the catchment (Prasanna & Ranjan 2010). The high volume of rainfall during the monsoon season increased the speed of discharge in the river. The TSS and turbidity were extremely high during the monsoon season.

Recommendation

Proper management of the river through sand mining monitoring is required to ensure the sustainability of the Kelantan River ecosystem. To minimise the negative effects of sand mining on the river ecosystem, the following recommendations are made:

i. The local authorities, such as the Department of Irrigation and Drainage and the Department of the Environment, must enforce regulations and be strict with the monitoring of the operating sand mining companies along the river. The guidelines must be followed.
ii. The state government should develop a policy that urges the miners to reinvest and repair the old (unused) mine sites. This can reduce the chance of landslides in the area.
iii. Improve the understanding of the public about the effect of river sand mining on aquatic ecosystems.
iv. Apart from monitoring the water quality using only physico-chemical parameters by the Department of the Environment, monitoring of the biological living communities in the river is required. The biological living communities are another environmental factor that can be assessed scientifically, and they are good indicators for river ecosystem health.

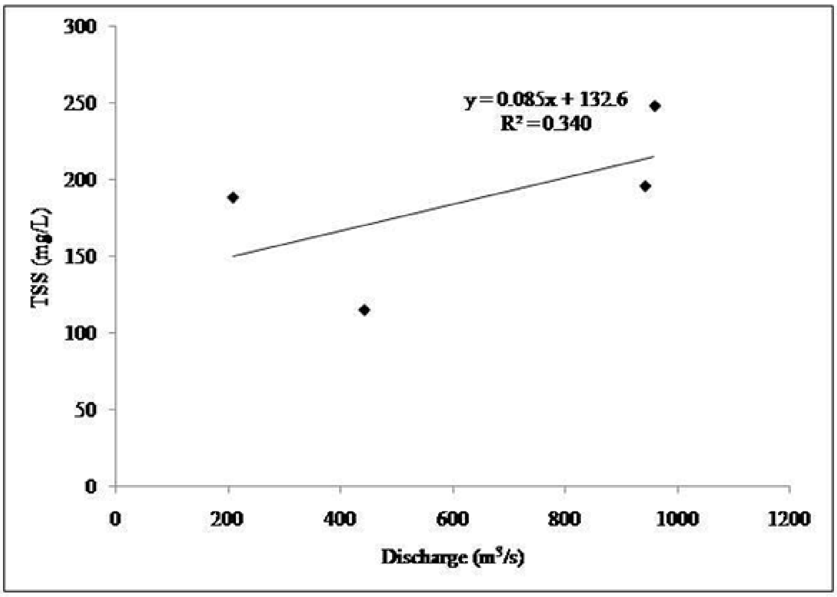


Figure 5: The relationship between TSS (mg/l) and the discharge (m^3/s) of the Kelantan River during sampling from November 2010 to February 2011.

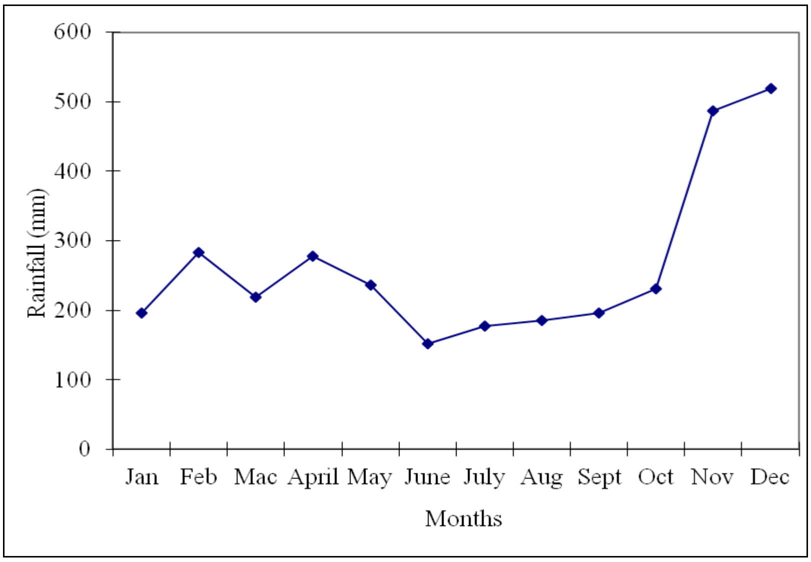


Figure 6: Average monthly rainfall (mm) for the Kelantan River from 2006 to 2010.
Source: DOE (2009a, b).

CONCLUSION

Physico-chemical analysis of the river water in the study area demonstrated that the Kelantan River was a clean river, with the exception that certain physico-chemical parameters (such as TSS, turbidity and nitrate concentration) had increased to extremely high levels that exceed the standards of the INWQS, as a result of sand mining activities and upstream logging activities (Lojing Highlands). Site KK had the greatest variation in terms of TDS, TSS, turbidity and nutrients. The effective management of river sand mining activities must be undertaken. Proper management and planning is required to prevent further damage of the river ecosystem from sand mining. It is noted that the recovery of the river from sand mining effects may take several years depending on the environmental dynamics.

ACKNOWLEDGEMENT

Our special appreciation to the river ecology team (Siti Zulfarina, Wan Mohd Amzar and Mohd Rezza Petra Azlan) for their help in collecting data. Thanks also go to En. Zakaria Kasim, Pn. Juskamini Jusoh, En. Md. Khairul Azuan and En. Mohd Kamarizan for helping the team in the field and laboratory. Our thanks also go to the Environmental and Occupational Health laboratory of School of Health Sciences, USM Health Campus for providing equipment. Special gratitude to the Department of Environment (Kelantan) and Department of Irrigation and Drainage (Kelantan) for secondary data and information. Cordial appreciation also goes to all staff from Research Office of School of Health Sciences. This research was sponsored by short-term grant (304/PPSK/6131633), USM.

REFERENCES

Ahmad A K, Mushrifah I and Shuhaimi-Othman M. (2009). Water quality and heavy metal concentrations in sediment of Sungai Kelantan, Kelantan, Malaysia: A baseline study. *Sains Malaysiana* 38(4): 435–442.

Ambak M A, Isa M M, Zakaria M Z and Ghaffar M A. (2010). *Fishes of Malaysia.* Kuala Terengganu: Universiti Malaysia Terengganu.

Ambak M A and Zakaria M Z. (2010). Freshwater fish diversity in Sungai Kelantan. *Journal of Sustainability Science and Management* 5(1): 13–20.

Department of Environment (DOE). (2009a). *Annual report of Department of Environment, Kelantan*. Kota Bharu Kelantan: Department of Environment.

———. (2009b). *Malaysia environmental quality report*. Petaling Jaya, Malaysia: Department of Environment, Ministry of Natural Resources and Environment.

Environmental Conservation Department (ECD). (2001). *State policy on river sand and stone*. Sabah: State Environmental Conservation Department. http://www.sabah.gov.my/jpas/programs/ecd-cab/technical/smpol260201.pdf (accessed on 4 May 2011).

Guasch H, Armengol J, Marti E and Sabater S. (1998). Diurnal variation in dissolved oxygen and carbon dioxide in two low-order streams. *Water Research* 32(4): 1067–1074.

Gubbay S. (2003). *Marine, aggregate extraction and biodiversity.* UK: Wildlife Trusts, WWF-UK.

Hitchcock D R and Drucker B R. (1996). *Proceeding of Conference on Oceanology International 1996,* vol. 2. Brighton, UK: Spearhead Exhibitions Ltd., 221–284.

Krishnamoorthi A, Senthil Elango P and Selvakumar S. (2011). Investigation of water quality parameters for aquaculture-A case study of Veeranam Lake in Cuddalore District, Tamilnadu. *International Journal of Current Research* 3(3): 013–017.

Lawal P O. (2011). Effects of sand/gravel mining in Minna Emirate area of Nigeria on stakeholders. *Journal of Sustainable Development* 4(1): 193–200.

Mandal S, Ray S, Debnath M, Ghosh P B, Roy M and Ray S. (2011). Dynamic modelling of dissolved oxygen in the creeks of Sagar Island, Hooghly Matlah estuarine system, West Bengal, India. *Applied Mathematical Modelling* in press.

Maun C and Moulton P. (1991). *Optimal water quality standards for aquatic ecosystems*. Olympia, WA: Nisqually River Education Council and Nisqually River Council. http://schools.csd509j.net (accessed on 28 April 2011).

Ministry of Natural Resources (MNR) and Department of Irrigation and Drainage (DID). (2009). *River sand mining management guideline.* Kuala Lumpur: Department of Irrigation and Drainage.

Parr L B and Mason C F. (2004). Causes of low oxygen in a lowland, regulated eutrophic river in Eastern England. *Science of The Total Environment* 321(1–3): 273–286.

Peck Yen T, Zulfarina F S and Rohasliney H. (2010). Comparison of the zooplankton community in Kelantan River and its tributary, Pengkalan Chepa River: A preliminary study. In S Harith, H Abdullah, R Suppian and H A Rahman. (eds.). *National Conference on Environment and Health 2010*. Kota Bharu, Kelantan: School of Health Sciences, Universiti Sains Malaysia, 1–6.

Phua C, Akker v d S, Baretta M and Dalfsen v J. (2004). *Ecological effects of sand extraction in the North Sea*. Portugal: University of Porto. www.vliz.be/imisdocs/publications/154975.pdf (accessed on 3 February 2010).

Prasanna M B and Ranjan P C. (2010). Physico chemical properties of water collected from Dhamra estuary. *International Journal of Environmental Sciences* 1(3): 334–343.

Radwan M, Willems P, El-Sadek A and Berlamont J. (2003). Modelling of dissolved oxygen and biochemical oxygen demand in river water using a detailed and a simplified model. *International Journal of River Basin Management* 1(2): 97–103.

Supriharyono. (2004). Effects of sand mining on coral reefs in Riau Islands. *Journal of Coastal Development* 7(2): 89–103.

Wonderful Malaysia. (2007). *Map of Kelantan State*. Malaysia: Wonderful Malaysia. http://www.wonderfulmalaysia. com/map-state-kelantan-malaysia.htm (accessed on 1 January 2010).

Yin K, Lin Z and Ke Z. (2004). Temporal and spatial distribution of dissolved oxygen in the Pearl River Estuary and adjacent coastal waters. *Continental Shelf Research* 24(16): 1935–1948.