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Bedload Characteristics of Lower Order Streams in Extremely High Rainfall Region: A Case Study of Um-U-Lah Watershed, Cherrapunji

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Abstract: *In high rainfall regions, basin and channel characteristics coupled with a unique hydrological regime, directly affect the character of the sediment load carried by the stream. The bedload character shows both spatial and temporal variations. The study of Um-U-Lah basin in Cherrapunji reflects the response of the fluvial system to the given geo-environmental conditions. The assessment of bedload revealed that there is varied distribution of sediment grain size along the longitudinal profile, with silt and clay obviously being negligible. Larger particles are distributed at varying proportions downstream, with sand constituting a major portion. The most interesting finding is that, the granules are deposited at shorter distances than pebbles due to their higher density. Concentration of sand at certain locations seems to indicate the influence of human activities.*

Introduction

Streams in high rainfall regions of the world display certain unique characteristics. The variables such as climate, geology, valley dimensions, vegetation, hydrology, channel morphology and sediment load affect the stream system depending on the temporal scale. These are reflected in the drainage area, drainage density, stream order, relief/length ratio, and channel and valley configuration. Out of these parameters, relief/length ratio seems to offer a good indication of sediment delivery (Roehl, 1962). In areas of high rainfall like Cherrapunji, runoff would be enormous, even from a small area and hence steep headwater streams represent an important component of sediment supply (Brummer and Montgomery, 2003). River flows are, in general, turbulent, non-uniform and unsteady in nature. The transport of sediment through the stream system depends highly on the grain size, quantity of sediment supply and the ability of the stream to transport that sediment. The dissolved load, suspended load and bed load move under different velocities and their relative contribution to the total sediment load of the stream varies significantly. Dissolved load is carried in solution, suspended load and bedload are particulate or solid material which are differentiated by the size of the particles such as clay, silt, sand, pebbles, cobbles and boulders.

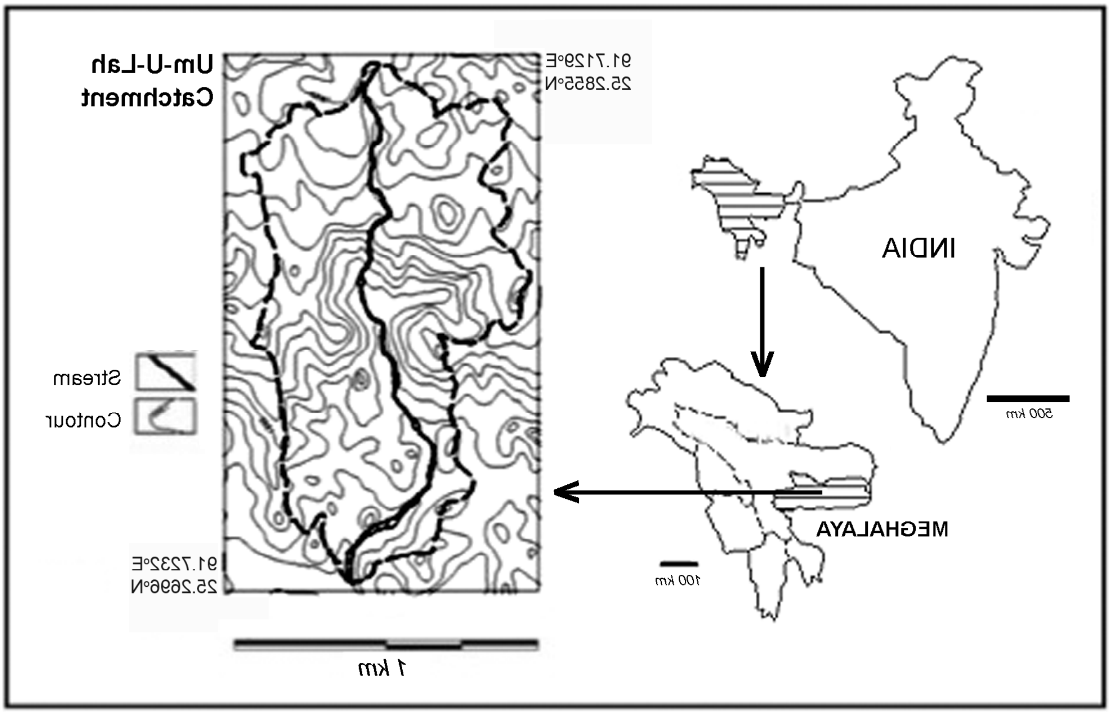

Figure 1a. Location of study area **Figure1b.** Um-U-Lah Watershed

Both sediment and water discharge are primarily determined by the nature and characteristics of the drainage basin, but anthropogenic processes also have considerable impact. The disturbances on land surface drastically increase the sediment load and also affect the course of streams. Landuse affects either the suspended or the bedload regime. Human activities such as agriculture, mining, deforestation, construction of dams, roads etc. disturb the land surface, thereby increasing the effect of overland flow, which ultimately lead to the increase in the sediment load of a stream. There is an increase of finer particles downstream as the carrying capacity of the stream is reduced. It is often thought that the entrainment and transport of particles will be similar under similar conditions (Yuill *et al.* 2011). However, field investigations show that the case may not be so, and such situations actually highlight the importance of understanding the hydro-geomorphic characteristics of specific drainage basins.

The paper investigates the grain size distribution in an Eocene sandstone micro-watershed with perennial flow located in one of the world's heaviest rainfall receiving area – Cherrapunji. The paper focuses on bedload characteristics along the designated part of the stream. The main objective is to quantify the distribution of sediment grain size along the longitudinal profile of the stream under different slope conditions.

Study area

The Um-U-Lah micro-watershed is an experimental watershed adopted by the Department of Geography, North Eastern Hill University for understanding a number of hydrologic parameters operating in one of the world's heaviest rainfall area. This micro-watershed had served as a representative study site for rainfall–runoff relationship and is being monitored for extreme events.

Um-U-Lah watershed lies to the south of

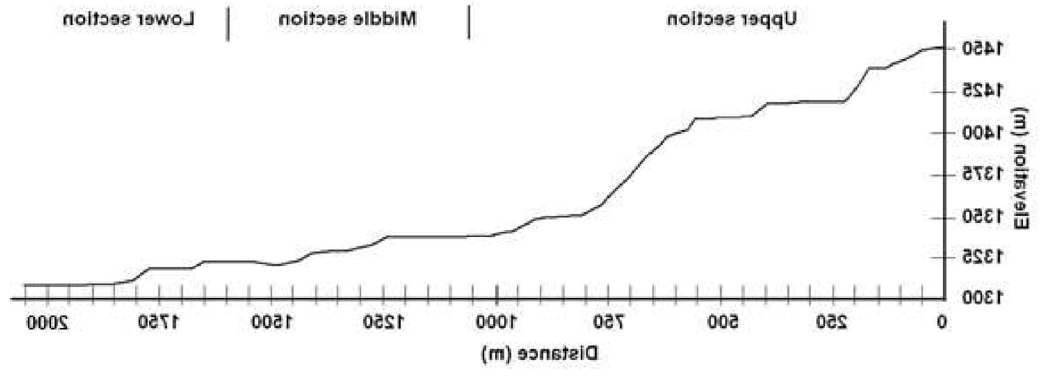

Figure 2. Longitudinal profile of Um-U-Lah stream

Cherrapunji town and is located on the southern slope of Meghalaya Plateau. This micro-watershed occupies an area of only 103.4 ha. It is located between 91°42′37″ to 91°43′31″ E and 25°16′0″ to 25°17′12″ N and the total length of the stream is around 2 km (2044 m). The section to be considered in the paper encompasses a third order drainage basin. This watershed is a part of the Umiew (Umiam) river basin.

Physiographically, the altitude of Cherrapunji decreases towards the south. In general, it represents a dissected area, but the terrain over the Cherrapunji spur is undulating. Towards the south of Cherrapunji, the plateau abruptly ends on a scarp face of thick sandstone, often associated with limestone, and then sloping down like a wall to the plains of Surma valley. This area has been deeply eroded by water caused by heavy rainfall. In the catchment, the northern section is hilly, having an elevation of 1200 m to 1530 m with prominent valleys while the southern section is less varied.

This area is under the influence of tropical monsoon climate. The moisture bearing winds obstructed by the scarp face of the plateau brings heavy precipitation over this area at an annual average of 11,940 mm. Generally, the climate of this area is humid subtropical with alternating wet and dry periods. Heavy rainfall and high velocity winds are the main characteristics of the area. Rainfall usually begins in the month of April and continues until October. Mean monthly maximum and minimum temperature during winter is 16.6 °C and 7.7 °C, while during summer it is 23 °C and 18.4 °C respectively. Cherrapunji and its neighbourhood experience a cool climate associated with foggy conditions. The atmosphere is almost saturated with water vapour in summer as reflected by relative humidity values of more than 95%, while it is relatively dry in winter with relative humidity around 60%. The response of the fluvial processes to such annual climatic variations results in differentiated bedload characteristics and distribution.

Methodology

Channel bed sediments samples were used for understanding the characteristics of bedload of the initial stream flowing over Eocene sandstones. Since this area experiences a sufficiently long dry winter, the streams are almost dry during this period of the year allowing adequate sediment sampling directly from the bed. Samples of 1 kg each from 26 cross section sites were collected using a small shovel. An amount of 200 g from each sample is oven dried and sieved to determine their physical characteristics.

For operational convenience, the grain

Table 1. Distribution of bed sediment fractions along the longitudinal profile of Um-U-Lah stream

Sample no.	Distance from source (m)	Elevation above msl (m)	Clay (g)	Silt (g)	Fine sand (g)	Coarse sand (g)	Very coarse sand (g)	Granules (g)	Small pebbles (g)	CV (%)	Slope (deg)	Channel width (m)
1	396.9	1412	0.02	0.1	0.77	4.16	26.19	34.95	24.96	93.06	10.08	2.00
2	844	1348	0.01	0.12	2.49	10.02	29.51	23.34	16.50	107.29	14.31	5.10
3	887.2	1345.5	0.03	0.08	1.93	5.07	23.68	28.76	18.33	95.84	5.79	5.90
4	906.4	1345	0.02	0.14	3.60	16.36	51.21	15.52	13.15	147.45	2.60	5.00
5	958.4	1341	0.02	0.06	0.76	6.76	6.76	25.93	18.27	102.81	7.69	5.30
6	1033.3	1339	0.07	0.15	2.93	17.48	17.48	17.98	13.40	123.92	2.67	7.00
7	1087.5	1337.5	0.01	0.02	0.63	3.11	3.11	34.26	28.30	92.19	2.77	7.00
8	1165.4	1336	0.01	0.03	1.12	6.45	34.93	26.06	15.75	107.30	1.93	6.20
9	1192.2	1335.7	0.03	0.07	0.68	8.34	46.82	18.71	8.19	140.35	1.12	16.50
10	1204.1	1335.5	0.07	0.12	3.36	10.91	22.73	14.77	25.17	104.07	1.68	10.40
11	1240.3	1334	0.03	0.05	1.02	5.51	28.66	30.34	20.69	95.97	4.14	5.00
12	1354.9	1329.5	0.06	0.08	1.99	15.05	38.84	20.15	12.78	129.08	3.93	8.00
13	1464.9	1328	0.02	0.02	0.37	10.11	61.41	21.51	2.92	159.55	1.36	4.80
14	1515.9	1327	0.02	0.04	1.15	7.29	31.94	19.57	16.64	108.94	1.96	5.30
15	1570.1	1326.5	0.04	0.07	2.14	8.70	20.38	18.17	30.76	96.64	0.92	4.43
16	1596.4	1326	0	0.03	0.46	1.90	19.82	27.27	25.39	92.00	1.90	5.80
17	1637.4	1320.5	0.01	0.02	0.98	10.00	37.93	19.93	20.18	112.67	13.41	7.20
18	1662.1	1320	0.02	0.04	0.77	3.44	31.49	29.54	13.98	103.89	2.02	12.50
19	1711.2	1316	0.02	0.03	0.49	2.39	27.21	30.34	27.32	91.41	8.15	13.00
20	1819.5	1311	0.06	0.14	7.23	8.76	15.70	10.34	25.86	107.21	4.62	18.80
21	1855.4	1310.5	0.04	0.03	1.01	7.21	30.37	17.18	21.39	104.85	1.39	16.00
22	1909.4	1310.25	0.01	0.04	0.44	1.25	18.11	33.61	32.08	96.36	0.46	4.30
23	1949.4	1309	0.05	0.08	4.97	18.42	29.64	16.30	24.97	115.94	3.13	15.70
24	1980.6	1307	0.03	0.04	2.09	11.40	25.34	18.18	21.01	104.24	6.41	14.70
25	2014.5	1305	0.02	0.02	0.32	2.45	33.19	33.24	17.65	99.65	5.90	10.50
26	2044.5	1304.5	0.03	0.04	2.67	14.84	43.01	17.94	6.75	148.78	1.67	9.00

segregation was done entirely by dry sieving and the range of particle sizes for the current work was restricted between 38 µm to 8 mm.

The longitudinal profile was plotted using MAPINFO Vertical Mapper. The stream is divided into three main sections namely Upper (0–1,087 m), Middle (1,087–1,596 m) and Lower (1,596–2,044 m) sections (Fig. 2).

Slope gradient was calculated using elevation values from the field, matched with topographical sheet (RF 1:25,000) and converted to percentage. The results were then tabulated as per the segregated size classes and their weight in percentage was calculated and analysed. Coefficient of Variation was calculated and plotted for each sample to understand the variation of bedload along the reach. The statistical analysis of the different components of bedload indicates that the percentage of silt and clay is not significant and hence is not included in the analysis.

The distribution of bedload is compared with elevation, slope and channel width of 26 cross sections for showing the effect of these geomorphic parameters on bedload distribution. For this, scatter diagrams were constructed and linear regression analysis was carried out to depict the changing pattern of bedload characteristics in relation to slope and channel width.

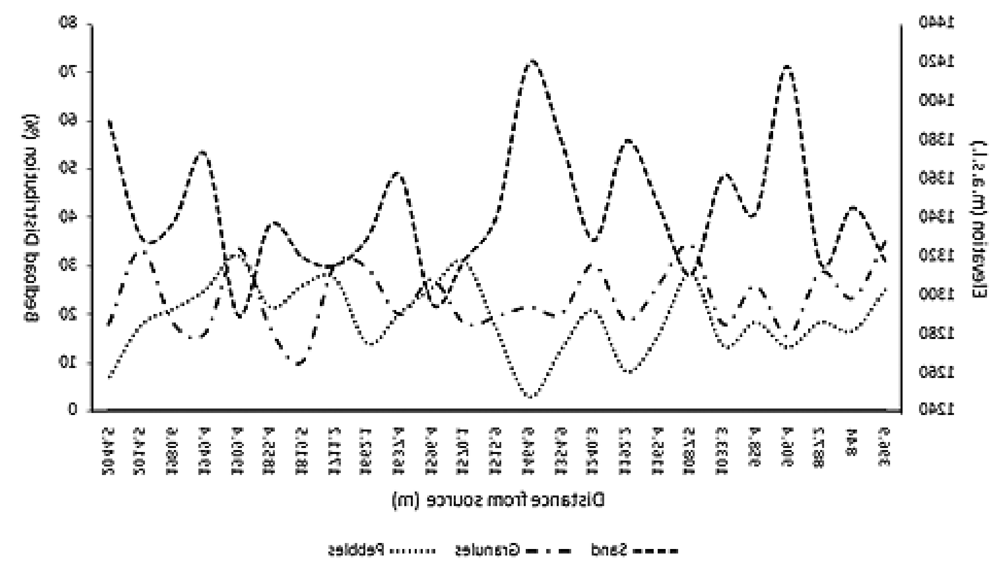

Figure 3. Distribution of bedload along different sections of Um-U-Lah stream

Near the source, the initial stretch of the stream is at an elevation of 1,450 m above sea level and is flanked by settled areas. In the upper reaches not much of the bedload is exposed. The presence of waste materials such as plastic wrappers, bottles, etc. together with turbid water in the stream can be observed. Small pools were present which were covered with careless disposal of domestic waste. Samples were taken from almost 400 m downstream.

Analysis and discussion

The distribution of bedload in different sections of the stream is depicted in Fig. 3. The upper section displayed an average distribution of clay (0.02%), silt (0.1%), sand (41.82%), granules (25.82%) and pebbles (18.98 %). Granules and pebbles constitute the largest volume of bedload. The grains in this section have moderately smooth surface and are less angular in almost all the size classes. However, some of the fine sand grains have sharp edges. At the initial point, fine bedload constitutes of clay (0.02%), silt (0.1%), fine sand (0.77%), coarse sand (4.16%), very coarse sand (4.16%) and pebbles (24.96%).

The middle section is composed of 0.034% of clay and 0.058% of silt. Sand particles constitute the largest share of bedload and reach up to 41.96% while larger particles like granules (21.68%) and pebbles (19.19%) are less. The shape characteristics of the sample are semi-round, oblong, and trapezoid but the grains have moderately rough surface.

In the lower section the average composition has changed slightly. Clay and silt particles have increased in percentage touching 0.034% and 0.55% respectively indicating downstream fining. Sand, granules and pebbles, which constitute the largest volume of bedload material, share 39.77%, 20.97% and 21.38 % respectively in this section. It is worth mentioning here that, at the outlet of the stream, fine bedload constitutes of clay (0.03%), silt (0.04%), fine sand (2.67%), medium sand (14.84%), coarse sand (43.01%), granules (17.94%) and pebbles (6.75%).The shape characteristics at the last section are varied.

Drawing inference from the linear analysis between the bedload fractions and slope, it is

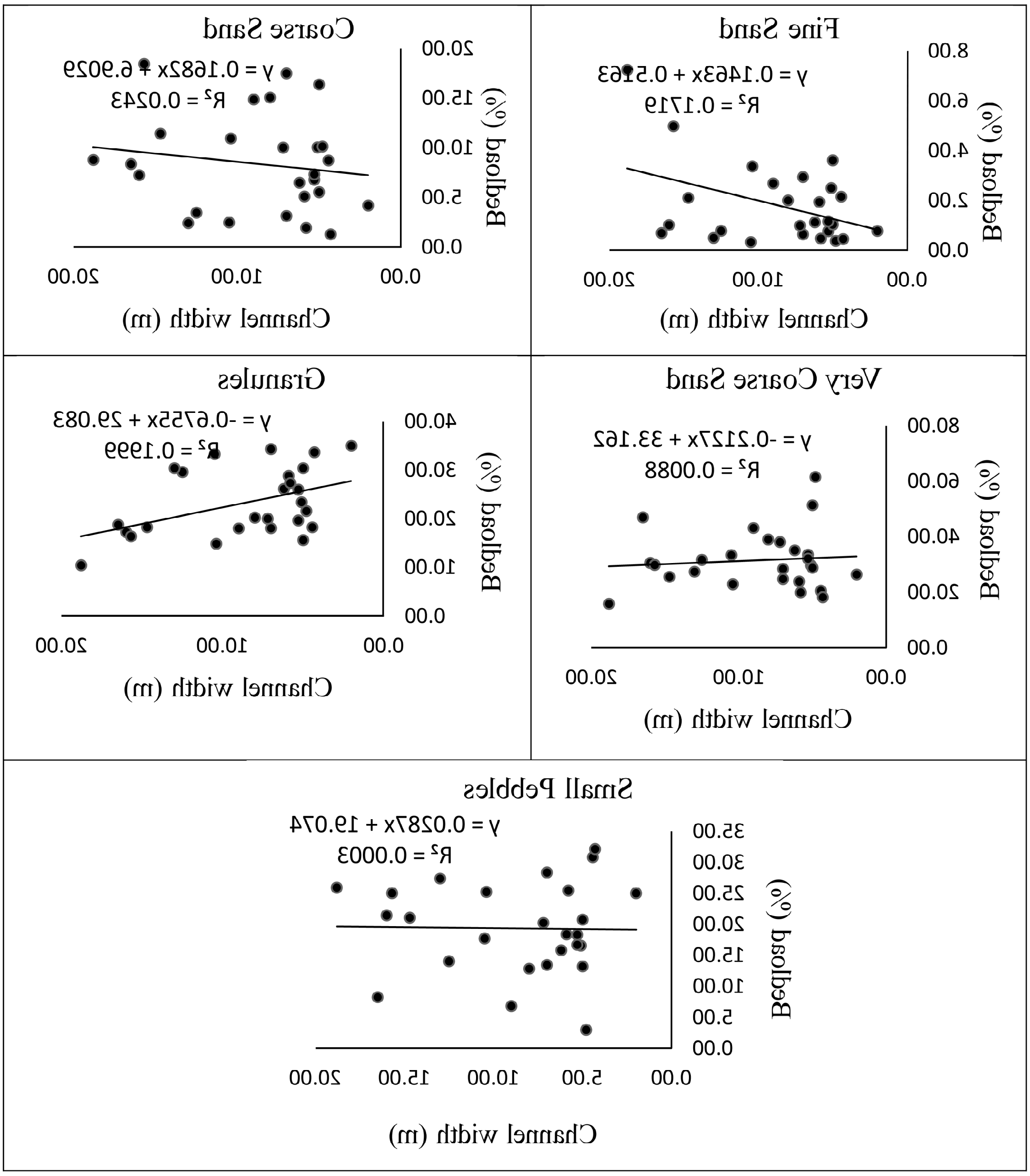

Figure 4: Scatter diagram and regression statistics showing effects of channel width on bedload of Um-U-Lah stream

found that there is a poor negative relationship (R: 0.001–0.008) with the exception of granules (R: 0.038) which indicated a poor positive relationship. The linear analysis between bedload fractions and channel depth represented no significant results.

The correlation analysis between bedload fractions and channel width yielded interesting results (Fig.4). Fine and coarse sand (38–250 µm) and small pebbles (0.5–8 mm) showed positive relationship with channel width. On the other hand very coarse sand and granules (250 µm–2 mm) showed negative relationship. This indicates that smaller particles are lesser at wider portions of the channel. This means that granule particles are deposited at shorter distances, even at constricted channel portions. Referring to the collected samples, it was found that the mean density of granules is higher than that of pebbles (granules=2.56 g/ mm^3; pebbles=1.53 g mm^{-3}). Usually finer material is transported and is deposited at longer distances provided the material is of the same density.

The Coefficient of Variation showed that in the upper and middle sections significant variation of sand fragments was found (Fig.4). Two major peaks of sand can be observed in the upper and middle sections along the profile (Fig.3).

It could be understood from field visits that the two locations of variation represent a situation which is different from the rest. It is revealed that very coarse sand that constitutes the largest share of the samples collected from these two locations was a result of human disturbance. In the upper section the landcover has been changed for development of a play ground and in the middle section, the surface has been disturbed due to construction of houses. It may be pointed out that, apart from natural factors, human interferences in many ways are reflected in the distribution of bedload.

Conclusion

While trying to understand the nature of distribution of sediment fractions along longitudinal profile of the Um-U-Lah stream, it is important to understand the nature of depositional patterns. The nature of deposition of most rivers was found to be a function of basin geology, geomorphic processes, discharge variations over time and landuse changes, besides other special characteristics (Subramanian, 1993). It is also important to note that rivers in the tropics and subtropics show evidence of higher erosion rates than rivers in temperate zones, flowing through forested stretches (Dedkov and Moszherin, 1992). Climatic factors play a very important role in this specific case due to intensity and duration of rainfall which probably makes this one of the world's highest runoff area (Starkel et al, 2004). Even though studies in Alemaya watershed, eastern Ethiopia did not show any significant relationship between sediment concentrations and rainfall intensities (Mengistu and Assefa, 2012), the combination of several factors mentioned above would relate to the following conclusions:

- Poor relationship of sediment grain size with slope indicates that it is not a major factor in determining distribution of fine bedload on the undulating landscape of horizontal Eocene sandstones of the plateau. However, these conditions may differ as the streams leave this landscape;
- Positive relationship of fine and coarse sand, negative relationship of granules and poor relationship of very coarse sand and pebbles with channel width indicates its role in determining distribution of fine bedload constituents. There is a need to understand more about the characteristics of granule fragments and their contributing areas;
- Very recent human activities like levelling of land for housing or creation of ponds and playgrounds may distort sediment contribution to streams leading to concentration of a particular size class.
- There is a need to refine research methods and focus into seasonal variations of sediment transport to understand the annual patterns of sediment deposition.

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