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A Study of Sedimentation in Chenab Basin in Western Himalayas

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The young Himalayas have a serious problem of soil erosion and consequent sedimentation in river reaches downstream. The study revealed the high rates of sedimentation in Chenab basin and its effect on an existing reservoir. Correct estimation of sediment yield at any given point in space and time is of vital importance for water resources development and management. In the present study data of 17 to 27 years were used to develop statistically significant spatial models to estimate sediment yield in the Chenab basin (22,000 km^2) using geomorphological, climatic and landuse parameters. The sediment yield was estimated for total and fine sediment for monsoon, premonsoon seasons and the year.

Introduction

A large number of dams have been constructed in India since independence for hydroelectric power generation, domestic water supply, irrigation, flood mitigation *etc.* Most of these dams have been designed to last for a period of 100 years, but excessive siltation from accelerated erosion due to human interference is threatening to reduce the live capacity of their reservoirs. The natural rates of denudation in Himalayas have also been reportedly high (Rawat and Rawat 1994). The fragile ecosystem of Himalayas has been an increasing cause of concern to environmentalists and water resources planners. The steep slopes in the Himalayas along with depleted forest cover, as well as high seismicity (Varsheney *et al.* 1986), have been major factors in soil erosion and sedimentation in river reaches. In order to reduce rate of the siltation of the reservoirs, soil and water conservation measures are now a major component of all operating river valley schemes. Prediction of sediment yield is a necessity if adequate provision is to be made in the design of conservation structures to offset the ill effects of sedimentation during their life time.

In India Joglekar (1965) and Varsheney (1975) have suggested a number of enveloping curves for the prediction of sediment yield for different catchment areas. Correlation studies conducted by Jose and Das (1982) revealed that area alone does not have any significant association with sediment production rate (SPR) and hence there is scope for multivariate analysis using climatic and physiographic parameters. Statistical models on a spatially distributed basis have been developed by Mishra and Satyanarayan (1991) and Bundela *et al.* (1995) for small watersheds in river Damodar in east India.

The present paper is intended to examine some aspects of sedimentation in the Chenab basin and its effect on an existing reservoir using extensive data collected by the Central Water Commission. Although large data exist for each station, the number of stations is rather limited. Therefore an attempt has been made to relate sediment yield with geomorphological, landuse and climatic parameters from a large basin such as Chenab (22,200 km^2) in the wider context of a region. This would help for assessing the sediment yield at any other point for development of water resources/hydroelectric projects in Chenab basin.

Description of Study Area

The Chenab river is one of the five main components of the great Indus system. The Chenab basin is located in western Himalayas and has the major part of its catchment in India. The upper half of this basin is located between the Zanskar and the Pir-Panjal and the Dhauladhar ranges. In this way the basin covers the outer, middle and greater Himalayas.

The Chenab catchment (Fig. 1) is elongated in shape and covers an area of about 22,200 km^2 up to Akhnoor. The elevation of the catchment varies from about 305 to 7,500 m asl. Mean elevation of the basin is about 3,600 m asl. The river gradient is very steep at its source and gradually reduces downstream. The Chenab river has the general character of terrain with a gradient of 10m/km in the higher reaches and 3m to 4m/km in the lower reaches.

Precipitation and Runoff Characteristics

Precipitation and runoff process of Himalayan catchments are complex phenomena controlled by a large number of climatic and physiographic factors that vary with both time and space. The precipitation and runoff characteristics in Himalayas have been described in great detail by Upadhayaya and Bahadur (1982) and for the Chen-

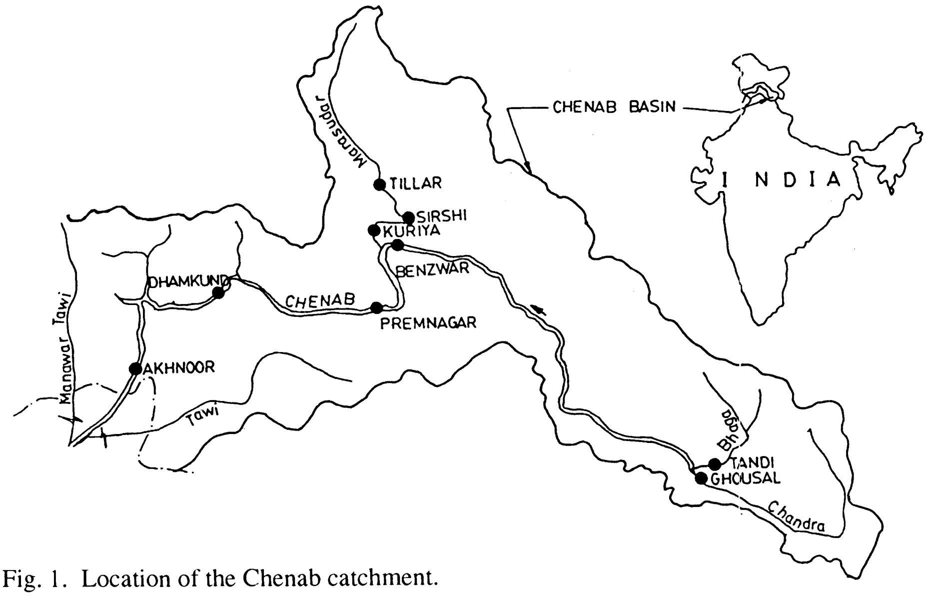

Fig. 1. Location of the Chenab catchment.

ab catchment in particular by Pratap Singh *et al.* (1995) and Rao *et al.* (1996).

The most important factors controlling the weather and climate in the Himalayas are the altitude and aspect. Largely due to variations in altitude, the climate varies from hot and moist tropical in the lower valleys, to cool temperate at about 2,000 m and tends towards polar as the altitude increases beyond 2,000 m. Altitude controls not only temperature but rainfall also. The second factor controlling climate is aspect. Usually the south facing slopes are more sunny and also get more rain.

Temporal variability of discharge and hence sediment yield, is another outstanding feature of Himalayan rivers. In the premonsoon season, snowmelt and glaciers produce high flows during May and June. Sometimes rainfall also contributes to the flows in this season. During the monsoon season, the flow is augmented by monsoon rains to produce higher discharges and peak floods. Air temperatures being highest during this period, snowmelt from permanent snow covered zones at higher elevations (glaciers *etc.*) is also high. In the postmonsoon season the flow is from springs, subsurface flow and runoff from winter rains.

Geology, Landuse and Soils

Extensive pioneering geological work in the area was carried out by Lydekker (1876) and Middlemiss (1909). The geological structure of the area is very complex consisting of a number of highly deformed tectonic units. Wadia (1928) classified the rocks of the area into three tectonic units, namely i) the foreland belt comprising

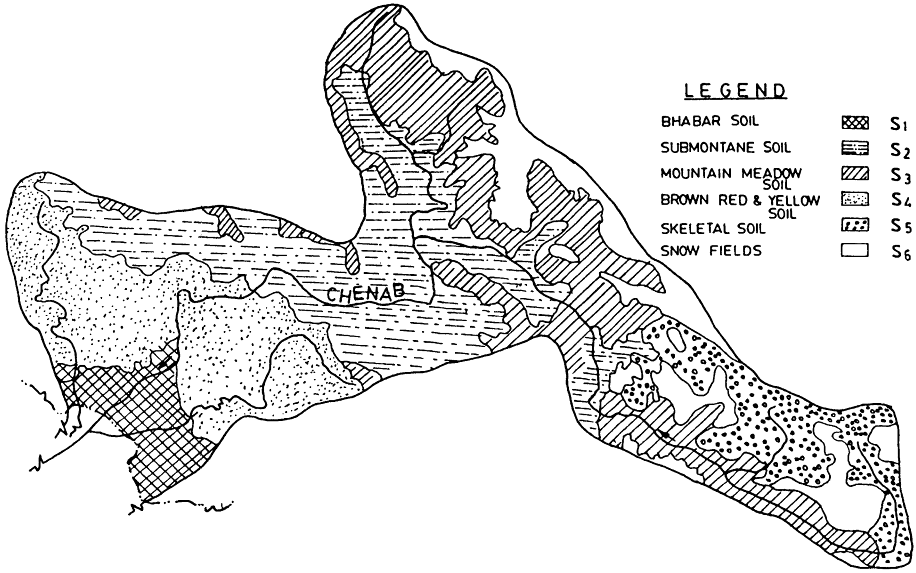

Fig. 2. Broad soil types in Chenab basin.

Murrees and Siwaliks with limestone inliers. ii) the autothorous folded belt comprising carboniferous Eocene rocks and iii) the Kashmir Nappe comprising ancient crystalline sediments with a cover of Paleozoic and Mesozoic rocks.

The Chenab river in its traverse right from its origin in Himachal Pradesh (HP) up to Akhnoor in Jammu and Kashmir runs through the formations belonging to different ages ranging from Salkhalese dogras, permocarboniferous eocenes and miocenes to quartzite. In the upper and middle reaches, it cuts through phyllite, quartzite, gneiss, schist and Dogra formations, comprising bands of quartzite, slate and phyllite *etc.* In the lower reaches the Chenab traverses formations belonging to Sirban limestones, eocene and lower Murees (Roohani 1986).

Landuse involving forest and agriculture are confined to elevations at about 2,500 m asl. At higher elevations subalpine and alpine conditions exist which are more or less in cold desert. Agricultural practices are confined to elevations below 1,600 m asl. A broad category of soil types in Chenab basin is shown in Fig. 2.

Data

The Central Water Commission has been collecting sediment related data in the Chenab basin, since 1967 (Table 1). Precipitation is recorded as rain and snow separately at 43 stations. Precipitation data are available in varying length from 12 to 22 years depending on the station.

As discussed earlier the Chenab catchment constitutes steep mountainous terrain.

Table 1 – Daily data available for Suspended Sediment sampling sites in the Chenab basin.

S. No	Gauge site	Basin area in km^2	Name of stream	Years of record
1.	Akhnoor	21,808	Chenab	1971-95
2.	Benzwar	10,040	Chandrabhaga	1972-95
3.	Dhamkund	18,750	Chenab	1968-95
4.	Ghousal	2,490	Chandra	1978-95
5.	Kuriya	3,960	Marusudar	1969-89
6.	Premnagar	15,490	Chenab	1968-95
7.	Sirshi	3,335	Marusudar	1968-95
8.	Tandi	1,530	Bhaga	1977-95
9.	Tillar	2,800	Marusudar	1968-87

During the flood season (monsoon), when the river carries most of the flood and sediment it is too dangerous to take observations in the river using boats. Therefore samples (6 litres) are collected from the left or right bank which ever is approachable, with a metallic sampling bottle of one litre capacity at 1,200 hrs IST daily at every site. The samples are collected from the surface only. Each litre of water/sediment mixture is collected in quick succession. The samples thus collected are taken to the field laboratory for sieve analysis to separate coarse (> 0.2 mm), medium (0.2-0.075 mm) and fine (< 0.075 mm) grades of sediment. The surface samples are taken to be representative of the entire cross section. However, an error may remain for not accounting for the vertical distribution of the suspended sediment, although flow turbulence renders the sample to be representative to some extent.

Rates of Sedimentation in the Chenab Basin

The sediment yield response of snow dominated catchments in the Himalayas is different from rainfed catchments in the rest of India. Sediment yield charactereristics in the Chenab basin vary depending on the season.

During the winter season (October-March) the sediment yield is minimal and is less than 5-10% of the annual yield. During premonsoon season (April-June) the seasonal snow cover melts in the intermediate and upper reaches. The lower reaches (<1,500 m approximately) receive rain and the intermediate reaches experience rain-on-snow causing occasional floods. The sediment yield during the premonsoon is significant. During the monsoon season (July-Sept) rainfall contribution to flows is very high in the lower reaches and gradually tapers at elevations of about 4,000 m (Pratap Singh *et al.* 1995). Air temperatures are also at their highest during the season resulting in snow and glacier melt from permanent snow covered zones. Consequently a major part of the sediment yield is received during the monsoon season. Average sediment yields for annual and monsoon season periods in terms of coarse,

Table 2 – Average sediment yields (t/km^2) in the Chenab basin and their composition during the Monsoon period (Jul.-Sept.).

Site	No* of years	Annual average t/km^2/yr	<—— Coarse	Monsoon Medium	Season Fine	——> Total \$
Akhnoor	24	1029	85.9	180.8	455.9	722.7
Benzwar	23	1597	169.6	360.9	694.5	1225.0
Dhamkund	27	1900	314.3	386.4	533.5	1234.3
Ghousal	17	513	69.7	90.3	221.2	381.3
Kuriya	20	878	138.9	152.4	300.9	592.3
Premnagar	27	1363	102.9	112.9	222.9	438.7
Sirshi	27	939	146.7	186.6	221.4	554.8
Tandi	18	371	51.3	70.6	164.0	286.0
Tillar	20	373	40.7	62.2	92.4	195.4

* data used for computations. \$ t/km^2/yr for Monsoon period (Jul-Sept)

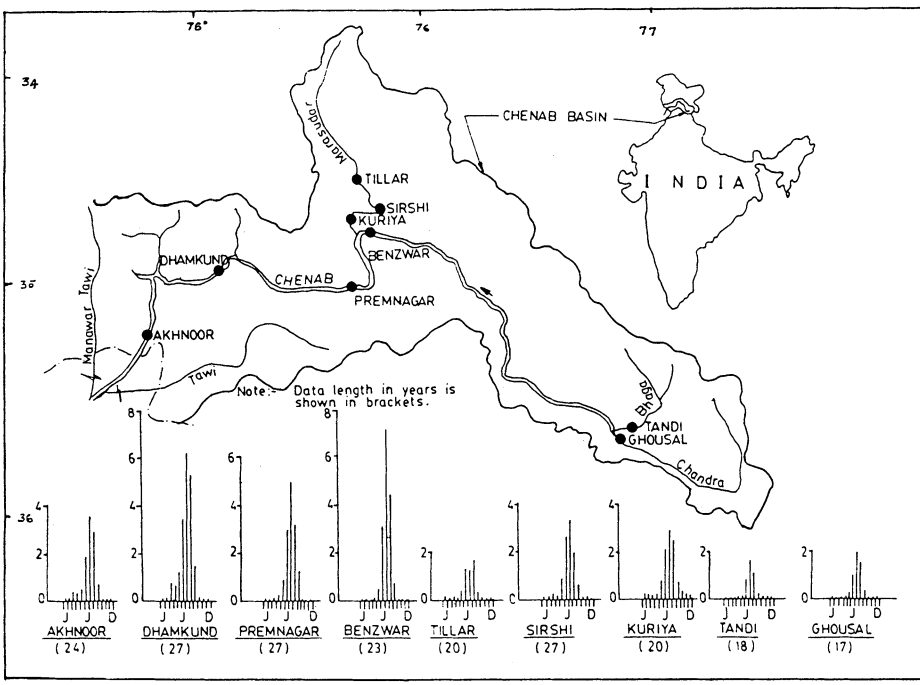

Fig. 3. Average monthly sediment rates in 100 t/km^2.

medium and fine sediment are shown in Table 2. The rates are high compared to other river systems in India (with exception of Ganges) (Sundd 1991) and in the world (Holeman 1968; Milliman and Meade 1983). Average monthly total sediment rates are shown in Fig. 3.

Table 3 – Correlation of mean basin rainfall with Sediment yield (t/km^2)

S No	Sediment Station	16 year* average of basin means mm	Elevation of sediment gauging stn. in m asl	16 year** average of basin means mm	Correlation co-efficient (*r*)
1.	Akhnoor	588	305	740	0.61
2.	Dhamkund	277	600	353	0.70
3.	Premnagar	201	886	252	0.75
4.	Kuriya	226	1,106	229	0.16
5.	Benzwar	408	1,135	197	0.66
6.	Sirshi	103	1,162	170	0.50
7.	Tillar	71	2,066	153	0.50
8.	Tandi	15	2,846	90	0.33
9.	Ghousal	17	2,850	90	0.44

Note: * Mean rainfall pertains to winter season from October to March for 1974-89.
** Mean rainfall pertains to monsoon season from July to Sept for 1974-89.

Sediment Yield, Elevation and Rainfall

The precipitation and runoff characteristics in the Chenab basin influence sediment yield to a large extent. Snowmelt/glacier contribution increases with elevation, while rainfall decreases with elevation in the upper reaches (Rao *et al.* 1996; Pratap Singh and Jain 1993). To verify, how far rain is responsible for sediment production in various subbasins of Chenab located at different elevations, mean weighted rainfall during the monsoon (Jul-Sept) in each subbasin was correlated (log-linearly) with sediment yield per unit area using 10 years of concurrent data, assuming that catchment characteristics remained unchanged during the period. The correlation coefficients, *r*, shown in Table 3, with the exception of Kuriya indicate less dependance between rainfall and sediment yield in the upper reaches as compared with the lower reaches of Chenab basin. In other words rainfall may have little to do with the sediment yield in the upper reaches of Chenab catchment. The amounts of 16-year mean rainfall during the monsoon season (Jul-Sept) and the winter season (October-March) decreases with increase in elevation (Table 3). Consequently sediment response characteristics vary markedly between the upper and lower reaches of the catchment and hence the low coefficient of correlation for Kuriya station in the transition zone. The transition zones also experience rain-on-snow phenomena. Some of the reasons besides rainfall may be attributed to the prevailing geologic and soil conditions and melt runoff from permanent snow cover zones with glaciers in the upper reaches, as compared with the lower reaches.

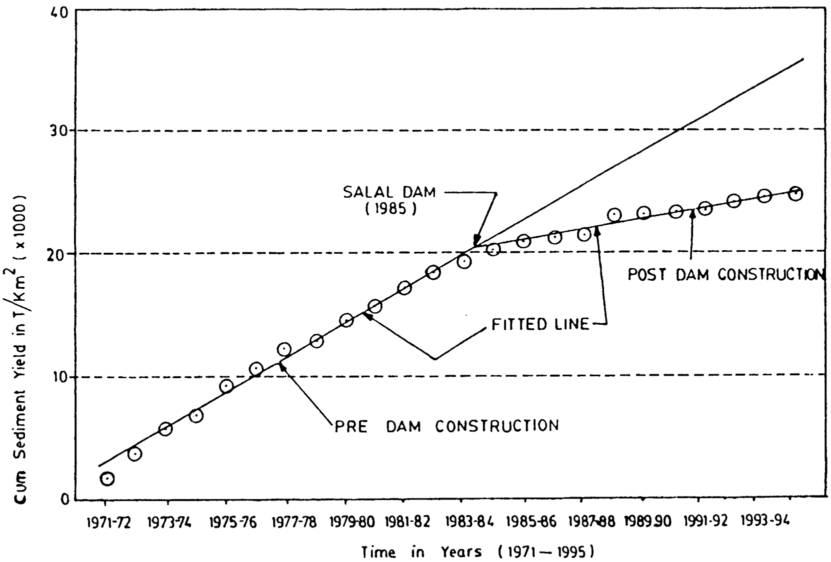

Fig. 4. Effect of Salal dam construction on average sediment down stream.

Effect of Reservoir on Downstream Sediment Yield

Salal dam was constructed between Akhnoor (near Jammu) and Dhamkund gauge sites in 1985 for hydroelectric power generation. The effect of the reservoir on sediment yield at the downstream Akhnoor site is graphically represented in Fig. 4. The figure also indicates the average rate per km^2 of sediment being trapped annually at Salal after the construction of dam.

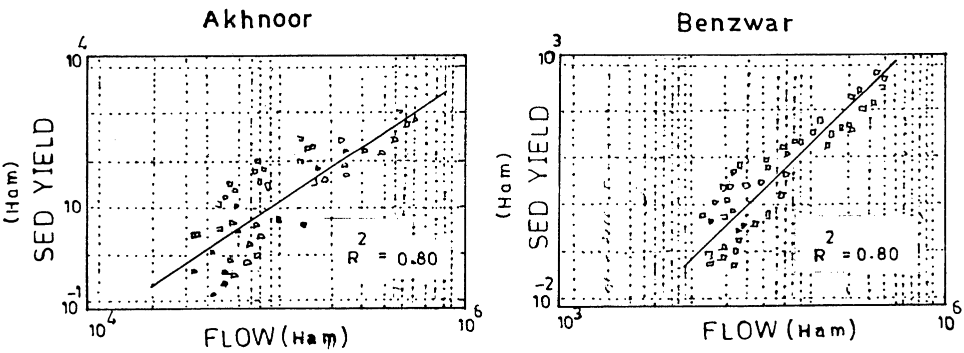

Fig. 5. Sediment rating curves at gauge sites in Chenab basin.

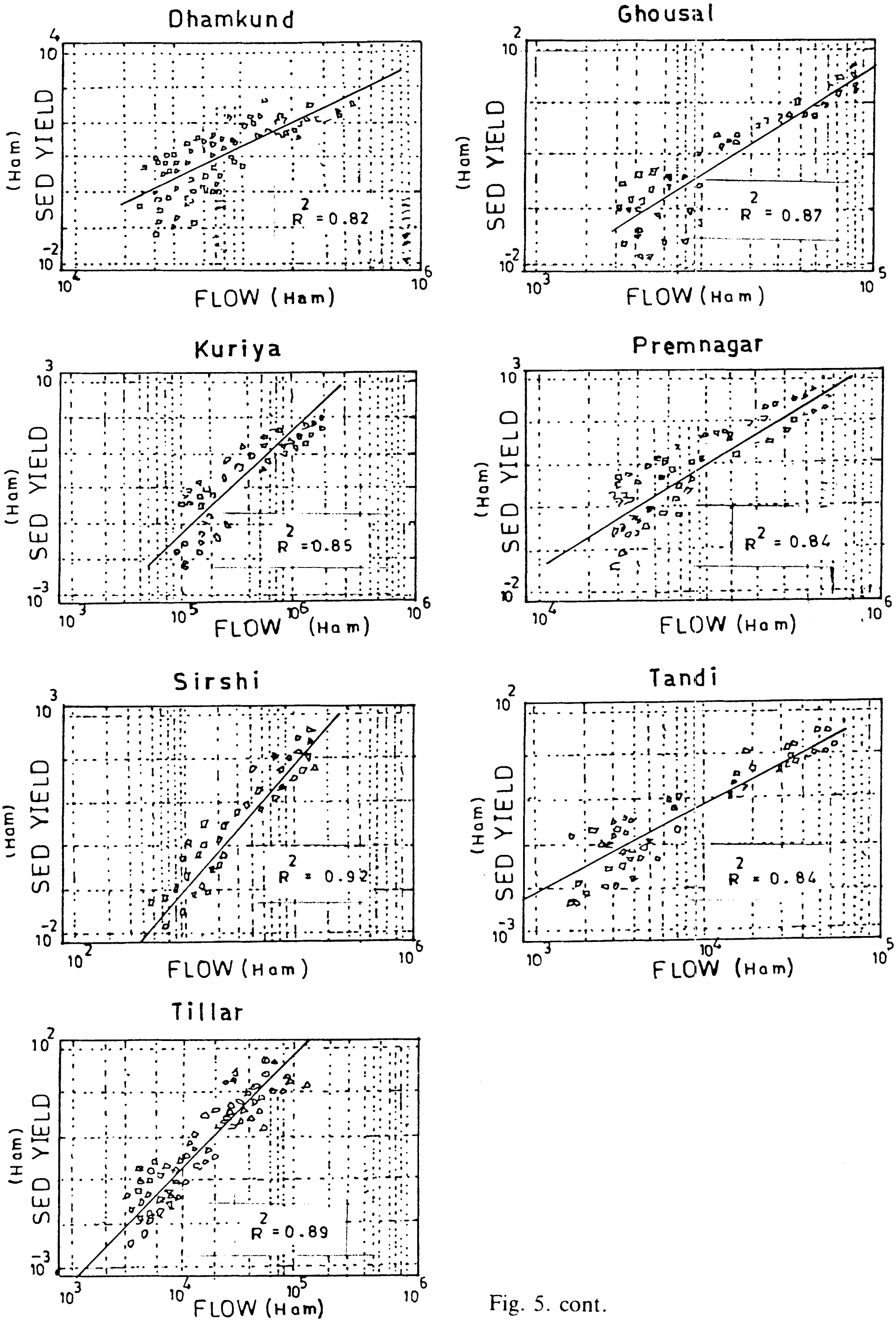
Dhamkund
SED YIELD (Ham)
FLOW (Ham)
R² = 0.82
Ghousal
SED YIELD (Ham)
FLOW (Ham)
R² = 0.87
Kuriya
SED YIELD (Ham)
FLOW (Ham)
R² = 0.85
Premnagar
SED YIELD (Ham)
FLOW (Ham)
R² = 0.84
Sirshi
SED YIELD (Ham)
FLOW (Ham)
R² = 0.92
Tandi
SED YIELD (Ham)
FLOW (Ham)
R² = 0.84
Tillar
SED YIELD (Ham)
FLOW (Ham)
R² = 0.89

Fig. 5. cont.

A Spatial Model for Suspended Sediment Yield

Chenab being a large catchment, spatial sediment yield modelling should be useful for future water resources projects in the region. The modelling is primarily intended to establish a relationship between sediment yield with its causative factors in space. Suspended sediment yield being highly related to discharge, sediment rating curves were developed as shown in Fig. 5. However, as discharge is itself a dependant variable, an attempt has been made to relate sediment yield to the controls represented by geomorphological and other parameters.

For model development multiple regression analysis is used with the data of 9 subbasins by relating sediment yield to several factors involving physiographic, landuse/landcover, soil types and climatic parameters. Since sediment yield varies during different seasons, as do also the causative factors, models for premonsoon, monsoon, and annual periods are presented separately. Separate relations for fine and total suspended sediment are presented keeping in view the method of sampling from the water surface. The winter season is neglected in view of its small sediment yield.

I) Sediment yield in ha m per thousand km^2 for the premonsoon, monsoon, and annual seasons was calculated as the dependent variable using basic data of daily discharge and unit weight/volume of sediment sample. Ten-to-twenty year averages (concurrent with rainfall) were used for computations after excluding extreme years. The extreme years were excluded assuming the sediment yield response to be different from those during normal years. In the case of the Akhnoor site data for only the pre dam construction period are used. Total sediment yields for the premonsoon, monsoon and annual periods are denoted as *Sypt, Symt* and *Syat* respectively. The corresponding notations for fine sediment yield are denoted as Sypf, Symf and Syaf respectively. Bed load has not been accounted for at all, although some authors do increase the total suspended sediment load by 10 to 20% arbitrarily to give a combined bed and suspended load.

II) The following geomorphological, landuse, climatic and soil parameters are taken as independent variables:

i) Shape factor, *Sb*,
ii) Drainage density, *Dd*,
iii) Channel slope, *Sl*,
iv) Relief ratio, *Rr*,
v) Channel length, *Lc*,
vi) Ruggedness number, *Rn*,
vii) Vegetal cover as %, *Pc*,
viii) snow cover as %, *Sc*,
ix) Rainfall as weighted mean basin rainfall during a season, concurrent with sediment yield. The rainfall for premonsoon, monsoon and annual periods are denoted by *Ppr*, *Pmr*, *Par*, respectively.
x) Soil types expressed as % area of total basin area (*S*1 though *S*6, as in Fig. 2)

Non Dimensional Analysis

Buckinghams π theorem (Lal 1987) is used to make selected parameters nondimensional. It was postulated that sediment yield rate, *Sy*, is dependent upon a set of 14 parameters that simulate the physiographic conditions of the watershed. The sediment yield could be expressed as follows

$$Sy = f(Sb, Lc, Dd, Rr, S1, Pc, Rn, Pr, Sc\ S1, S2, S3, S4, S5, S6, A) \tag{1}$$

Using the theorem Eq. (1) reduces to the following

$$\phi\left(\frac{Sy}{\sqrt{A}}, \frac{Pr}{\sqrt{A}}, \frac{Lc}{\sqrt{A}}, \frac{Dd}{\sqrt{A}}, Rr, Pc, Sb, Rn\ Sc, S1, S2, S3, S4, S5, S6\right) = 0 \tag{2}$$

where, *A* is area of subbasin.

Interrelationship Among Independent Variables

The intercorrelation matrix among independent variables is presented in Table 4. The correlation matrix indicates low to moderately high correlations.

Table 4 – Intercorrelation matrix among independent variables

	Sb	*Rr*	*Sl*	*Pc*	*Dd*	*Lc*	*Rn*	*S*1	*S*2	*S*3	*S*4	*S*5	*Par*
Sb	1.00												
Rr	-0.87	1.00											
Sl	-0.70	0.87	1.00										
Pc	0.56	-0.67	-0.56	1.00									
Dd	0.77	-0.89	-0.76	0.89	1.00								
Lc	0.77	-0.78	-0.74	0.67	0.81	1.00							
Rn	0.70	-0.74	-0.66	0.84	0.92	0.66	1.00						
*S*1	0.59	-0.49	-0.26	0.69	0.72	0.36	0.87	1.00					
*S*2	-0.15	0.43	0.56	-0.29	-0.34	-0.5	0.04	0.39	1.00				
*S*3	0.48	-0.53	-0.45	0.89	0.70	0.63	0.61	0.46	-0.3	1.00			
*S*4	-0.24	0.00	-0.18	-0.18	-0.16	0.2	-0.4	-0.7	-0.8	-0.1	1.00		
*S*5	-0.38	0.24	-0.05	-0.65	-0.55	-0.2	-0.6	-0.9	-0.4	-0.4	0.76	1.0	
Par	0.07	0.10	0.25	0.40	0.19	-0.1	0.47	0.76	0.68	-0.1	-0.8	-.8	1.0

Results and Discussion

To keep the number of variables small, only eight parameters having significant correlation with sediment yield were used in the regression analysis. These are *Sb, Rl, Sl, Pc, Dd, Lc, Pr* and *Rn*. Table 5 shows models obtained for total and fine sediment

Table 5 – Final models

Model	R^2	*SEE*	*F* Value
Premonsson			
1. *Sypt* = -0.45+0.08*Sb*+16.6*Rr*-0.07*Sl* -0.28*Pc*+0.006*Dd*-0.1*Lc*	0.99	0.003	399.8
2. *Sypf* = -0.071+0.03*Sb*+3.85*Rr* -0.03*Sl*+0.02*Ppr*	0.96	0.007	24.4
Monsoon			
1. *Symt* = 0.2+0.1*Sb*-0.19*Sl*-2.11*Pc* +0.16*Lc*+0.18*Pmr*	0.96	0.061	15.4
2. *Symf* = 0.06+0.08*Sb*-0.1*Sl*-0.78*Pc* -0.003*Dd*+0.12*Lc*+0.09*Pmr*	0.99	0.018	54.6
Annual			
1. *Syat* = -0.73+0.34*Sb*-0.22*Sl*+28.4*Rr* -0.004*Dd*+0.1*Rn*	0.98	0.035	58.0
2. *Syaf* = 0.3+0.1*Sb*-0.026*Par*-0.11*Sl* +0.11*lc*-0.007*Dd*	0.96	0.039	15.6

Note: R^2 = Coefficient of determination
SEE = Standard error of estimate
All models significant at 5% level

Table 6 – Observed and Predicted Sediment Yield (ha m)

Station/ Variable	Akh-noor	Benza-war	Dham-kund	Ghou-sal	Kuri-ya	Prem-nagar	Sirshi	Tandi	Tillar
Sypt (Obs)	27.3	22.4	31.2	6.9	17.1	23.5	22.1	6.4	9.8
Sypt (Pre)	28.9	26.9	32.0	7.7	19.2	25.5	23.4	7.7	11.6
Sypf (Obs)	15.9	12.9	12.3	4.0	9.0	12.4	10.0	3.9	4.9
Sypf (Pre)	19.4	15.4	16.7	5.3	11.6	13.9	11.9	5.1	7.7
Symt (Obs)	74.3	101.3	80.7	26.7	39.5	52.8	36.2	21.6	12.2
Symt (Pre)	69.9	97.5	70.5	26.6	41.1	52.3	30.1	20.2	11.8
Symf (Obs)	48.4	57.8	35.7	14.8	20.3	28.0	15.9	12.2	5.5
Symf (Pre)	47.3	55.1	37.0	14.8	21.1	25.4	16.3	12.3	6.7
Syat (Obs)	103.5	124.2	118.1	34.2	57.2	77.1	58.7	28.3	22.7
Syat (Pre)	97.8	124.9	114.8	33.8	55.8	81.2	59.7	29.9	23.6
Syaf (Obs)	65.7	71.1	51.6	19.4	29.7	40.9	26.1	16.4	10.4
Syaf (Pre)	78.1	73.4	56.5	21.6	31.0	43.4	24.6	12.5	11.9

Note: Notations defined in text.
Obs – Observed
Pre – Predicted

yield for different seasons in the Chenab basin. Table 6 shows observed and predicted sediment yields for various stations.

The regression equations developed need to be understood in a proper perspective. As already discussed sediment yield response in the upper reaches (consisting of the Shirshi, Ghousal, Tandi and Tillar stations) changes with respect to lower reaches (consisting of Akhnoor, Dhamkund, Benzawar and Premnagar stations) with Kuriya station in the transition zone for various reasons. Some of the factors not accounted for in the model include the effect of changing precipitation forms such as snow in the upper reaches, rain in the lower reaches and rain-on-snow in the middle reaches. Quantified information pertaining to geologic and soil conditions in the upper reaches is also limited.

A negative sign for slope parameter (in *Sypf* or *Symf* equations in Table 5) may not be logical in the sense that, the larger the slope, the smaller the sediment, although it is true from data obtained and is evident from Fig. 3. The upper reaches of the Chenab basin have high slopes (or relief ratio) but the sediment yield per unit area is low, hence the negative correlation between sediment yield and slope. Similarly there is poor and negative correlation between % of vegetal cover and sediment yield. In other words the sediment yield response to relief ratio, slope or vegetal cover in the upper reaches of Himalayan catchments is the converse of what is normally expected in rainfed catchments in the rest of India. The reason could be attributed to geologic/land cover conditions in the upper reaches (roughly beyond 3,000m corresponding to the treeline) with diminishing soil cover. Rainfall showed positive correlation with sediment yield and enters most of the regression equations.

Although the regressors show negative correlations (opposite to what was expected) the developed equations being statistically significant should be useful, since very limited data/information exist for fitting for the snow/glacier dominated upper reaches of Chenab basin. Data limitations pertaining to sample size and its representativeness must be given due consideration before applying the equations to any other point in the region.

Conclusions

The study reveals the high rates of sedimentation occurring in Chenab basin and presents statistically significant models for estimation of sediment yield. It also shows the effect of construction of a reservoir on sediment yield downstream. However limitations of data and sample size do exist. The number of sediment gauging sites should be increased at least 2-3 times, even if it could be for a short period of, say 5-10 years, to support more detailed sampling. Locations could be decided based on WMO norms and on practical considerations such as accessibility and representativeness.

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References

Bundela, D. S., Singh, R., and Mishra, K. (1995) Sediment yield modeling for small watersheds in Barkar river valley, *Inst. of Eng. (I) Jr., Vol. 76*, pp 22-25.

Holeman, J. N. (1968) The sediment yield of major rivers of the world, *Water Resources Research, Vol. 4*, No 4, pp.737-747.

Joglekar, D. V. (1965) Irrigation research in India, Central board of Irrigation and Power publ., India, No 78.

Jose, C. S., and Das, D. C. (1982) Geomorphic prediction models for sediment production rate and Inters priorities of watersheds in mayurakshi catchment. Proc of the Int Sym on hydrological aspects of mountainous watersheds, School of Hydrology, Uni. of Roorkee, India, Nov 4-6, Vol. 1, pp. 15.

Lydekker, R. (1876) Notes on the geology of Pir Panjal and neighboring districts, Proc Geological survey of India, Vol. 9 (40), pp. 115-168.

Lal, Jagdish. (1987) *Dimensional and model analysis*, Text book on Fluid Mechanics and Hydraulics. Metropolitan educational paper backs Publishers, New Delhi, India, pp. 347.

Middlemiss, J. (1909) Ground water and related marine sedimentary system of Kashmir, Geological survey of India, *Wl 37 (4)*, pp. 281-328.

Mishra, N., and Satyanarayan, T. (1991) A new approach to predict sediment yield from small ungauged watersheds, *Jr. of Inst. of Engg. (India) Agri. Engg. Divn., Vol. 73*, pp. 30-36.

Milliman, J. D., and Meade, R. H. (1983) Worldwide delivery of river sediment to the oceans, *Jr. of Geology, Vol. 91*, pp. 1-21.

Singh, Pratap, Ramasastri, K. S., and Kumar, N. (1995) Topographical influences on precipitation distribution, in different ranges of western Himalayas, *Nordic Hydrology, Vol. 26*, (4/5), pp. 260-286.

Singh, Pratap, and Jain, S. K. (1993) Snow and Glacier contribution in Chenab basin upto Akhnoor, *NIH publication, CS/AR 131*, Roorkee, India.

Rao, S. V. N., Ramasastri, K. S., and Singh, R. N. P. (1996) A simple monthly model for snow dominated catchments in western Himlalayas, *Nordic Hydrology, Vol. 27 (4)*, pp. 255-274.

Rawat, J. S., and Rawat, M. S. (1994) Accelerated erosion and denudation in the nana kosi watershed, Central Himalaya, India. Part I: sediment load. *Jr of Mountain research and development, Vol. 14, (1)*, pp. 25-38.

Roohani, M. S. (1986) Studies on hydromorphometery and snowmelt runoff using data of Chenab Catchment, Phd thesis submitted and awarded, University of Roorkee, India.

Sundd, D. K. (1991) Sediment transport in Indian rivers, Proceedings of Regional training course on reservoir sedimentation and Control, Central Water Commission, New Delhi, India, p. 189.

Upadhayaya, D. S., and Bahadur, J. (1982) On some hydrometeorological aspects of Precipitation in Himalayas, Proc Int Sym on Hydrological aspects of mountainous watersheds', School of Hydrology, Univ. of Roorkee Nov 4-6, Vol, I, pp. 125-140.

Varsheney, R. S (1975) Text of *Engineering Hydrology, Nemchand brothers publication, Roorkee, India*, p. 24.

Varsheney, R. S, Prakash, S., and Sharma, C. P. (1986) Variation of sediment rate of reservoirs in Himalayan region with catchment, Proc of 53rd R & D Session, CBIP Bubhaneshwar, India., Technical session IX paper.

Wadia, D. N. (1928) Geology of Poonch State (Kashmir) and adjacent portions of the Punjab, Memoirs of Geological survey of India, Vol (2), pp 185-370.

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