Sediment impacts on aquatic ecosystems of the Bukit Merah Reservoir, Perak, Malaysia

WAN RUSLAN ISMAIL[1], ZULLYADINI A. RAHAMAN[1], SUMAYYAH AIMI MOHD NAJIB[1] & ZAINUDIN OTHMAN[2]

1 *HydroGeomorphology Research Group, Section of Geography, School of Humanities, Universiti Sains Malaysia, 11800 Minden, Penang, Malaysia*
wruslan@usm.my

2 *Department of Geography, School of Humanities and Social Sciences, Universiti Pendidikan Sultan Idris, 35900 Tanjong Malim, Perak, Malaysia*

Abstract In recent decades interest in suspended sediment dynamics has increased. There are many issues related to high suspended sediment concentrations, such as reservoir sedimentation, channel and harbour silting, as well as the ecological and recreational impacts of sediment management. This paper describes a study of the input and output of sediment in the small Bukit Merah Reservoir (BMR) in Perak, Malaysia. The reservoir received inputs from four rivers totalling about 37 600 t year^{-1}. More than 90% of the sediment input (approx. 35 000 t) came from the Sg. Kurau River. The average lake sedimentation rates were 0.36 mm year^{-1} (1995–2000) and 0.48 mm year^{-1} (2000–2005). The average suspended sediment concentration in the lake was between 8.6 and 13.5 mg L^{-1}, while turbidity ranged between 5.8 and 64.1 NTU. The reservoir is slightly eutrophic, caused by the impact of sediment and nutrients on the receiving water body.

Key words sediment inputs; Sg. Kurau; turbidity; secchi depth; eutrophication; Bukit Merah Reservoir (BMR)

INTRODUCTION

Human activities exacerbate soil erosion within catchments and this causes increased delivery of sediment to aquatic systems. Some examples of human activities affecting sediment delivery include mining, urban development, construction and the presence of roads (e.g. Gruszowski *et al*., 2003; Motha *et al*., 2004; Rijsdijk *et al*., 2007). Land-use change over the last half century has also altered the hydrological and geochemical regime of rivers, and lakes and reservoirs (Hatton *et al*., 2003). In many regions of the world, land clearing for agriculture is responsible for much of the sediment transported out of catchment areas and delivered to waterways and lakes (Dai *et al*., 2007). Sedimentation of reservoirs has become a serious problem due to the synergistic action of population growth, intensity of agricultural operations, poor soil conservation and deforestation (Bowonder *et al*., 1985). Although the delivery of sediment to lakes has reduced in some regions owing to the introduction of sediment control programmes and improved soil conservation practices, excessive sediment loading remains one of the primary forms of anthropogenic disturbance of aquatic ecosystems in both tropical and temperate regions (Donohue & Molinos, 2009).

This paper describes a study on the fate of sediment inputs into the small Bukit Merah Reservoir (BMR), a shallow reservoir which was principally built for irrigation of paddy fields and for water supply in North Perak, Malaysia.

MATERIALS AND METHODS

Study area

Bukit Merah Reservoir (4°59.3′–5°4.4′N; 100°39.2′–100°42.8′E; Fig. 1), in north Perak, is the oldest reservoir in Malaysia, built in 1902 during the British colonial period. Bukit Merah Reservoir (BMR) is categorized as a shallow human-made lake, with a maximum depth of 5 m located in the thalweg of the pre-existing, main river channel. The river inlets are the Sg. Merah, Sg. Jelutong, Sg. Selarong and Sg. Kurau. The main purpose of its construction in 1902 was to supply water to the rice fields in the Kerian District. It was created by damming the Sg. Kurau River, which is the main source of water to the dam. The capacity of the reservoir is 70 × 10^{6} m^{3} at a water depth of 8.63 m. The BMR is the main source of fish for the people in the surrounding area. The estimated fish yield from BMR has been estimated at approx. 3.7 kg ha^{-1} $year^{-1}$ (Ali & Lee, 1995).

BMR is located in an equatorial climate, with an average daily temperature ranging from 23°C to 33°C. The mean annual rainfall recorded at Bukit Merah for the period 1953–2008 was 2904.7 mm (range 2200–3700 mm). The land use of the main catchment, the Sg. Kurau catchment (Fig. 2), based on the 1986 topographic map was: rubber, oil palm and coconut (46%); forest (40%); sundry tree (5.8%); paddy (5.4%), shrubs (2.1%); grass (0.3%) and sundry non-trees (0.14%).

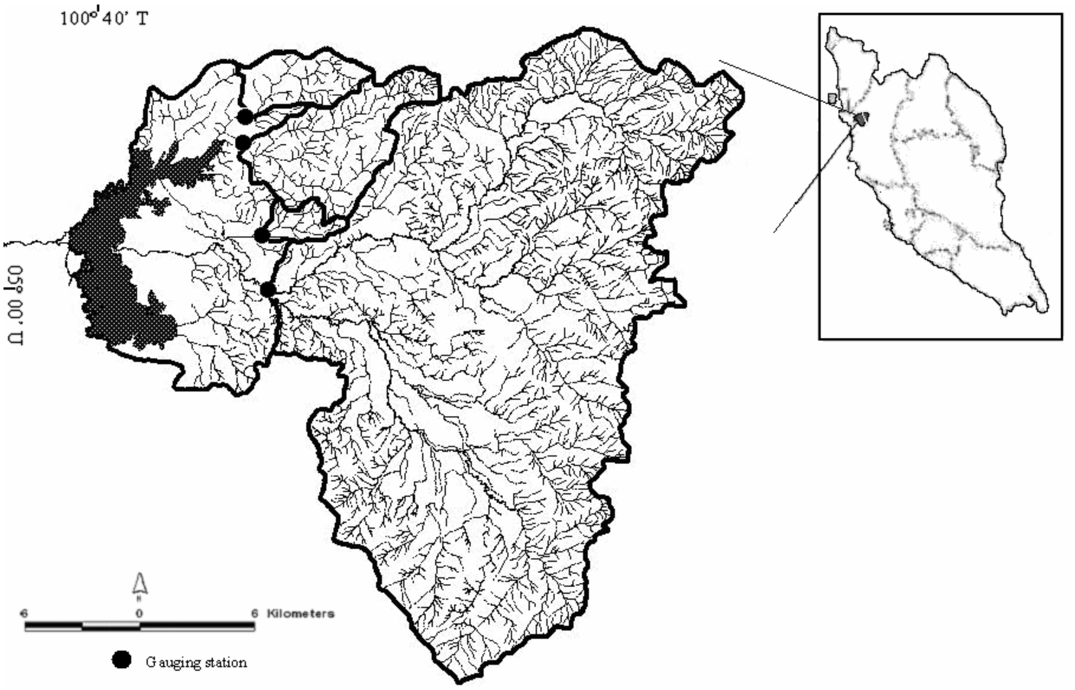

Fig. 1 The Bukit Merah reservoir and catchment, and the gauging stations.

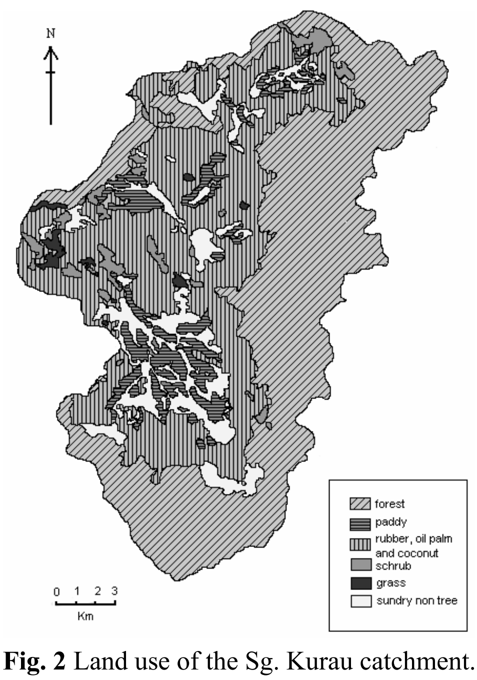

Fig. 2 Land use of the Sg. Kurau catchment.

Field measurement and sample collection

Monitoring of the physico-chemical and biological variables of the river inputs, the BMR, and the reservoir output (Fig. 1) was carried out between January 2007 and December 2008. Measurements of water quality, river cross section and flow were undertaken every fortnight at the four river inlets to BMR, namely (from north to south): Sg. Merah, Sg. Jelutong, Sg. Selarong and Sg. Kurau (Fig. 1). River flow was measured using a current meter and discharge at each station was then estimated by the velocity-area method (Shaw, 1994). Gulp water samples were collected at the middle, left bank and right bank of river cross-sections, and also at the surface of the reservoir. Water samples were analysed for suspended sediment concentration (SSC), total phosphorus (TP), and chlorophyll-*a* based on APHA standard methods (APHA, 1992). Suspended sediment concentration was determined by filtration using 0.45-µm Whatman GFC filter papers and oven drying at 105°C for 24 hours. Total phosphorus concentrations were determined with the ascorbic acid method, while chlorophyll-*a* concentrations were determined by the fluorometric method after acetone extraction. Water transparency in the lake was estimated by the Secchi disk (SD) extinction depth method. Secchi disk, TP and chlorophyll-*a* were used for the calculation of the trophic status index (TSI). Other physico-chemical parameters are not described here.

The sedimentation rate was estimated from six sediment cores collected by pushing PVC pipes down into the bed of the reservoir from a boat. Dating of the sediment cores was determined using measurements of ^{210}Pb undertaken at the Nuclear Agency of Malaysia.

Data analysis

Loadings of nutrients and suspended sediment between time intervals were calculated by multiplying the discharge Q (m^3 s^{-1}) by concentration S (mg L^{-1}) over the time interval K (s) between samples, based on the average sample load approach (Littlewood, 1992). All statistical and data analysis were conducted in Microsoft Excel and SPSS.

RESULTS

Suspended sediment loading

A simple sediment balance between the river inputs and output is shown in Table 1. BMR received inputs from four rivers totalling 55 165 and 19 981 t in 2007 and 2008, respectively, and the average load was 37 573 t. The sediment load of the Sg. Kurau River was 51 270 t (93% of the total) in 2007 and 18 877 t (96%) in 2008. The average sediment load of Sg. Kurau was approx. 35 000 t. It was estimated that approx. 54 000 t (98%) of the sediment delivered in 2007 was trapped in the reservoir. Similarly in 2008, 16 361 t (almost 82%) of the sediment was trapped in the reservoir. The average amount of sediment trapped was approx. 35 000 t, which is almost equivalent to the input from Sg. Kurau. It is also interesting to note that most of the sediment output is through the spillway (99%) during very wet months and a few flooding events (see Table 1).

Table 1 Sediment budget for the Bukit Merah Reservoir.

	2007		2008		Average	
	Suspended sediment load (t)	Percentage (%)	Suspended sediment load (t)	Percentage (%)	Suspended sediment load (t $year^{-1}$)	Percentage (%)
(A) **Input**						
Sg. Merah + Jelutong + Selarong	3894.81	7.05	1104.31	5.53	2499.6	6.65
Sg. Kurau	51270	92.95	18876.9	94.47	35073.5	93.35
Total Input	55164.81	100	19981.21	100	37573.0	100
(B) **Output**						
Utama Canal	7.15	0.61	4.59	0.13	5.87	0.245
Selinsing Canal	3.32	0.28	1.36	0.03	2.34	0.097
Spillway	1160.40	99.11	3613.8	99.84	2387.1	99.66
Total Output	1170.87	100	3619.75	100	2395.3	100
Input – Output	53993.94	97.87	16361.46	81.88	35177.7	93.62

Suspended sediment concentrations and turbidity

In 2007, 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 (13.52 ± 19.98 mg L^{-1}). The mean turbidities in 2007 and 208 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 2008 (mean = 0.74 m).

Lake sedimentation

The rates of sedimentation increased from the 1970s onwards (Fig. 3), associated with an increase in human activities and land-use changes, especially agriculture in the areas surrounding the lake. The average lake sedimentation rates were 0.36 mm $year^{-1}$ (1995–2000) and 0.48 mm $year^{-1}$ (2000–2005).

Table 2 Suspended sediment concentration (SSC), turbidity and Secchi depth of BMR.

	2007		2008	
Parameter	Range	Mean ± Std Dev	Range	Mean ± Std Dev
SSC (mg L^{-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

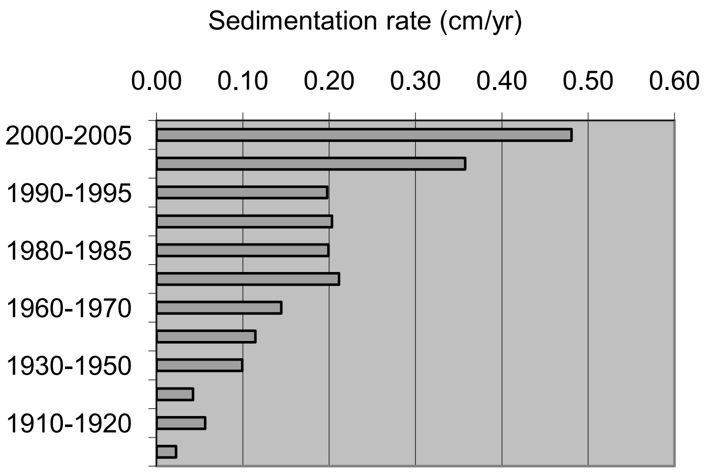

Fig. 3 Rates of sedimentation based on ^{210}Pb measurements of six sediment cores in the reservoir.

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

Site	TSI (SD)	TSI (TP)	TSI (chlorophyll-*a*)
ST1	66.21	46.85	50.28
ST2	68.49	43.84	55.40
ST3	61.46	42.15	52.18
ST4	61.27	43.88	53.98
ST5	63.38	44.75	54.82
ST6	63.94	45.73	61.38
Average	64.12	44.53	54.67
TSI	Eutrophic	Mesotrophic	Mesotrophic

TSI, Trophic Status Index; SD, Secchi Disc; TP, Total Phosphorus.

Trophic status

Various methods have been adopted for the classification of lakes and to indicate their trophic status. This study used Carlson's Trophic State Index (TSI), also known as the Carlson Index, which was developed to compare SD depth, chlorophyll-*a* concentrations and TP concentrations (Carlson, 1977), and to independently estimate algal biomass (Table 3). Although chlorophyll-*a* is the most direct measure of algae biomass, Carlson (1977) used SD depth as the primary indicator.

Average SD depth transparency for the entire study period was 0.76 m, and TSI (SD) was 64.12, which is indicative of a eutrophic status, caused by sediment and nutrient inputs to the reservoir. Eutrophic water, according to the Naumann (1932) classification, is extremely rich in nutrient concentrations, with high biological productivity. Water is also clouded by organic matter, sediment, suspended solids and algae, and some species may be eliminated. However, the trophic state of BMR is mesotrophic if it is based on TP (54.7) and chlorophyll-*a* (44.5) (Table 3). Naumann (1932) classified mesotrophic water as water with moderate nutrient concentrations, and therefore more biological productivity, and the water may be lightly clouded by organic matter, sediment, suspended solids or algae.

DISCUSSION

Large amounts of sediment are deposited in the BMR annually (Table 1). The main contribution of sediment to the reservoir is from the Sg. Kurau (35 000 t year^{-1}) which is about 93% of the total annual sediment input of about 37 600 t. Although a natural and important component of lake ecosystems, the delivery of sediment typically increases 5- to 10-fold following major human impact (Dearing & Jones, 2003), with considerable implications for biological diversity (Donohue & Molinos, 2009).

The transport of suspended sediment derived from upstream sources affects the biogeochemical flux of downstream river systems (Meybeck, 1984). Most of the suspended sediment load came from Sg. Kurau, which drains a very dynamic catchment with vast differences in land uses, which cause a lot of erosion and sediment transport in the catchment (Fig. 2). Furthermore, due to its large size, the Sg. Kurau catchment produced a much higher river discharge in the wet months, when most of the sediment is transported from the catchment into the reservoir.

The high sediment discharge of the Sg. Kurau affects the turbidity and Secchi depth transparency, especially at the river mouth (Table 2). The increase in sediment loading in aquatic systems in recent decades, as demonstrated for the BMR (Fig. 3), is one of the most important and pervasive anthropogenic impacts on aquatic ecosystems globally. By modifying both bottom-up and top-down ecological processes, and by restructuring energy flow pathways, increased sediment loads not only alter biotic assemblage structure and ecological functioning significantly, but frequently result in reduced biological diversity and productivity (Donohue & Molinos, 2009). Studies in the USA show that increased sedimentation of rivers and streams have been linked to the decline of imperiled fish (Warren *et al.*, 2000), and the direct impacts of excessive sediment loading may also contribute to the decline of native fish (Sutherland & Meyer, 2007).

CONCLUSION

This study shows that a lot of sediment is deposited and trapped in the BMR. Most of the sediment is associated with erosion of the catchment areas affected by land clearing and agriculture, which have caused an increase in the sediment and nutrients transported into the lake. In turn, this has caused a change in water quality and the current state of the reservoir is mesotrophic to slightly eutrophic. We have shown that the main cause of reservoir sedimentation is the high sediment discharge from river inputs, especially from the Sg. Kurau River, which has the largest catchment upstream of the BMR. The current estimate of the total sediment discharge for Sg. Kurau is about

35 000 t year^{-1} and almost 93% of the total sediment input is trapped in the reservoir. Such sedimentation is causing a reduction in the water storage capacity of the reservoir.

Acknowledgements We would like to thank the Drainage and Irrigation Department, Kerian, Perak, for permission to carry out this study and the Ministry of Science of Malaysia for supporting this research under the E-Science Grant Scheme.

REFERENCES

Ali, A. B. & Lee, K. Y. (1995) Chenderoh Reservoir, Malaysia: a characterization of a small-scale, multigear and multispecies artisanal fishery in the Tropics. *Fisheries Res.* **23**, 267–281.

American Public Health Association (APHA) (1992) *Standard Methods for the Examination of Water and Wastewater* (18th edn). American Public Health Association, Washington, DC, USA.

Bowonder, B., Ramana, K. V. & Hanumantha Rao, T. (1985) Sedimentation of reservoirs in India. *Land Use Policy* **2**(2), 148–154.

Carlson, R. E. (1977) A trophic state index for lakes. *Limnol. Oceanogr.* **22**, 361–369.

Dai, S. B., Lu, X. X., Yang, S. L. & Cai, A. M. (2007) A preliminary estimate of human and natural contributions to the decline in sediment influx from Yangtze River to the East China Sea. *Quatern. Int.*, doi:10.1016/j.quaint.2007.10.003.

Dearing, J. A. & Jones, R. T. (2003) Coupling temporal and spatial dimensions of global sediment flux through lake and marine sediment records. *Global and Planetary Change* **39**, 147–168.

Donohue, I. & Molinos, J. C. (2009) Impacts of increased sediment loads on the ecology of lakes. *Biol. Rev.* **84**, 517–531.

Gruszowski, K. E., Foster, I. D. L., Lees, J. A. & Charlesworth, S. M. (2003) Sediment sources and transport pathways in a rural catchment, Herefordshire, UK. *Hydrol. Processes* **17**, 2665–2681.

Hatton, T. J., Ruprecht, J. & George, R.J. (2003) Preclearing hydrology of the Western Australia wheatbelt: target for the future? *Plant and Soil* **257**, 341–356.

Littlewood, I. G. (1992) *Estimating Contaminant Loads in Rivers: A Review*. Institute of Hydrology Report no. 17, Institute of Hydrology, Wallingford, UK.

Meybeck, M. (1984) Geochemical process in lotic flow. *Water Res. Bull.* 11, 546–553.

Motha, J. A., Wallbrink, P. J., Hairsine, P. B. & Grayson, R. B. (2004) Unsealed roads as suspended sediment sources in an agricultural catchment in south-eastern Australia. *J. Hydrol.* **286**, 1–18.

Naumann, E. (1932) Grundzuge der regionalen Limnologie. *Die Binnengewässer* **11**, 1–176.

Rijsdijk, A., Bruijnzeel, L. A. S. & Sutoto, C. K. (2007) Runoff and sediment yield from rural roads, trails and settlements in the upper Konto catchment, East Java, Indonesia. *Geomorphology* **87**, 28–37.

Shaw, E. (1994) *Hydrology in Practice*, 3rd edn. Chapman & Hall, London, UK.

Sutherland, A. B. & Meyer, J. L. (2007) Effects of increased suspended sediment on growth rate and gill condition of two southern Appalachian minnows. *Environ. Biol. of Fishes* **80**(4), 389–403.

Warren, M. L. Jr., Burr, B. M., Walsh, S. J., Bart, H. L. Jr, Cashner, R. C., Etnier, D. A., Freeman, B. J., Kuhajda, B. R., Mayden, R. L., Robison, H. W., Ross, S. T. & Starnes, W. C. (2000) Diversity, distribution and conservation status of the native freshwater fishes of the southern United States. *Fisheries* **25**(10), 7–29.