Simplified method of sediment monitoring and estimation: A case study of the Narayani River

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ABSTRACT:

A simplified method of sediment monitoring and estimation considered here is based on easily available inexpensive equipment and minimum level of training. Sediment samplings were carried out both by standard and simplified methods. A sediment rating curve was obtained by establishing a relationship between bank sediment concentration (simplified sampling) and mean sectional sediment concentration (standard samplings) sampled at different water level stages. The simplified method of sampling was found satisfactory, and hence, could be used for long-term monitoring and estimation of sediment in difficult conditions where standard equipment and skilled human resources are not available. A sediment rating curve for the Narayani River shows a good correlation over a range of values obtained during the monitoring period.

Keywords: sediment, concentration, simplified sampling, sediment rating curve

1. INTRODUCTION

Steep slopes, intensive agricultural activities, and high intensity rainfall in hilly terrain are responsible for accelerated soil erosion and transport. Huge amount of sediment transported by rivers has been a serious problem and major challenge in water resources development activities in the Himalayan region (WECS, 1987; Sharma, 2002). Measurement of sediment concentration is important to monitor sediment transport in a river for optimal design and efficient operation of water resource development schemes.

Depth Integrated (DI) and Point Integrated (PI) sampling techniques are two standard methods commonly used in monitoring sediment transport by a river. In DI method, one sediment sample from each vertical section of a river is collected by lowering and lifting a sampler at uniform speed. In this method, the ratio of intake velocity to ambient velocity is equal to one (Yuqian, 1989). The sediment concentration is representative of the average concentration of the vertical section. In PI method, one representative sample of the vertical section is prepared by mixing several samples taken from different depths along the vertical (Yuqian, 1989). Since the point integration method is difficult in a complex topography than depth integration method of sampling, DI method has been adopted in Nepal.

Sediment concentration varies both in vertical and horizontal directions with time as well as location in each cross section. It is, therefore, important to take a numbers of samples from several vertical sections to obtain a mean sectional sediment concentration. Although DI method is simpler than PI, it still requires expensive samplers and high level of expertise. Such facilities are usually not available in remote areas resulting gaps and error in sediment data (DHM, 2003). Simplified procedure introduced in this paper is expected to be helpful for filling the gaps of information in such instances. The term-simplified sampling, described here, refers to the simple procedures of sediment sampling with a sampling bottle from free water surface near a riverbank.

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2. EXPERIMENT

Simplified sediment sampling procedure was introduced as an experiment at a gauging site on the Narayani River near Narayanghat. The site is located at 27° 42' 30" N and 84° 25' 50" E at an elevation of 180 m above mean sea level. The gauge site is equipped with staff gauges, cableway, automatic water level recorder and crest gauges. The drainage area of the river at the gauging site is 31,100 km² (DHM 2004). It is a major tributary of the Ganga Rver. Figure 1 shows the location of gauging site in this basin. The river, with width exceeding 200 m at the site and an average annual discharge of 1570 $m^3 s^{-1}$, is one of the three major rivers of Nepal (DHM, 2004). The experimental study covers two monsoon seasons in 2002 and 2003.

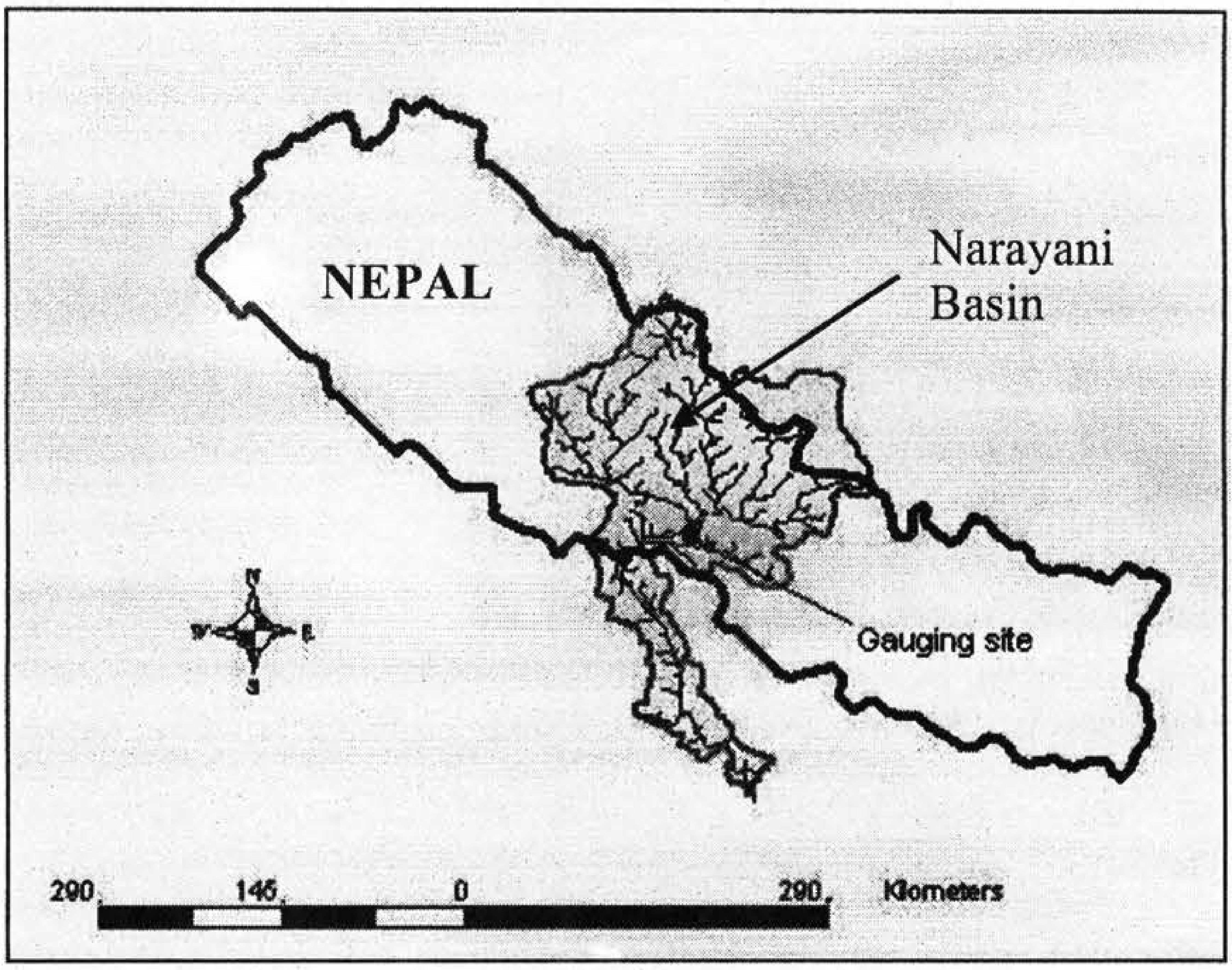

Figure 1: Location of gauging site of Narayani Basin.

2.1 SIMPLIFIED SAMPLING

Samples were obtained on the river surface close to a bank by immersing 500 ml sampling glass-bottle. The sampling point was fixed and located on a platform constructed at the cableway site. The sample was taken by local gauge reader everyday at 8.00 AM (Nepal Standard Time) from river surface at a convenient distance of about 0.30 m from the bank for consistency in day-to-day sampling. The samples thus collected by the samplers were analyzed by filtration method at the gauging site using a graduated cylinder and a Butchner funnel as shown in Figure 2(a). Before filtration of the sample, the sampler noted the total volume of the sample using a graduated cylinder. A suitable filter paper is generally used to filter the sample (Finlayson, 1981). Whatman 10 paper was used in this experiment. The wet filter papers containing the sample were dried in a locally fabricated solar drier as shown in Figure 2(b). The dried samples were then packed in a sealed plastic bag and sent to the sediment laboratory located at the central office in Kathmandu for further processing. The sediment concentration was calculated using Equation (1).

$$Sc_b = \frac{(W_g - W_d)}{V} \qquad (1)$$

Where

Sc_b = Sediment concentration on the bank (mg/litre)

W_g = Gross weight of sediment and filter paper (mg)

W_d = Weight of filter paper (mg)

V = Volume of sediment sample (litre)

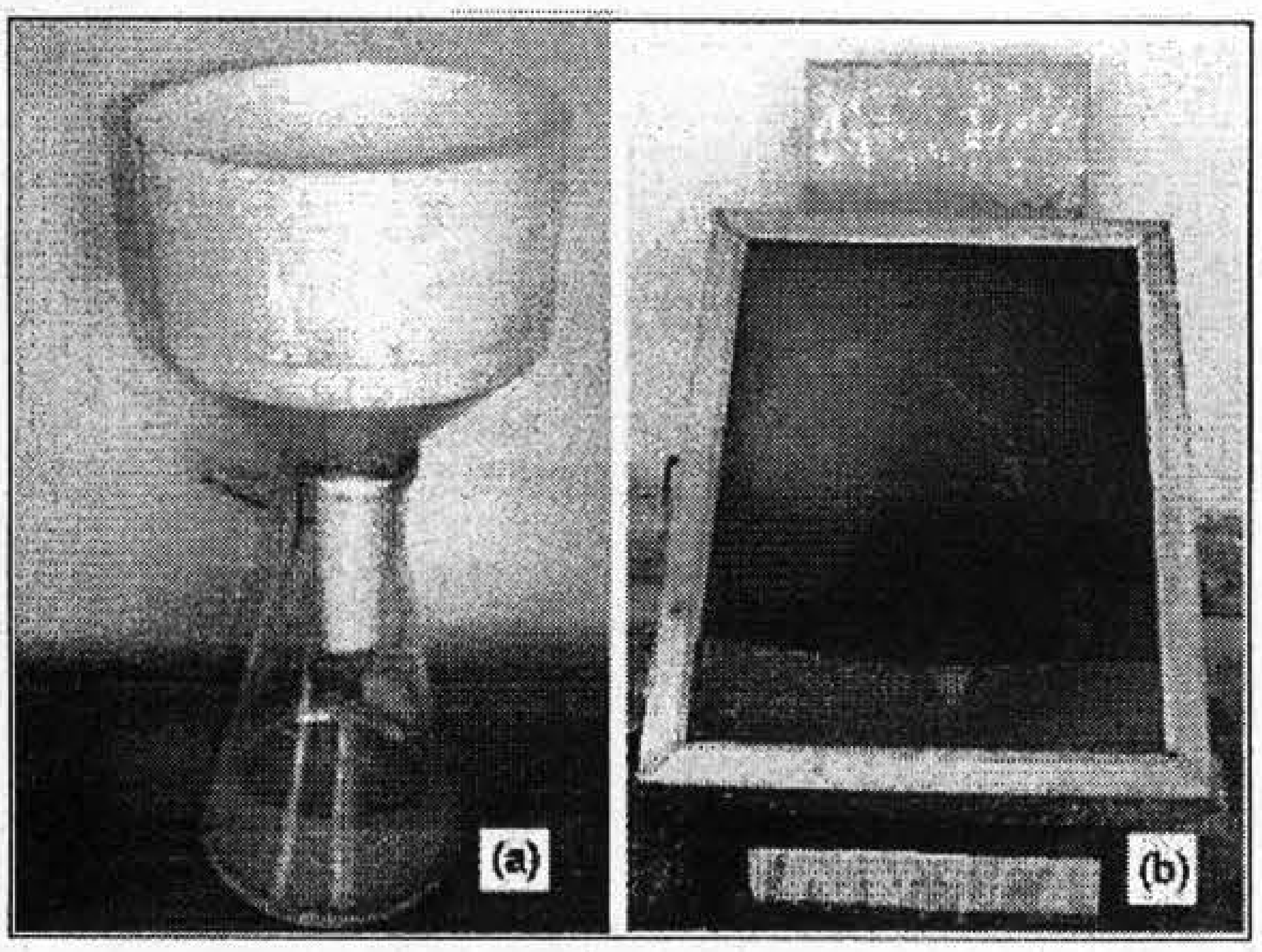

Figure 2: Instrument used in filtration method (a) Butchner funnel (left) and (b) solar drier (right).

2.2 DEVELOPMENT OF SEDIMENT RATING CURVE

Sediment rating curve is a relation between concentrations of simplified sample and mean sectional sediment concentration samples obtained by a standard method of sampling. Standard samplings for the development of a sediment rating curve were carried out by skilled hydrologists and technicians. Simplified sediment samples, as described in Section 2.1, were also carried out at the time of standard sampling. The standard sediment obtained in this experiment was based on depth-integrated methods using US D49 (30 kg) sampler from seven equally spaced verticals across the river cross-section (Yuqian, 1989). Therefore, one set of calibration sample consisted of seven standard samples and one simplified sample. Altogether twenty calibration samples were taken in this case study during the experimental period. Five calibration samples were taken at different stages of water level during 2002 monsoon and fifteen calibration samples at different stages during the 2003 monsoon. The calibration samples covered the gauge height range from 1.89 to 6.11 m as shown in Table 1. The standard samples were analyzed using two procedures: evaporation and filtration (Yuqian, 1989) by splitting each sample into two equal parts by volume. Average concentration value obtained from the filtration and the evaporation method was taken as sediment concentration of the standard sample. The mean sectional sediment concentration of a calibrated sample for a stage of water level was obtained from averaging concentration of the seven standard samples using Equation (2).

$$Sc_m = \frac{\sum_{i=1}^{n=7} Sc_i}{n} , \qquad (2)$$

where

Sc_m = Mean sectional sediment concentration of river cross section (mg/l)

Sc_i = Sediment concentration at i^{th} vertical (mg/l)

A sediment-rating curve was obtained by developing a correlation between the mean sectional sediment concentration (Sc_m) values and the sediment concentration on the bank (Sc_b) samples taken simultaneously.

3. RESULTS AND DISCUSSION

The sediment concentration of simplified samples collected during the collection of calibration samples, in the range, considered varied from 396 to 5626 mg/l, while the mean sectional sediment concentration of the calibration samples varied from 662 to 8038 mg/l (Table 1). The sediment concentrations values obtained from simplified sampling techniques (Sc_b) were always found lower than the mean sectional sediment concentration values except for one sample taken on 3 July 2003. The result of calibration sample taken on 3 July

2003 was considered as an outlier for development of sediment rating curve and further analysis.

The ratios of the mean sectional to bank sediment concentration were, however, not uniform. The ratios ranged from 0.87 to 3.21 with mean value of 1.987 and standard deviation of 0.61 indicating the complex nature of sediment variation. Similarly Table 2 presents the relative variations of sediment concentrations at a vertical section within the level of water from 1.89 m to 6.11 m gauge. The ratios of point sediment (Sc_i) to mean sectional sediment (Sc_m) were not consistent and uniform at different stages of river.

These observations indicated that a single sample either taken from a bank or at the mid section of a river could not represent the true average of the whole river section. The ratio of mid sectional concentration (Sc_4) to mean sectional sediment concentration (Sc_m) found in the range of 0.35 and 1.32 with average value of 0.90 during the monitoring period (Table 2). It showed that the computation of sediment transport rate of a river on the basis of single sample was not reliable.

Table 1: Summary of Calibration Sample Analysis for Sediment Rating Curve.

Sample no	Date	Gauge Height (m)	Bank sample Conc. Sc_b (mg/l)	Mean Sectional Sediment Conc. Sc_m (mg/l)	Ratio of Sc_m/Sc_b
1	27 July 2002	5.02	2037	5462	2.68
2	28 July 2002	6.11	5259	8038	1.53
3	25 Sept 2002	3.45	535	1717	3.21
4	25 Sept 2002	3.45	535	1342	2.51
5	26 Sept 2002	3.90	773	2161	2.80
6	9 June 2003	1.89	396	662	1.67
7	11 June 2003	2.90	1883	2196	1.17
8	12 June 2003	2.50	589	793	1.35
9	14 June 2003	2.32	495	879	1.78
10	18 June 2003	2.62	719	1440	2.00
11	20 June 2003	3.04	551	1551	2.81
12	22 June 2003	3.89	2585	5416	2.10
13	24 June 2003	3.98	1846	3643	1.97
14	25 June 2003	3.79	1685	2913	1.73
15	26 June 2003	3.34	581	1496	2.58
16	27 June 2003	3.72	2370	3207	1.35
17	29 June 2003	4.59	3661	4343	1.19
18	30 June 2003	5.31	2283	3986	1.75
19	3 July 2003	4.95	5626	4909	0.87
20	5 July 2003	5.04	2138	3365	1.57

Table 2: Ratio of sediment concentration at different verticals with mean sectional concentration.

Sample no	Date	Gauge Height (m)	Values of Sc_i/Sc_m						
			i=1 Left 1	i=2 Left 2	i=3 Left 3	i= 4 Centre	i=5 Right 1	i=6 Right 2	i=7 Right 3
1	27 July 2002	5.02	0.92	0.70	1.88	0.35	1.51	1.00	0.38
2	28 July 2002	6.11	1.92	1.59	0.87	0.57	0.73	0.62	0.55
3	25 Sept 2002	3.45	1.51	0.83	0.46	0.81	1.03	1.57	0.77
4	25 Sept 2002	3.45	1.08	0.71	1.24	0.64	1.30	1.15	0.85
5	26 Sept 2002	3.90	1.99	1.64	0.63	0.82	0.44	0.72	0.82
6	9 June 2003	1.89	0.87	0.85	0.82	0.94	1.33	1.24	0.86
7	11 June 2003	2.90	1.34	0.94	0.76	1.32	0.95	0.87	0.82
8	12 June 2003	2.50	1.02	0.91	0.84	1.19	1.01	1.08	0.95
9	14 June 2003	2.32	0.85	1.15	0.84	0.81	0.91	1.12	1.31
10	18 June 2003	2.62	0.58	0.66	0.92	1.11	1.17	1.35	1.64
11	20 June 2003	3.04	0.97	0.84	1.01	1.22	1.00	0.89	1.07
12	22 June 2003	3.89	1.41	1.20	0.69	0.86	1.00	0.87	0.97
13	24 June 2003	3.98	1.20	0.81	0.87	1.05	1.11	0.86	1.09
14	25 June 2003	3.79	0.79	0.67	0.70	1.12	1.17	1.14	1.41
15	26 June 2003	3.34	1.11	0.65	0.80	0.79	1.38	1.19	1.08
16	27 June 2003	3.72	0.89	1.03	0.72	1.00	1.20	1.22	0.94
17	29 June 2003	4.59	1.20	0.87	0.90	0.82	0.94	0.93	1.33
18	30 June 2003	5.31	1.16	0.98	0.83	0.76	0.91	0.86	1.50
19	3 July 2003	4.95	1.39	1.05	0.98	0.84	0.94	0.91	0.88
20	5 July 2003	5.04	0.69	1.05	0.81	0.92	0.95	1.29	1.28
Average			1.14	0.96	0.88	0.90	1.05	1.05	1.02

Regression plot i.e. sediment rating curve of mean sectional sediment concentration (Sc_m) versus bank sediment concentration (Sc_b) for the river showed a good correlation between these parameters over the range of values obtained during the monitoring period as shown in Figure 3. This was reflected by the regression coefficient ($R^2 = 0.85$) obtained from 19 samples.

Equation (3) presents the model for the best-fit curve based on the data presented in Table 1.

$$Sc_m = 7.2 \times Sc_b^{\ 0.81} \qquad (3)$$

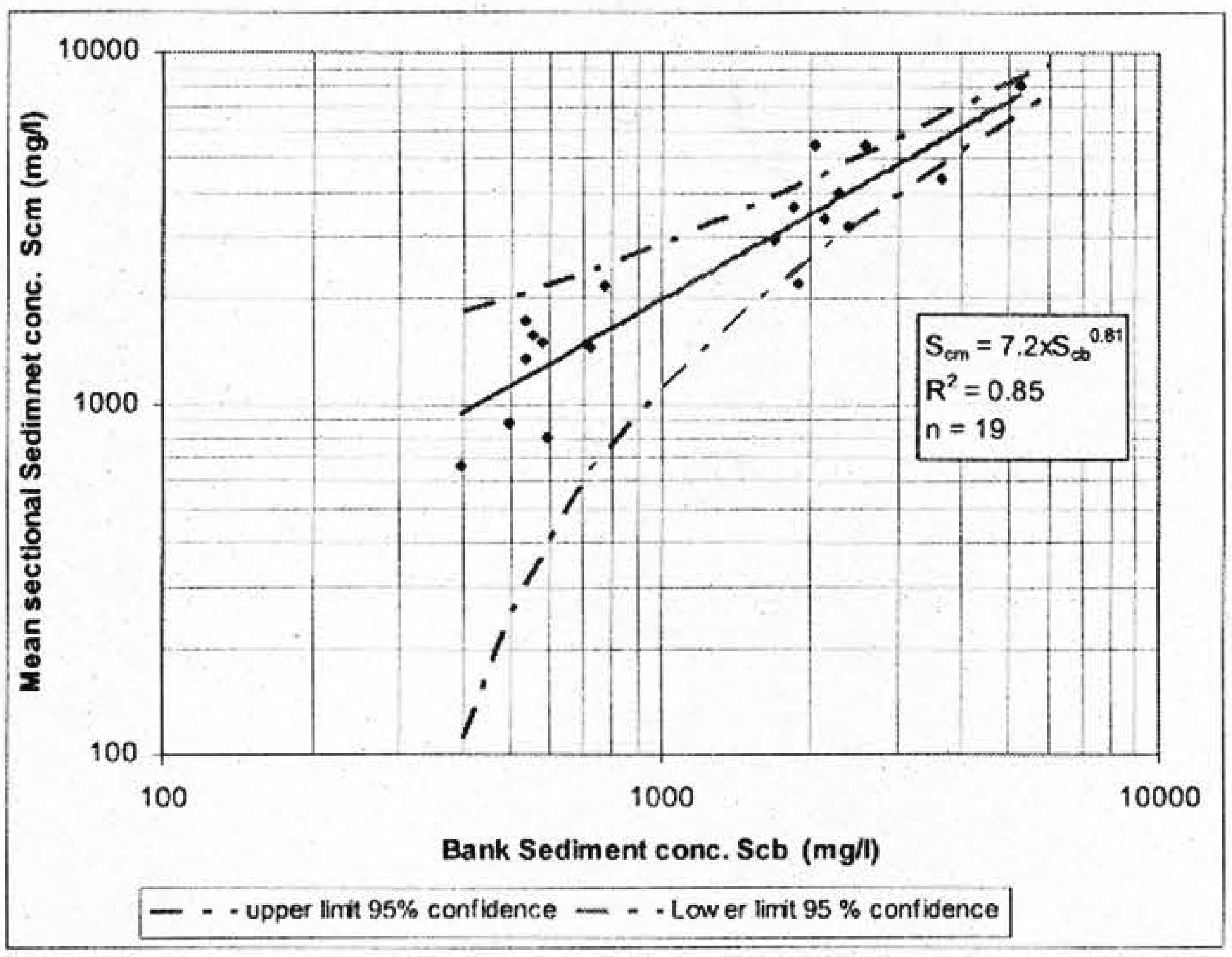

Figure 3: Relationship between mean sectional and bank sediment concentration.

The standard error of estimating Sc_m based on the Sc_b values from the Equation 3 was found to be 786.48 with standard deviation value of 1939 mg/l. The bandwidth of the 95% confidence level shown by dotted line in Figure 3 showed that the most of the observations were within the bandwidth or close to the boundary of the confidence level.

The sediment rating curve (Figure 3 and Equation 3) can be used to transform sediment concentration values obtained from simplified samples to mean sectional sediment concentration. Daily mean Sc_m values can, thus, be computed from Sc_b values of regularly observed sediment sample based on simplified method. The daily sediment transport rates at the gauging site can then be obtained from the computed mean sectional sediment concentrations using Equation (4).

$$S_y = 0.086 \times Sc_m \times Q \qquad (4)$$

Where

S_y = Mean daily Sediment transport rate (ton/day)

Sc_m = Mean sectional sediment concentration (mg/l)

Q = Mean daily flow rate ($m^3 s^{-1}$) obtained from discharge rating curve (DHM, 2004)

Figure 4 and Figure 5 compare the mean daily sediment transport with the mean daily flow from 1 July to 30 Sept in 2002 and 2003 respectively. The averages of daily flows during those periods were 3,855 $m^3 s^{-1}$ (in 2002) and 4,400 $m^3 s^{-1}$ (in 2003) and the averages of computed daily mean sectional sediment concentrations were 2,809 mg/l (in 2002) and 4,987 mg/l (in 2003). The respective cumulative sediment flux during those periods, thus, comes to be 88 × 10^6 ton in 2002 and 191×10^6 ton in 2003. The higher values of sediment flux in 2003 are justifiable with higher average value of daily mean flow and mean sectional sediment concentration.

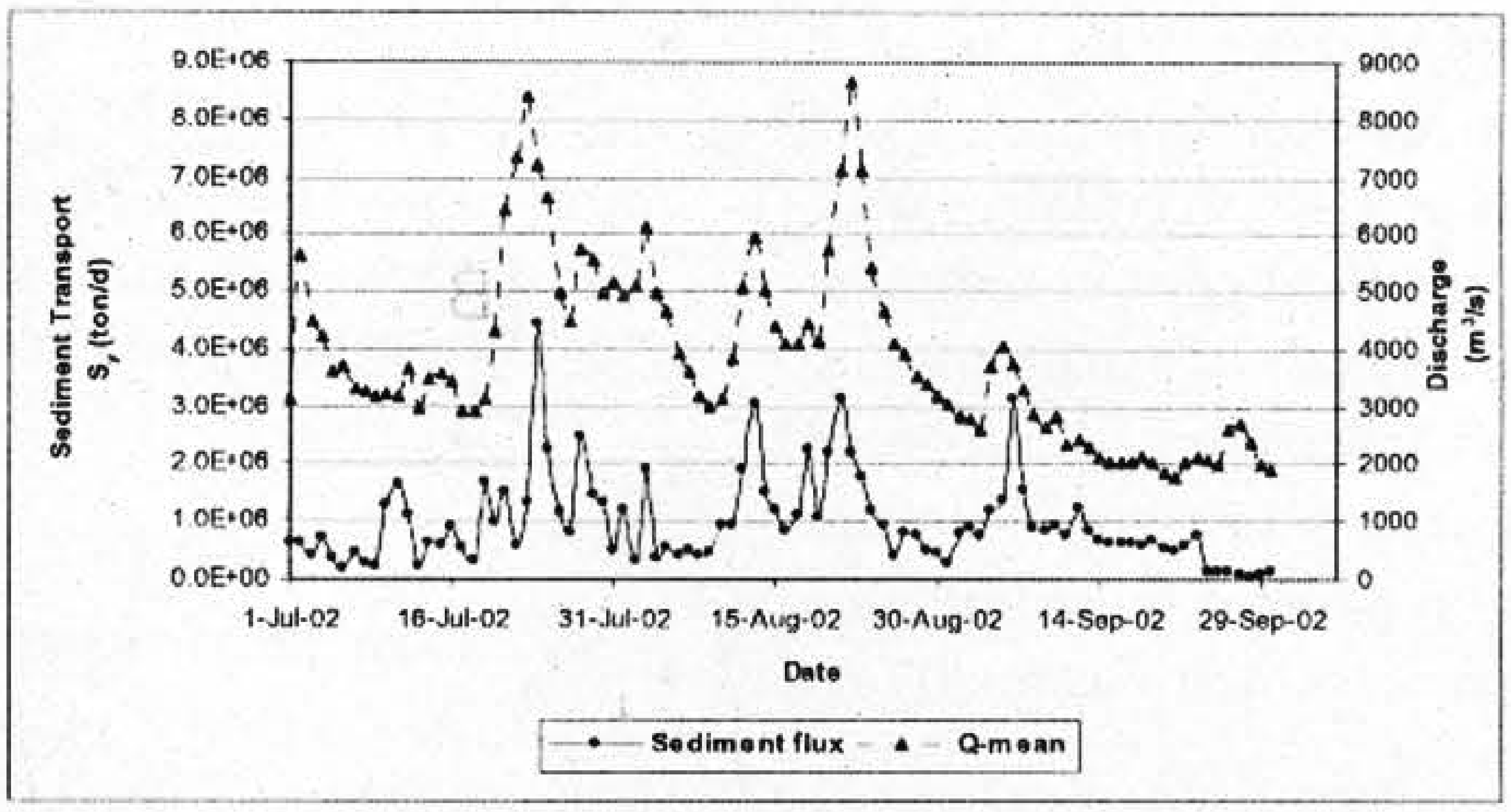

Figure 4: The variation of daily mean sediment flux rate with daily mean discharge for the period 1 July to 30 September, 2002.

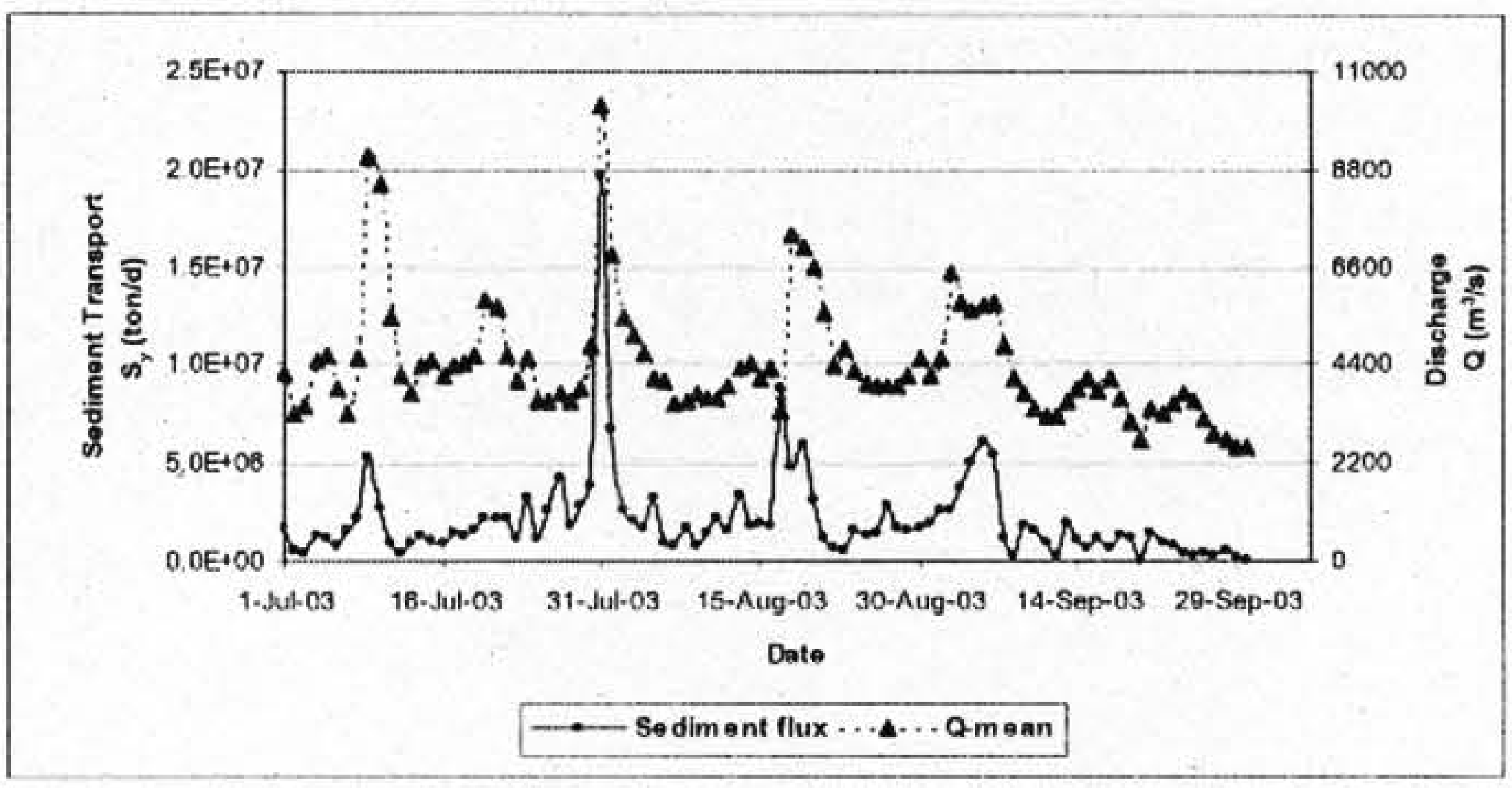

Figure 5: The variation of daily mean sediment flux rate with daily mean discharge for the period 1 July to 30 September, 2003.

Assuming the average specific weight of suspended sediment material as 1280 kg m^{-3} (Linsely, et al 1982), the thickness of total sediment transported is equivalent to 2.22 mm in 2002 and 4.81 mm in 2003 over the drainage basin during the period of three months. The total annual soil removal from the catchment area during rainy season (July-September), determined by dividing cumulative sediment yield by total catchment area, was 2,835 $t/km^2/yr$ in 2002 and 6,153 $t/km^2/yr$ in 2003. These values fall in the range of observed sediment yields rates reported in the literature (UNEP, 2001).

4. CONCLUSIONS AND RECOMMENDATIONS

Simplified procedures are useful for sediment monitoring in rivers flowing particularly in remote areas, as the standard procedures are difficult primarily due to the involved cost and complexities in measurement. The analysis of results obtained from this experiment, presented here, indicated that the simplified method could be applied for long term monitoring of sediment in difficult conditions. It can have greater acceptability and has potential for wide application especially for filling gaps in sediment information. Increased frequency of bank sampling is recommended to enhance accuracy of computed mean daily sediment transport rate. Regular updating of the calibration curve is recommended as the watershed and channel conditions are likely to change with time.

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REFERENCES

DHM, 2004. Hydrological Data (2002-2003). Department of Hydrology and Meteorology, Kathmandu.

DHM, 2003. Suspended Sediment Concentration Records. Department of Hydrology and Meteorology, Kathmandu.

Finlayson, B., 1981. The analysis of stream suspended loads as a geomorphological teaching exercise, The Journal of Geomorphy in Higher Education Vol. 5 No.1

Linsely, R. K., M. A. Kohler and J. L. H. Paulhus, 1982. Hydrology for Engineers. McGraw-Hill Series in Water Resources and Environmental Engineering.

Sharma, K.P. 2002. Sediment fluxes to coastal zone in South Asia and their relationship to human activities. In: Ratnasiri Janaka (ed), Proceedings of the South Asia Regional Workshop on Assessment of Material Fluxes to the Coastal Zone in South Asia and their Impacts; a joint APN/SASCOM/LOCIZ Workshop 08-11 December, 2002 Negombo, Sri Lanka.

UNEP, 2001. Soil Degradation in Nepal. Nepal: State of the environment 2001. United Nations Environment Programs, Thailand.

WECS, 1987. Erosion and Sedimentation in the Nepal Himalaya. Report No. 4/3/010587/1/1 seq.259. Kathmandu: Water Energy Commission Secretariat.

Yuqian, L., 1989. Manual on Operational Methods for the Measurement of Sediment Transport Operational Hydrology Report no.29, WMO-No. 686. Secretariat of the World Meteorological Organization Geneva, Switzerland.