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Sediment yields from selected catchments in Peninsular Malaysia

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Abstract Virtually half the suspended sediment discharged into the oceans annually is contributed by Asia (Lopatin, 1950). The highest fluxes appear to be associated with the large islands of the western Pacific, particularly those affected by earthquakes. Although Peninsular Malaysia is not affected by volcanic activity, sediment yields can be high, particularly for drainage basins where much development is taking place. Sediment and runoff data for 38 catchments ranging in size from 21 to 19 000 km^2 were analysed. The catchments were broadly categorized into two groups: (a) basins with <50% forest cover; and (b) basins with >50% forest cover. While the sediment yield/runoff relationship for the former was straightforward, results for the latter were less clear. Subsequent analyses using longer-term sediment yield and runoff data for Sungai Kelantan, Sungai Pahang and Sungai Langat showed great year to year variability. The preliminary findings in this paper suggest that other controls such as catchment relief, sediment sources and anthropogenic activities are important when dealing with large catchments.

INTRODUCTION

Of the *ca* 336 700 km^2 total land area of Malaysia, 134 700 km^2 is found in the peninsula. Competition for land in this part of the country has been largely from agriculture, in particular the rubber and oil palm industry. By 1986, the forest cover in the peninsula had been reduced to 48% of the land area. The species rich tropical rainforest had, for centuries, afforded protective cover, keeping soil erosion at low levels. While sediment loads increased for most small and large rivers affected by land conversion, mining, urbanization and forest practices also influence basin sediment production.

At the regional level, high sediment yields are associated with the large islands of the western Pacific, particularly those affected by earthquakes. Virtually half of the suspended sediment discharged from the land surface of the globe to the oceans comes from Asia (Lopatin, 1950, cited in Lisitzin, 1972). Although Peninsular Malaysia is not affected by volcanic activity, sediment yields can be high, particularly in basins where much development is taking place. This paper aims to examine the sediment yields from small and large drainage basins in the peninsula affected by land use changes to varying extents.

PHYSICAL CHARACTERISTICS

Geology

Tectonically, Peninsular Malaysia is part of the Sunda Shelf. While sedimentation occurred throughout the Palaeozoic and Mesozoic, igneous intrusions also occurred during the Late Carboniferous, Middle and Late Triassic, and Late Cretaceous (Yin, 1986). Granite formations, however, are largely found in the more rugged parts of the peninsula. The Main Range, about 480 km long and averaging about 65-80 km in width, rises to 2100 m above sea level in some places (Yin, 1986). This granitic mass largely forms the backbone of the peninsula and runs approximately northwest to southeast. Except for much of the south, the mountains form a natural divide for basins draining to the South China Sea in the east and to the Straits of Malacca in the west. Based on radiometric dates obtained from granite samples from southern Thailand and parts of the peninsula, Burton & Bignell (1969) believe that the Main Range is Triassic or older.

The rugged granitic formation which is found in about half of the peninsula has been constantly eroded by the drainage systems that existed even during the Pleistocene (Gupta *et al.*, 1987). Keller & Richards (1967) believe that the strait was formed by a rise in sea level in post glacial times: the properties of bottom sediments in the Malacca Straits suggested the importance of the rivers in discharging sediments of terrestrial origin. Kaolinite and mixed layer minerals were the dominant clays found while large areas of mud with high concentrations of carbon were also discovered near river mouths.

Climate

The climate is equatorial with high but uniform annual temperature, humidity and rainfall. The general climatic pattern of southwest and northeast monsoon affects the rainfall and largely determines the runoff generation and sediment transport in the catchments. The rainfall distribution is strongly influenced by the major airstreams across the peninsula that produce four annual "seasons" (Dale, 1959): (a) the northeast monsoon of November or early December through March; (b) the inter-monsoonal season of April and May; (c) the southwest monsoon of June through September or early October; and (d) the inter-monsoonal season of October through early November.

The study catchments

Thirty-eight catchments ranging from 21 to 19 000 km^2 were selected (Fig. 1). The catchments, representing about 60% of the peninsula, vary in topography, rainfall input and land use. About 22% of Peninsular Malaysia is above 300 m with 61% under 100 m. The area above 1500 m constitutes only about 4% of the total. In terms of slope, 67% of the land mass is characterized by slopes $<2°$ and about 10% is characterized by slopes $>13°$ (Table 1).

Accurate information of land use distribution, topography and other major controls of sediment production for each catchment could provide a valuable basis for comparing sediment yields at the catchment scale. However, such details were difficult to obtain

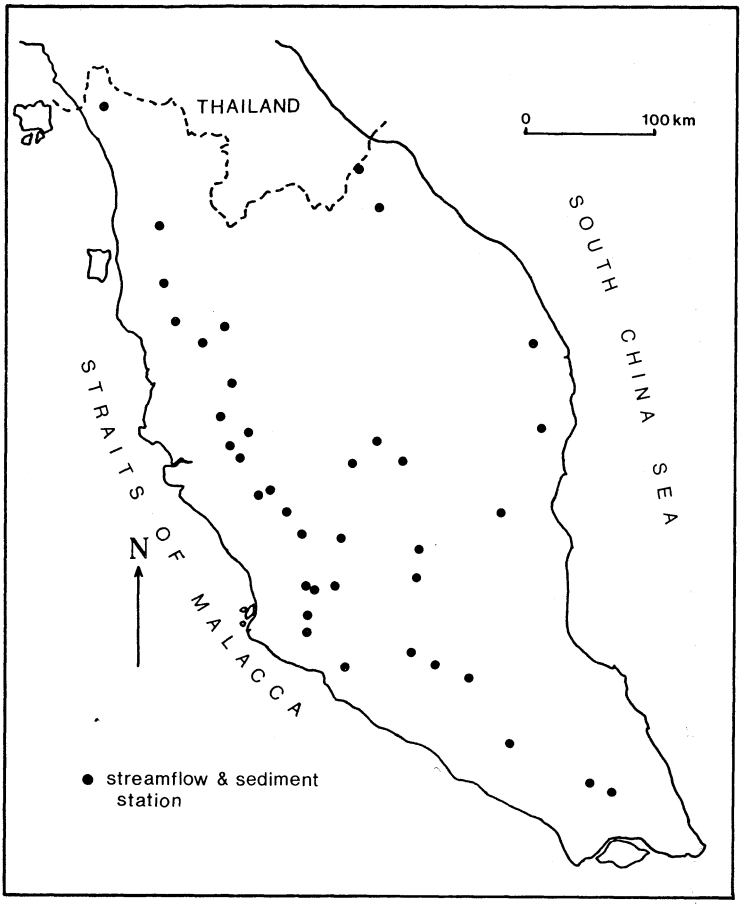

Fig. 1 Location of streamflow and sediment sampling stations in Peninsular Malaysia.

because of the large data base involved and its dispersion across a variety of agencies. We therefore categorized the study catchments into two groups: (a) those with forest cover of greater than 50%; and (b) those with forest cover less than 50%.

Table 1 Land elevation and slope distribution of Peninsular Malaysia.

Elevation (m)	<100	101-200	201-500	501-2000	>2000
% of land	61	13.4	13.3	12.2	0.03
Slope (°)	1-2	3-6	7-12	13-20	>20
% of land	67.4	14.3	8.6	5.9	3.8

Data

Monthly suspended sediment and runoff data computed by the Drainage and Irrigation Department for the period 1981-1985 were used. Incomplete annual records were ignored. A short 5 year period was chosen to avoid using information which could be complicated by large scale physical changes to the basins resulting from human activity. This period saw a general slow down in the national economy and few land schemes were implemented. We have assumed that short-term perturbations due to the effects of land use change on sediment yield are minimal and that the inter-annual variations in catchment sediment output documented in this study are more runoff related.

One major problem in the study of sediment yields at the local or regional level is the year to year variability. Reliable estimates of annual sediment yield depend on long term records. An analysis of longer term runoff and sediment yield data for three large catchments, namely the Sg. Kelantan, Sg. Pahang and Sg. Langat, was therefore undertaken to examine the variability problem.

RESULTS AND DISCUSSION

Sediment yield and land use

A positive relationship between mean annual specific suspended sediment yield and mean annual runoff was evident for catchments having less than 50% forest (Fig. 2). Least squares regression analysis provides a relationship of:

$$S = 0.0003Q^{2.062} \qquad (r = 0.91)$$

where S is sediment load in t km^{-2} year^{-1} and Q is runoff in mm.

Mean annual specific suspended sediment yields range from 12 to 2600 t km^{-2}. The lowest sediment yield is associated with Sg. Jerneh in Perlis where the mean annual rainfall is about 2000 mm. While only 30% of this drainage basin is under forest, much of the 24 km^{2} basin has a good vegetation cover: padi cultivation forms the dominant land use. The low sediment yield may be attributed to the generally gentle terrain and the use of much of the stream water in padi lands which keep the sediment discharges low.

Under agriculture, much of the soil loss depends on the crops planted and perhaps more importantly, on the type of land preparation involved. For example, soil erosion is high for plantation crops such as rubber and oil palm during the initial land preparation stage when large tracts of land are clear felled. The severity depends on the terrain involved. Erosion is greatly reduced when cover crops, such as *Centrosema pubescens* and *Pueraria javanica*, become sufficiently established after the young rubber and oil palm seedlings are planted. Erosion is further reduced when the trees mature. Fermor (1939, cited in Leigh, 1973) estimated that between 1905 and 1939, 33.5 million tonnes of sediment entered the river systems of the peninsula from rubber plantations. Most of these plantations were previously virgin forests.

Other sources of sediment include areas affected by mining and urbanization. Tin mining has been reported to produce high sediment yields of up to 600 t km^{-2} year^{-1} in

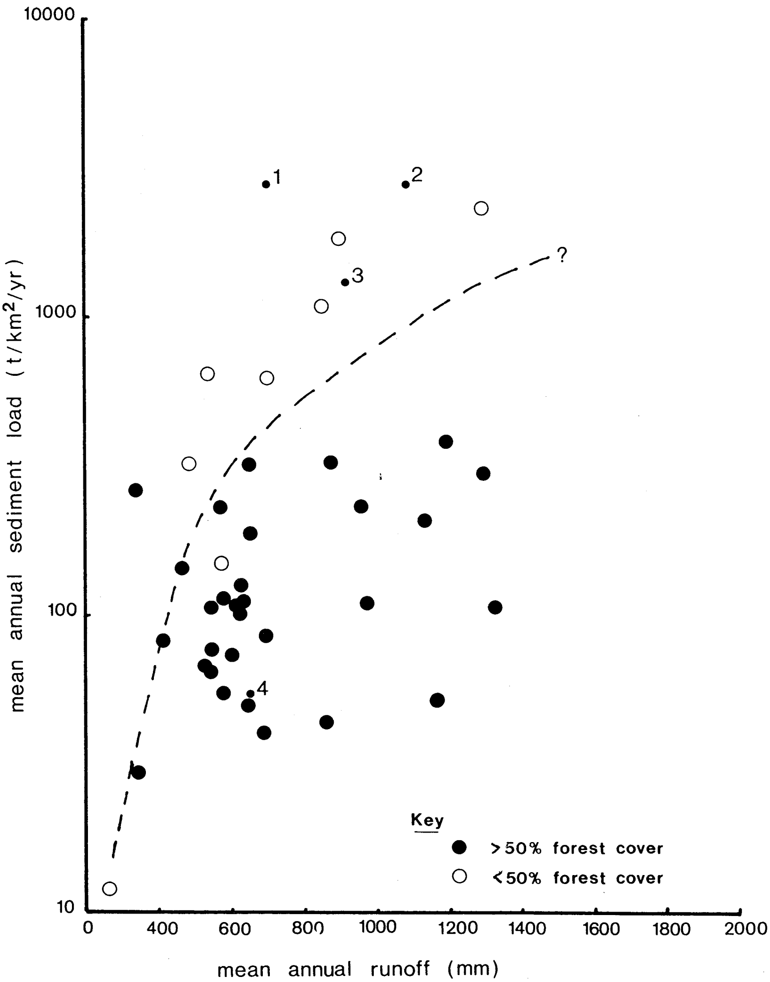

Fig. 2 The influence of land use upon suspended sediment yield in Peninsular Malaysia: 1 – Sg. Batangsi, logging ongoing; 2 – Sg. Chongkak, first year after logging; 3 – Sg. Chongkak, second year after logging; and 4 – Sg. Lawing, undisturbed forest.

some catchments (Chong, 1985). While mining discharges may contain high suspended sediment concentrations of between 5000 and 20 000 mg l^{-1}, erosion from closed mines is equally high. Because post- mining lands are low in fertility, natural re-vegetation is slow, thereby frequently exposing large tracts of bare earth to rain. Balamurugan (1991), for example, reported far higher loads of about 5900 t km^{-2} $year^{-1}$ for the 27 km^2 Sg. Jinjang catchment where large abandoned mines had been left to erode. Urbanization also produces high annual sediment loads, especially when extensive infrastructural development is carried out. The Sg. Kelang basin (380 km^2), within which much of Kuala Lumpur is located, has a sediment yield of about 800 t km^{-2} $year^{-1}$ (Balamurugan, 1991).

Unlike the catchments dominated by non-forest land use, the relationship between mean annual specific sediment yield and mean annual runoff is not so clearly defined for basins where the forest cover is greater than 50% (Fig. 2). Least squares regression analysis provides a relationship of:

$$S = 10.399Q^{0.347} \qquad (r = 0.269)$$

Sediment yields in these catchments ranged from 42 to 381 t km^{-2} $year^{-1}$. The lowest yield was found in Sg. Bidor, where the forest cover is about 70% and the elevation rises to 1220 m. Some cultivation of rubber and a number of residential units are also found in the 339 km^2 basin. The highest yield was found in Sg. Golok. Here about 90% of the 560 km^2 catchment is under forest with some rubber and padi cultivation. Although the annual runoff for both catchments is about 1900 mm, their specific sediment yields differed by a factor of nine. This comparison, taken with others shown in Fig. 2, implies that other controls, such as catchment relief, sediment sources and the impact of human activity are important. Identification of the relative importance of geophysical processes and hydrological variables at the catchment scale is necessary but may be difficult to achieve. Douglas (1967) and Meade (1969) have indeed previously pointed to the need for careful interpretation and examination of sediment records, implying that the effects of anthropogenic activities ought to be considered separately when dealing with large catchments.

Despite problems associated with large catchments when relating annual sediment output to annual runoff, the broad categorization reported above does provide an approximate representation of the magnitude of sediment load in the peninsula. For catchments having reduced forest cover for example, the separating line suggested could be used as a general reference.

Despite the importance of forest cover in protecting the underlying soil from erosion, forest practices, even on a selective basis, can generate large amounts of sediment especially in steep hill forest catchments. To determine how the sediment yields of logged catchments compared with those of catchments used in this study, data from four hill forest basins, ranging in size from 4.7 to 19.8 km^2 (Lai, 1993) were superimposed on the plots for the two groups (Fig. 2). The values fell within the limits of the sediment yields from the forest and non-forest dominated catchments. Sediment yields

Table 2 Summary statistics for runoff, sediment load of Sg. Kelantan, Sg. Pahang and Sg. Langat.

	Mean	Standard deviation	Coefficient of variation	Maximum	Minimum	Data
Sg. Kelantan (11 900 km^2)						
Runoff (mm)	1760	325	0.18	2327	1213	1980-1990
Suspended load (t km^{-2} $year^{-1}$)	233	180	0.77	507	51	
Sg. Pahang (19 000 km^2)						
Runoff (mm)	975	551	0.57	2699	555	1975-1990
Suspended load (t km^{-2} $year^{-1}$)	152	139	0.91	504	31	
Sg. Langat (1240 km^2)						
Runoff (mm)	754	201	0.27	1100	423	1977-1990
Suspended load (t km^{-2} $year^{-1}$)	492	171	0.35	886	223	

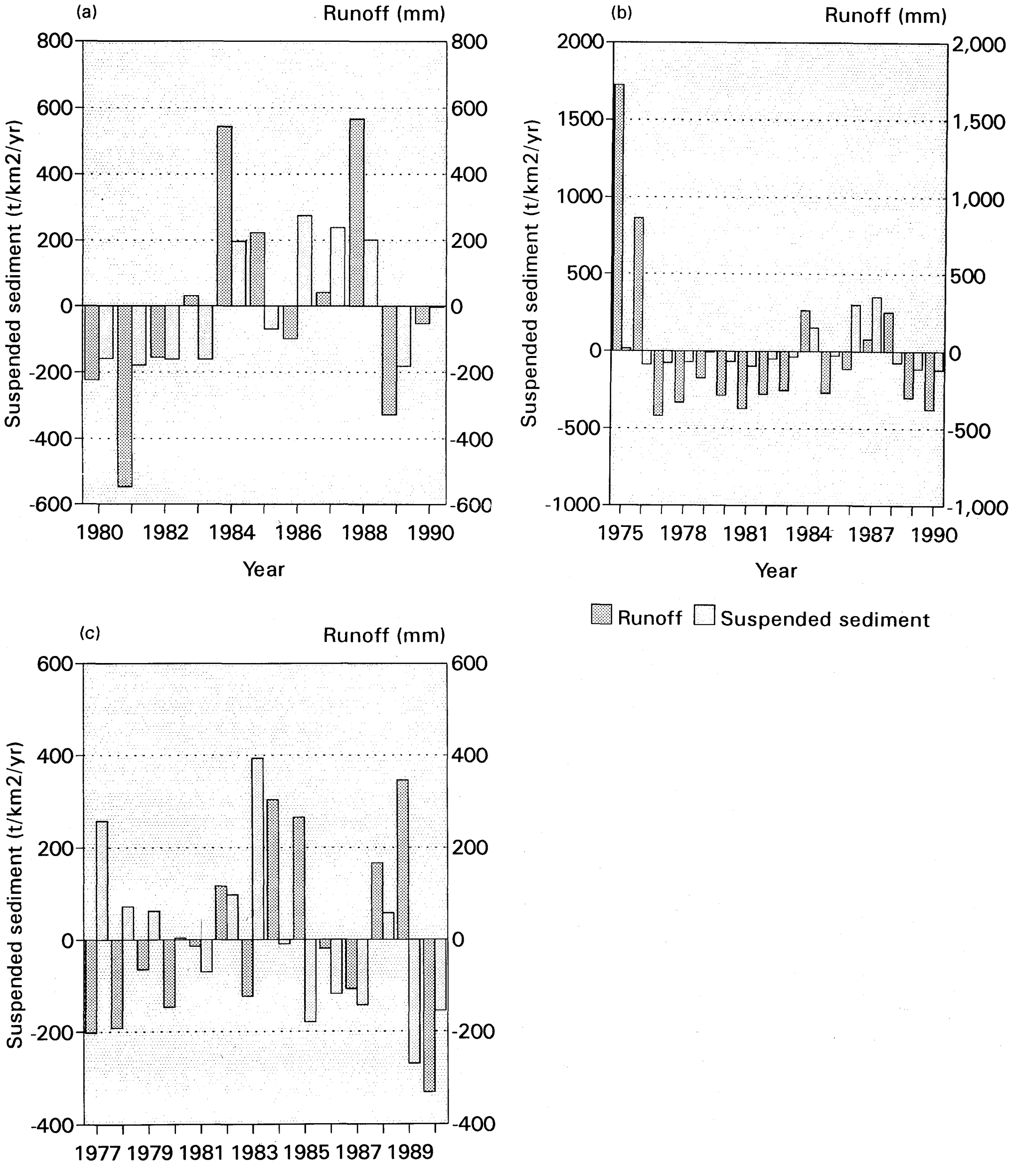

Fig. 3 The variation of annual runoff and sediment yield around the long-term mean values for Sg. Kelantan (a), Sg. Pahang (b) and Sg. Langat (c).

from logged catchments can be up to 50 times greater than from unlogged catchments. Sediment production can therefore increase by about the same proportion if catchments are altered, although this interpretation is limited to a small sample of basins. There is a need for forestry data for the respective catchments to gain a better understanding of catchment scale erosion.

Sediment yield variability

Hydrometeorological events dominate the movement of material in catchments. Rainfall is important in determining the amount of catchment runoff. The arrival and departure of the monsoons in Peninsular Malaysia determines the basic rhythm of the annual rainfall: this can be early or delayed by one or two months (Chia, 1968). High coefficients of variability of annual rainfall occur in the northeast (about 22%), while lower variabilities are associated with areas along most of the west coast (Dale, 1960).

In view of variation of rainfall both spatially and temporally, we examined the variability of annual runoff and sediment yield for three drainage basins where more than 10 years of data were available. The Sg. Kelantan and Pahang basins fall into the >50% forest limit while the Langat belongs to the other group. The coefficient of variability for annual sediment yield is greater than that for annual runoff in all cases (Table 2). The deviation of annual sediment yields from the mean in Fig. 3 does not show any consistent relationship with runoff. Much depends on the magnitude and frequency of occurrence of hydrological and geomorphic events. For example, Yu (1995) reported that the one-third of total rainfall with the highest intensity contributed 46% of the annual runoff and 87% of the annual sediment transport in the wet tropics of Australia, where the annual rainfall is over 2500 mm. In the peninsula, 50% of the annual sediment load of the Sg. Gombak was transported over 24 days (Douglas, 1968). In the logged catchments of Batangsi and Chongkak, half the annual load was carried in 5.7 and 3.2 days respectively (Lai, 1993).

The high variability of runoff and sediment yield for the selected catchments probably reflects the combined effects of hydrometeorology and natural and human-induced changes in the catchments which have not been well-defined in this study.

CONCLUSIONS

An approximate relationship between sediment yield and mean annual runoff for broad categories of forest and non-forest dominated land use has been established. The relationship is well-defined for catchments in the <50% forest category, but where forest cover is >50% the relationship is less clear. The results might be improved by examining catchment relief factors and land use details at the catchment scale, particularly with respect to sediment sources. Further research on the frequency of sediment sampling and analysis of short-term sediment discharge data is needed to gain a better understanding of temporal variability of suspended sediment yields.

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