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Determination of a Relationship Between Discharge and Sediment Yield Carried by River Narmada at Rajghat

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ABSTRACT

The study is a combination of statistical and hydrological computations to obtain the best-fit model using software Curve Expert 1.4. Numbers of iterations are performed and the most suitable model is selected for further analysis. The model so obtained has been tested for its validity for different sets of data.

The most important outcome of the study, which is determination of sediment yield, is done by rating curve flow duration method. This method can compute the sediment yield precisely and its outcome can be compared to the field conditions.

Keywords: Sediment yield, discharge, narmada river.

INTRODUCTION

The management of water resources often requires the construction of dams and creation of reservoirs, for flood control, irrigation, hydropower, water supply, navigation etc. More complicated problems are encountered in modern times because of uncontrolled deforestation, unwise agricultural practices, improper method of tillage and with the increase in population, more and more rivers are being harnessed for multipurpose use, for which artificial changes are being made in the watercourses. These problems have become complicated because of the fact that rivers and other watercourses run through loose material and the water carries some of this material along with it.

SEDIMENT

The loose material, which is eroded or weathered away from land surface and transported by action of water, wind or ice is known as '***Sediment***'. Fluvial sediment is the term used to describe the case where water is the key agent for erosion. As reservoirs formed by dams on sediment carrying rivers are subjected to some degree of sedimentation, it is in fact a matter of vital concern to all water resources development projects. Silting not only occurs in the dead storage but also encroaches into the live storage capacity, which impairs the intended benefits from the reservoirs. So the main concern confronting the project planner is to estimate the rate of sedimentation and period of time before the sediment will interfere with the useful life of reservoir.

In all the sediment problems, the amount of sediment carried by the river or channel is one of the most important variables. Such large variation rules out the possibility of assuming an approximate value of sediment transport rate and lays emphasis on the necessity of an analytical procedure for estimating the sediment transport rate. Hence several analytical and experimental investigations have been carried out for establishing methods for sediment load computations. The amount of sediment in a river depends on the extent of erosion in its catchment area, which depends on the nature of soil in catchment area, topography of the catchment area, vegetal cover and intensity of rainfall.

Sediment Load

The sediment load carried by a river may be divided into following two parts:

(a) The ***Suspended Load*** is that part of sediment load, which is maintained in suspension against gravity due to turbulence of flowing water. It consists of relatively finer material, which remains dispersed throughout the flow cross-section of river.

(b) The ***Bed Load*** is that part of sediment load, which moves in contact with the bed of the river with occasional jumps. It consists of relatively coarser material.

Mechanics of Sediment Transport

The knowledge of hydraulic conditions at which sediment particles of a given size just starts moving is of considerable importance to hydraulic engineers. When the velocity of flow through the river is very small, the riverbed does not move at all and the river behaves as rigid boundary layer. As the velocity of flow increases steadily, a stage is reached when the shear force exerted by the flowing water on the bed particles will just exceed the force opposing their movement. At this stage, a few particles on the bed will just start moving intermittently. This condition is called the ***incipient motion condition*** or the critical condition or the threshold point. The study of this incipient motion is of great use in studying the mechanism of deposition in reservoirs and in study of riverbed variations.

Due to stochastic nature of sediment movement along the alluvial bed, it is difficult to define precisely at what flow conditions a sediment particle will begin to move. A force exerted on the grains by the flowing water, which is known as the ***Tractive Force*** or fluid drag, causes the movement of the bed grains. The tractive force per unit area will be equal to boundary shear stress $\tau_{o.}$ When the tractive force exceeds the frictional resistance between the bed grains they start moving. The tractive force required to start the general movement of bed grains is called critical tractive force $\tau_{cr.}$

STUDY AREA

The Narmada is the largest west flowing and fifth largest river of India. Its basin lies in the central part of India, with a drainage area of 98796 sq. km and a mean elevation of 760 m, higher than other peninsular rivers. The total length of the river is 1312 km.

Precipitation has a predominant influence on river water flow and suspended sediment discharge. As a consequence, the annual flow patterns in the basin are intimately coupled to the monsoon season. Peaks and dips in water discharge show spatial variations among the different locations, depending upon rainfall distribution patterns and other local catchment characteristics (catchment area, soil properties, topography and vegetation cover).

The Narmada River allows 70–99% of water and 90–99% of suspended sediment load to be transported during the monsoon season, whereas the tributaries transport 85–99% of water and 95–100% of suspended sediment load during monsoon.

Throughout the Narmada basin, water discharge and suspended sediment loads are measured at a number of locations by State and Central Government agencies, such as the Central Water Commission (CWC). In the present study daily water discharge and suspended sediment load data measured by CWC at gauging station, upstream of the Sardar Sarovar dam (Rajghat), which is the largest man-made structure on the river, on the Narmada mainstream, is being used.

SEDIMENT MEASUREMENT

Suspended sediment observations are conducted simultaneously once a day, starting at 0800 h (except Sunday and holidays), from various vertical marks along the cross-section of the river at the gauging station using boats or specially designed instruments. Suspended sediment samples are collected at 0.6 m depth from each vertical where velocity observation is made for computation discharge, provided depth of flow is 0.3 m. Punjab bottle-type sampler is commonly used for collection of suspended sediment samples for analysis.

METHODS

Following methods are used for calculation.

(A) The Mean Discharge-Weighted Concentration of a stream can be used directly to compute the rate of sediment discharge moving in the stream,

Qs = Qw x Cs x k ... (1)

Where,

Qs = instantaneous suspended sediment discharge, tonnes/day

Qw = stream flow rate, in m^3/sec or ft^3/sec

Cs = discharge-weighted mean concentration, in mg/l

K = appropriate conversion factor

(B) UNIT CONVERSION

It is a simple unit conversion in which sediment concentration given in mg/l is converted to tonnes/day with the help of proper constants. The measured value of discharge is also used in the conversion.

(C) PLOTTING POSITION

The purpose of the frequency analysis of an annual series is to obtain a relation between the magnitude of the event and its probability of its exceedence. The probability analysis may be made either by empirical or analytical methods.

The following method is based on Weibull formula. According to this formula;

$$P = \frac{m}{(N+1)} \quad \ldots (2)$$

Where
P = probability of occurrence of event
N = no of years of record,
m = order number.

(D) MODEL GENERATION

The relationship between river discharge and sediment yield is established by regression analysis. In order to find best relationship between discharge and sediment yield, Curve Expert 1.4 software has been used. Models are prepared for each of ten sets in four different combinations. The models are generated for combinations of 60%, 65%, 70%, 75% of the data and validations are done for 40%, 35%, 30%, and 25% of the data respectively.

The difference of predicted sediment yield and observed sediment yield gives the error for sediment curve model. The square of this error is taken and its average is found. Then the square root of this averaged error is found. This is known as Root Mean Square Error (RMSE). Also Curve Expert 1.4 gives the values of coefficients of correlation. Taking into consideration both coefficient of correlation and RMSE, the best fit curve is selected among the four combinations.

RESULTS AND DISCUSSIONS

Table 1:- RESULTS OF SEDIMENT YIELD BY UNIT CONVERSION AND MEAN DISCHARGE SEDIMENT CONCENTRATION METHOD

Sr. no.	Year	Sediment load, tones		% error
		Unit Conversion Method	Mean Discharge-Sediment Concentration Method	
1	1991-92	18923899.23	12869240.57	0.3199
2	1992-93	16588451.49	16466698.48	0.0073
3	1993-94	33862404.53	38875487.17	0.1480
4	1996-97	18324190.80	11351752.53	0.3805
5	1997-98	18986071.92	11187515.65	0.4108
6	1998-99	23153873.35	20355894.5	0.1208

It is observed from the above results that the % error is very small. Hence the mean discharge weighted concentration method can be used for determining mean sediment yield if daily data are not available.

Table 2:- RESULTS OF MODEL GENERATION FOR DATA SETS OF RAJGHAT (91-99)

Trial no.	Combination in %	Equations	R	RMSE, tonnes / week
1st Trial	60	4^{th} degree polynomial $y=a+bx+cx^2+dx^3+ex^4$	0.9081	816933.1
	40			560311.4
2nd Trial	65	4^{th} degree polynomial $y=a+bx+cx^2+dx^3+ex^4$	0.9039	810508.7
	35			491549.2
3rd Trial	70	4^{th} degree polynomial $y=a+bx+cx^2+dx^3+ex^4$	0.9157	765803.1
	30			626647.9
4th Trial	75	4^{th} degree polynomial $y=a+bx+cx^2+dx^3+ex^4$	0.905	966493.3
	25			822535.6

- From the above result table it is observed that value of coefficient of correlation (r) is maximum for combination of 70%-30%
- The minimum error is observed for the model combination using 70% data for model formulation, while minimum error for model combination using 40% for model testing is observed.

Table 3:- RESULTS FOR DISCHARGE & SEDIMENT CONCENTRATION FOR DIFFERENT PROBABILITES FOR THE MONTH OF JUNE

Probability P%	Probability P	Return period T, years	Discharge, cumec	Sediment Concentration, g/l
9.9448	0.0994	10.05556	380.0	0.145
19.890	0.1989	5.027778	258.8	0.058
29.834	0.2983	3.351852	240.9	0.030

39.779	0.3978	2.513889	177.0	0.022
49.724	0.4972	2.011111	111.0	0.018
74.586	0.7459	1.340741	79.00	0.013
79.558	0.7956	1.256944	77.50	0.011
90.055	0.9006	1.110429	67.01	0.007
99.448	0.9945	1.005556	44.75	0.002

Table 4:- RESULTS OF MODEL GENERATED FOR SEDIMENT CONCENTRATION v/s DISCHARGE

Month	Equations	R
June	3rd degree polynomial: $y=a+bx+cx^2+dx^3$	0.9923
July	4th degree polynomial: $y=a+bx+cx^2+dx^3+ex^4$	0.9999
August	4th degree polynomial: $y=a+bx+cx^2+dx^3+ex^4$	0.9998
September	Sinusoidal fit: y=a+b*(cx+d)	0.9996
October	4th degree polynomial: $y=a+bx+cx^2+dx^3+ex^4$	0.9994
November	4th degree polynomial: $y=a+bx+cx^2+dx^3+ex^4$	0.9990

- It is observed that the value of coefficient of correlation(r) is maximum for JULY month and minimum for JUNE month.
- As observed the value of coefficient of correlation is higher for all the months hence sediment concentration and discharge can be related in the best manner for monsoon months.

Conclusions

- It is concluded that the mean discharge weighted concentration method can be used for determining mean sediment yield even if daily data are not available.
- A 4th degree polynomial relationship is developed between discharge and Sediment yield. The minimum error is observed for the model combination using 70% data for model formulation, while minimum error for model combination using 40% for model testing.
- The sediment concentration and discharge can be related in best manner for monsoon months as the value of coefficient of correlation is higher for all the months.
- Among the four trials performed, the combination of 70%-30% gives the best result, hence this can be used for future prediction of sediment yield.

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