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Longitudinal Changes in Suspended Sediment Loading and Sediment Budget of Merbok River Catchment, Kedah, Malaysia

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ABSTRACT

Merbok river catchment situated in the Kedah State receives its input from Bongkok River and Puntar River flowing down and joining Lalang River to flow down to the Merbok Estuary. The Merbok catchment (440 km^2) is experiencing several degrees of complex land uses activities that poses some impact on the suspended sediment production of the Merbok river. A study was conducted to investigate the suspended sediment loading of rivers draining the Merbok catchment from January to December 2013. Suspended sediment budget of the Merbok catchment were estimated. The river suspended sediment concentrations (SSC) and suspended sediment (SS) load increased during wet season compared to dry season. The SS loads increases from upper catchment to river mouth. The sediment loadings were divided into three segments- the upstream, middle segment and lower segment. The SS loads increased from 10 t yr^{-1} in the upper part of Bongkok river to 3336 t yr^{-1} in upper segment. The sediment loading then increase to 4299 t yr^{-1} in the middle segment of the catchment (at Bongkok 4), and then exiting the Merbok Estuary, as the lower segment, with a total amount of sediment output estimated at 7156 t yr^{-1}. From this total sediment output, most of the sediment source came from the tributaries; the Bongkok River at B3 (3337 t yr^{-1}), Puntar River (2924 t yr^{-1}) and Lalang River (1370 t yr^{-1}), which were much higher than its proportion in terms of its length and drainage area. As a conclusion, the inconsistence in SSC in the river were influenced by the various anthropogenic activities (especially agriculture and urbanization activities) in

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the catchment area which necessitate future land use and sediment control to avoid sediment and possible nutrient loading into the estuary.

Keywords: Kedah, land use changes, Merbok River catchment, sediment load, sediment budget

INTRODUCTION

Sediment eroded from slope land, bare land and agricultural lands, all ended up in the rivers draining the whole of the world's landscape. Sediments play an important role in the river ecosystem where they are responsible for transporting many materials and contaminants to the river (Ismail, 1996). Sediment ended up in water bodies could also brought damages to water quality when eroded soil enters surface waters. The characterization of suspended sediment transport in rivers is difficult due to the rapid of human exploitation and unpredictable natural hydrologic events. Excessive soil loss is linked to lack of the sustainable use of natural resources, land exploitation and degradation and poor land management.

Concerns regarding the effects of human activities on degradation in river systems, erosion and sedimentation have frequently been raised. High sediment loads can, in particular, result in major problems for human such as affecting flood risk and boat traffic (Sheffield et al., 1995); decrease of water quality and water supply, increasing the cost of treating water and other related purposes (Walling, 2009). High sediment suspended in the river can kill or irritate fish gills and suffocates organisms if significant concentrations and durations occur (Bash et al., 2001).

A sediment budget is an application of the continuity equation and it can be regarded as a form of geomorphic accountancy (Slaymaker, 2003). It is also considered as a quantitative inventory of all the sediment inputs, outputs and storage within a defined system. An understanding of the sources of sediment delivered to, stored within, and exported from, an estuary is important for a number of environmental issues including maintenance of navigational channels, light availability for primary productivity, reduction of dissolved oxygen concentrations and the transport and accumulation of particle-bound nutrients and contaminants and their eventual transport to the continental shelf (Balls, 1992; Cloern, 1987; Eyre & McConchie, 1993).

The sediment production is expected to increase in the near future due to rapid economic activities which could lead to the widespread changes in erosion rates, sediment flux and sediment loads transported by the world's rivers shown the high-frequency of human activities and climate change. The amount of the sediment load transported by rivers in the catchment area has a very important implication for biology (Wood & Armitage, 1997), geomorphology (Brandt, 2000) and hydrological system (Syvitski, 2003). Additional, the sediment input from several catchment is important in the management of rivers and water resources, particularly in the context of integrated water resources for domestic use, ecotourism, and biodiversity of rivers, hydrology and hydraulics (O'Keeffe, 2009). The sediment loads may influence on crop productivity and food security, changes in nutrient cycling and flux of many key elements and nutrients, water quality, river channel morphology, delta development and also the aquatic ecosystems and numerous of habitats supported by the river (Walling, 2009). The sediment loads can be estimated by developing sediment budget. The budget is suitable for identifying and accounting of the sediment movement, into and out of a site on the catchment. Developing sediment budget is an attempt to identify the sources, sinks and pathways of eroded material content within catchment area (Slaymaker, 2003). For many years, sediment budget has been developed at scales ranging from small catchment to a large catchment (Owens et al., 1997; Walling et al., 2002).

This paper aims to estimate a simple sediment budget in the Merbok catchment area in Kedah, and to assess the various pathways and sediment sources from various land uses and tributaries in the catchment. This study also investigates the role of seasonal effect and the impact of human activities on variations in the concentration of SSC and the amount of input/output of suspended-sediment (SS) load.

MATERIALS AND METHODS

Study Area

The investigation focused on the Merbok River Catchment area from Gurun area down to the Merbok river at Kampong Sg. Lalang, Kedah within the latitude within latitudes and 5° 39' N to 5° 41' N and longitudes 100° 20' E to 100° 24' E, respectively (Figure 1). The catchment area of Merbok river is 440 km^2. Figure 1 shows all 15 sampling sites in the Merbok river catchment chosen in this research based on relation between the main river and its tributaries. The river is classified into the upper, middle and lower segment longitudinally according to the dominant gradient of the river (Rosgen 1994), where the uppermost segment called segment A+ should have a slope of more than 10%; followed by A between 4-10%, B between 2-4%; C having less than 2% and so on. Table 1 shows the river classification for Bongkok and Merbok river.

Land Uses

Land use in the Merbok river catchment (440 km^2) is very complex. The catchment area is experiencing several degrees of complex land uses activities ranging from some major activities for example oil palm (24%) and rubber (9.7%) in the upper and middle part of the catchment. Some part of the middle and lower part of the catchment is urbanized with urban and residential land uses (22%), and the lower part of the catchment is dominated by swamp and mangrove (9.4%). Other types of land uses in the Merbok catchment area includes, forest (6.7%) which is diminishing; and some industries (5.5%) in areas like Gurun, Bakar Arang and Sungai Petani, and some paddy (5.9%) and mixed horticulture (3%) in the lower part of the catchment area (Figure 2) (Malaysia, 2010).

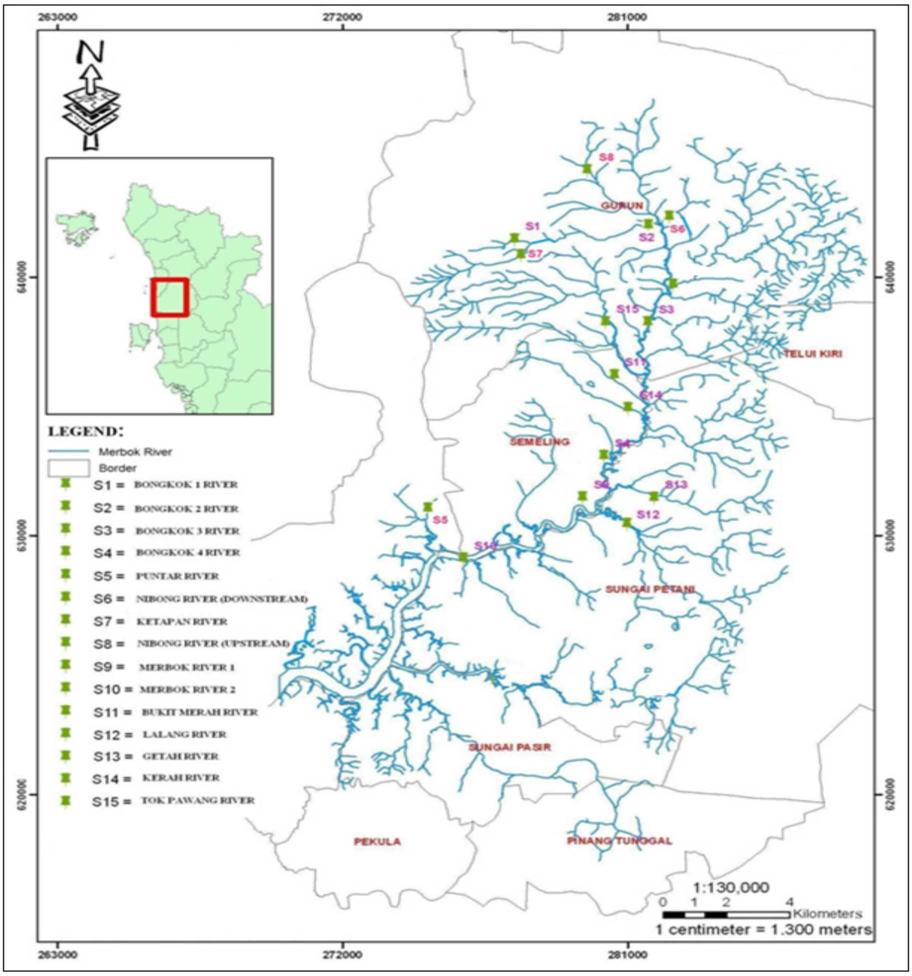

Figure 1. Location of all the sampling stations from the upper Merbok to the estuary

Table 1
The distance, gradient and classification of the river reach of the main river Bongkok and Merbok

Segment	River Reach	Distance (km)	Gradient (%)	Classification
Upper	Bongkok 1	2.05	20.46	A+
	Bongkok 2	4.42	18.56	A+
	Bongkok 3	7.27	11.28	A+
Middle	Bongkok 4	14.15	5.54	A
Lower	Merbok 1	18.9	3.08	B
	Merbok 2	26.65	1.16	C

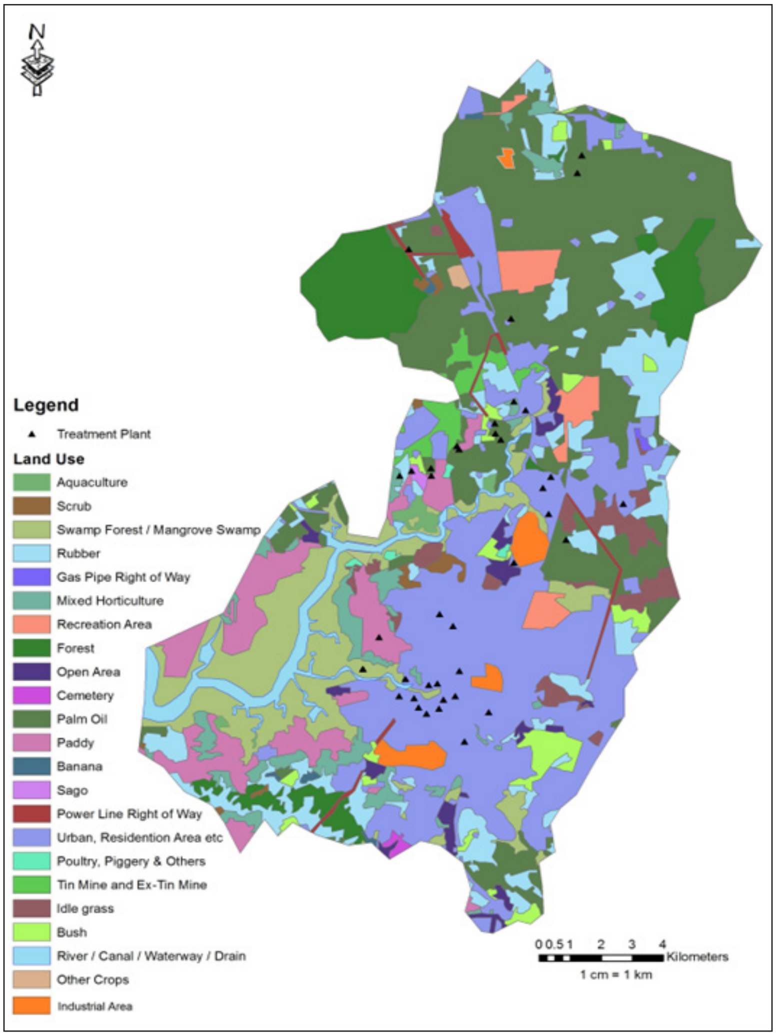

Figure 2. The land uses in the catchment area of Merbok (Malaysia, 2010)

Climate

Rainfall data were recorded at two rainfall stations in the catchment area namely the Jerai Peak and Jambatan Syed Omar. Jerai Peak recorded range of rainfall from 65 mm - 536 mm in five months period from September 2011 to February 2012 (Malaysia, 2012) shown in Figure 3. Jerai Peak or Gunung Jerai is a major water source flowing into the Merbok River. Jambatan Syed Omar Station recorded a little lower rainfall range within the same period (61 mm- 435 mm). Figure 3 shows that the rainfall patterns in the catchment area are divided into dry season in the months of September, December and January, and wet months occur in October, November and February.

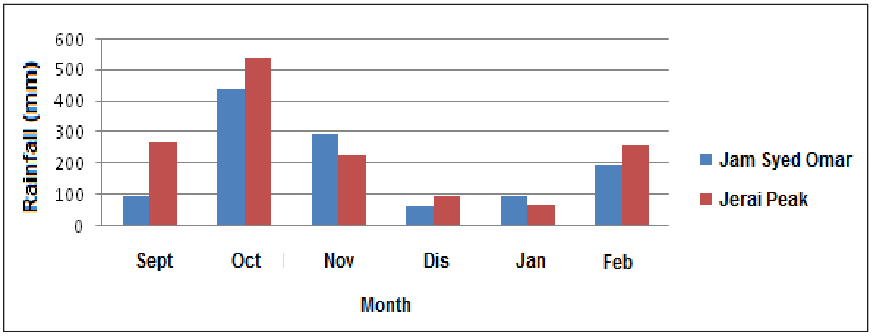

*Figure 3***.** Rainfall in the Merbok catchment recorded at two stations; Jerai Peak and Jam Syed Omar in between September 2011 until February 2012

The Sampling Protocol

The water quality and physical parameters sampling was carried out every fortnight at selected river cross sections (15 sites) throughout the catchment area from January to December 2013. Figure 4 shows five main river cross sections for the main tributary the Bongkok River. The river width ranging from 3 m at B1; 10-15 m at B2 and B3; 40 m at B4 and nearly 60 m at M1.

Water samples were collected in three replicates representing a river cross-section segments and preserved in a polyethylene bottle. The water sampling procedure was done together with an *in situ* water quality monitoring scheme using YSI 556 multi-parameter. The water samples were collected at depths of about 0.5 m from water surface, and at the center of each segment, after dividing the river width into 3 equal segments. Water samples were transported in an ice-cooled container to the Hydrology laboratory, School of Humanities, Universiti Sains Malaysia for further analysis.

River discharge which is the volume of water that flows past a certain point in a stream over a specific period of time, was calculated based on the velocity area method (Shaw et al., 2010) and the calculation of SS loading was based on Littlewood (1992).

Determination of Suspended Sediment Concentration (SSC)

The determination SSC was carried out using filtration methods using membrane Glass Fiber Filter ADVANTEC 47mm. After filtration, the membrane filter was placed in a petri dish for drying in an oven at 105ºC and was left overnight. The membrane filter was cooled at room temperature before being weighed for it final weight. SSC in the sample was calculated by using an equation following APHA (1992). To obtain an estimate of SSC, the difference between weight of filter + dried residue and weight of filter was calculated (APHA, 1992).

Sediment Loading Calculation

The sediment loading is based on the calculating the product of suspended sediment concentration (SSC) with river flow (Q) in a given period. The total amount of suspended load (in tonnes/year) was then calculated by multiplying the weighed sediment concentrations (SSC) in mg/L with the stream discharge (m^3s^{-1}) with an interval of 14 days.

To calculate the sediment loading, the average sample load estimation has been used. The load of sediments transported through a river cross-section during a time interval using calculation described by Littlewood (1992);

$$L = K\left(1/n\sum_{i=l}^{n} Q\,(i).C(\mathrm{i})\right)$$

where:

L = load

K = the period of load estimation

C = sample concentration

Q = discharge

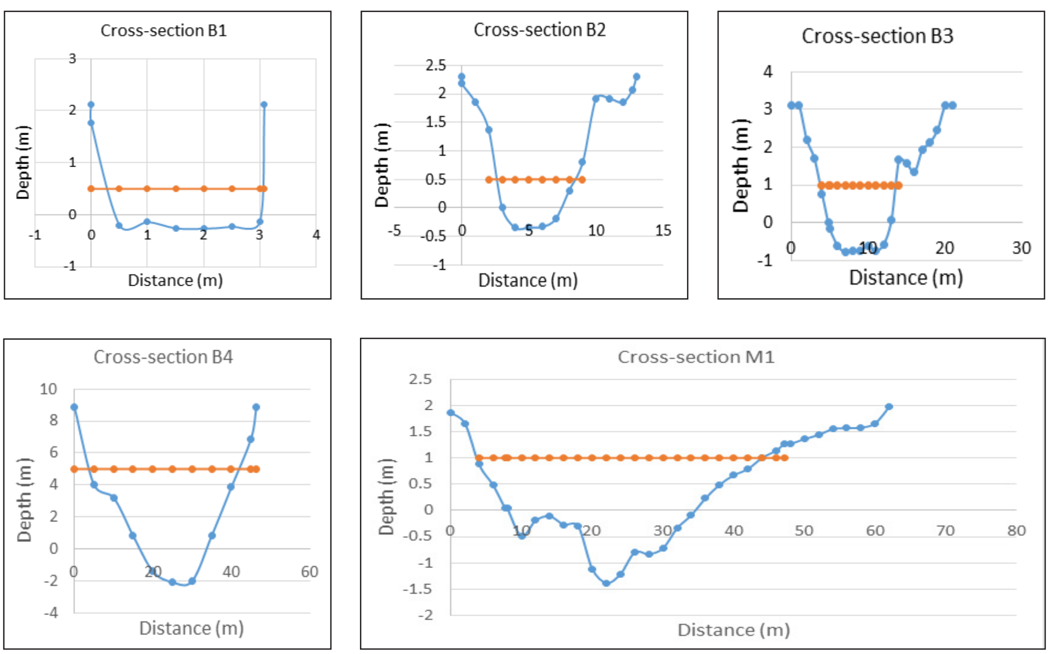

Figure 4. Five main river cross sections from the upper segment B1 to the lower segment at M1. The river cross section is shown by the blue lines, while red lines are the water depth at the time of measuring the cross sections.

The accuracy of estimating the sediment load depended upon the availability of the river flow and concentration data at a sufficiently high frequency (relative to the variation in flow and concentration during the period of estimation) (Littlewood, 1992).

RESULTS

The Suspended Sediment Load

The result in Table 2 shows the sediment loading of each station and were placed into three segments of the catchment i.e the upstream segment, middle segment and the lower segment towards the river estuary (Table 2). The main river of the Merbok catchment originated as Bongkok river as the upper, middle and part of the third segment, then it became the Merbok river. So the longitudinal flow was from Bongkok 1 (B1) to Bongkok 4 (B4) and Merbok 1 (M1) (Table 2).

The total SS loads increased from 10 t yr^{-1} in the upper part of B1 to 261 t at B2. This is about 25 fold increases in the SS loads. Then the SS loads further increases downstream to 3337 t yr^{-1} at Bongkok 3 (B3). This represents an increase of only 12 fold between B2 and B3. The sediment loading then increase to 4299 t yr^{-1}at Bongkok 4 (B4). The increase in SS load was only about 0.3 fold but later it increases to 0.66 fold at Merbok 1, where the sediment loading was estimated at 7156 t yr^{-1}. Based on the total SS load, Merbok River catchment was experiencing a lot of sediment removal. Most of the sediment source came from the tributaries like the Puntar River and Lalang River, which was much higher than its proportion in terms of its length and drainage area.

In wet season, the SS loads increased, with a much higher increases were noted in the upper segment (34 and 26 fold, respectively in Table 2). However, the wet period loading decreased slightly (0.25 fold) between B2 and B3, but later increased 0.8 fold between B4 and M1. In the dry season however the SS loading was much lower due to the lower rainfall activity that drive the hydrological processes in the catchment. The SS loading was very little ranging from 12 fold in the upper segment, 9 and 0.13 fold between B2 and B3, and 1.6 fold in the lower segment (Table 2).

The overall SS loading increased, from the upper to lowest segment, by almost 700 fold for total SS load ranging from 400 fold in the dry period to about 1250 fold increases in the wet period. The SS load was higher at M1 because it received all the sediment from the upper tributaries.

The overall loading between wet and dry period was not much different which was only about 26 tonnes (3.5%). However, there was very significant difference in SS loading between the wet and dry period observed at B3 (123%) and B4 (48%). These two stations were located in the middle part of the catchments which is highly active in the human activities and land use changes. With a characteristics of great seasons variations and precipitation in an alternation in wet period and dry period, the annual sediment load from

Table 2
Summary of suspended sediment (SS) loading of Merbok River catchment at the main channel of Bongkok and Merbok River in Wet and Dry Season

Catchment Segment	Sites	Total Loads (t yr^{-1})	Wet Season (t)	Dry Season (t)	Increase in total SS load (fold)	Increase SS load in wet season (fold)	Increase in SS load in dry season (fold)
	Bongkok 1	10	0.6	1.8			
	Bongkok 2	261	20.8	23.4			
(B2-B1)/B1					25.1	33.7	12.0
	Puntar	2924	469.7	206.5			
Upper	Ketapan	242	34.8	19.7			
Segment	Nibong 1	384	40.2	30.7			
(S1)	Nibong 2	483	61.8	43.9			
	Bongkok 3	3337	557.0	248.7			
(B3-B2)/B2					11.8	25.8	9.63
	Bukit Merah	208	23.6	14.2			
Middle	Getah	310	68.6	24.3			
Segment	Kerah	241	33.8	13.0			
(S2)	Tok Pawang	284	45.5	25.4			
	Bongkok 4	4299	415.6	280.7			
(B4-B3)/B3					0.29	-0.25	0.13
	Lalang	1370	1442.7	115.1			
Lower Segment	Merbok 1	7156	748.5	722.6			
(M1-B4)/B4					0.66	0.80	1.57
(M1-B1)/B1					714.6	1246.5	400.4

the Merbok River catchment discharged to sea showed a very high SS load (ca. 7000 t/year) exported to the river mouth. However, this amount is small compared to Sg Kurau (51, 270 t/year) feeding into Bukit Merah reservoir (Ismail and Najib, 2011); but comparable to Sg. Jarum (5,400 t/year) and Pelarit River (11,400 t/year) reported by Rahaman and Ismail (2010) reaching into Timah Tasoh lake which is also flowing through agricultural land use activities.

DISCUSSION

Naturally, the sediment is transported from land surfaces and slopes to river channel during rainy season. The sediment sources may originate from sources such as landslides in cleared areas (Collison and Anderson, 1996); slope collapses along rivers (Madej, 2001); raindrop impact and subsequent surface wash of exposed soils on roads, agriculture area and open area with poorly compacted soil (Ziegler & Giambelluca, 1997). The understanding of the pattern of sediment delivery and its pathways related to hydrological processes is needed in these investigations of sediment budget. It is very difficult to develop prudent long-term management plans for limitation and reduce the sediment budget in large catchments (Walling, 1983).

Human disturbance, such as agriculture and urbanization activity, makes sediment available for transport during rainfall events (Ismail and Hashim, 2014). The SS load trend showed an increase during wet season but decline during dry season. This is due to the increase sediment mobility during rainy season when the surface runoff increases, transporting more sediment (Ismail, 1996; Sarria-Villa et al., 2016). The annual SS load also showed an increasing trend from the upper segment to lower segment. However, the rate of increases in sediment loading slightly reduced between the middle to lower segment by about 29%, but toward the lower end of the segment of the catchment, the percentage of sediment load increased by 66%, suggesting a higher sediment loading happened in the lower part of the catchment where a lot of urbanization was taking place. The increase in human activities for example a lot of housing and industrial development takes place in the middle and lower part of the catchment.

Changes in the sediment load of a river can give rise to numerous problems. Erosion and sediment transport processes are sensitive due to their close links to climate, wide range of human activities, land cover, land use and the hydrology of a river catchment (Walling, 2009). This reflects a combination of factors. Human activities that affect the river ecosystem by sedimentation and higher suspended solids from forest cutting and land-clearance, the expansion of agriculture, land use practices, urbanization and infrastructural development and dam construction (Walling & Fang, 2005). These impacts have been especially severe in river ecosystems. Ziegler et al. (2000) found that surface erosion rates from agricultural roads, the main source of sediment to the river was more than eight times higher than from footpaths and agricultural lands.

In future, the variability in sediment loading necessitates the need for long-term monitoring of sediment yield. River management is imperative to promote harmonious relationship between humans and nature in reducing sediment input to the river systems. Sediment budgeting approach facilitate in identifying the sediment sources urgently needed attention. The variations of discharge flow and runoff due to seasonal factors shows difference in SS load related to sediment concentration during the wet season period compared to that during dry season period. Other than that, SSC content in the river can also be affected by the influence of anthropogenic activities in the catchment area.

CONCLUSION

This study shows that the sediment load increases from the upper segment of river catchment (B1) which has very little disturbances in terms of land use activities as compared to many land use activities in the catchment, between B3, B4 and M1. The downstream changes in SS loads and increasing loading suggest that sediment is being added to the main rivers from various tributaries in the catchment. The total suspended sediment loading was around 7000 t yr^{-1} and was comparable to other Malaysian river fluxes associated with agricultural activities. The various land uses in the catchment areas contributed to the varying SS loads as shown by the results. The loading in wet period was almost 50% and more than the dry period loads especially in the middle segment of the catchment due to varying land uses in this region suggesting the effect of rainfall on the eroding the land surfaces with varying land cover. The inconsistencies in SSC in the river were influenced by the various anthropogenic activities (especially agriculture and urbanization activities) in the catchment area which necessitate future land use and sediment control to avoid sediment and possible nutrient loading into the estuary.

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