JOURNAL OF ENVIRONMENTAL GEOGRAPHY
Journal of Environmental Geography 10 (3–4), 1–8.
DOI: 10.1515/jengeo-2017-0007
ISSN: 2060-467X

SUSPENDED SEDIMENT AND PHOSPHORUS BUDGET AND TROPHIC STATUS OF BUKIT MERAH RESERVOIR, PERAK, MALAYSIA

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Research article, received 6 April 2017, accepted 3 October 2017

Abstract

Bukit Merah Reservoir (BMR) is one of the 51 impoundments in Malaysia. BMR is the oldest reservoir built in the early 1900s originally to store water for irrigation, but nowadays its functions include also flood control and water supply. Nowadays, it is threatened by land use change in the upper catchments and surrounding activities, which feeding eroded material and chemicals into the reservoir. Suspended sediment, as well as, nutrient fluxes into BMR are becoming an increasing threat to the reservoir, as its sedimentation and eutrophication accelerate. This paper discusses our study on the BMR carried out between March 2008 and April 2009 to assess the water quality status, and to determine the sediment and Total Phosphorus (TP) influx into the south pool lake. An estimated amount of suspended sediment fluxes of about 2,900 t year^{-1} came from the north pool lake (18%) and 12,900 t year^{-1} from the main Kurau River inlet (82% of the total input to the BMR). Of these total sediment input (nearly 15,800 t) about 5,600 t (36%) of the total sediment influx was trapped in the BMR. TP influx was about 18.8 t year^{-1} and about 7 t (37%) was trapped in the reservoir. The amount sediment and TP stored in the BMR affect the water quality of the lake, therefore the mean trophic state of the lake is eutrophic (TSI of 54.4) related to high productivity. Increasing sediment input into the reservoir has affected the reservoir volume and frequent flooding downstream of the reservoir during rainy seasons, while eutrophication has caused the lake water quality deterioration.

Keywords: suspended sediment, total phosphorus, eutrophication, trophic state, Bukit Merah Reservoir

INTRODUCTION

Suspended sediment is an important source of phosphorus (P) to freshwater ecosystems including many lakes and reservoirs (Wetzel, 2001). The use of fertilizers in order to increase crop yield in catchments (Hart et al., 2004) can increase pressure on aquatic systems. Terrestrial soils provide the parent material from which sediments are derived, and therefore the speciation of P in lake sediments may be largely governed by the P contents of the catchment soils. However, the selective erosion and transportation of eroded material with different grain sizes in overland and stream flow may alter the composition of suspended sediments related or relevant to the bulk source material.

The transport of sediment-associated nutrients such as phosphorous (P) from the soil to the river network is complex, because it is influenced by many processes such as soil erosion, sediment transport, and deposition within the catchment (e.g., Gburek et al., 2000). Sediments can function either as sources or losses of phosphorous. Sedimentary P can act as an internal load to the overlying water column for a long period (Pant and Reddy, 2001).

Total phosphorus (TP) loading resulting from watershed development has long been recognized as an important factor affecting lake trophic status (Vollenweider, 1968; Dillon and Kirchner, 1975; Canfield, 1983). The effect of excessive TP loading to shallow lakes is especially pronounced as it can lead to high macrophyte production, which on senescence contributes significant amounts of nutrients to both sediments and overlying waters (Nichols and Keeney, 1973; Carpenter, 1980; Carignan and Kalff, 1982; Sabah and Wanganeo, 2008). Lake enrichment resulting from the mobilization of TP from watersheds is often, over time, followed by internal TP loading from bottom sediments (Ahlgren et al., 1988; Nürnberg, 1984; Nürnberg and Lazerte, 2004; French and Petticrew, 2007). Exploration of the geochemical association and potential bioavailability of particulate P is required, since once P is introduced to lake ecosystems it will accumulate in the bottom sediments. The stored P in the sediment can be released into the overlying water under some environmental conditions, which may have a significant impact on water quality and ultimately result in continuing eutrophication (Lennox, 1984; Abrams and Jarrell, 1995; Xie et al., 2003).

Phosphorus release is influenced by a variety of environmental factors including water temperature, pH, phosphorus, dissolved oxygen (DO), nitrate, redox potential and hydrological conditions (Jensen and Andersen 1992; Gao et al. 2005; Zhu et al., 2007). Phosphorus distribution in lake sediments is not uniform over an entire lake and environmental conditions are equally variable. Consequently, the release of phosphorus and the factors affecting this release is likely to vary within a lake. According to Carlson (1977), the accuracy of the index values based on TP depends on the assumption that phosphorus is the main algal biomass limiting factor, and that the concentration of all forms of phosphorus present in the water body is a function of algal biomass.

Bukit Merah Reservoir (BMR) in Malaysia is under threat from eutrophication due to increased intensity of agriculture in the upper catchments, agricultural development and an eco-tourism development surrounding the lake. Recent work has highlighted the growing problem of siltation (Ismail et al. 2010) and attention is now turning to nutrient fluxes. Against this background, this paper, aims to quantify suspended sediment and nutrient loadings into BMR and assessing the trophic status of the lake.

MATERIALS AND METHODS

Study area

The climate of BMR is an equatorial with an average daily temperature ranging from 23°C to 33°C. The mean annual rainfall recorded at BMR for the period 1953–2008 was 2905 mm (range 2200–3700 mm/year). The river inlets to BMR, are the Merah (M) River, Jelutong (J) River, Selarong (S) River and Kurau (K) River (Fig. 1). The river discharge of Merah, Jelutong, Selarong river are low with an average discharge of 1.03$\pm$0.59 m^3/s, 1.04$\pm$0.47 m^3/s and 0.11 $\pm$0.1 m^3/s, respectively. Major input to BMR lake is from Kurau River with an average discharge of 27.2 m^3/s ranging from 6.6-65.7m^3/s. The capacity of the reservoir is 70×10^6 m^3 at a water level depth of 8.5 m asl (Ismail et al. 2010).

Based on the data the Department of Survey, Malaysia, the land use of the BMR catchment area comprises oil palm (48.3 km^2); rubber (98.9 km^2); forest (196.9 km^2); paddy (15.5 km^2); and others (47.9 km^2) (Hidzrami, 2010). The land use changes in the catchment area covering the Merah, Jelutong and Selarong subcatchments have also been described by Amirin and Hasmadi (2010). They found that from 1989 to 1999, forest cover decreased from 64% to 60% and 94% of bushes were mostly replaced by oil palm. The areal extension of oil palm plantations increased by 13% and of the paddies it increased by as much as 65%.

Field measurement and sample collection

The sampling programme reported here covers a one-year period from March 2008 to April 2009 on several monitoring sites of the BMR (Fig. 1). The locations of the monitoring sites for the physico-chemical and biological variables of the river inputs and the reservoir outputs namely the Kurau outlet and canals are represented on Fig. 1. Measurements of water quality and river flow were undertaken every fortnight at Kurau River (K) and at the north pool outlet (ONP). River flow were measured using current meter and discharge was calculated using a velocity-area method (Shaw, 1994). Discharge in the main inlets and the outlets was measured, and the water level was recorded continuously. In minor inlets and a few outlets, discharge was measured fortnightly and some time daily during rainy period. Mean discharge was estimated by establishment of relationships between these instantaneous values and the calculated mean discharge from nearby hydrometric stations.

The topmost water layer of BMR (at 0.5m depth) was analysed in situ for pH, dissolved oxygen (DO) using a portable field pH meter (YSI Portable meter), described by Ismail and Najib (2011) and Ismail et al. (2010). Water transparency was tested using Secchi disk. Water samples were collected every fortnight and analysed for suspended sediment concentration (SSC), total phosphorus (TP) concentrations and chlorophyll-a based on APHA standard methods (APHA 1989). SSC was determined by filtration using 0.45-µm Whatman GFC filter papers and oven drying at 105°C for 24 hours (APHA, 1989). TP concentrations were determined with

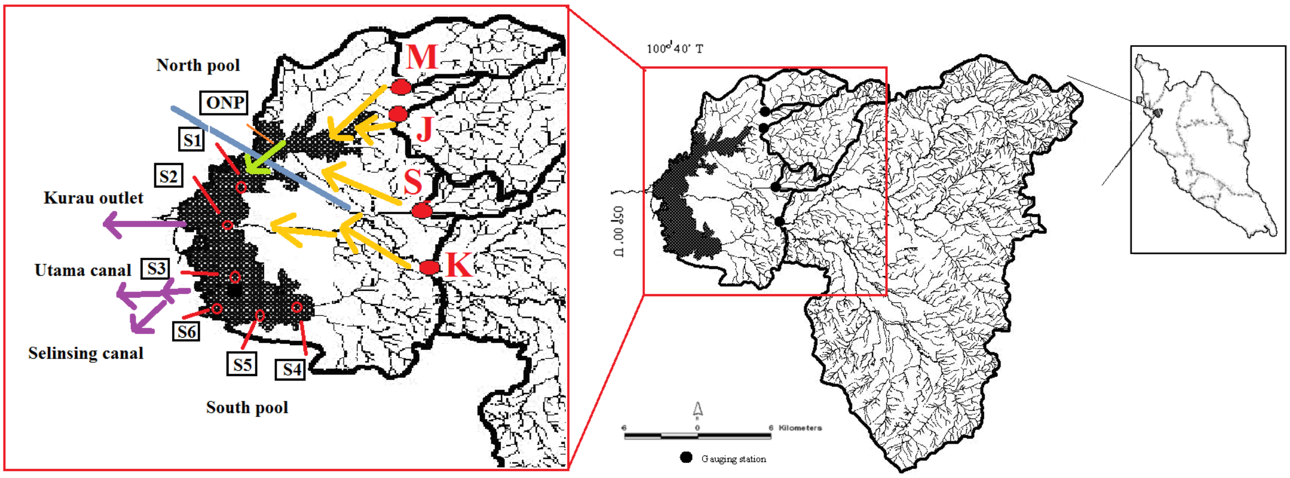

Fig 1 Bukit Merah Reservoir (BMR) and its catchment area located at north Perak. The reservoir receives inputs from Kurau (K), Selarong (S), Merah (M) and Jelutong (J) Rivers. Six sampling stations in the lake are shown for S1 to S6. The water from the lake flows out of the system through the Kurau outlet and 2 irrigation canals (Selinsing and Utama canal). Yellow arrows show the input from the catchment, green arrow is the output from north pool and purple are output arrows from the south pool.

the ascorbic acid method (APHA, 1989), while chlorophyll-a was extracted with acetone for 48 h under dark and cold conditions (3–5 °C). The transmittance percentage of the extracts was read at 664-665 nm using a Perkin Elmer 25 UV–Vis spectrophotometer following APHA (1989). The estimation of sediment and nutrient loading is expected to be underestimated due to the sampling frequency, as during storms samples were not taken.

Trophic Status Index (TSI)

This study used Carlson's Trophic State Index (TSI), also known as the Carlson Index, which was developed to compare Secchi disk depth (SD), chlorophyll-a concentrations and TP concentrations (Carlson, 1977), thus to classify regional surface waters, including streams and rivers. Although chlorophyll-a is the most direct measure of algae biomass, Carlson used Secchi disc depth as the primary indicator since these three variables are highly correlated and are considered good estimators of algal biomass. The TSI was determined by the first three equations (Eq. 1, 2 and 3) where TSI is in natural logarithm, and Carlson TSI (Eq. 4) is the average of the three TSI.

$$\mathrm{TSI\ (SD)} = 60 - 14.41 \ln (\mathrm{SD}) \qquad \text{(Eq. 1)}$$

where SD is mean Secchi disc depth (m)

$$\mathrm{TSI\ (Chla)} = 9.81 \ln (\mathrm{Chla}) + 30.6 \qquad \text{(Eq. 2)}$$

where Chla is mean chlorophyll-a (μg L^{-1})

$$\mathrm{TSI\ (TP)} = 14.42 \ln (\mathrm{TP}) + 4.15 \qquad \text{(Eq. 3)}$$

where TP is mean total phosphorus (μg L^{-1})

$$\text{Carlson's TSI} = [\mathrm{TSI\ (SD)} + \mathrm{TSI\ (Chla)} + \mathrm{TSI\ (TP)}]/3 \qquad \text{(Eq. 4)}$$

The TSI range is related to productivity. A range between 40-50 is usually associated with mesotrophy (moderate productivity). Index values greater than 50 are associated with eutrophy (high productivity), while values less than 40 refer to oligotrophy (low productivity).

Data analysis

Loadings of nutrients and suspended sediment in tonnes (t) between time interval K, were calculated by multiplying the discharge Q (m^3 s^{-1}) by concentration S (mg L^{-1}) over the time interval K (seconds) between samples based on the average sample load approach (Littlewood, 1992).

RESULTS

Sediment and phosphorus budget

The simplified sediment and TP budget between the river inputs (Kurau River and outlet from north pool) and the outputs (Kurau outlet and Selinsing and Utama Canals) is summarised in Table 1. The south pool lake received sediment inputs from Kurau River (K) and outlet from north pool (ONP) totalling almost 15,800 t year^{-1} and about 19 t year^{-1}of TP load. Kurau River, which is the main river inlet to the BMR, contributed almost 82% of the total sediment input, amounting to about or 12,900 t year^{-1}, while the TP load about was 11 t year^{-1} (60% of the total) during the study period. During the studied year-long period water discharge, Q (m^3s^{-1}) and suspended sediment loading of Kurau River altered considerably (Fig. 2). Higher Q and SS loads were observed from September to December 2008 (the north-east monsoon period), and April 2009 (early onset of inter-monsoon month).

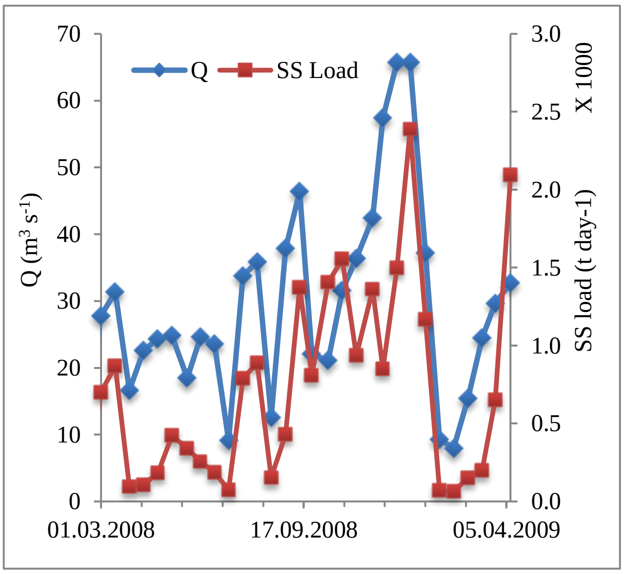

Fig. 2 Water discharge (Q) in m^3 s^{-1} and suspended sediment loads (t day^{-1}) of Kurau River during the study period

Table 1 Sediment and phosphorus budget for Bukit Merah Reservoir (2008-2009)

	Suspended sediment load (t)	Percentage (%)	Total Phosphorus load (t)	Percentage (%)
Kurau River (K)	12871.5	81.6	11.32	60.3
Ouput from north pool (ONP)	2899.6	18.4	7.45	39.7
Total Input	15771.2	100	18.77	100
Output				
Utama canal	4783.1	47.1	5.60	47.5
Selinsing canal	1461.4	14.4	0.92	7.8
Kurau outlet	3912.0	38.5	5.26	44.7
Total Output	10156.5	100	11.78	100
Input–Output	5614.6	35.6	6.99	37.2

The total amount of suspended sediment flushed out from the lake system through the Kurau outlet was about 3,900 t year^{-1} (38.5%), besides, nearly 4,800 t year^{-1} (47%) was delivered through the Utama canal and 1,500 t year^{-1} (14%) through the Selinsing canal. Thus, altogether the total sediment output from the reservoir was 10,157 t year^{-1}. It was estimated that approximately 5615 t (36%) of the sediment delivered in 2008 to 2009 was trapped in the reservoir (see Table 1).

The total amount of TP flush out of the lake system through the Kurau outlet was 5.3 t year^{-1} (45 % of the total outflux); while 5.6 t year^{-1} (47.5 % of the total outflux) were through the Utama canal and only 0.92 t year^{-1} (8%) through the Selinsing canal, amounting to a total TP output about 12 t year^{-1}. Hence, it can be estimated that approximately 37% of the TP was stored in the reservoir (see Table 1).

Relationship between SSC and turbidity

The relationship between SSC and turbidity at Kurau River and outlet from north pool (ONP) are shown on Fig. 3 and 4. The relationship was good with $R^2 = 0.73$ and $R^2 = 0.65$, respectively. Previous studies in 2007, including Ismail et al. (2010) showed that the mean SSC in the lake was 8.61 mg L^{-1} ranging from 0.93 mg L^{-1} in the dry months to 38.0 mg L^{-1} in the rainy season (Table 2). The mean SSC was higher in 2008 (13.5 ± 19.98 mg L^{-1}). The mean turbidities in 2007 and 2008 were 12.4 and 23 NTU, respectively. The Secchi disk depth, which is inversely related to SSC and turbidity, was higher in 2007 (mean = 0.85 m) than in 2008 (mean = 0.74 m) (see Table 2).

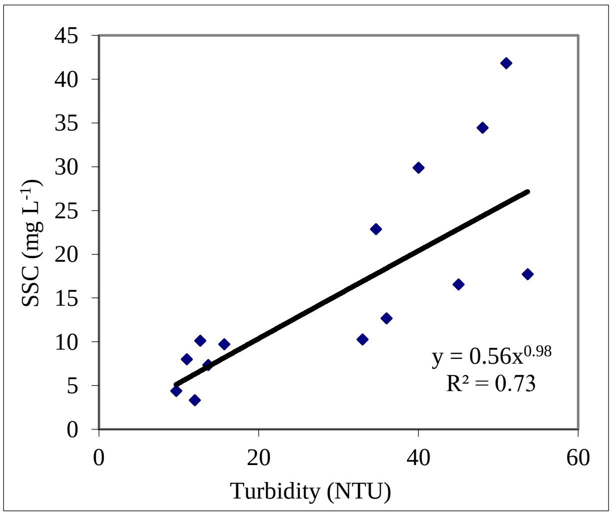

Fig. 3 Regression SSC and turbidity at Sg. Kurau

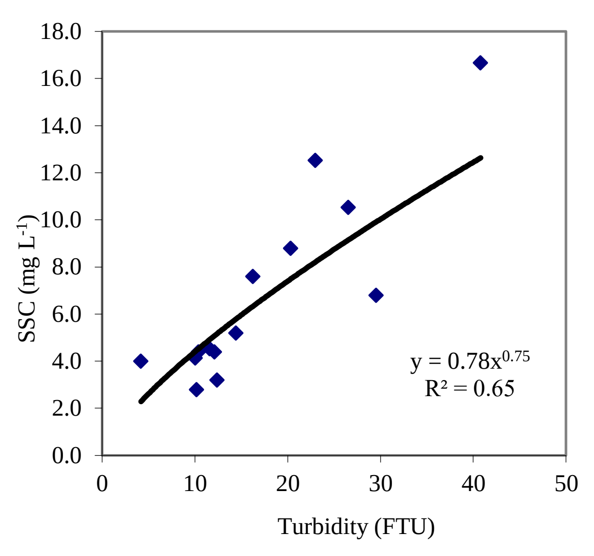

Fig. 4 Regression between SSC and turbidity at outlet from the north pool

TP and SSC relationship

Fig. 5 and 6 shows the relationship between TP contents of water and suspended sediment concentrations of samples collected at the Sg Kurau inlet and in the lake. The relationship is a strong positive log-linear function observed between logTP and logSSC at Kurau River ($R^2 = 0.69$; Fig. 5) and in the lake (R^2=0.76, Fig. 6).

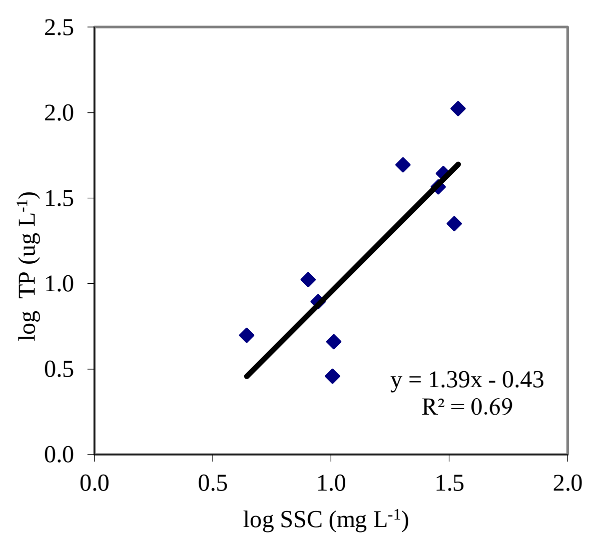

Fig. 5 Regression of log TP and log SSC at Kurau River

Table 2 Suspended sediment concentration (SSC), turbidity and Secchi disk depth values of BMR in 2007 and 2008

	2007		2008	
Parameter	Range	Mean ± StdDev	Range	Mean ± StdDev
SSC (mgL^{-1})	0.93–38.00	8.61±6.26	0.13–202.0	13.52±19.98
Turbidity (NTU)	6.33–31.73	12.40±5.25	5.88–64.10	22.92±15.95
Secchi disk depth (m)	0.3–1.85	0.85 ± 0.25	0.26–1.20	0.74 ± 0.21

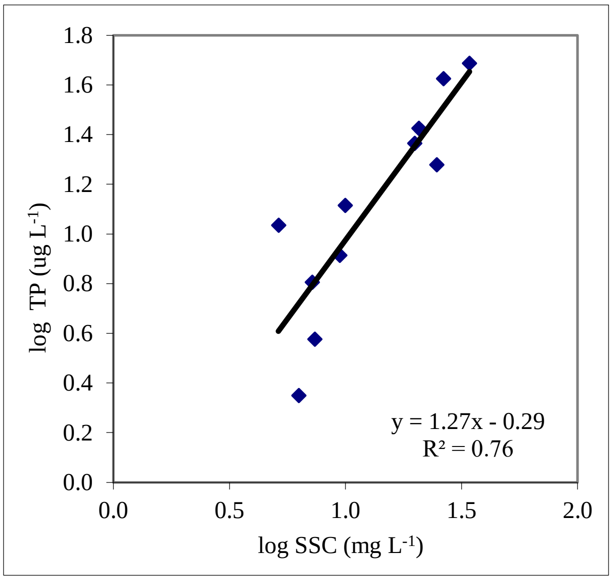

Fig. 6 Regression between log TP and log SSC in the lake

Trophic status

Table 3 shows the 3 TSI at 6 different sites of the lake. The average TSI (SD) was 64.12, which is indicative of an eutrophic status. The average SD transparency for the entire study period was 0.76m, with a minimum SD of sometime 0.3m after storms usually at the station near the Kurau river mouth. During clear water SD could reach a maximum depth of 1.0m. This average SD is very shallow, less than 1 m showing less penetration of light cause by many factors ranging from maybe colloidal organic matter or colour (Schindler, 1971), or turbidity from suspended inorganic particulates (Zettler and Carter, 1986) and phytoplankton (Ostrofsky and Rigler, 1987).

Table 3 Trophic status based on three indicators for six sites in Bukit Merah Reservoir

Sites	TSI (SD)	TSI (TP)	TSI (Chl-a)	Mean TSI
S1	66.21	46.85	50.28	54.45
S2	68.49	43.84	55.40	55.91
S3	61.46	42.15	52.18	51.93
S4	61.27	43.88	53.98	53.04
S5	63.38	44.75	54.82	54.32
S6	63.94	45.73	61.38	57.02
Mean TSI	64.12	44.53	54.67	54.44
Class	Eutrophic	Mesotrophic	Eutrophic	Eutrophic

Notes: TSI is Trophic Status Index;
SD is Secchi Disc Depth; TP is Total Phosphorus;
Chl-a is chlorophyll-a.

The lake was classified as mesotrophic based on TP (TSI = 44.5); but slightly eutrophic based on chlorophyll-a (TSI = 54.5). The average classification was however slightly eutrophic with the value of 54.44, as it slightly exceeds the maximum limit for a mesotrophic classification (see Table 3).

DISCUSSION

Sediment fluxes

The transport of suspended sediment derived from upstream sources affects the biogeochemical flux of downstream river systems (Meybeck, 1984). Into the studied reservoir most of the suspended sediment load came from Kurau River, which drains a very dynamic catchment with vast differences in land uses, which in turn caus significant erosion and sediment transport in the Kurau River catchment (see Table 1). Furthermore, due to its large size, the Kurau River catchment produced much higher river discharge in the wet months when most of the sediment is transported from the catchment into the reservoir.

Large amount (36%) of sediment is deposited in the BMR annually (see Table 1). The main contribution of sediment to the reservoir is from the Kurau River, where about 82% (12,900 t year^{-1}) of the total annual sediment input compared to the contribution from the north pool, which is about 18.4% (2,900 t year^{-1}). The sediment yield of the Kurau River is only about 39.8 t km^{-2} year$^{-1,}$ which is an underestimation because of the sampling frequency. However, it is comparable to other sediment yields in Malaysia, which are affected by mixed land use dominated by agriculture (see Table 4).

Large amount of sediment input to the BMR from Kurau River is related to the recent land use change where about 46% of land uses consists of oil palm and rubber plantation. This cause high erosion and sediment transport, especially during rainy seasons. The rate sedimentation in the lake were reportedly to increase from a rate of 0.36 mm year^{-1} (1995–2000) to 0.48 mm year^{-1} (2000–2005) (Ismail et al. 2010). Such results go in line with other evidence illustrating that sediment delivery can be increased from 5 to 10 fold following major human impact (Dearing and Jones, 2003). The high sediment discharge of the Kurau River also affecting the river and lake water turbidity and Secchi disk depth transparency, especially at the river mouth (station S3, S4 in Table 3). The increase in the sediment loading in aquatic systems in recent decades as demonstrated by the BMR (Table 1) is an example of many cases of anthropogenic impacts on aquatic ecosystems globally.

Total Phosphorus

The primary sources of new nutrients to lakes are terrestrial runoff and atmospheric input. With the exception of some of the great lakes, internal reservoirs in lakes are relatively small, and lakes are therefore very responsive to seasonal inputs (Guildford and Hecky, 2000). The TP input for BMR was about 19,300 t year^{-1}. This is probably related to the fact, that rubber, paddy and oil palm plantations cover 39% of the catchment area.

Table 4 Sediment yield of selected Malaysian catchments

Catchment	Area (km^2)	Sediment Yield ($t\ km^{-2}\ yr^{-1}$)	Source
A. Forested Catchments			
Bukit Berembun, Negri Sembilan	0.04	20	Baharuddin (1988)
Telom River, Cameron Highland	77	53	Shallow (1956)
Mupor River, Johor	21.8	41	Leigh and Low (1973)
Chuchuh River	0.96	58-72	Rahaman and Ismail (2006)
Air Terjun River (94% forest)	31.5	102	Ismail (2000)
B. Secondary Forests			
Tekam River	0.47	35	DID (1986)
Sipitang, Sabah	0.15	60	Malmer (1990)
C. Cleared or logged catchments			
Tekam River, Pahang	0.47	660	DID (1986)
Sipitang, Sabah	0.15	300	Malmer (1990)
Ulu Segama, Sabah	0.56	1600	Douglas et al (1992)
Berembun	0.13	189	Baharuddin (1988)
D. Urbanised catchments			
Relau River, Penang	8.9	3100	Ismail (1996)
Jinjang River, Selangor	10.3	1056	Balamurugan (1991)
Kelang River, Selangor	14.2	1480	Balamurugan (1991)
E. Mixed Land use			
Pelarit River (quarry, forest)	49.5	151-310	Rahaman and Ismail (2006)
Jarum River (urban, agriculture)	94.5	92-156	Rahaman and Ismail (2006)
Kurau River (agriculture, forest)	323	40	This study

The amount of TP retained in the lake was 36%, which is most likely absorbed to fine sediment. It suggests that large influxes of P into the lake may be held only temporarily in the reservoir, and subsequently it is released to growing plants and algae (Harter, 1968).

The high nutrient concentration recorded in Bukit Merah Reservoir could be explained by the concurrence of various diffuse sources including intense agricultural (rubber, oil palm and paddy) throughout the basin accounted for almost 59% of TP flux into BMR (see Table 1). Usually lake sediments act as a sink for phosphorus (Kaiserli et al., 2002). However, under certain conditions the sediment may become a phosphorus source that can support the trophic status of the lake system (Ramm and Scheps, 1997; Zhou et al., 2001). Not all of the phosphorus fractions, however, can be released from sediments into the overlying water and lead to lake eutrophication (Gonsiorczyk et al. 1998). Therefore, the phosphorus behaviour in lake sediments for promoting lake eutrophication can be more efficiently evaluated based on the examination of phosphorus geochemical distribution instead of the total phosphorus content (Kaiserli et al., 2002).

Trophic Status Index (TSI)

The lake was slightly mesotrophic based on TP but eutrophic based on chlorophyll-a and SD. Naumann (1932) classified mesotrophic water as water with moderate nutrient concentrations and therefore it has more biological productivity and the water may be lightly clouded by organic matter sediment suspended solids or algae, while eutrophic water is extremely rich in nutrient concentrations with high biological productivity.

The BMR lake water was also found to be slightly eutrophic, which is related to high productivity (see Table 3). The high sediment load had a significant influence on the clarity or transparency of water in the lake, especially near the Kurau river inlet and the inlet from North Pool. Secchi depth transparency is more strongly associated with the concentration of a particulate suspended matter than a dissolved organic matter (Wetzel, 2001). Thus, TSI (SD) is influenced by sediment from inlets and potentially by re-suspension of bottom sediment since the lake is shallow. The high sediment load causes significant influence on the clarity or transparency of water in the lake especially near the river inlet of Sg. Kurau river and Inlet from North Pool.

Chlorophyll has been significantly correlated with phytoplankton density (Nicholls and Hopkins, 1993). High chlorophyll concentrations are common in the Bukit Merah Reservoir, eutrophication is related to high productivity and nutrient such as nitrogen and phosphorus, which are well-known essential nutrients for algal productivity. N and P can promote excessive algal growth. The combination of nutrient additions coming from streams and rivers, and the recirculation of nutrients from the bottom sediments can considerably cause more productivity than the waters of open lakes (Stoermer, 1978).

Regarding the nutrient availability and recycling of phosphorus from the sediments, it has long been accepted that productivity in the reservoir is limited by phosphorus because of the extremely low concentrations present in the water column. It is also known that phosphorus is recycled into the aquatic system through sediment re-suspension events, dissolution and re-adsorption at the sediment and water interface (Heath, 1995). This is probably a factor of the heightened nutritional input that the Bukit Merah reservoir receives from point and non-point source pollution.

CONCLUSIONS

In conclusion, both sediment and TP loading into BMR were reasonably high at about 15,800 t year^{-1} and 19 t year^{-1}, respectively. These values were, however, underestimated due to the sampling programme that excluded storm samples. The main cause of reservoir sedimentation is the high sediment discharge from river inputs, especially from Kurau River, which has the largest catchment upstream of BMR. The high nutrient concentration recorded in BMR could be explained by the concurrence of various diffuse sources, including intense agricultural activity throughout the basin, as well as, the increasing development in the drainage basins. Most of the sediment is associated with erosion of the catchment areas affected by land clearing and agriculture, which cause the increase in the sediment and nutrients transported into the lake. In turn, this has caused a change in the water quality and the current state of the reservoir is slightly eutrophic with average TSI of 54.4. These data are critical in supporting future catchment management decisions for future improvement of the lake's trophic status.

Acknowledgements

The authors would like to thank Professor William Blake, University of Plymouth, for his comments on the first draft of this manuscript. Thanks are also extended to the Drainage and Irrigation Department, Kerian, Perak for the permission given to carry out this study and their help with data and boat during lake sampling. This study was supported by the Ministry of Science of Malaysia under the E-Science Grant Scheme (No. 04-01-05-SF0007).

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