J. Engg. and Appl. Sci. Vol. 32 No. 2 July - December 2013 ISSN 1023-862X

ASSESSMENT OF SEDIMENT TRANSPORT LOAD FROM GOAML RIVER AND ITS IMPACT ON THE GOMAL ZAM DAM LIFESPAN

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ABSTRACT

This paper estimates the sediment load transported by Gomal River at Khajuri Katch and Kot Murtaza on yearly-basis. An eight years sediment data (1981-88) compiled by the surface water hydrology division of WAPDA was analyzed. Based on the available data and using regression analysis a model is developed to establish a correlation between water discharge and sediment load. The model is an attempt to ascertain the rate of erosion in the catchment of the Gomal River since no generalized model has so far been developed to explain the nature of such weathering activities and all such works are situation specific. Relation between the water discharges to sediment load that it carries has been developed to signify the Gomal River catchment's erosion. The analysis shows that the catchments is eroding at the rate of 1.67 acre-feet and the sediment water ratio is 3.0% which is the second highest value the world over after Yellow River in China. The variation of different parameters in sediment-water system i.e. water discharge, sediment load, sediment concentration and sediment quality have been estimated from the actual data and are shown by histograms and bar graphs. The relations developed are applicable only to the Gomal River system. It is hoped that the study will invite interest and attention of planners, researchers, and all those concerned with the problems and menace of soil erosion, sediment load concentration in hydraulic structures and its impact over the life span of hydraulic structures i.e dams deemed to be constructed across the river with the objective to minimize the sedimentation problems.

KEY WORDS: *Sedimention, Canals, Dam Life.*

INTRODUCTION

The Gomal River, which drains parts of Waziristan and Zhob agency, is notorious for its highest sediment transport capability in Pakistan. The highest sediment transport capability has been the main deterrent to the construction of dams at Khajuri katch and Kot murtaza and is a prime source of objection to many critics. This has compelled designers to consider sediment excluder mechanism in the design of hydraulic structures across this river system. Sediment and water gauging stations have been established and operated by surface water hydrology division of WAPDA at Khajuri katch and Kot Murtaza. Khajuri katch discharge station is located upstream and Kot Murtaza down stream of Gomal Zam dam. As per drainage area map the reach between the two stations is intercepted by no major tributary. The surface water hydrology division publishes the data annually. Total drainage area of Gomal River at Khajuri katch is 32780 square kilometers. The location and drainage area map of Gomal River at Gomal Zam dam site is shown in Figure 1.

Although, it is difficult to ascertain the effects of man-induced soil disturbances upon the sediment load of major rivers, most investigators agree that land cultivation has greatly increased the sediment load of most rivers. The increase in man's activities is taught to be two times more than the geologic norm of the entire world land area. For more strongly affected river basins, the factor may be ten times larger than the geologic norm[1]. The sediment load carried by a larger river is of considerable importance in planning the construction of large storage reservoir and canal irrigation system. This is so because sediment will be trapped in the reservoir behind a dam, eventually taxing its entire useful capacity and ending its economic life. At the same time, depriving the river of its sediment in the lower region below the dam may cause serious upsets in river activity. It will result in deep scouring of the bed and lowering of the bed level, ultimately upsetting the grade of irrigation systems.

Knowledge of the sediment load quantity and sediment classification in Gomal River is of great significance for planners after construction a large stor-

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age reservoir at Khajuri katch. Taking the sediment factor in the design criteria and its control will result in enhancing the life of Gomal Zam dam.

OBJECTIVES

The main objective of this study was to estimate the quantity of sediment transported by the Gomal River at Gomal Zam Dam site and to assess the impact of sediment load on the useful life of Gomal zam dam. Such studies have been rarely conducted and reported for local rivers. The purpose of the publication of the study is to increase the visibility of the work and give access to a wider community of researchers. The results presented may serve as a reference for further studies.

METHODOLOGY

Selected Sites and data

Hydrological and sediment data in Pakistan are available with the following organizations

1) The hydrology directorate, Department of Irrigation KPK

2) The irrigation research institute

3) Surface water hydrology division WAPDA

4) Survey of Pakistan

After scrutinizing the data collected from different agencies. It was decided to analyze the surface water hydrology division of WAPDA data, because of its reliability .The help of survey of Pakistan was sought to obtain the map of watershed (Figure 1).

The following procedure is adopted to achieve the desired objective

1. The selected data was analyzed to obtain mean daily water discharge in cusecs, average sediment concentration in ppm and average percentages of sand, silt and clay for each month of the available data for the two selected gauge sites.

2. Average daily suspended sediment discharge from the corresponding average daily water discharge was determined by using the following formula.

$$Q_{sd} = k_* C_{s*} Q_w \quad 1$$

Where

Q_{sd}= Average daily suspended load in tons/day

C_s=Sediment concentration in ppm by wight

Q_w = Water discharge in cusecs

K = Constant =0.0027 (1 ppm =0.0027 short-ton /day)

3. For each month of the years under study mean daily suspended sediment discharge in short tons and water discharge in cusecs are determined. Averaging the mean daily water discharge and sediment discharge of all months for the year, average annual water discharge in cusecs are calculated.

4. Total sediment discharge on daily and yearly basis is determined by adding bed load discharge to suspended load discharge. Bed load is taken as 10% of suspended load for flooded season and 15% for non- flooded season as it is commonly assumed in sedimentation engineering.

5. Relationship between suspended, total sediment load and water discharge is developed using the following model [2].

$$Q_s = aQ^b \quad 2$$

$$Q_b = aQ^b \quad 3$$

Where

Q_s = suspended sediment load

Q_b= Bed load

Q= water discharge

a=numerical constant

b=regression coefficient.

Total sediment load ($Q_t = Q_s + Q_b$) 4

Equation 2 can also be written in the logarithmic from as

$$Q_s = \ln(a) + b\ln(Q) \quad 5$$

Which is the linear equation of the form y= a+bx. By comparing the two equation "ln(a)" represents the intercept and "b" denotes the slope of rating curve. The slope "b" shows the incremental increase in the sediment load with the incremental increase in the water discharge. Average annual water discharge in cusecs and yearly total sediment discharge in short tons per year are co-related using the above model.

6. Results obtained on yearly basis from the above steps are used to analyze the constants "a" and "b" of the regression model with the help of regression analysis. Co-relation coefficient "r" and coefficient of determination " r^2" are determined for each set of data.

8. From the average percentages of sand silt and clay unit weight of sediment samples is computed for the selected two stations (Khajuri katch and kot Murtaza) by using the Lane and Koelzer formula[3].

$$Y_m=Y_1X_1+Y_2X_2+Y_3X_3 \quad 6$$

Where

Y_m = specifc weight of mixture of soil sample

Y_1 Y_2 Y_3= specific weight of sand, silt and clay of soil sample respectively

X_1 X_2 X_3= Percentages of sand, silt and clay of soil sample respectively

The average volume of sediments eroded on yearly basis from the catchments in acre-feet was determined from the total load expressed in short-tons by using " Ym" Dividing the volume of eroded soil by catchments area, the extent of erosion in acre-feet is ascertained.

Table -1: Average annual water discharge, annual suspended sediment and total sediment load in short tons in Gomal River at Khajuri Katch and Kot Murtaza (1981-1988)

Year	KHAJURI KATCH (Catchment Area 11200 sq. Miles)				KOT MURTAZA (Catchment Area 13900 Sq. Miles)			
	Q(cfs)	Q_s	Q_b	Q_t	Q(cfs)	Q_s	Q_b	Q_t
1981	343.50	2816.140	282.42	3098.56	624.58	6166.84	616.95	6783.80
1982	555.58	9247.82	282.42	10172.9	789.33	11547.0	1155.00	12702.2
1983	1208.33	29225.42	925.07	32148.4	1446.92	19770.5	1977.52	21748.1
1984	809.50	48531.16	2923.04	53384.9	842.25	47882.7	4758.89	52641.6
1985	546.00	13979.73	4853.80	15378.2	685.25	13739.3	1374.44	15113.8
1986	822.33	13656.29	1398.41	15022.2	907.00	33611.9	3361.59	36973.5
1987	926.58	16470.29	1365.88	18117.6	1271.41	27851.8	2785.67	30637.5
1988	-	-	1647.35	-	1991.00	50728.1	5073.03	55801.2

Table 2: Relationship between yearly suspended sediment load in short tons and average water discharge (cfs)

Gauge Site	Khaujri Katch	Kot Murtaza
Constants	Ina = -4.958	Lna =8.788
Corelation Coefficient	b= 1.787	b= 1.165
Coefficient of determination	R= 0.843	R=0.678
Derived Relationship	R^2= 0.708	R^2= 0.460
	InQ_s= Ina+b InQ	InQs= Ina + b InQ
	Q_s= 131 (Q) 1.787	Q_s= 6024(Q)1.165

Table 3: Relationship between yearly total sediment load in short tons and average water discharge in (cfs)

Gauge Site	Khaujri Katch	Kot Murtaza
Constants	In a= 4.988	In a= 8.79
Corealation Coefficient	b= 1.783	b=1.18
Coefficient of determination	R= 0.844	R= 0.678
Derived Relationship	R^2= 0.712	R^2= 0.460
	InQ = Ina+ b InQ	InQ_t = Ina+ b InQ
	Q_s= 146.64 (Q) 1.783	Q_s= 6627 (Q

RESULTS AND DISCUSSION

Average annual water discharge, total suspended and total sediment load in short-tons at Khajuri Katch and at Kot Murtaza on Gomal river is given in Table 1. The regression analysis has been worked out on annual basis for the selected gauging stations. Mathematical relationship established between annual water discharges, suspended sediment load and annual total sediment load in short tons shown in Table- 2

Where

Q=Average annual water discharge in acre-ft

Qs=Average annual suspended sediment load in short tons / year

Qh= Average annual bed loading short tons / year

Qt= Average annual total load in short tons / year

The sparse natural vegetal cover over the catchment consists of common wood species, shrubs and grasses. Most of the catchment is consisted of poorly cemented sand stone and clay stone rocks. George Fleming's equation[4] for a desert and shrub type of vegetal cover is as under:

$$Qs= 38000(Q)^{0.72} \quad 6$$

Whereas finding for both the selected stations on Gomal River are

Q_s= 131 $(Q)^{1.787}$ (Khajuri Katch)

Q_s= 6024$(Q)^{1.16}$ (Kot Murtaza)

Both the derivations show lower coefficient values and extremely higher values for the exponents as against George Fleming findings. Whereas the derived relationships give sediment loads with an error of + 50% which is well with in the approved range of error.

The high values of exponent may be attributed to quick response of catchment to rainfall mainly due to the extreme conditions of climate in that part of the country. It makes soil more vulnerable to erosion due to tropical conditions i-e high temperature and monsoon rain with their high intensities. The other reason is the geographical differences and variation in soil properties.

The relationships have also been developed for the total sediment load for both the selected catchments and are shown in Table 3. The relationship gives satisfactory correlation for the Khajuri Katct which is 0.84 whereas poor correlation coefficient of 0.68 is obtained for Kot Murtaza station.

The percentages of sand, silt and clay sizes, for each month, making up the soil are averaged for all the years under study to obtain the average annual percentages for the two gauging stations and are shown in Table 4.

The quality of the sediment transported by a river is determined by proportion of sand, silt and clay in it. For newly deposited soil, the specific weight of sand, silt and clay are taken as 39 lb/ft^3, 60 lb/ft^3 and 30 lb/ft^3 respectively.

Table-4: Textural classification of sediment load of Gomal Zam River at Khajuri Katch and at Kot Murtaza

Station	Sand%	Silt%	Clay%	Specific Weight (lb/ft^3)
Khajuri Katch	4.70	61.85	33.45	49
Kot Murtaza	5.27	61.83	32.9	52.23

As mentioned in Step No.8 of methodology, specific weight of sediment passing through Khajuri Katch and Kot Murtaza station are found to be 49 lb/ft3 and 52.23 lb/ft^3 respectively and are shown in Table 4. The erosion rates obtained, from Step No.9 of the methodology for the catchment area of respective gauging stations, are shown in Table 5.

The mean of one year sediment flow to the Gomal river from the catchment is 21.046125 million short tons and if the dam is constructed across the river at Khajuri Katch then the rate of loss of the capacity is 0.01415% (1602.4429 acre feet per year) . This will take 11 years to tax fully the dead storage capacity and about 70 years to fill the whole reservoir thus ending its life. The proposed dame reservoir has a capacity of 1,138,000 acre feet and dead storage capacity of 1.80.000 acre feet.

Where Q_s = Suspended sediment load in short tons

Q_t =Total sediment load in short tons

CONCLUSIONS

The following conclusions are inferred from the above discussion.

1. The 3% sediment to water ratio is pretty high and makes the Gomal River as the second heaviest sediment laden river in the world. The catchments of Khaujuri Katch and Kot Murtaza are eroding at the rate of 1.58 and 1.75 acre-ft/sq.mile respectively.

2. The relationship established between water discharge and the sediment load, provides basis of design for the engineers, planners, researchers and those in charge of implementation processes and those engaged in the field of water related structures across the Gomal River laden with sediment load.

3. The mathematical equations established and rating curves drawn can be utilized for estimating sediment discharge at the respective gauging sites on the Gomal River.

4. The equations with high exponents values show steepness of rating curves and thus gives quick response to heavy showers indicating its vulnerability to erosion.

5. Sediment classification identifies the type of soil erosion and can help in ascertaining sediment load and treatment of the most vulnerable zones eroding in the catchment area.

TABLE- 5: Erodibility

	Khaujri katch (Catchment area 11200 sq . miles)					Kot Murtaza (Catchment area13900 sq. miles)				
Year	Qs in (1000)	Q_T in (1000)	Q_t/sq. milIn (1000)	Erosion in acre. ft/sq.mile	%age of sedi. Load to discharge	Qs in (1000)	Q_t in (1000)	Q_t/sq. mile in (1000)	Erosion in acre-ft /sq.mile	%age of sedi.load to water
1981	2816.14	3098.56	276.65	0.2326	1.348	6166.8	6783.8	488.04	0.4077	1.05
1982	9247.87	10172.9	908.3	0.7636	2.11	1547.1	12702.3	913.83	0.7634	1.72
1983	29225.42	32148.5	2870.4	2.4133	3.075	19770.5	21748.1	1564.61	1.3078	1.644
1984	48531.16	53384.9	4766.5	4.007	7.541	47882.7	52641.7	3787.17	3.1637	6.77
1985	13979.73	15378.2	1373.1	1.1154	3.26	13739.4	15113.8	1087.37	0.9083	2.303
1986	13656.29	15022.2	1341.3	1.1277	2.095	33611.9	36973.6	2659.96	2.222	3.877
1987	16470.3	18117.6	1617.6	1.360	2.324	27851.8	30637.6	2204.14	1.8413	2.582
1988	-	-	-	-	-	50728.2	55801.3	4014.47	3.3533	2.953
Total	19132.41	21046.1	1879.1	1.579	3.108	26412.3	29050.3	2089.96	1.746	2.862

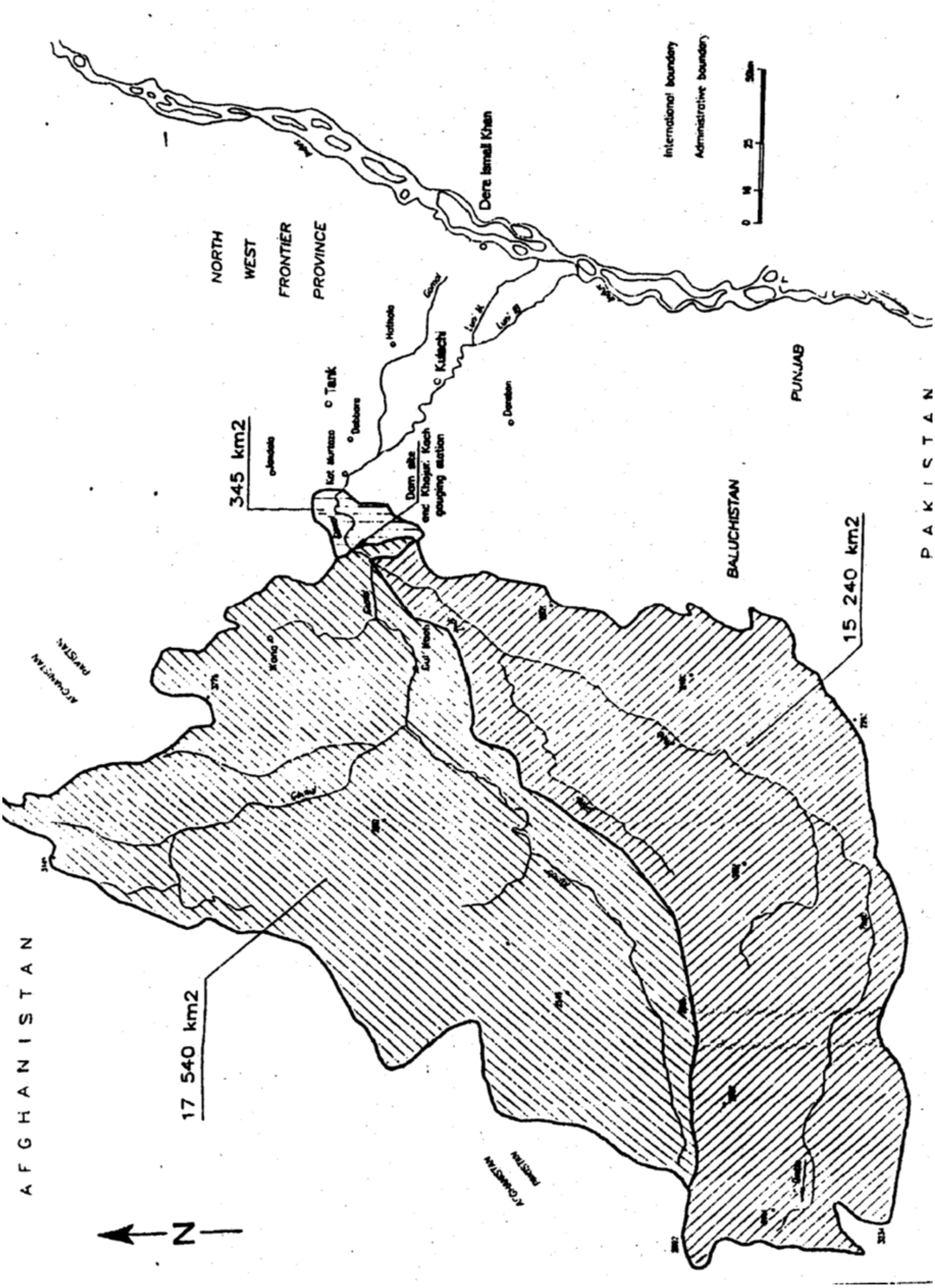

Figure-1 Drainage Area Map Location of Discharge Station

RECOMMENDATIONS

It would be unrealistic to think that sedimentation process, as they are associated with the sequence of geologic and climatic event, can be stopped. However by applying the understanding and knowledge gained through experience, evaluation and research, the sedimentation menace can be minimized up to a great extent. Therefore the following recommendations are made for control of the sedimentations problem:

Watershed management, agricultural and concerned engineering department should co-ordinate their activities to implement various land treatment activities and structural methods of reducing sediment load from watershed.

The following watershed protection control measures should be taken into account

1. Preservation and beneficial use of soil and water resources.
2. Improving and managing vegetal cover of trees and grass for sustained timber and forage yield as well as watershed protection where such cover represents the optimum land use.
3. Planting vegetative cover on excessive sediment producing area. Such planting may include grasses or legumes crops to provide long term ground cover.
4. Contour strip cropping should be followed.
5. Construction of embankments or ridges on slopes at suitable spacing, are formed to reduce erosion damages by reducing the slopes.
6. Structural measures for sediment control :
   - i) Detention reservoirs
   - ii) Guide bunds
   - iii) Groynes
   - iv) Debris basins
   - v) River course shortening
7. Reckless deforestation by villagers should be strictly abandoned and alternate arrangement of cheap fuel should be made. Other sources of energy should be mobilized, encouraged and give incentives to reduce deforestation practice there by reducing the erosion.
8. Soil erosion is a threat, which shortens the useful economic life of dams therefore appropriate measures should be taken to check and manage the soil erosion.

SUGESTIONS AND RECOMMENDATIONS FOR FUTURE STUDY

1. The validity of the derived equations proposed to estimate total sediment discharge should be investigated by the modified Einstein procedure.
2. The total sediment discharge sampling stations should be located at natural channel constriction or man- made turbulence flumes where in depth integrated suspended sediment samples are assumed to represent all of the sediment in transport. The total sediment discharge sampling stations are located downstream of the normal sampling stations and a comparison is to be made with the Einstenin procedure, Lane-Kalinske's procedures and Toffaleti's approach.
3. A similar study may be conducted for assessing the current situation of the river and then an interesting comparison may be drawn using the results presented in this paper as a historical reference.

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