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Discharge Characteristics and Suspended Load from Rivers of Northern Indus Basin, Pakistan

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ABSTRACT: *An overview of the discharge and sediment load of eight important rivers of North West Frontier Province is presented with a view to analyse the available surface water resource potential of this region most of which is originated from the northern Indus basin. The amount of total suspended solids being very high in most of the rivers have resulted in rapid silting and subsequent loss in the storage capacity of the existing reservoirs and it is time that priority is given to the construction of new dams.*

INTRODUCTION

Pakistan is an agrarian country with agriculture based economy. In order to have optimum crop yields, it depends heavily on its water resources 50% of which comprises the surface water. The surface water resources of Pakistan include a large network of rivers, mostly derived out of a huge glaciological complex housed at 5000 m above m.s.l. in the Himalayan-Karakoram-Hindu Kush mountain belt. These rivers and their tributaries not only serve as the backbone of the country's irrigation system - one of the world's most extensive - but also produce about 6000 M.W. of cheap electricity. The 2737 km long Indus river drains the largest basin in Pakistan and together with its tributary system caters for nearly 90% of the country's agricultural water requirements (Arain & Khuhawar, 1982; Bell et al., 1994). The 69 year mean annual flow (1922-94) of Indus river has been reported as about 137 million acre feet (MAF) at Kotri (WAPDA, 1994).

The northern Indus basin including the North West Frontier Province (NWFP) is primarily drained by the Indus river along with a tributary network of perennial streams including the Kabul, Swat, Chitral, Kunhar, Panjkora, Bara, Kurram, Gambila, Gomal and Haro. Together these streams cover most part of the drainage basin of north Pakistan and as such the NWFP constitutes the headwater and a source of sediment supply into its fluvial system (Tamburi, 1974).

WAPDA has been monitoring the discharge and sediment load of these rivers at various stations since 1962 and publishing the subsequent reports more or less at regular intervals. This paper is intended to discuss and review the surface runoff and suspended sediment data of some of the above mentioned rivers to analyze the flow variations on annual and seasonal scale as well as to ascertain areas of high sediment input. This type of information is useful not only for watershed management but also for public health, irrigation, hydel power generation and fisheries.

THE STUDY AREA

The collision between Indian and Asian plates about 45-50 Ma ago resulted in the rapid uplift of the Himalayas, Karakoram and Hindukush ranges around the northern and northwestern rim of the Indian plate. The tectonic activity has continued ever since and at least three major phases of uplift and denudation have been completed till Quaternary (Khan et al., 1995). Subsequently, the north Pakistan has attained rugged topography and steep relief as is evident from five peaks of > 8000 m and sixty eight peaks of > 7000 m altitude in a small region. In NWFP the more northerly districts of Kohistan, Chitral, Dir, Hazara and Swat are largely mountainous, whereas, Karak, Bannu, Dera Ismail Khan, Kohat and Peshawar regions are partly plain areas. There are a great number of small and large intermontane basins in the central and southern part of the province including some flat river valleys (Kruseman & Naqvi, 1988).

The subtropical location of Pakistan has a marked influence on its generally hot, dry climate, however, the highland climate - characterized by low temperatures and high precipitation - prevailing in the west and north is in sharp contrast to the remaining area (Khan, 1991). For most parts of the country, the bulk of rainfall is restricted to monsoon period (July-Sept), but Western Depressions (Nov-April) also bring some precipitation. Climatic information for high altitude areas in the north are very scarce. The climate of the Karakoram and Hindukush region is said to be transitional between the Central Asian and monsoon dominated south Asian (Holmes, 1993). Precipitation is primarily derived from depressions moving in from west during winter and spring but occasionally monsoon rains also succeed in extending sufficiently north to cause secondary summer precipitation (Mayewski et al. 1980; Wake, 1987). The rainfall is low but comes in pockets of storms having notable geomorphological significance and more importantly, the magnitude and intensity of rainfall definitely increases with altitude (Collins, 1988; Bell et al., 1994). Subsequently, at times there is no rainfall in the valley bottom, where a rain gauge is installed, but significant precipitation may be occurring at higher elevation.

The Himalaya and Karakoram ranges possibly posses more ice cover than any other extra polar mountain system in the world and in fact some of the valley glaciers are considered longest outside the polar regions (Goudie et al. 1984a). Historically, valley glaciers of this region have shown secular variations over a variety of time scales ranging from decades to millennia but Goudie et al. (1984b) have suggested that they have been generally advancing in the late 19th and 20th century followed by predominant retreat during the period 1930-60. Since then, however, both advance and retreat have been recorded for different parts of the region. These secular variations, caused by climatic changes viz., temperature and precipitation, control the mass balance and ultimately affect the snow-melt runoff.

Streams of the Himalayan Karakoram region often originate at glacial snouts and drain water derived from glacial ablation but they may also partially contain some input from extraglacial sources such as rainfall, valley side snow-melt or ground water springs (Ferguson et al. 1984). The geomorphic impact of these streams is enhanced because more than 75% of the snow-melt is released during the 6-10 weeks period of intense melting in summer (Hewitt, 1993). The main rivers of this region including the Indus river are fed by glaciofluvial streams and melting snow and as a result they respond to seasonal and diurnal variations likewise. Characteristically, glaciofluvial streams attain exceptionally high erosion rates during summer months not so much because of the monsoon rains but because of the rapid melting of winter snow and glacial ice. The same is reflected in the Indus river where the discharge increases 20-50 time and the sediment load 500-1000 times during summer (Ferguson, 1984).

Mountain glaciers in temperate climate, with high snowfall input and high ablation rates, tend to have high potential for erosion (abrasion) and transportation of debris than glaciers of other climatic regions. Thus in areas of active uplift such as the north Pakistan, this may result in abundant supra-glacial debris and high sediment load in the ensuing melt streams

(Derbyshire, 1984). Some of the sediment derived by rockfall or avalanches may not be readily transported by the streams but stored as lateral/terminal moraine or river terraces for sufficient length of time before being ultimately released due to intense rainfall or river flooding (Goudie et al. 1984b).

The Indus river rises on the Tibetan Plateau and after passing through Baltistan and Gilgit Agencies enters the NWFP through Kohistan district. Near Tarbela the Indus is dammed for flood regulation and electricity production. Downstream Tarbela it continues its journey through the remaining part of the province and enters Punjab near D.I.Khan. In between Tarbela and D.I. Khan, the Indus is joined by the Kabul, Haro, Soan, Kurram and Gomal rivers. Upstream Tarbela, the major tributaries of the Indus include Shyok, Shigar, Zaskar, Giligit, Hunza, Astor and Tangir rivers. According to Jorgensen et al. (1993) the Indus is a dynamic river which is evident from changes in its channel platform, flooding behavior and flow path. Several workers have reported the sediment load of Indus river, for instance Gibbs (1981), has given a figure of 1 million m^3 of sediment deposited on the alluvial plains and 175 million m^3 in the Arabian Sea. Similarly, Milliman et al. (1984), has estimated the sediment load of Indus, prior to the construction of barrages and dams to be, 270-600 million tonnes annually. In comparison the present day sediment load is reported to be 40-50 million tonnes annually (Arain, 1987; Qureshi, 1992).

The second largest river passing through NWFP is the Kabul river. It is a 700 km long river rising from the base of the Unai Pass in Paghman mountains, about 70 km west of Kabul city (Sabir, 1996; IUCN, 1994). Flowing east on the northern flank of Sufed Koh range, it enters Pakistan near Shalman in the Khyber Agency and joins the Indus at Kund about 70 km away from Peshawar. It has four major tributaries in Afghanistan namely, the Logar, Kunar, Panjsher and Alingar but the source of the Kunar river lies in the Hindukush range in Chitral (Pakistan) and is so known as the Chitral river. It drains an extensive area of high relief and snow cover in Chitral and subsequently contributes well over half of the discharge of the Kabul river. On entering Afghanistan near Arandu the Chitral river is called the Kunar river which joins the Kabul river near Jalalabad. About 30 km west of Peshawar, the Kabul river was dammed for irrigation and hydel power generation with an optimum capacity of 250,000 kW. However, due to extensive silting during the last thirty years, the reservoir is almost full and power generation has dropped to a range of 20,000-64,000 kW during winters and summers, respectively (Sabir, 1996).

Downstream Warsak the Kabul river is divided into three distributaries - the Sardaryab, Naguman and Shah Alam. The three branches converge into a single channel near Charsadda and are meanwhile joined by two more streams i.e., the Swat (locally known as Khiali river) and Bara rivers. The Swat river is formed by the union of Gabral and Ushu rivers at Kalam and flows southward past Mingora. Near Chakdara, two canals are taken out for irrigation of about 65,000 ha of land, and generation of 20,000 kW of hydel energy. The Panjkora river is an important tributary of the Swat river and drains the Dir district. The confluence of the two is at Kalangal village near the border of Bajaur and malakand agencies. The Bara river descends from Khyber hills and enters the Peshawar vale from southwesr near Jhansi post (Kruseman & Naqvi, 1988; Sabir, 1996).

The Kurram river again originates across the border in Afghanistan, on the southern slopes of the Sufed Koh range, it enters the Kurram valley and lower Wazir hills and flows through the Bannu basin. Five kilometers downstream Lakki, it is joined by the Tochi/Gambila river, which drains north Waziristan. It discharges into the Indus near Isa Khel. The WAPDA gauging station is located near Thal village on Thal Miranshah Road. The Gomal river also rises in Afghanistan in Khumbur Khule Range and enters Pakistan near Domandi, southwest of Wana (South Waziristan). Beyond this point it is joined by Kandar river, Wana Toi and Zhob river. It falls into the Indus just south of D.I.Khan after traversing a course of 240 km. The data of Gomal river included in this paper has been taken from Kot Murtaza Gauging station.

HYDROLOGICAL CHARACTERISTICS

Water Discharge

For the purpose of this paper, data of eight rivers of the northern Indus basin from nine gauging stations in NWFP have been selected. These data are compiled from "River and climatological data of Pakistan", volume 1 of the annual reports of the Surface Water Hydrology Project, WAPDA, for years 1970-1991. Tables 1&2 present a summary of various hydrological parameters covering a period of 22 years. The sediment data have been taken from WAPDA (1997a), a report covering the period from 1961-1990. Figures 1 and 2 show graphic representation of the mean annual and mean monthly discharges in m^3s^{-1} for the stations of the study area.

TABLE 1 HYDROLOGICAL CHARACTERISTICS OF DIFFERENT RIVERS FROM NORTHERN INDUS BASIN

River/Station	Drainage Area (km^2)	Mean Annual Runoff (MAF)	Mean Annual Discharge (m^3/s)	Maximum Instantaneous (m^3/s)	Summer to annual flow ratio %	Total suspended solids (million tonnes)
Indus/Besham	162400	61.00	2391.00	14294 (30-7-89)	85.0	218.18
Indus/Mandori	264000	87.00	3322.00	19880 (06-8-78)	75.0	196.36
Kabul/Noshera	88500	22.00	826.00	4757 (09-7-78)	82.0	36.60
Chitral/Chitral	11400	7.00	272.00	1586 (16-7-73)	82.0	21.00
Swat/Chakdara	5775	4.36	171.76	1331 (19-7-85)	82.8	1.21
Bara/Jhansi. Post	1846	0.16	4.70	569 (07-8-83)	69.6	1.01
Kunhar/G. Habibullah	2382	2.57	101.70	881 (14-7-91)	84.8	3.70
Kurram/Thal	5542	0.63	26.80	2073 (13-7-91)	60.6	3.21
Gomal/Kot Murtaza	36001	0.72	28.30	1614 (07-7-78)	72.1	30.09

TABLE 2

River/Station	Maximum Annual Discharge (m^3/s)	Minimum Annual Discharge (m^3/s)	Maximum Monthly Discharge (m^3/s)	Minimum Monthly Discharge (m^3/s)	Maximum Daily Discharge (m^3/s)	Minimum Daily Discharge (m^3/s)
Indus/Besham	3115 (1973)	1917 (1974)	7063 (July)	438 (January)	13842 (31-7-89)	362 (9-2-86)
Indus/Mandori	4700 (1973)	2530 (1982)	7428 (July)	1257 (January)	19257 (21-7-73)	158 (75)
Kabul/Noshera	1271 (1991)	555 (1982)	1856 (June)	232 (December)	4673 (09-7-78)	98 (28-2-82)
Chitral/Chitral	367 (1973)	221 (1982)	777 (July)	68 (March)	1535 (16-7-73)	54 (21-3-83)
Swat/Chakdara	251 (1991)	122 (1982)	399 (June)	40 (January)	1026 (14-7-91)	20 (28-1-87)
Bara/ Jhansi. Post	9 (1975)	1 (1985)	12 (April)	2 (December)	125 (07-8-83)	negligible
Kunhar/ G. Habibullah	144 (1991)	65 (1985)	282 (June)	23 (January)	749 (14-7-91)	24 (31-12-91)
Kurram/Thal	43 (1983)	15 (1983)	49 (May)	18 (January)	834 (13-7-91)	15 (22-2-83)
Gomal/Kot Murtaza	98 (1990)	6 (1974)	71 (July)	4 (October)	1020 (07-7-78)	0.62 (13-7-71)

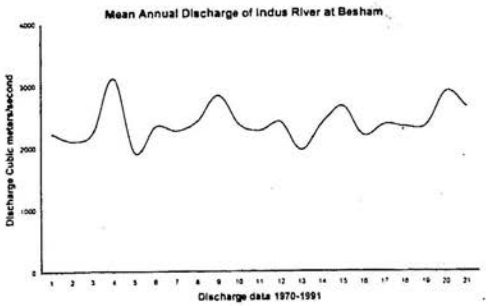

Fig. 1a. Mean Annual Discharge of Indus River at Besham.

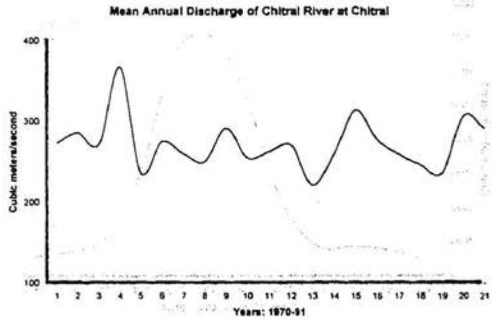

Fig. 1c. Mean Annual Discharge of Chitral River at Chitral.

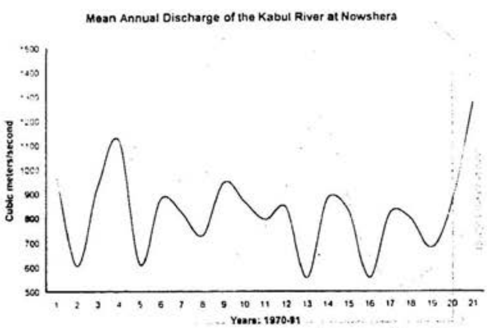

Fig. 1b. Mean Annual Discharge of Kabul River at Nowshera.

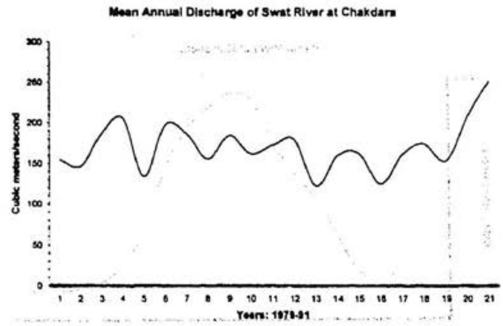

Fig. 1d. Mean Annual Discharge of Swat River at Chakdara.

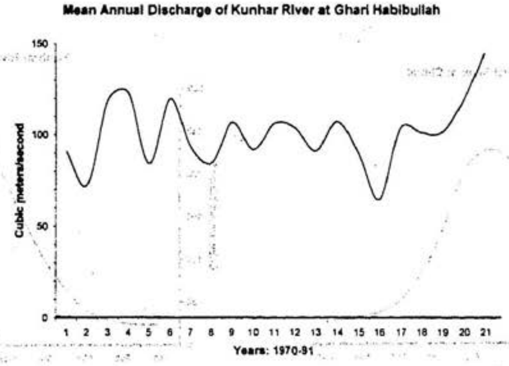

Fig. 1e. Mean Annual Discharge of Kunhar River at Ghari Habibullah.

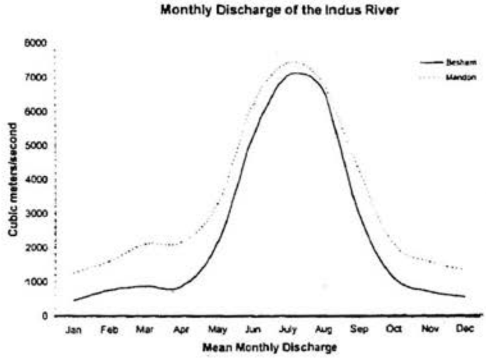

Fig. 2a. Mean Monthly Discharge of Indus River at Besham.

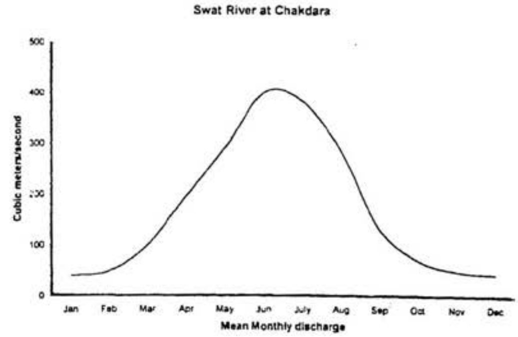

Fig. 2d. Mean Monthly Discharge of Swat River at Chakdara.

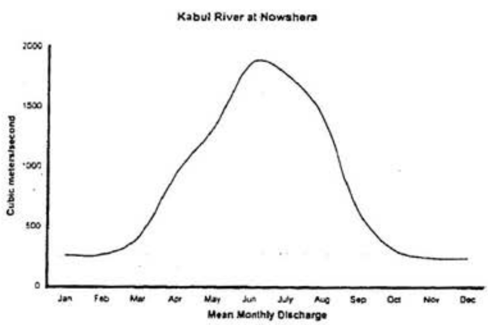

Fig. 2b. Mean Monthly Discharge of Kabul River at Nowshera.

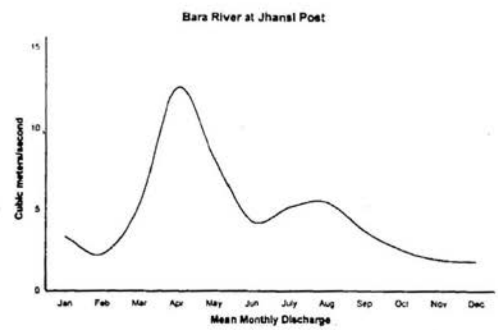

Fig. 2e. Mean Monthly Discharge of Bara River at Jhansi Post.

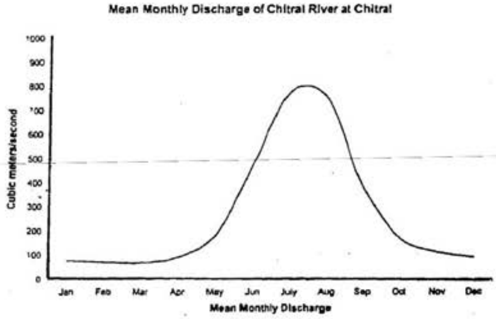

Fig. 2c. Mean Monthly Discharge of Chitral River at Chitral.

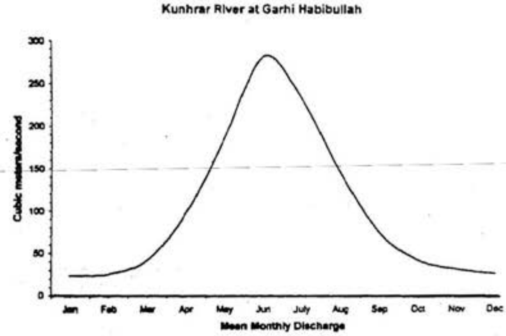

Fig. 2f. Mean Monthly Discharge of Kunhar River at Garhi Habibullah

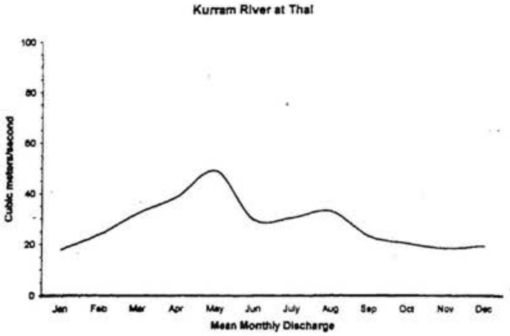

Fig. 2g. Mean Monthly Discharge of Kurram River at Thal.

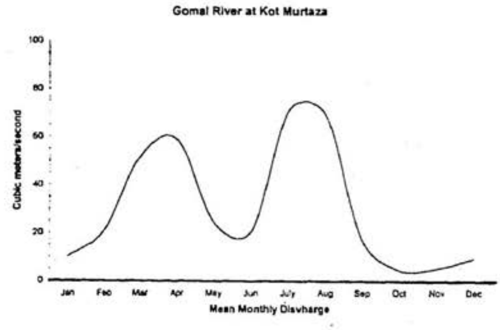

Fig. 2h. Mean Monthly Discharge of Gomal River at Kot Murtaza.

In order to examine the influence of rapid snow melting on river discharge during summer months, the percentages of the summer to annual runoff have been determined. This relationship shows that the more northerly rivers record > 80% runoff during the April-September period, whereas southern rivers (Bara, Kurram and Gomal) have < 80% runoff during summer which reflects upon their lesser dependence on the snow melt compared to the northern streams. The maximum instantaneous discharge of almost all rivers in the study area is recorded during July, which is a high flood month.

The flow of Indus river is natural (unregulated) up to Tarbela where the river has been dammed since 1974 to store water for irrigation and hydroelectric power generation. The average runoff into Tarbela has been 64 MAF since 1868, however, after 1974 the outflow has been regulated, released partly through the power house and two spillways. The data from next gauging station located at Mandori about 10 km downstream the confluence of the Kabul river with the Indus river, includes discharge of the Kabul river and its tributaries - Swat and Bara rivers - besides the regulated outflow from Tarbela.

The gross storage capacity of the Tarbela reservoir has been reduced from an initial 11.62 to 9.099 MAF during the last 25 years of its operation (WAPDA, 1997b). Thus, data from the Besham station is significant in terms of natural characteristics of the Indus river flow. It shows that during 1973 about 79.63 MAF of water was discharged from this station at a mean rate of 3115.2 m^3s^{-1}, whereas in 1990, the total flow was 73.9 MAF at 2890 m^3s^{-1}. As opposed to these higher values, low discharges of 49.01, 49.88 and 53.86 MAF were recorded during 1974, 1982 and 1971, respectively. The highest discharge of the Indus river at this station usually records during July when the mean flow exceeds 7000 m^3s^{-1}. It appears that more than 85% of the annual discharge takes place during the Kharif season while the remaining 15% flows during Rabi (Oct.-March). The highest discharge of Indus river at Mandori was 120.17 MAF during 1973, while the lowest was 64.65 MAF in 1982, including 28.59 and 14.2 MAF of the Kabul river, respectively.

It is evident from the data that the next important river after Indus is Kabul which drains an area of 88500 km^2 at its Noshera gauging station. During the 22 years' record, the maximum volume of water discharged in a single year has been 32.5 MAF during 1991, followed by 28.6 MAF during 1973. The minimum recorded runoff in this period has been 14.2 MAF in 1982 and 1985. The Kabul river usually swells to its maximum during the month of June when the discharge rate increases to a mean 1860 m^3s^{-1}. In 1973 about 6 MAF of water passed Noshera in June only. Upstream Noshera the Kabul river is fed by two other local tributaries i.e. the Bara and the Swat rivers. The earlier has a small catchment and discharge rate. The two maximum flood years of Bara are 1975 and 1983 when 0.23 and 0.18 MAF of water was discharged, respectively, while the smallest runoff (0.02 MAF) was recorded in 1985. It appears that the two streams flow out of phase as the usual flood month of the Bara river is April compared to the Kabul river's June. The record of Swat river from its Chakdara gauging station shows that the maximum runoff was recorded in 1991 (6.4 MAF) and minimum (3.1 MAF) in 1982. Likewise, the maximum discharge of the Swat river also takes place in June when its mean discharge reaches up to 400 m^3s^{-1}.

The Kunhar and Chitral are the next two rivers to the Kabul river in terms of their significance within the study area. The <200km long Kunhar river runs from Babusar pass to Domel (Muzaffarabad) and drains a catchment of just 2382 km^2 of the Kaghan valley in northern Hazara. After its union with the Neelum river it becomes an important tributary of the Jhelum river which has been dammed at Mangla since 1967 for irrigation and hydel power generation. On its way from > 4600 m high Babusar pass to Balakot, the Kunhar river receives its water and sediment supply from the glaciers and snow cover of the Lesser and Higher Himalayan peaks, details of which can be found in Spencer et al. (1991). It is very interesting to note that despite originating from a relatively smaller drainage of low relief compared to other streams, the specific discharge (ratio between annual runoff/catchment area) of this river is highest in the study area. Our estimates show that every square km area of the drainage basin discharges about 1080 acre feet of water annually. During the study period the minimum volume of water discharged in a single year has been 1.65 MAF during 1985, followed by 1.85 during 1971. Whereas, the maximum runoff during this period has been 3.7 MAF in 1991 followed by 3.15 MAF in 1973. The peak flood of this river usually records in June when its discharge increases to a mean 282 m^3s^{-1}, whereas, December is the least water contributor towards annual discharge of the river. The most devastating flood of this river is said to be that of 1992 which lead to a major loss of lives and property but the data are not yet published. However, August 10, 1969 and July 14, 1991 are the two other occasions when the Kunhar river recorded high discharges of 1158 and 881 m^3s^{-1}, respectively.

The Chitral river is formed by the union of Lutkho and Mastuj rivers near Chitral town. Its 11000 km^2 drainage basin comprises the northwestern NWFP i.e., the Chitral district and high altitude (> 6000 m) peaks of the Hindukush Range. The Mastuj river, larger of the two tributaries, drains the area northeast of the Chitral city and the Lutkho river collects water from northwest. The record shows that the mean annual runoff of the Chitral river, as measured at Chitral town, has been about 6.96 MAF but the extreme high and low flows of 9.4 and 5.66 MAF were recorded in 1973 and 1982, respectively. The other flood years of the Chitral river in order of decreasing discharge include 1984, 1990 and 1978. The highest ever discharge monitored at the Chitral gauging station is reported as 1586 m^3s^{-1}. The entire drainage basin of this river lies in arid climatic zone (<500 mma^{-1} rainfall) with 80% precipitation during the winter-spring period, yet about 82% of its annual discharge takes place during summer indicating the significance of the snow melt in river discharge.

The southern part of NWFP is drained by two important tributaries of the Indus river - the Kurram and Gomal rivers. Though the Kurram river rises in Afghanistan but its catchment largely comprises the North Waziristan agency and Bannu basin. Unfortunately, the only gauging station of the Kurram river is located at Thal which is far upstream of the confluence of the Kurram with its important tributary, the Gambila river. At Thal the catchment area is rather small i.e., 5542 km^2 and the mean annual runoff is 0.63 MAF . However, in 1983 about 1.1 MAF of water was discharged which is the highest known runoff of this station. Similarly, the lowest annual runoff, here, was during 1971 when only 0.37 MAF of water was discharged. The highest ever instantaneous flow was recorded on 13th July 1991 when the discharge rose to 2073 m^3s^{-1}. Interestingly, the maximum runoff of the Kurram river has been taking place in May and April as opposed to July/August of other rivers which indicates that its catchment (Sufed Koh range) has relatively less snow cover than the Himalaya or Karakoram region and most of it has already melted away before the peak summer arrives.

The most southerly of the studied rivers is the Gomal river with a mean runoff of 0.72 MAF per year. The two high flood years of the Gomal river have been 1990 and 1989 when 2.5 and 2.1 MAF of water was discharged from the Kot Murtaza gauging station, respectively. The lowest recorded flow has been 0.16 MAF in 1974. The highest flood months of the Gomal river are July and August indicating the influence of monsoon runoff while the lowest discharge is found in October. The exceptionally high discharge of July 1989, was 0.6 MAF . The highest ever discharge of this river is 1614 m^3s^{-1}, recorded on 7th July, 1978.

Sediment Load

Of the eight river included in this study, the smallest suspended load is found in the Swat river at Chakdara i.e., 1.2 million tonnes per anum (mta^{-1}) whereas, maximum load is found in the Indus river at Besham i.e., about 218 mta^{-1} (WAPDA, 1997a). In pre-Tarbela Dam days, WAPDA had a gauging station at Darband (in between Tarbela and Besham) where the mean annual suspended solids were about 287 mta^{-1}. However, after the Tarbela reservoir became operational, suspended solids of the Indus at Mandori (downstream the dam) abruptly dropped as the 15 year mean for 1974-87 was 52 mta^{-1}. Keeping the mean annual silting rate at 235 million tonnes (suspended solids) would result in 6 billion tonnes of sediment already deposited in the lake excluding about half a billion tonnes (calculated from Maddok, 1969) of the bed load during the 25 years of its operational age. WAPDA (1997b) estimates a loss of about 2.5 MAF (21.7%) in the gross storage capacity of the Tarbela reservoir since 1974.

A comparison of the mean annual sediment yield from various catchment basins shows that Chitral river has the highest sediment yield i.e., 1842 tkm^2a^{-1} (tonnes/square kilometer/year) followed by the Kunhar river i.e., 1553 tkm^2a^{-1}. The sediment yield of the Swat river has been found to be the least i.e., 209 tkm^2a^{-1}, indicating that its catchment basin is relatively stable in terms of soil erosion/denudation.

Sabir (1996), has estimated that the suspended sediment concentration of the Kunhar river at Garhi Habibullah has ranged from a maximum of 5.2 gl^{-1} (grams/litre) in early summer to 1.9 gl^{-1} in winters during 1994. This works out to a mean concentration of about 3 gl^{-1} per month. Multiplying this figure with the mean annual discharge (181 m^3s^{-1}) gives the total sediment load to be ~17 mta^{-1} as opposed to the WAPDA (1997) data which shows the same as 3.7 mta^{-1} (Table-1). The sediment load of 17 mta^{-1} translates into a yield of more than 7000 tkm^2a^{-1} which is one of the highest rates in Pakistan and reflects upon the severity of soil erosion in the Hazara region in general and Kaghan valley in particular due to extensive deforestation in recent years. It is possible that the difference between the two sediment yields is not an artifact of the calculation but actually soil erosion rates may have increased after 1990 where the WAPDA data ends. Abnormally high rates of soil erosion in Hazara have also been reported by Dijk & Hussain (1994), who have given a range of 15000-16500 tkm^2a^{-1}.

Hussain (1995) describes the Gomal river as notorious for its high concentration of total suspended solids and has placed it next to the Yellow river of China. Our compilation (Table-1) confirms the above and shows the Gomal river as ranking fourth in the list of studied streams with a mean annual load of 30 mta^{-1} or an average concentration of 41.8 gl^{-1}, which is certainly the highest in the study area. But because the Gomal river drains a 36000 km^2 area, its sediment yield (835 tkm^2a^{-1}) is less than the Kunhar and Chitral river stations which drain relatively smaller basins.

CONCLUSIONS

On the basis of the foregone analysis it is concluded that:

1. 1978, 1988 and 1990 have generally been years of high flood (above average discharge) as opposed to 1971, 1974, 1982 and 1985 which have been years of rather low (below average) discharge during the record period.

2. For most rivers of the region, the highest discharge occurs in the month of July but for southern rivers highest discharge may occur in June or May.

3. The ratio of summer to winter discharge varies from northern part of the basin to south. Most northern rivers have <80% flow during the Kharif season (April-September) and <20% during Rabi.

4. About 235 million tonnes of total suspended solids are deposited in the Tarbela reservoir annually, thus during the last 25 years of operation ~ 6 billion tonnes of sediment has been trapped in the lake resulting in about 2.5 MAF (21.7 %) loss in its gross storage capacity.

5. Kabul river is the largest tributary of the Indus river in this region while Bara river is the smallest river in terms of discharge and sediment load.

6. The Chitral river (at Chitral) is the most significant river in the study area in terms of its annual sediment yield. It yields the highest sediment load per square kilometer of the drainage basin (1842 tkm^2a^{-1}) indicating a very high denudation rate in the Chitral valley.

7. The Swat river (at Chakdara) has the lowest sediment load in the region.

8. The Gomal river (at Kot Murtaza) has the highest concentration of suspended solids of all the rivers in the study area with an average concentration of about 42 grams of sediment per litre of water.

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