American Journal of Environmental Sciences 5 (5): 657-663, 2009
ISSN 1553-345X

Temporal Variability on Lowland River Sediment Properties and Yield

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Abstract: Problem statement: A sediment analysis study was conducted at the Chini River on 16 and 31 August 2008. This study was conducted to review the formation of suspended sediment load in the Lake Chini catchment area, which flows into the Pahang River via the Chini River. **Approach:** Three sampling stations were chosen, the first one at upstream Chini River (S1), mid-stream Chini River (S2) and downstream Chini River (S3). Three parameters were quantified for this study, namely: distribution of sediment grain size (g), concentration of suspended sediment (mg L^{-1}) and river discharge values (in m^3 sec^{-1}). **Results:** The findings of the study show that the sizes of sediment fall between phi Ø-1.00 and phi Ø-2.00 with very rough particle sizes falling between phi-1.00 and phi 0.00. At the study area, the daily discharge value is estimated at 722, 304, 00 L day^{-1}. The average suspended sediment concentration recorded for each station shows varying values for both timelines. The values were 27.33 mg L^{-1} on 16/08/08 and 2.233 mg L^{-1} on 31/08/08. **Conclusion:** The average value for all stations calculated based on the formation of suspended sediment load per day falls between 16,480.4627 kg day^{-1} on 16/08/08 and 1,540.43 kg day^{-1} on 31/08/08. Overall, when this number was extrapolated to every square kilometre, the result showed that the estimated average sediment that flows out of Lake Chini is 73.22 tonnes km^{-2} $year^{-1}$.

Key words: Suspended sediment yield, sediment concentration, particle size, river flow values

INTRODUCTION

Sediments are defined as the organic and inorganic materials or solid fragments derived from the weathering processes of sand, pebbles, silt, mud and loess (fine-grained soil). These are then carried by wind, ice or other naturally occurring agents. Sediments can also be defined as the material deposited at the bottom of rivers, which are silt and deposits[1].

In general, sediment comprises many shapes and sizes. The sediment size can be small, such as sand, small pebbles and silt, or large such as boulders, which are normally found upriver. Sediments found in estuaries are mostly fine-grained, such as sand and silt. The speed at which water flows in rivers plays an important part in determining its capacity to carry away sediments. Slower moving rivers will have a lower rate of sediment movement.

The process of sediment deposition is also dependent on river discharge and speed of river flow. As such, a higher discharge value and water velocity would result in higher amounts of sediment. In addition, time is a factor whereby the longer the sediment deposition process, the higher the sediment load[2].

The river is one of the most important sources of water for all living things in addition to lakes, seas, water catchments and underground water. Rivers are very important to humans and other organisms as they are essential resources for living. A number of processes influence the sedimentary content and quality of river water. These include erosion, transport and deposition.

These processes mutually interact along the river, from the ridges up to the mouth of the river. One of the characteristics of a river is its unidirectional flow[3]. The river will exhibit different water levels, rates of flow and rates of erosion during different seasons such as during monsoons and droughts. This situation is influenced by the frequency and intensity of rainfall in the area.

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Sediment has an important role in the nutrient cycle of aquatic environments. In some cases, sediment is responsible for the transport of essential nutrients as well as pollutants. Most surfical sediments in water originate from surface erosion and contain mineral, bedrock erosion and organic components during the process of soil formation[4].

Soils that contain minerals in large quantities produce strong chemical bonds in the soil and are highly stable. Soils on which cover crops or vegetation grow and where soil conservation such as mulching and contour terraces are practised, also help prevent erosion as they reduce run-offs and provide a damping effect to the kinetic energy of rainfall on soil surfaces.

Nevertheless, any increase in velocity and volume of surface run-offs will also increase the rate of erosion as increasingly large quantities of soil will be swept down the slopes. This increases the amount of suspended sediments and water turbidity in stream channels, thus reducing the water quality.

River quality is assured when it is sufficiently maintained[5]. However, river quality may be adversely affected by sudden severe flooding or drought. Therefore, the characteristics of the river discharge are important in terms of its geomorphology, hydraulics, flood control, navigation, stabilisation or development, depending on the purpose of the water resource for aquatic organisms, domestic use, et cetera.

Purpose of study: This study was carried out to identify the following:

- To determine the sediment yields of the Chini River
- To determine the factors influencing sediment mobility
- To determine the range of sediment grain size in the Chini River

Area of study: Lake Chini is the second largest natural lake in Malaysia and it is situated in the southeast region of Pahang state. Its surface area varies (ranging from 150-350 ha) depending on the season, whether the monsoon or dry season. It consists of 12 water bodies, referred to as ‘sea’ by the local inhabitants, which are fed by the tributaries surrounding the water catchment areas of the Chini forest before flowing into the Pahang River via the Chini River.

The Chini River is the only river that channels water from Lake Chini into the Pahang River. The length of this river is 4.8 km from Lake Chini to the Pahang River[6].

In 1995, a barrage was built at the estuary of the Chini River to raise the lake water level to benefit tourism. The barrage has drastically reduced the dynamism of the water movement of the lake.

Furthermore, extensive human activities such as farming, mining and logging have adversely affected the ecosystem of the lake, causing the widespread growth of the aquatic weed *Cabomba furcata* and reduction of water quality, lotus plant density and fish population, as well as increase in the number of coliform bacteria and *E. coli*[7,8].

In the area surrounding Lake Chini are about 500 settlers at the lakeside, two tourist resorts and one tourism complex[8]. Lake Chini has been developed as a tourism destination in Pahang.

Activities such as the continued development of eco-tourism facilities, farming and logging have negatively affected the lake and have possibly caused soil erosion and an increased amount of sediment deposited into the lake. Likewise, the tropical rainforest which encircles the Lake Chini basin has been turned into a secondary jungle owing to logging. In addition, the serious receding of the lake water volume during droughts has contributed to the process of sedimentary settlement.

MATERIALS AND METHODS

Three sampling stations representing the 4.8 km length of the Chini River were selected: station 1 (S1) upstream Chini River, station 2 (S2) mid-stream Chini River and station 3 (S3) downstream Chini River. As this river is the only outlet from the Chini Lake, the selection of station 1 (S1) is important to indicate the volume of sediment being transported from the Lake, while the sediment yield from station 3(3) can be used to estimate the sediment production along the Chini River, particularly those from boat operators which carry the tourists in and out from Chini lake. Detail GPS location of each station is illustrated in Table 1 while Figure 1 shows the Chini River, the lake and sampling location on the map.

Water samples were taken from each station and kept in special 500 mL bottles for analysis in order to find the Total Suspended Sediments (TSS) in the Chini River.

Table 1: Location of sampling stations at the Chini River

Station	Longitude	Latitude
Upstream Chini River (S1)	3°26’36.413”E	102°54’31.946”N
Mid-stream Chini River (S2)	3°26’36.400”E	102°54’31.900”N
Downstream Chini River (S3)	3°26’03.268”E	102°53’35.497”N

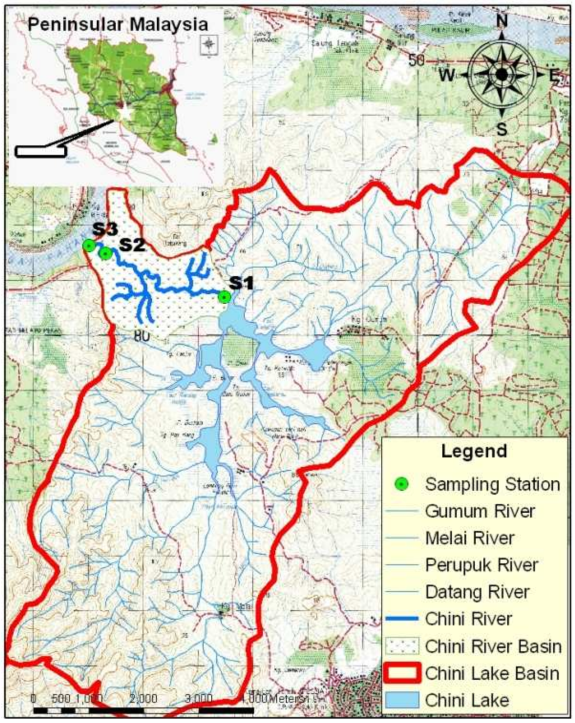

Fig. 1: Location of sampling stations at the Chini River

Sediment samples were also collected using sediment scoops. Three sample replications were collected from each station and the finding was presented by the average of the replicated samples. The cross-section length and water velocity were also measured at each station using several types of apparatus such as the flow meter, depth measuring gauge, measuring tape and poles. The samples collected were analysed in the laboratory.

Parameters, such as the flow velocity, width and depth of the river, were determined *in situ* and used for purposes of measuring specific discharge values and sediment sampling.

Sampling of suspended solids was carried out using plastic bottles. Before taking a sample, the bottle was first rinsed with water from the river. It was then slowly lowered into the water until all the air spaces in the bottle were replaced with water. The Gravimetric method was used to analyse the TSS. The total suspended solids was also measured in mg L^{-1} unit or parts per million (ppm).

This study required a 250 mL water sample for each study area plot. The measurement of suspended solids was carried out by weighing the membrane filters with 0.45 μm diameter pores. A membrane filter was placed onto a filtration apparatus connected to a vacuum pump and clipped in place.

The river water sample was then slowly poured into the filtration jar, following which the membrane filter was removed, allowed to dry in a drying jar and then weighed. Unlike dissolved solids, particles are physically separated from water. Precautionary measures need to be taken while taking water samples.

Disturbance to water flow had to be kept at a minimum to avoid the measurement of deposition of suspended solids. Readings were taken and calculated using the following formula:

$$\begin{aligned} TSS &= \frac{\{(\text{weight of membrane filter} + \text{dry residue}) \\ -\text{weight of membrane filter}\}(\text{mg}) \times 1000}{\text{Volume of filtered water (mL)}} \\ &= \text{mg } L^{-1} / 1000 / 1000 / 1000 \\ &= \text{tonne } L^{-1} \end{aligned} \quad (1)$$

Discharge value (Q) is the product of average velocity (v) and cross-section area (A) or Q = vA. Cross-section area is derived from the product of depth (d) and width (w). Since the cross-section area is trapezium or triangular shaped, its value is half the produce:

$$A = dw\ (m^2) \text{ or } A = \tfrac{1}{2}\, dw\ (m^2) \quad (2)$$

Velocity (v) is calculated by multiplying distance with time:

$$V = m\ sec^{-1} \quad (3)$$

Discharge value (Q):

$$\begin{aligned} &Q = vA, \text{ or } Q = \tfrac{1}{2}\, vA \quad (4) \\ &Q = m^3\ sec^{-1} \end{aligned}$$

To obtain the unit L day^{-1}, the following formula is used:

$$\begin{aligned} Q &= m^3\ sec^{-1} \times 86400\ sec\ day^{-1} \times 1000\ L\ m^{-3} \\ &= L\ day^{-1} \end{aligned} \quad (5)$$

The calculation of suspended Sediment Load value (SL) is based on the discharge value, TSS value and area of sampling basin. The data to be analysed would be used to detect changes in the concentration of suspended matter and its relationship with hydrological parameters and other variables:

$$\begin{aligned} \text{MS} &= (\text{Q} \times \text{TSS}) / \text{area of sampling basin} \\ &= (\text{L day}^{-1} \times \text{kg L}^{-1})\ \text{km}^{-2} \\ &= \text{kg km}^{-2}\ \text{day}^{-1} \times 365 \text{ days} \\ &= \text{kg km}^{-2}\ \text{year}^{-1} \end{aligned} \quad (6)$$

The sieving method was done by spreading sediments on a clean plastic sheet and leaving them to dry at room temperature. During the process, clumps of sediments were broken up into smaller pieces to expedite the drying process. The sediment sample was left to dry and then ground with a wooden pestle. The soil sample was divided into 100 g samples and sieved 15 min with a mechanical shaker. The sizes of sieve tray used in this study were 2.0, 0.71, 0.180, 0.045 mm and pan.

Once all soil samples had been categorised and separated according to size, they were transferred to Petri dishes and weighed on an electronic weighing machine to the nearest two-point decimal. The weight of each soil sample size represented a percentage size of the soil. The Udden-Wentworth[9] scale was used in this study. According to the Udden-Wentworth method, analysis would be made easier with the construction of an ordinate arithmetic graph using the weight values obtained. The x-axis scale is the phi value. The y-axis is the cumulative percentage scale value (0-100%) using a linear scale (Fig. 2).

The cumulative curve was used to determine the phi size of each phi value (phi at 5%, phi at 16% and so on, where % refers to cumulative percentage) (Table 2). Table 3 shows the determination of the phi min size of each phi value, while Table 4 is use to determine sediment size skew values.

Ø5, Ø16, Ø25, Ø50, Ø75, Ø84 and Ø95

Using the above to calculate the various statistical values with the following equations:

$$\text{Median} = Ø50 \quad (7)$$

$$\text{Min(M)} = \frac{Ø16 + Ø50 + Ø84}{3} \quad (8)$$

$$\text{Skew (S)} = \frac{Ø84 + Ø16 - 2(Ø50)}{2(Ø84 - Ø16)} + \frac{Ø95 + Ø5 - 2(Ø50)}{2(Ø95 + Ø5)} \quad (9)$$

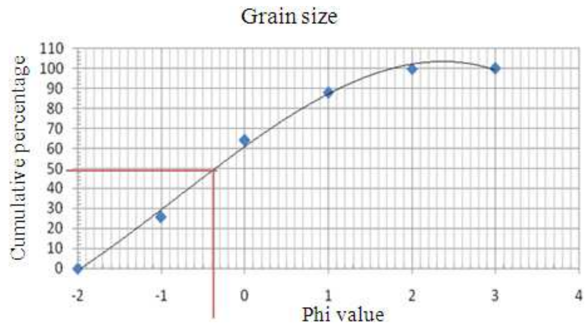

Fig. 2: Soil grain size graph obtained through the calculations in sieving analysis

Table 2: Phi value derived from calculations in sieving analysis

Percentage	Ø5	Ø16	Ø25	Ø50	Ø75	Ø84	Ø95
Phi value	-1.95	-1.85	-1.73	-1.35	-0.33	1.00	3.68

Table 3: Distribution size of mean value

Distribution size (min)	Phi value (phi)
Rock	-12 to -8
Stone	-8 to -6
Pebble	-6 to -2
Sand	-2 to -1
Very rough grain	-1 to 0.0
Rough grain	0.0 to 1.0
Medium grain	1.0 to 2.0
Fine grain	2.0 to 3.0
Very fine grain	3.9 to 4.0
Rough silt	4.0 to 5.0
Medium silt	5.0 to 6.0
Fine silt	6.0 to 7.0

Table 4: Sediment size skew values

Sediment size	Phi value
Very fine	+1.00 to +0.30
Fine	+0.30 to +0.10
Medium	+0.10 to -0.10
Rough	-0.10 to -0.30
Very rough	-0.30 to -1.00

Table 5: Total Suspended Sediment (TSS) at the Chini River

Sampling station	16/08/08 (mg L^{-1}) high level	31/8/08 low level	Average
S1	17.2	2.05	9.625
S2	42.4	2.35	22.375
S3	22.4	2.30	12.350
Total	82.0	6.70	-
Max	42.4	2.35	22.750

RESULTS

The findings of this study are shown in Table 5. The outcome showed a higher amount of suspended sediment on 16/8/08 as compared to 31/8/08. This could have been due to the effects of water level which was higher on 16/8/08. Sedimentation is a complex problem in tropical areas as soil erosion due to very high rainfall contributes to it[10]. Through long-term research on changes in suspended sediment load and taking into account the weather variable, it has been found that the rate of loss of surface soil is very high during the monsoon season.

The density of forest canopy plays an important role towards reducing surface erosion which contributes to sediment load in rivers. The multi-tiered canopy layers function as a filter in the process of interception[11] and reduce the effects of rainsplash erosion[10]. However, the average values of suspended sediment yields found in this study are low compared to studies of areas in other parts of Malaysia. For example, the average value recorded in Air Terjun River, Perlis was 111.04 mg L^{-1}[12], Tekam River at 158.3 mg L^{-1} and Bebar River at 104.2 mg L^{-1}[4].

Referring to Table 6, the observed value (Q) at station 1 or upstream Chini River showed the highest value at 17.115 $m^3\ sec^{-1}$. Station 3 at downstream Chini River however, indicated the lowest value (Q) at 2.987 $m^3\ sec^{-1}$. This is a normal reading for a river, where the observed value (Q) or water velocity in the elevated upstream is higher than the downstream. In flat areas, excess water flows out of Lake Chini into the Pahang River via the Chini River and the difference in depth and width of the river significantly influences the flow value of the river.

This study showed a correlation between observed values (Q) and suspended sediment values in the Chini River. Figure 3 shows a significant relationship of $R^2 = 0.998$ between observed values (Q) and TSS values in the Chini River, indicating that an increase in observed value (Q) would cause an increase in TSS value, thus causing an increase in water turbidity. Therefore, discharge value (Q) is a factor that could influence the mobility or TSS values. The higher the velocity of water, the higher the rate of erosion and more suspended sediments are produced as a result.

Table 6: Hydrological data (Q) at the Chini River

	16/8/08		31/8/08	
Sampling station	(Q) Observation ($m^3\ sec^{-1}$)	Q day^{-1} (L day^{-1})	(Q) Observation ($m^3\ sec^{-1}$)	Q day^{-1} (L day^{-1})
S1	17.115	1,478,736,000	17.115	1,478,736,000
S2	4.978	430,099,200	4.978	430,099,200
S3	2.987	258,076,800	2.987	258,076,800
Max	17.115	-	17.115	-
Min	2.325	-	2.325	-
Total	25.080	2,166,912,000	25.080	2,166,912,000
Average	8.360	722,304,000	8.360	722,304,000

Table 7: Suspended sediment load in the Chini River

Sampling station	Area (km^2)	∑ TSS	TSS (kg L^{-1})	Estimated Q ($m^3\ sec^{-1}$)	Estimated Q ($m^3\ day^{-1}$)	Estimated Q (L day^{-1})	Total sediment day^{-1} (kg day^{-1})	Total sediment $km^2\ month^{-1}$ ($kg^{-1}\ km^{-2}\ month^{-1}$)	Total sediment year ($kg^{-1}\ km^{-2}\ year^{-1}$)	Total sediment $year^{-1}$ (tonne $km^{-2}\ year^{-1}$)
Chini River	4.36	14.78	0.00001478	8.36	722.304	722, 304, 000	27,031,345	6199.8	74,387.6	73.22

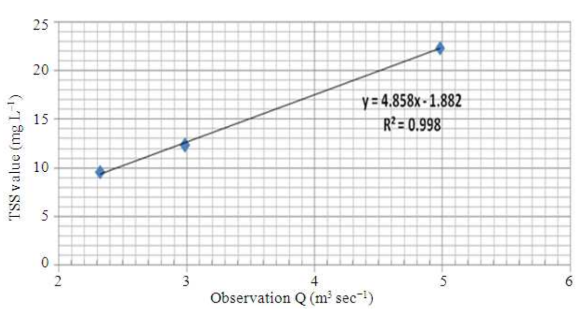

Fig. 3: Relationship between observation Q and TSS value in the Chini River

DISCUSSION

In summary, the observation (Q) is a factor that could influence mobility and deposition of sediments at a particular basin. Generally, water velocity influences the rate of erosion and deposition of sediments along river stretches and river-mouths. The higher the water velocity, the higher the intensity of erosion and increasingly more sediments are produced.

Sediment load is the total mobility of sediments scoured from the lake bottom. The annual increase in suspended sediment load has a negative impact on the drainage system of rivers in the Lake Chini catchment area. Alluvial deposition, if not addressed, will be an increasingly serious problem in the future.

It will affect water quality and cause increasing shallowness of riverbeds and lakes, leading to flooding within the surrounding area. In effect, it will adversely impact all living things, including the local inhabitants.

Daily suspended sediment yields were calculated to obtain the suspended sediment load in the river. This information is crucial as suspended sediments from catchment areas are residues of soil erosion. Results and calculations of the analysis are shown in Table 7.

Overall, the estimated daily suspended sediment load on 16/8/08 was between 5,780.92 kg day^{-1} and 25,424.26 kg day^{-1}. The highest daily suspended sediment load was caused by highest discharge value and highest suspended sediment yield. The increase in water level during the monsoon season is owing to the softening of soil slopes, causing them to be eroded easily[13].

Therefore, it was unsurprising that station 1 showed the highest suspended sediment load values (owing to the high flow value at 115 m^3 sec^{-1}). Other factors including the dumping of garbage and other domestic activities by local inhabitants also contributed to the increasing sediment deposition in the area.

Additionally, the inflow of alluvial into the lake contributed to the increased values of suspended sediments in November. The high values of suspended sediments in Lake Chini during the monsoon were due to the large quantities of sediments delivered from the Pahang River through the Chini River.

The analysis of sediment grain size in this study is shown in Table 8. The measurement of phi (ø) introduced by Wentworth was used. The parameters involved include median, mean and skew[9].

The median value is the mid-value in a set of data arranged in ascending order. The mean size of an individual particle size is the marker for comparison in the consideration of weight force and flow force required before water movement can occur. Assuming similar range sized particles, the mean size of a particular sedimentation would therefore depict energy flow. Tiered layers, for instance, record energy flow from a point that fluctuates through time. Rough grains depict a strong energy flow, whereas fine grains depict weak energy flow[9].

The median value at station 3, downstream Chini River, is the highest of the three stations at phi 0.66. The mean size analysis mainly exhibited very rough particle sizes between phi -1.00 and phi 0.00. The mean values of the upstream and mid-stream stations of the Chini River showed very rough particle sizes at phi -0.333 and 0.00667 respectively. The values therefore indicated that energy flow at the two stations was high. The station at downstream Chini River, on the other hand, showed a rough particle size at phi 0.0267. Energy flow at this station was relatively high. Thus, the overall energy flow of the Chini River at the time of study (16/8/08) was high.

Table 8: Sediment grain size distributions

Station	Median	Mean	Skew
S1	-0.38	-0.33300 (very rough grain)	0.082 (medium-size sediment)
S2	0.57	0.00667 (very rough grain)	-0.475 (very rough-size sediment)
S3	0.66	0.02670 (rough grain)	-0.579 (very rough-size sediment)

The skew values of a particular sample showed sensitivity towards environment sedimentation. A portion of river sand exhibited positive skew because most of the fine grains were deposited after the river had receded following floods, whereas coastal sand exhibited negative skew due to the separation of fine granules[9]. In the grain size distribution Table 8, the sediment size skew values in the samples indicated mostly very rough sizes between phi -0.30 and phi -1.00. The stations exhibiting very rough sizes were those at mid-stream and downstream Chini River with skew values at -0.475 and -0.579 respectively. The skew value at the upstream Chini River station, on the other hand, showed a reading of 0.082, the highest amongst the stations, indicative of moderate size sediments.

In summary, the study showed that sediment grain size in the Chini River was in the category of very rough, poor levels of uniformity and very rough sediment sizes, all indicative of kurtosis of the platykurtic type.

CONCLUSION

In conclusion, this study showed that suspended sediment yields of the three stations in the Chini River were relatively low. Therefore, necessary steps towards its rehabilitation and prevention must be initiated and implemented immediately as suspended sediment load would affect water quality.

The increasing suspended sediment load in river basins could lead to increased turbidity, high alkali content in water, emission of unpleasant odours and water discolouration and reduced penetration of sunlight which in turn would jeopardise the process of photosynthesis by aquatic plants. Consequently, aquatic organisms would be impacted by the lack of oxygen and unbalanced pH of the water.

The observed values (Q) at the Chini River were amongst the primary factors that affected sediment mobility in the area. As such, the increased rate of water flow could cause suspended sediment yields. Suspended sediment yields were closely related to incidence of rainfall that affected the increasing values of river discharge. However, the reason for increased sedimentation in the Chini River was not water flow alone. Activities within the vicinity of the basin such as logging, agriculture and mining also contributed to the increasing levels of sediment.

Environmental factors such as flooding were also contributing factors. Based on observations during the sampling period and data obtained from local inhabitants, the Lake Chini catchment area faced frequent flooding and overflow from the Pahang River during the monsoon season.

In relation to the distribution of sediment grain size, very rough grains and sediments were found in these areas, demonstrating a possibility of mining activities within the catchment area. The high levels of silt showed the presence of agricultural activities or deforestation which caused the problem of 'nudation' within the catchment area. Therefore, preventive measures must be taken immediately to curb the periodic increase in sedimentation in Lake Chini specifically and the Chini River generally.

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