Is Sediment Discharge Controlled More by Climate or Tectonics? Studies of Suspended and Dissolved Loads from Rivers in Active Orogens of Indonesia

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We challenge the inference that high annual rainfall or high uplift rates results in high fluvial sediment discharge. Our investigation of fluvial sediment discharge in active orogens of Indonesia, where other factors (catchment basin size, relief, gradient, tectonic setting, uplift rates and bedrock) are similar, demonstrates the primary importance of climate (seasonality) in controlling sediment discharge.

Our investigation involves active orogens that span different climate zones so that most other factors contributing to sediment discharge were similar (Cecil et al, 2003). For example, the islands of Sumatra and Java are both part of the active Sunda arc-trench system, but annual rainfall in Java is much less and more seasonal than in Sumatra. A similar situation exists with the islands of Seram, Irian Jaya and Timor, which are active arc-continent collision zones with similar uplift rates, but Timor is much drier and rainfall is more seasonal. Tectonic and geologic settings in these regions are similar, but the number of consecutive wet months per year is the primary variable that controls differences in sediment discharge (supply) among fluvial systems.

Rainfall in the equatorial islands of Sumatra, Seram (perhumid climate) exceeds evapotransporation for all months of the year (>100 mm/month and >2.4 m/yr), and in Irian Jaya (3º south) it is near equal (humid). In contrast, 85 percent of all rainfall (1.4 m/yr) occurs during a 3-4 month rainy season in Java and Timor (dry subhumid climate). The nature of stream channels (braided or meandering), stream-bed materials, degree of fluvial estuarine fill, degree of delta formation, nature of coast lines, and stream sampling of solid suspended sediment concentrations, solute concentrations, and pH in rivers indicate that the absence of fluvially derived bed loads, river mouth deltas, the lack of fluvial fill of estuaries, and mud-dominated coastal zones in perhumid regions are indicative of a very low fluvial sediment discharge. This also includes very low suspended and dissolved sediment concentrations (10 mg/l suspended and 10mg/l solute) in modern rivers in Sumatra, Seram and Irian Jaya. In contrast, sediment discharge in dry subhumid climates of Java (same uplift rate as Sumatra) and Timor (same uplift rate as Seram) is very high as indicated by coarse-grained braided stream bed materials with cobbles transported to the coast, the complete fluvial fill of estuaries, the formation of river-mouth deltas, and coarse grained beaches. Very high suspended and dissolved sediment concentrations (2100 mg/l suspended and 340 mg/l dissolved) during rainy season discharge in Timor and Java are also observed.

The dominant variable affecting fluvial sediment discharge among the islands of Indonesia, therefore, is the degree of seasonality in rainfall regardless of tectonic setting, relief, or catchment basin size. Differences in bedrock geology causes noticeable changes in solute concentrations in both humid and perhumid climates. Chemical weathering of massive limestone thrust sheets in high mountainous areas of Seram and Irian Jaya results in solute concentrations that approximate the solubility of calcite (~50 mg/l). Humid and perhumid areas without significant limestone bedrock geology have solute concentrations that approximate that of rainwater (~10 mg/l).

Most studies of sediment discharge generally compare it with annual rainfall (Milliman, 1997) rather than monthly rainfall amounts and monthly distribution throughout the year. As a result, there is a tendency to assume that high annual rainfall results in high fluvial sediment discharge. Other studies point out that there is little (if any) correlation between sediment discharge and annual rainfall (Milliman and Meade, 1983; Hooke, 2000). In Indonesia, and other regions with high rainfall, it is commonly assumed that erosion rates and sediment loads must be high because the climate is perhumid (Keller and Richards, 1967). Another common assumption is that tectonic uplift is the primary control of sediment discharge. However, neither rising or high mountainous areas nor perhumid climates equate to high sediment discharge, which is demonstrated by the exceedingly low sediment discharge from rivers that debouch from the mountainous perhumid regions of equatorial Sumatra, Seram and Irian Jaya. Little to no correlation with these assumptions is also demonstrated by the low annual sediment discharges of the Zaire (Congo) in perhumid climate, and comparison between sediment discharge from the tectonically active catchments of the Amazon and Ganges/Brahmaputra Rivers. Although sediment discharge from these rivers is nearly equal, water discharged from the Amazon is nearly six times that of the Ganges/Brahmaputra (Table 1).

There are exceptions, such as the Fly River of New Guinea, which is in a humid climate setting, and has a sediment load derived primarily from intense slope failure in high and very steep mountainous areas (Markham and Day, 1994). The combined effects of steep mountains, high rainfall, and frequent earthquakes are conducive to extreme volumes of landslide debris. The relatively high sediment discharge (derived from erosion of landslide debris in high mountains in a tectonically active area and a humid climate) has contributed to the concept that high mountains and high annual rainfall always equates with high sediment discharge. Yet, the rivers of Indonesia and most other comparisons where climate is the major variable informs us otherwise.

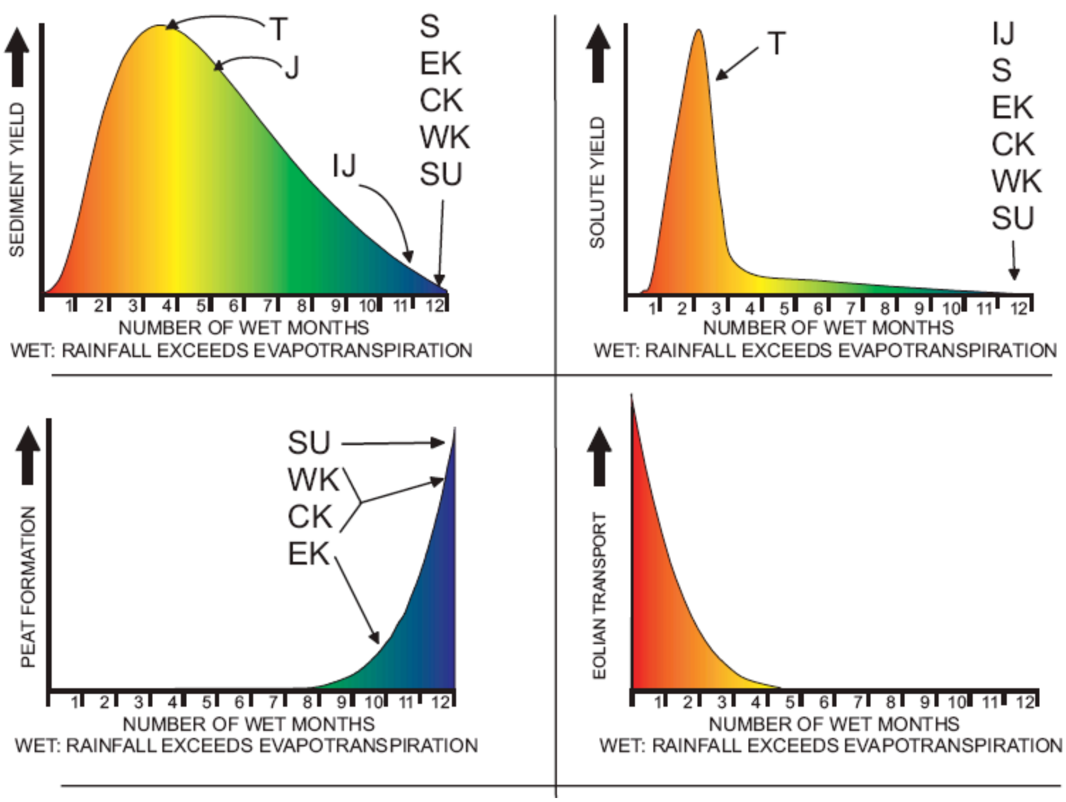

Figure 1. Schematic representation of sediment yield of tropical rivers in Indonesia as a function of

climate. Su – Sumatra; K - Kalimantan (Borneo); T – Timor; S – Seram; IJ – Irian Jaya; J – Java.

River system	**Approximate Mean Number of wet months**	**Water discharge 10^9 m^3/y**	**suspended sediment discharge 10^6 t/y**	**alized sediment concentr (10^6 t/km^3 of water discharge)**
Zaire (Congo)[2]	11	1,250	43	0.034
Amazon[2]	8 - 10	6300	1000-1300	0.21
Fly[1]	9	150	81	0.54
Ganges/ Brahmaputra[2]	5	970	900-1200	1.2

Table 1. Annualized sediment concentrations (mass/unit volume) for four tropical/subtropical rivers. Data are average annual water and sediment discharge. Data sources: (1) Markham and Day, 1994, and (2) Meade, 1996. Approximations of mean seasonality of rainfall for each catchment basin are based on data from EARTHINFO, 1966

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