Global Journal of Researches in Engineering: J General Engineering
Volume 14 Issue 6 Version 1.0 Year 2014
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Appraisal of Sediment Load in Rainfed Areas of Pothwar Region in Pakistan

By Zakaullah, Muhammad Ashraf, Muhammad Afzal, Muhammad Yaseen & Khalida Khan

University of Engineering & Technology, Pakistan

Abstract- Inadequate watershed management, natural, and man induced erosion of soils in the barani areas have threatened the sustainability of soil and water resources. In this study, sediment loads in the main streams passing through rainfed areas of the Pothwar region has been estimated for verifying the impacts of projects being implemented for agricultural development in the regions, especially the construction of small dams. The study has been carried out in three major basins namely Soan, Kanshi and Haro of Pothwar region. The daily discharge, sediment and rainfall data for the period 1982-2004 were analyzed and correlated accordingly. The sediment load has increased with the increase of river flow and vice versa. The unit rate of sediment yield decreased as the drainage area increased. Moreover, the observed sediment concentrations were low in low rainfall areas (Dhok Pathan) and high in areas fall under high rainfall zone (Chirah and Rawalpindi). Generally, the sediment concentration was low during January to June (low rainfall) and high during months of October to December (high rainfall). The study concluded that sediment load beyond sustainable limits can affect the land and water resources negatively which can be identified by exploring basin hydrology and predicting sediment load as well as mitigating potential threats through application of computer simulation model.

Keywords: *sediment, watershed, pothwar.*

GJRE-J Classification : *FOR Code: 091599*

Strictly as per the compliance and regulations of:

Appraisal of Sediment Load in Rainfed Areas of Pothwar Region in Pakistan

Zakaullah [α], Muhammad Ashraf [σ], Muhammad Afzal [ρ], Muhammad Yaseen [ω] & Khalida Khan [¥]

Abstract- Inadequate watershed management, natural, and man induced erosion of soils in the barani areas have threatened the sustainability of soil and water resources. In this study, sediment loads in the main streams passing through rainfed areas of the Pothwar region has been estimated for verifying the impacts of projects being implemented for agricultural development in the regions, especially the construction of small dams. The study has been carried out in three major basins namely Soan, Kanshi and Haro of Pothwar region. The daily discharge, sediment and rainfall data for the period 1982-2004 were analyzed and correlated accordingly. The sediment load has increased with the increase of river flow and vice versa. The unit rate of sediment yield decreased as the drainage area increased. Moreover, the observed sediment concentrations were low in low rainfall areas (Dhok Pathan) and high in areas fall under high rainfall zone (Chirah and Rawalpindi). Generally, the sediment concentration waslow during January to June (low rainfall) and high during months of October to December (high rainfall). The study concluded that sediment load beyond sustainable limits can affect the land and water resources negatively which can be identified by exploring basin hydrology and predicting sediment load as well as mitigating potential threats through application of computer simulation model.

Keywords: sediment, watershed, pothwar.

I. Introduction

Water is a very important resource for any country, especially for an agrarian one like Pakistan. It is a resource, which cannot be generated but can be preserved. Every country is doing its best to manage the water resources for the fulfillment of its needs. Water resources are affected by many natural hazards like sedimentation, earthquakes, floods etc. It has been documented that World's 13 large rivers carry 5.8 billion tons of sediments to the reservoirs every year (Nasir et al., 2006). Poor management of erosion prone areas has resulted in flooding and rapid filling of water reservoirs (Butt et al. 2010; Bradley et al. 2005; Nasir et al. 2006).

The Indus River is one of the world's largest rivers in term of water discharge and sediment loads, and the backbone of Pakistan's economy for agriculture and hydropower (Ali, 2004). Much of Indus River flow originates in the mountains of the Himalayas, Karakoram and Hindu Kush. Indus basin carries about 350,000 acre feet (AF) of suspended sediment per year, perhaps one of the greatest sediment load in the world, and about 200,000 AF of these sediments is deposited in the reservoirs and canals (Belaud *et al.*, 1998).

It is estimated that the Indus and its tributaries carry about 0.35 MAF of sediment load annually, almost 60% (0.2 MAF) of which deposits in the reservoirs, canals and irrigation fields (Kahlown et.al., 2002). Annual silt removal practices are undertaken in the canal systems to remove the deposited silt. Costa (1994) made the experiment on sediment of yield of two rivers i.e. South Fork Toutle River and Muddy River. Under the drastic change of sediment yield from 1980 to 1993 in these rivers, it was concluded that suspended sediment yields in all monitored streams have decreased since 1980, and fluctuate in response to annual runoff. Revegetation and natural armoring of channels and floodplains have reduced sediment yields at all sites. Freshwater resources are tremendously limited as 2.79 percent of the total water resources on the earth, of which only 0.03 per cent are available for human uses (Khalid, 2010).

Inadequate watershed management, natural, and man induced erosion of the barani soils has resulted in the depletion of the soil and water resources. The high runoff in these areas is associated with the erosion and sediment transport. A huge amount of soil is being transported which is being deposited in the reservoirs. For a slope of 1-10%, soil is being lost at a rate of 17-41 Tons/ha under fallow conditions and at a rate of 9-26 tons/ha under vegetative cover in the Fateh Jang Watershed (Ahmed et al., 1990). The high rate of soil erosion in these areas is due to the desire of bringing more land under cultivation that has led to the degradation of virgin lands.

Pothwar plateau, located in the northern part of Punjab province in Pakistan, is characterized by a high but irregular amount of precipitation has been developed as rainfed agricultural land mainly for wheat cultivation. This area is mostly covered with loess soils which are highly erosive. The natural conditions of this land may be suitable for crop production provided that rainfall is stable and soil erosion is well controlled. However, highly erratic climatic conditions for a long period of time and inadequate land management in addition to the existence of highly erosive soils have

Author α σ: Pakistan Council of Research in Water Resources, Islamabad.
Author ρ: Centre of Excellence in Water Resources Engineering, University of Engineering & Technology, Lahore, Pakistan.
e-mail: afzelbutt@yahoo.com
Author ω ¥: Centre for Integrated Mountain Research (CIMR), University of the Punjab, Lahore, Pakistan.

resulted in the expansion of severely eroded and degraded land in this area. Out of total 1.8 Mha of Pothwar region, about 0.77 Mha (43%) are cultivated and the remaining is mostly grazing land. While of the cultivated area only 4 percent is irrigated, while remaining (96%) is under rain-fed agriculture (Khan 2002). About 60% of the land area has been highly eroded leaving the rest as a flat land which constitutes the main cultivated area.

Using traditional techniques in Pothwar plateau soil loss of 3.0-4.5 tons/ha/year has been observed in cropped fields (Ahmed, 2002). Soil erosion is responsible for silting up of small dams and contamination of surface and groundwater. Soil erosion may contain chemicals that may be toxic to plants and animals. More importantly, small dams in Pothwar region are subject to silt problems as the average annual sediment yield of various catchments of Soan and Haro (excluding Chirah) is 3.83 AF/mile^2 (NESPAK, 1991). Another study shows that for a slope of 1-10%, soil is being lost at the rate of 17-41 tons/ha under fallow conditions and of 9-26 tons/ha under vegetative covers in the Fateh Jang watershed (Ahmad *et al.*, 1990). Out of 1.82 Mha of Pothwar Plateau only 0.61 are cultivated and the remaining 1.21 Mha are affected by gully erosion (Ahmad *et al.*, 1990). The high rate of soil erosion in these areas is due to the horizontal expansion of agricultural activities. However, inadequate watershed management and natural as well as man induced erosion of the fragile barani soils led to the depletion of the soil and water resources. The vegetative growth in the dams' lakes indicates that top fertile soil from the catchment is being brought into these reservoirs, thus converting the productive land into non-productive (Ashraf, *et al.*, 2000).Thus developments of efficient soil erosion management technologies are required to preserve valuable natural resources for human development and environmental protection.

The protection and management of this element is of crucial importance for sustainable agriculture development in Pothwar region. Appropriate activities must be carried out to reduce the soil erosion and to conserve soil moisture for enhancing the agricultural productivity of the soils. The Government started various projects for watershed development in the upstream of storage reservoirs such as Watershed Management Programme by Pakistan Water and Power Development Authority (WAPDA). Similarly, soil and water conservation activities have also been carried out in Pothwar region for erosion control and land development through series of Barani Areas Development Projects. The projects though contributed in the agricultural development of the areas, the actual appraisal of these projects with reference to sediment control, have not been made so far.

It is estimated that approximately 1% of the storage volume of the world's reservoir is lost annually due to sediment deposition (Fan and Morris, 1998). In some developing countries like Pakistan, there is rapid reduction in reservoir storage due to improper watershed management. Water shed management is the best option to reduce the sedimentation rate.

Viewing the scenario, there is a need to find the sediment yield of the streams and rivers located in the upstream catchments, particularly Pothwar region. This would help to assess the effectiveness of the watershed management activities carried out by various agencies and would further help to suggest innovative soil and water conservation techniques. The overall objective of this study is to assess the sediment load in the main streams/rivers passing through rainfed areas of the Pothwar region for sustainability of land and water resources.

II. Materials and Methods

a) Location of the study area

The study was carried out in the Pothwar region comprising of three major basins: Soan, Kanshi and Haro as shown in Fig.1. The total area of Pothwar is 1.8 Mha (4.45 million acres). The project area falls under the administrative control of Attock, Rawalpindi, Islamabad, Jhelum, Chakwal and some part of Khushab Districts. The study area lies in semi-arid to sub-humid zone of climatic region with hot summers and cold winters except Murree which falls in humid zone. The average annual rainfall in the area varies from 250 mm to 1,675 mm, the maximum being in the north. The average annual rainfall at Murree in the north-eastern part of the area is about 1,685 mm. whereas the average annual rainfall in the western part of the area is at Tamman, about 290 mm. About 40% of total annual precipitation occurs in spring and winter seasons and the rest in the monsoon season. The Pothwar has a complex geologic history of mountain building, alluvial and loessial deposition and erosional cycles. The result is a varied landscape of mountains, stony plateau, level alluvial plains and rolling sand plains and intricately dissected uplands.

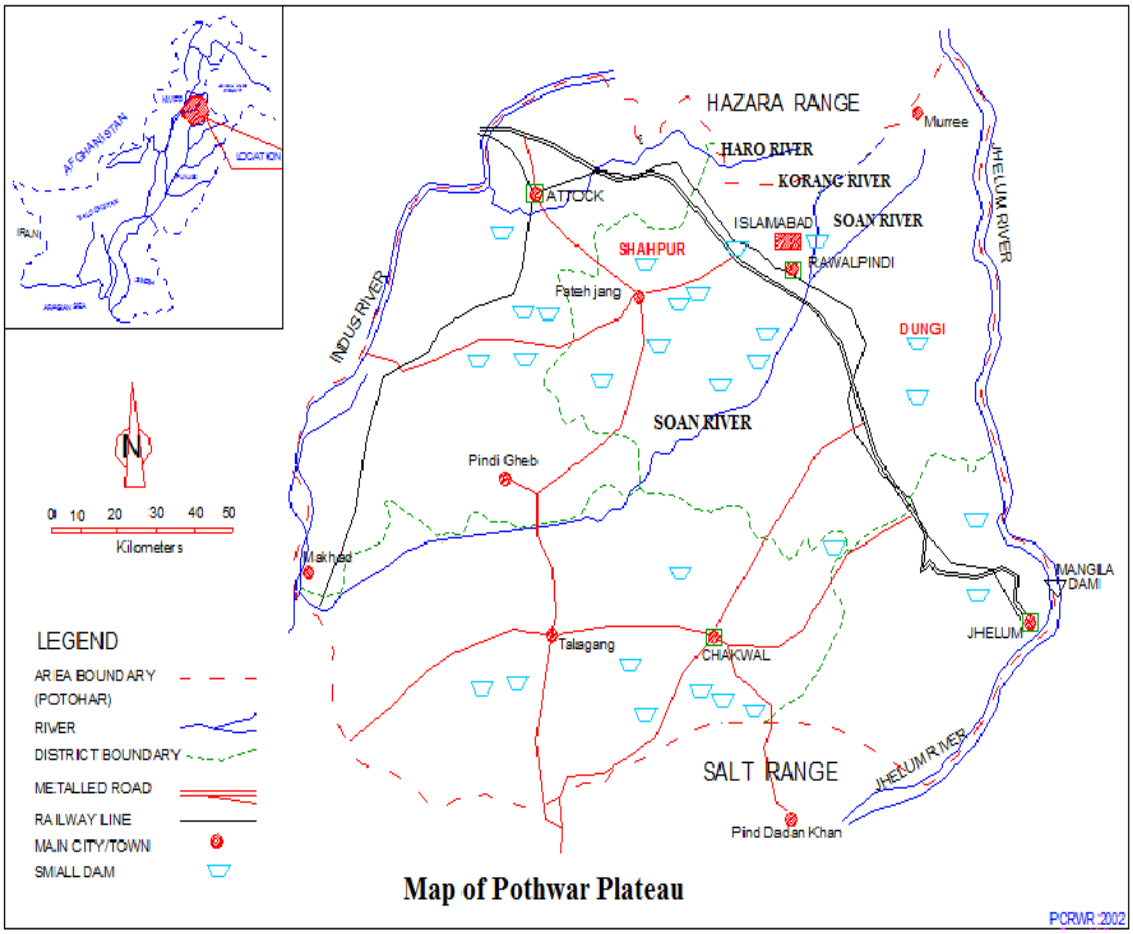

Fig. 1 : Location of study area

III. Data Collection

The daily discharge, sediment load and rainfall data of Soan, Haro and Kanshi River basins were collected from Surface Water Hydrology Project (SWHP), WAPDA. The collected data sets were analyzed and average annual discharge and sediment load were calculated to monitor the detailed trend of each basin.

IV. Results and Discussion

a) Status of sediment load at Soan basin

There are three major river basins in the Pothwar region: Soan, Haro and Kanshi basins comprising of many small tributaries. The Soan River basin is the major hydrological unit of Pothwar Plateau. The drainable area of this basin is about 11,085 km^2. The Soan Basin forms the central part of Pothwar Plateau. The sediment load from Soan basin was analyzed at different reaches of Soan River i.e. Chirah, Rawalpindi and Dhoke Pathan, covering about 60% basin area. The overall average annual sediment yields of the Soan basin were ranged from 0.02 to 0.38 million tons per year as shown in Table 1.

Table 1 : Summary of sediment yield in sub catchment of Soan basin

Sub Catchment	Drainage area (km^2)	Years of record	Average sediment yield (million tons/year)	Unit sediment yield (tons/km^2/year)
Chirah	323	1982-2006	0.02	61.92
Rawalpindi	1,342	1982-2006	0.11	66.00
DhokPathan	4,736	1982-2006	0.38	59.36

The unit rate of sediment yield is inversely proportional to the drainage area because there is an association between the rate of sediment production and size of catchment area as the total runoff yield is dependent upon the aerial extent of the watershed. The unit sediment yield of Chirah is 33%, while 35% and 32% for Rawalpindi and Dhok Pathan, respectively. It is clear that the drainage area of the Chirah is 5% of the total draining area of the Soan basin from Chirah to DhokPathan but the unit sediment yield is 33% whereas the Dhok Pathan having 74% and Rawalpindi 21% drainage area accumulates 32% and 35% sediment yield respectively.

The sediment yield from Soan basin is highly temporal and spatial because the rainfall and runoff are highly variable. Theaverage annual sediment yield rate may not provide sufficient information to interpret causes and effects of proper land management. The annual sediment yield, however, provides a general basis of comparison between the sub catchments. Hydrologic, geomorphic and watershed characteristics influence the sediment yield. The peak flow decreases as the area increases while the period of surface runoff increases with the more area because the catchment of larger area has greater time of concentration showing that more time is available to the water for leaching into the soil, ultimately there is reduction in runoff and soil loss or sediment yield. Barnson et al. (1981) also presented a graph illustrating the relationship between sediment yields and draining area based on the research work. In general, the unit rate of sediment yield decreases as drainage area increases (Fig.2).

The relationship in average monthly discharge and sediment concentration of Chirah, Rawalpindi and Dhok Pathan are plotted in Figures 3-5. The sediment concentration increases from July-September with peak in August i.e. monsoon season at Chirah which is due to high rainfall this period but the sediment concentration is very low during January-June and October-December due to low rainfall during these months (Fig.6).

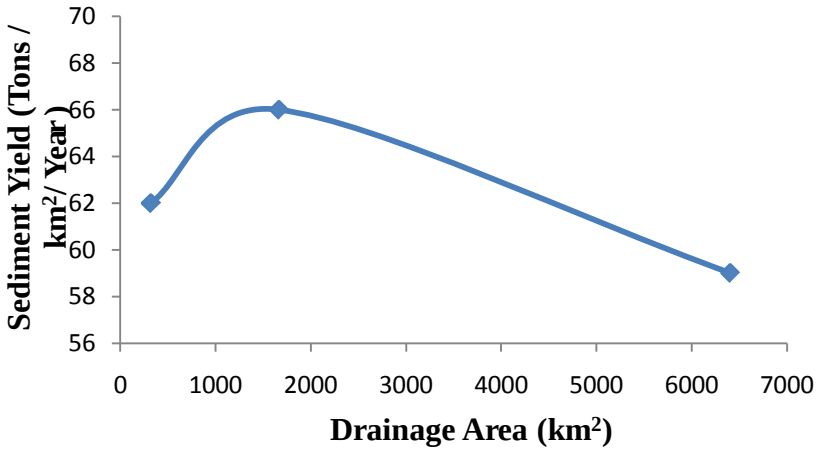

Fig. 2 : Relationship between drainage area and sediment yield

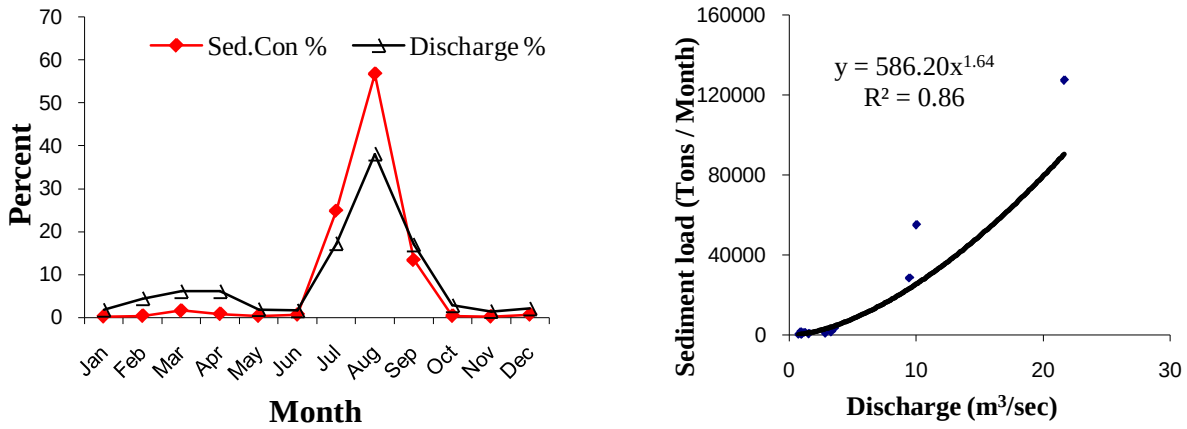

Fig. 3 : Relationship between discharge and sediment concentration at Chirah

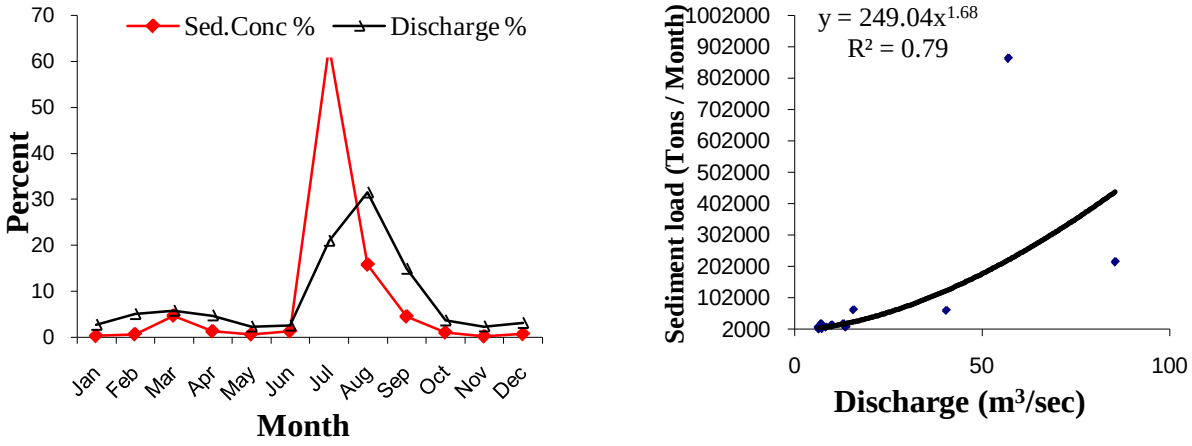

Fig. 4 : Relationship between discharge and sediment concentration at Rawalpindi

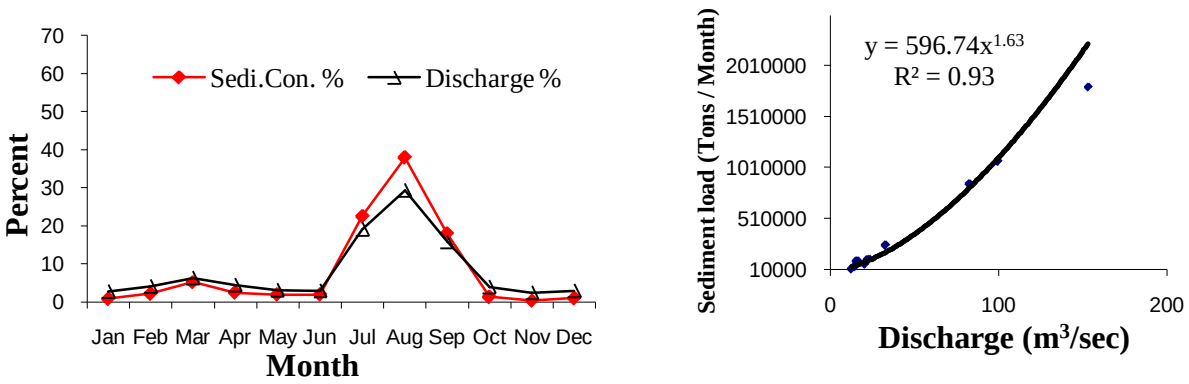

Fig. 5 : Relationship between discharge and sediment concentration at Dhok Pathan

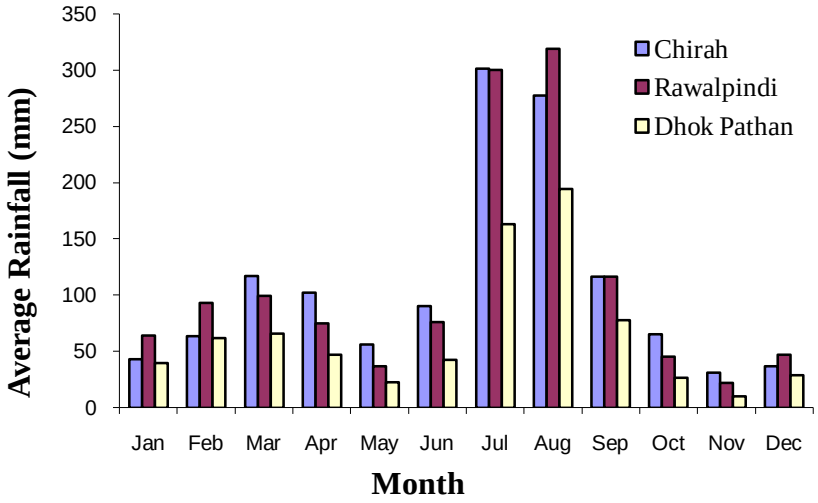

Fig. 6 : Average monthly rainfall trend (1982-2006) of Soan River Basin

The discharge at Chirah is comparatively low as compared to Rawalpindi and Dhok Pathan as Chirah is located at upstream of the Soan River. The R^2 (coefficient of determination) value was 0.86 at Chirah and 0.79 at Rawalpindi, whereas 0.93 at Dhok Pathan. The Dhok Pathan station has greater sediment-discharge correlation as compared to other stations.

Whereas, there was sudden increase in sediment concentration during July due to high intensity rainfall but the discharge was maximum during August due to high rainfall at Rawalpindi. At Dhok Pathan, the sediment concentration was high from July-September with peak in August and discharge was also maximumduring August.

There is good correlation between the discharge and the sediment concentration. The best fit rating curve between the discharge and the sediment is power function. Also other empirical relationships were applied but most commonly used relationship is the power function. The same results were reported by Walling, 1977; Holubová, 1998; Asselman, 1999; Bhutiyani, 2000 and Rondeau, 2000.

$$C = aQ^b$$

Where C is the suspended sediment concentration in mg/l.

Q is the water discharge in m^3/sec.

a and b are empirically derived regression coefficients.

The percentage of sediment concentration at Chirah ranged from 13-57% and at Rawalpindi were 5-63% during the monsoon season (July-August) due to high intensity rainfall in this season but the sediment concentration at Dhok Pathan were 17-38%. As Dhok Pathan is lying in low rainfall area the sediment concentration was relatively low at this point whereas Chirah and Rawalpindi falls at high rainfall zone and accordingly high sediment concentration. Most importantly, the sediment concentration at all points is low during January-June and October-December due to low rainfall.

b) Status of sediment load at Haro river basin

The sediment load from HaroRiver basin was analyzed at Garrialawhich islocated at the end of the basin, covering about 100% basin area.

c) Haroriver basin at Garriala

The maximum sediment load was observed during the months of July and September which also has correlation with the monthly flow pattern (Fig. 7). The high intensity and short duration rainfall during monsoon period has direct influence to erode the soil particles. Further, the long term yearly pattern of sediment load at Gurriala were indicating an increase in sediment load with increase in discharge(Fig.8).

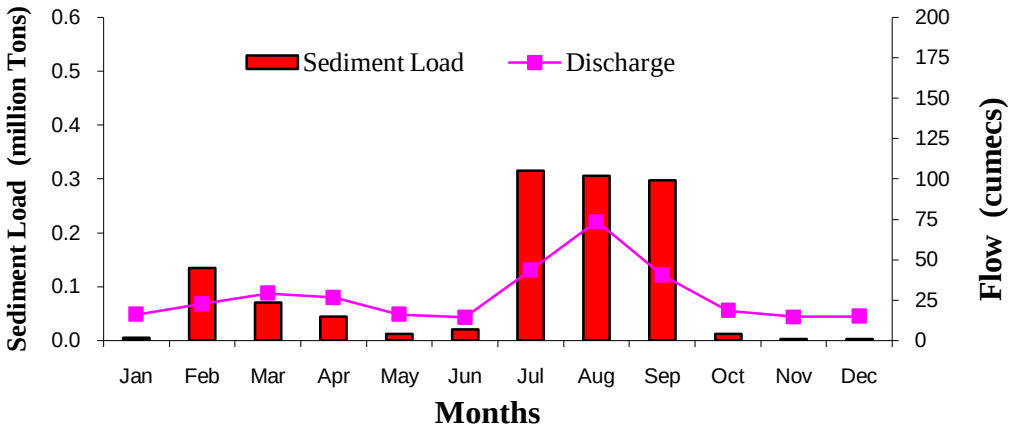

Fig. 7 : Monthly sediment load of Haro basin at Gurriala

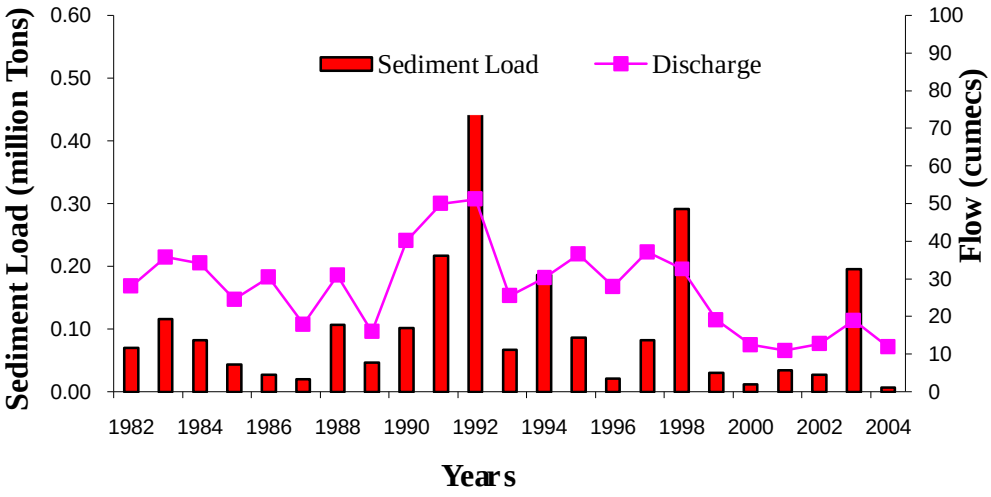

Fig. 8 : Annual sediment load of Haro basin at Gurriala.

d) Status of sediment load at Kanshiriver basin

The Kanshi river basin is adjacent to Soan basin and located with Jhelum River in Pothwar Plateau with drainable area of about 1,300 square kilometers (km^2). The area lies in semi-arid zone of climatic region with hot summers and cold winters. The sediment load from Kanshi basin was analyzed at Palote covering about 85% basin area.

e) Kanshiriver basin at Palote

The analysis of long term data of suspended sediment load at Palote indicating that the monsoon period i.e. months of July and August have maximum sediment load which also has correlation with the monthly flow pattern (Fig. 9). The rainfall during monsoon period was associated with high intensity and short duration which has direct influence to erode the soil particles. Almost the same pattern was observed when long term yearly data of sediment load and discharge were plotted (Fig. 10).

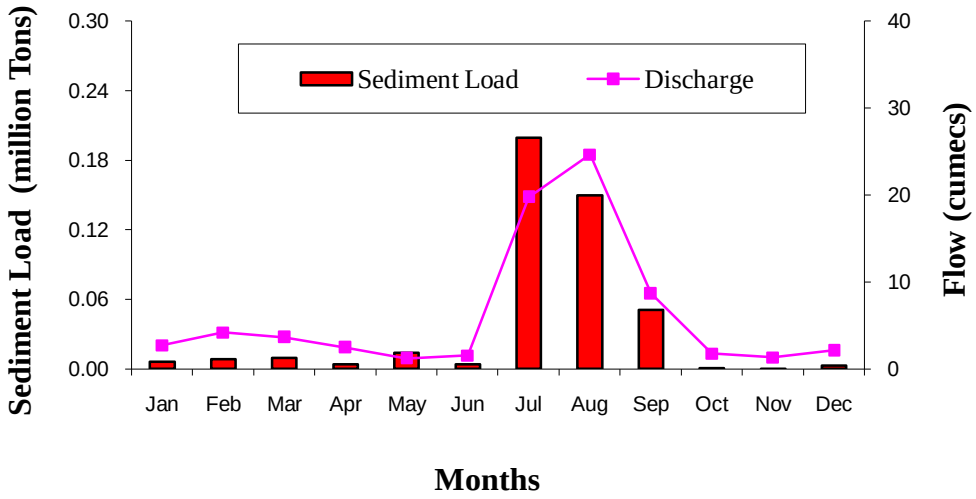

Fig. 9 : Monthly pattern of sediment load of Kanshi River basin at Palote

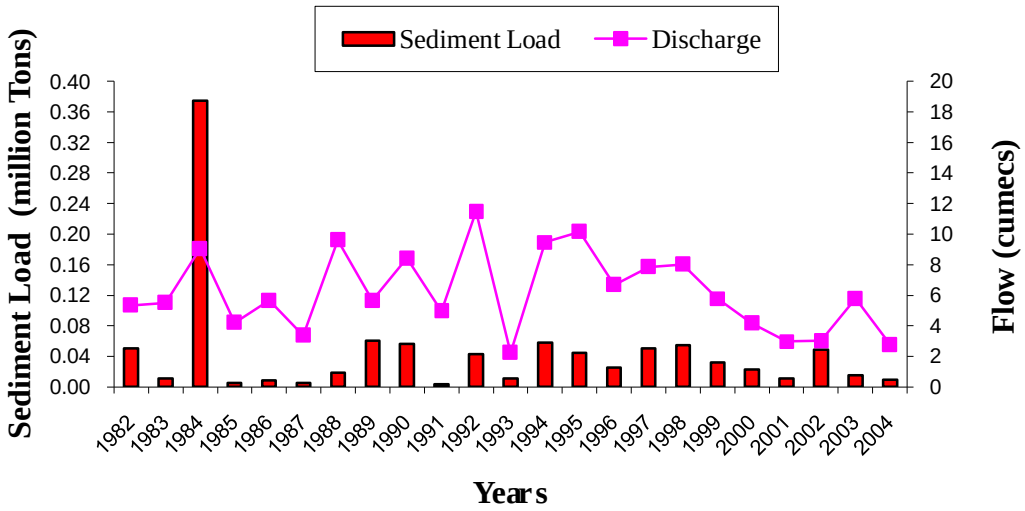

Fig. 10 : Average annual of sediment load of Kanshi River basin at Palote

V. Status of Total Sediment Load

Resultantly, the total sediment load of Soan Basin at Dhoke Pathaninstigating that this basin was relatively producing more load as compared to the other two basins. However, the maximum load is gradually decreased from 1990 to 2001 (Fig. 11). As compared to Soan Basin, total sediment load at Harrow rive basin is low and fluctuating periodically from 1990 to 2001. Moreover, the total sediment load at Kanshi Basin is also comparatively low like the Haro Basin.

VI. Conclusions

The study indicates that sediment load increases as the river flows towards down stream. In high flow season, the sediment load was high and vice versa. However, the sediment load may increase during low flow periods because of some earthen work e.g. cutting of trees, construction of dams etc. It was further observed that abrupt change in flow increased the sediment load which is normally observed at the start of pre-monsoon i.e. in the months of June and July. The observed sediment load was comparatively high at uplands as compare to flat land. The total sediment load from Soan Basin is relatively high as compared to Haro and Kanshi Basin. Given the spatial variability of basin characteristics (topography, land use and cover, geology, soils etc.), applying a computer simulation model can better capture basin hydrology subject to good quality data. The appraisal of this study can be further proceeded for exploring basin hydrology and predicting sediments loadings to identify the critical sub-basins as well as studying land use management scenarios to mitigate potential threats by conservational and watershed management techniques to the precious land and water resources.

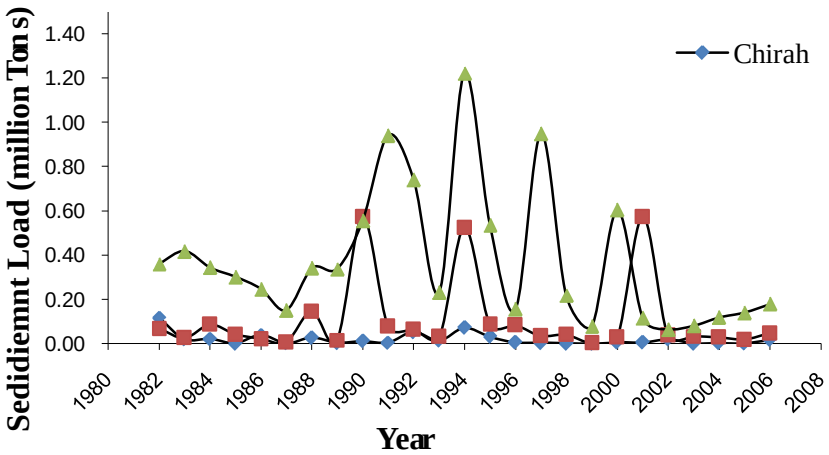

Fig. 11 : Annual sediment load at different sites

References Références Referencias

1. Ahmed, M.2002. Investigation of Soil Erosion and Sedimentation Problems using Radioisotopes, Newsletter of the Pakistan Atomic Energy Commision, December.
2. Ahmad, S. M.,Ikram M.A. 1990. Soil and water conservation and integration land use in Pothwar, Pakistan. In: Soil Physics: Applications under stress environments. Pakistan Agricultural Research Council, Islamabad, pp. 301-312.
3. Ali, K., de Boer, D.H., Martz, L.W. 2004. Spatial Patterns of Suspended Sediment Yield in the Upper Indus River Basin, Northern Pakistan, American Geophysical Union, Spring Meeting, abstract # H41F-03.
4. Ashraf M., Hassan,F.U., Khan,M.A. 2000. Sustainable environment management: impact of agriculture. Journal of Science, Technology and Development. 19(4): 51-57.
5. Asselman, N. E. M. 1999. Suspended sediment dynamics in a large basin: the River Rhine. Hydrological Processes, 13, 1437-1450.
6. Belaud G., Khan,A. H., GhulamNabi. 1998. Sediment behaviour of Sangrodistributory Mirpurkhas sub-division, Sindh. International Irrigation Management Institute (IIMI) Report No. R-50, p. 69.
7. Bhutiyani, M. R. 2000. Sediment load characteristics of a proglacial stream Siachen Glacier and the erosion rate in Nubra valley in Karakoram Himalayas, India. Journal of Hydrology 227, 84-92.
8. Branson, F.A., Gifford, G.F., Renard, K.G., Hadley, R.F. 1981. Rangeland Hydrology, Range Science Series 1, Society for Range Management, Denver, CO.
9. Butt, M. J., Waqas, A., Mahmood, R.2010. The combined effect of vegetation and soil erosion in the water resource management. Water Resource Management, 24, 3701–3714. doi:10.1007/s11269-010-9627-7.
10. Fan, J., Morris, G.L. 1992. Reservoir Sedimentation II: Reservoir Desiltation and long-term Storage Capacity, J. Hydr. Engrg., Vol. 118, No.3, p.370-384.
11. Holubová, K. 1998. Problems systematic monitoring of erosion-sedimentation processes in the water works. 135 Volume of Work and study/Water Research Institute in Bratislava.
12. Kahlown M.A., Abdul Majeed., Bhatti M.A. 2002. Contribution of Mountains in Pakistan's Water Resources-Status and Prospects.
13. Khan, R. S. 2002. Pothwar's Agricultural Potential, Pakistan Agriculture Overview, courtesy Daily Dawn, 24 May.
14. Khalid, I. 2010. Trans-Boundary water sharing issues: A Case of South Asia. Journal of Political Studies 1:79-96.
15. Nasir, A., Uchida,K., Ashraf, M.2006. Estimation of soil erosion by using RUSLE and GIS for small mountainous watershed in Pakistan. Pakistan Journal of Water Resources, 10(1), 11–21.
16. NESPAK. 1991. Evaluation of small dams in Punjab and N. W. F. P. Vol. II-Part A-C, Government of Pakistan, Ministry of Planning and Development Division.
17. Rondeau, B., Cossa, D., Gagnon, P., Bilodeau, L. 2000. Budget and sources of suspended sediment transported in the St. Lawrence River, Canada. Hydrological processes, 14, 21-36.
18. Siddique, M. 1999. Sedimentation technology: Achievements and issues for the next millennium, Proceedings National Workshop on Water Resources Achievements and Issues in 20th Century and Challenges for the next Millennium, PCRWR, June.
19. Walling, D. E. 1977. Limitations of the rating curve technique for estimating suspended sediment loads, with particular reference to British rivers. In: Erosion and solid matter transport in inland waters (Proceedings of the Paris symposium, July 1977), IAHS Publ., 122, 34-38.

This page is intentionally left blank