

Hydro-meteorological Characteristics of Indus River Basin at Extreme North of Pakistan

Salma Khalid*, Muhammad Qasim and Dilawar Farhan

Department of Environmental Sciences, Abdul Wali Khan University, Mardan, Pakistan

Abstract

This paper presents the impact of climate change on three tributaries of Indus River, in four gauge stations, situated in the extreme North of Pakistan i.e. Himalaya, Karakoram and Hindukush ranges. The analysis revealed that change in temperature has a profound influence on the snow/glacial melt in comparison to the mean monthly rainfall. This is because majority of the northern area rivers are faded by the snow and glacial melt and receive a lot of snowfall from winter (Dec-Feb) to pre-monsoon (April-May). In studied rivers 21% of the times the discharge rate remain above the mean in the monsoon period (Jul-Sep), while 64% of the time the discharge is less than the mean in the pre-monsoon (April-May) period. It means that 15% of the time the discharge is in excess of 200 to 500% of the mean flow, indicating that a rise in water yield and river discharge rate due to increase in mean monthly maximum temperature. Higher water contribution rate was found in Astor and Indus/Skardu rivers with significant differences compared to other studied rivers. In monsoon period approximately 20% discharge rate was recorded with mean monthly maximum temperature (32°C) and rainfall (17 mm). In pre-monsoon period the discharge rate was (9%) at mean monthly maximum temperature (26°C) and highest mean monthly rainfall (32 mm). This shows that the transfer of climate change signals into hydrological changes is more significant and consistent among the studied rivers. Our findings are useful for hydropower, agriculture, watershed management sectors in the future planning. In countries like Pakistan, water resources estimation under climate change scenario is important for planning especially in dry season for sustainable food security and for operation of hydrological installations regarding electric power crisis.

Keywords: Indus River; Maximum temperature; Rainfall; Water discharge; Climate change

Introduction

Global warming induced changes in rainfall pattern and its combined impact on river flows are already evident in many parts of the world, particularly in South Asia. Heating of the earth is not only due to natural processes but mainly because of non-environment friendly anthropogenic activities [1]. Because of this phenomenon certain unpredictable changes occurred in the climate of Pakistan. Hazards like floods, droughts, cyclones and others adverse consequences are being experienced more frequently than ever before. Rising temperature and uneven temporal and spatial distribution of rainfall is causing floods on one hand and droughts on the other. Changes in water resources mainly depend on changes in precipitation and temperature and have direct effect on river discharge [2-6]. In countries like Pakistan the changes in temperature and the amount of precipitation could have diversified effects on river flows of arid and semi-arid regions of the country. This may be due to the melting of snow and glaciers at a higher rate and changes in precipitation patterns. Glaciers in Pakistan cover about 13,680 km² which is 13% of the mountainous regions of the Upper Indus Basin. Glacier and Snowmelt water from these glaciers contributes significantly to the river flows in Pakistan [7]. It has one of the largest river networks which consist of mainly; river Indus, river Jhelum, river Chenab, river Kabul, river Ravi and river Sutlej. Several tributaries of the two big rivers i.e. Indus and Kabul originate from areas included in extreme north of Pakistan. These two rivers are fed by the snow and glacial melt as receive a lot of snowfall in winter and the pre-monsoon dry season (April-May). The freshwater supply derived from snow and ice melt serves as a critical resource for irrigation and hydropower generation in the country. In addition, demand for agricultural and domestic water in particular increases significantly at hotter and drier times of the year as agriculture has always been the dominant user of surface water for irrigation. Meanwhile due industrial growth in the country water demand for the industry is also on rise

and might compete with agriculture and domestic water consumption. However, in regions where agriculture is heavily dependent on the timing of runoff, from winter accumulation and spring-melt, changes in temperature pose a greater difficulty for water management. During dry season the crops experience water stress because of the absence of precipitation, but can be supported by surface and groundwater irrigation from glacial melt [8].

According to IPCC [9] report, the effect of temperature and precipitation is more pronounced in stream flow volume as well as its distribution in hydrological cycle throughout the year and temporally causing significant water stress. Furthermore, Kundzewicz et al. [10] describe in a report that discharge in glacier fed Rivers will remain increase in the short term but decrease over the next few decades as slowly and gradually ice storage will diminished. In short the glaciers are vital for the Indus River and once they retreat, the water supplies in Pakistan will be scarce. Therefore, we attempted to investigate the temporal variations and trends of the river discharge of the major glacier melt basins in the upper Indus catchments and also to find out the influence of temperature and rainfall on discharge rate. In this way the present study will be useful for hydropower, agriculture, watershed management sectors in the future planning, because in Pakistan, water resources estimation under climate change scenario is important

***Corresponding author:** Salma Khalid, Department of Environmental Sciences, Abdul Wali Khan University, Mardan, Pakistan, Tel: +92-937-9230657-8; E-mail: anagalious_79@yahoo.com

Received September 12, 2013; **Accepted** November 07, 2013; **Published** November 14, 2013

Citation: Khalid S, Qasim M, Farhan D (2013) Hydro-meteorological Characteristics of Indus River Basin at Extreme North of Pakistan. J Earth Sci Clim Change 5: 170. doi:[10.4172/2157-7617.1000170](http://dx.doi.org/10.4172/2157-7617.1000170)

Copyright: © 2013 Khalid S, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

for planning especially for food production and for electric power generation in the country.

Description of Study Area and Rivers

Pakistan experiences diversified climate due to its large latitudinal extent from north to south and also due to large variations in the topography. Pakistan is geographically situated approximately between 24-37°N latitudes and 62-75°E longitudes in the western zone of South Asia. The country is bordered by Iran on the west, India in the east, Afghanistan in the northwest, China in the north and the Arabian Sea in the south. The plains of Pakistan, drained by the river Indus and its tributaries, are surrounded by many mountain ranges in the north, northwest and the west [11]. Because of high altitude, precipitation mostly comes in the form of snowfall that feeds snowfields and glaciers of Himalaya and Karakoram ranges. The Indus River is a major river which flows through Pakistan. It also has courses through western Tibet in China and Northern India. Originating in the Tibetan plateau and runs in a course through the Ladakh region of Jammu and Kashmir, and enter in extreme north of Pakistan through Skardu region and flows to merge into the Arabian Sea. The total length of the river is

3,180 km and has a total drainage area exceeding 1,165,000 km². Its estimated annual flow stands at around 207 km³, making it the 21st largest river in the world in terms of annual flow. For present study, three rivers having four gauge-stations from northern areas of Pakistan have been selected (Figure 1). Their longitude and latitude and other basic geographical information are shown in Table 1.

Astor river

Astor River a tributary of the Indus River rises in a glacier on the north-facing slopes of the great Himalayan range near the Burzil Pass in the Ladakh region of Jammu and Kashmir. It flows in northwest direction and joins Gilgit River at coordinates between 34°00' and 74°41'. Many small snow-fed streams originating from different depressions on the great Himalayan range join the Astor River in its short course.

Gilgit river

Gilgit River is a tributary of the Indus River, and flows through the town of Gilgit. It is located in the Northern Areas of Gilgit-Baltistan, Pakistan. The Gilgit starts from Shandur Lake. Gilgit River



River	Gauge Station	Basin	Catchment area (km ²)	Altitude (m)	Latitude	Longitude	Dominant source in Summer	Dominant source in Winter	No. of meteorological stations
Astor	Doyan	Indus	4040	1550	35° 31'	74° 44'	Snow/Glacier melt and no influence of Monsoon	Winter rainfall+Base flow	1
Gilgit	Alam Bridge	Indus	25900	1295	35° 45'	74° 37'	Snow/Glacier melt and no influence of Monsoon	Winter rainfall+Base flow	2
Indus/ Skardu	Kachura	Indus	112665	2341	35° 27'	75° 25'	Snow/Glacier melt and no influence of Monsoon	Winter rainfall+Base flow	1
Indus/ Chilas	Partap Bridge	Indus	142709	1100	35° 44'	74° 37'	Snow/Glacier melt and no influence of Monsoon	Winter rainfall+Base flow	1

Source: Pakistan Water and Power Development Authority, 1990

Table 1: Characteristics of the study area.

at Alam Bridge is a junction point between Indus and Gilgit rivers at coordinates between 35°45' and 74°37'.

Indus river/Skardu

Indus River at Skardu located between coordinates 35°27' and 75°25' on right bank 32.18 km downstream from Skardu town, 3.22 km upstream Ayub bridge on Kachura Kuwardo road.

Indus river/Chilas

Indus River at Chilas station coordinates at 35°44' to 74°37' over the old suspension bridge, historically known as Partab Bridge, it forms part of Astor district of the Gilgit-Baltistan region. The Gilgit River joins the Indus a few kilometres above Bunji, while the Astor River falls into the Indus a little below Bunji from the south-east.

Data and Methodology

For the present study, river discharge time series with record length of twenty five years from 1976-2000 has been selected for northern area rivers of four different gauge-stations. The river discharge data is acquired from Water and Power Development Authority (WAPDA) of Pakistan while temperature and rainfall data are acquired from Pakistan Meteorological Department (PMD).

Data quality and statistical analysis

Temporal changes and trends determination in hydro-meteorological parameters are sometime complicated due to missing values, seasonal and other short-term fluctuations in temperature

and rainfall and lack of homogeneity of the data e.g. due to changes in instrument and observation techniques and location change of the climate station and river gauge station. The time series used have been chosen according to the PMD and WAPDA data quality check and in function of the length of the period of records and homogeneity of time series. All time series used are continuous from 1976 to 2000, as the PMD and WAPDA have estimated the missing values. For statistical purpose Analyses of Variance (ANOVA) test along with Duncan Multiple Range test, using SPSS version 20. ANOVA test is designed for the situations in which we obtained a significant value and difference among the means of more than two groups (with and within the groups) by assuming equal variances or normal distribution of the data. In this sense, the application of statistical test makes it easy to compare the means of different periods and to assess the significance of the changes for each station has been used to identify the significant trend in entire study period. Hydro-meteorological characteristics of each river have been determined through water yield calculation and basin analysis.

Results and Discussion

Hydro-meteorological characteristics

Hydro-meteorological characteristics have been determined through water yield/contribution per annum in catchment's basin and each river basin analysis (Tables 2 and 3).

Water Yield calculation

For computing the daily water yield D, an annual average value

Rivers (m ³ /s)	Astor	Gilgit	Indus/Skardu	Indus/Chilas
Mean	138	613	1091	1786
Sig.	0.00**	0.51	0.01*	0.39
Catchment's area (Km ²)	4040	25900	112665	142709
Water yield per annum	1,074,488	746,271	305,434	394,714

** indicates the most significance level (p<0.05).

Table 2: Water yield per annum in Catchment's Basin.

Rivers	Hydro-meteorological characteristics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Astor River													
	Min temp	-6.63	-6.14	-1.5	4.1	7.4	11.12	13.42	14.3'	9.94	4.71	-1.1	-4.6
	Max temp	2.53	4.25	8.5	15.2	19.7	24.4	27.21'	27.05	23.44	17.7	11.3	5.67
	Rainfall	46.02	44.12	88.93'	78.93	66.02	27.76	26.13	33.34	28.05	23.6	27.54	35.18
	Discharge	31.53	28.78	29.9	56.71	183.92	372	408.72'	261.48	130.26	65	46.71	36.76
Gilgit River													
	Min temp	-1.98	-0.06	5.48	8.81	11.67	14.62	17.41'	17.2	12.44	6.28	0.24	-1.63
	Max temp	10.06	12.44	17.7	24.45	28.91	33.96	36.43'	35.33	32.09	25.5	18.52	12.18
	Rainfall	4.57	7.16	13.1	26.29'	31.9	9.96	15.59	19.63	11.84	9.53	5.68	8.75
	Discharge	115.9	102.06	95.3	124.85	422.81	1222	2029.36'	1791	821.46	310	181.43	138.02
Indus River/Skardu													
	Min temp	-7.76	-4.42	1.6	6.62	9.93	13.12	16.46'	15.74	11.44	4.19	-1.51	-5.14
	Max temp	2.99	5.93	12	19.23	23.75	28.83	32.07'	31.35	27.75	20.6	13.64	6.94
	Rainfall	34.3	27.1	37.35'	28.22	25.24	11.15	11.38	15.75	11.89	16.4	14.53	21.06
	Discharge	200.82	186.25	184	260.9	821.58	2123	3460.96'	3234.8	1532.32	520	325.52	244.27
Indus River/Chilas													
	Min temp	1.66	4.29	8.42	14.26	18.8	24.03	27.49'	26.48	22.64	14.8	7.7	2.38
	Max temp	11.1	14.44	19.2	26.05	31.15	36.98	39.48'	38.43	35.08	28.2	20.88	13.9
	Rainfall	14.53	15.3	27.1	40.5'	26.3	14.49	14.42	11.08	7.31	15.3	17.31	16.27
	Discharge	344.94	312.72	307	413.71	1249.1	3660	5675.64'	5230.4	2424.24	875	532.5	409.61

* Indicates significant value (p<0.05).

Table 3: Mean monthly analysis of Northern area Rivers.

X was calculated from the mean annual values of different years. This average value was then multiplied with the factor 86400 (seconds are changed into days) to get amount of water in cubic meters per day Y. Y was then divided by the catchments area Z of a particular station to get daily yield in m³ of the catchment area.

$$D=Y/Z$$

Where (Y=X*86400)

River basin analysis

In this section characteristics of each river basin along with their temperature and rainfall record have been described to examine their influence on the river flow (Table 2).

Astor river: The mean annual discharge rate of Astor River is approximately, 138 m³/s (Table 2), whereas the maximum discharge of 400 m³/s takes place in July while the minimum discharge or base flow is recorded in February i.e. approx. 29 m³/s (Table 3). A comparison of the mean monthly maximum temperature of Astor station for the month of July with the discharge of Astor river for the same month corresponds very well because the temperature of July (27.21°C) is highest among all the months. In similar manner, the Figure 2 shows that 49% flow takes place in the monsoon period i.e. Jul-Sep while 36% flow is received in the pre-monsoon period (Apr-Jun). The flow duration curve for Astor River (Figure 3) indicates that approximate 20% of the time the discharge remains above the mean while 65% of the time the discharge is less than the mean. It also shows that up to 15% of the time the discharge in access of 200 to 500% of the mean flow.

Gilgit river: Likewise, the Gilgit River shows the maximum discharge rate in July i.e. approximately 2030 m³/s with highest mean maximum temperature of 36°C while minimum discharge rate is recorded in March (95 m³/s) with mean maximum temperature of 18°C (Table 3). Further mean annual discharge rate from 1976-2000 is found 613 m³/s as indicated in the Table 2. The Figure 2 shows that 63% flow takes place in the monsoon period i.e. Jul-Sep while 25% flow is received in the pre-monsoon period (Apr-Jun). The flow duration curve for Gilgit River (Figure 3) indicates that approximate 25% of the time the discharge remains above the mean while 60% of the time the discharge is less than the mean. It also shows that up to 15% of the time the discharge in access of 200 to 500% of the mean flow.

Indus river/Skardu: As shown in Table 2 the mean annual discharge rate of Indus River at Skardu is approximately 1091 m³/s, whereas the maximum discharge of 3461 m³/s takes place in July with mean monthly maximum temperature 32°C and average rainfall 11 mm while the minimum base flow is recorded in March i.e. approximately 184 m³/s with mean monthly temperature 12°C (Table 3). Similarly 24% flow is received in the pre-monsoon period (Apr-Jun). The flow duration curve for Indus River (Figure 3) indicates that approximate 20% of the time the discharge remains above the mean while 65% of the time the discharge is less than the mean. It also shows that up to 15% of the time the discharge in access of 200 to 500% of the mean flow.

Indus river/Chilas: The data of Indus River at Chilas station indicates the mean annual discharge of 1786 m³/s (Table 2) with monthly variance ranging from a maximum of 5657 m³/s in July to a minimum of 307 m³/s in March (Table 3). It has also been observed that July is the hottest and driest month of the year having maximum temperature of 39°C and 14 mm of average rainfall whereas the mean maximum temperature of March is about 19°C and an average of 27 mm rainfall. Hence it is clear from the Figure 2 that maximum flow (62%) takes place in the monsoon period i.e. Jul-Sep followed by 25% flow

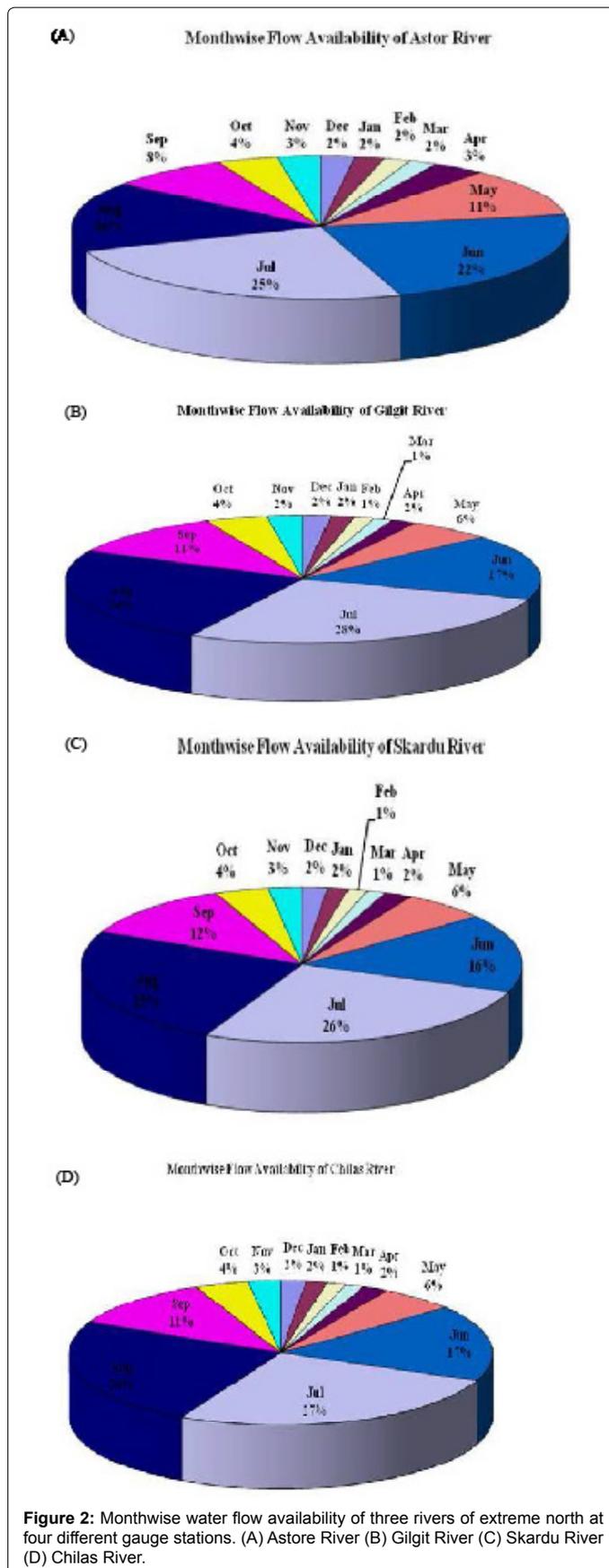


Figure 2: Monthwise water flow availability of three rivers of extreme north at four different gauge stations. (A) Astore River (B) Gilgit River (C) Skardu River (D) Chilas River.

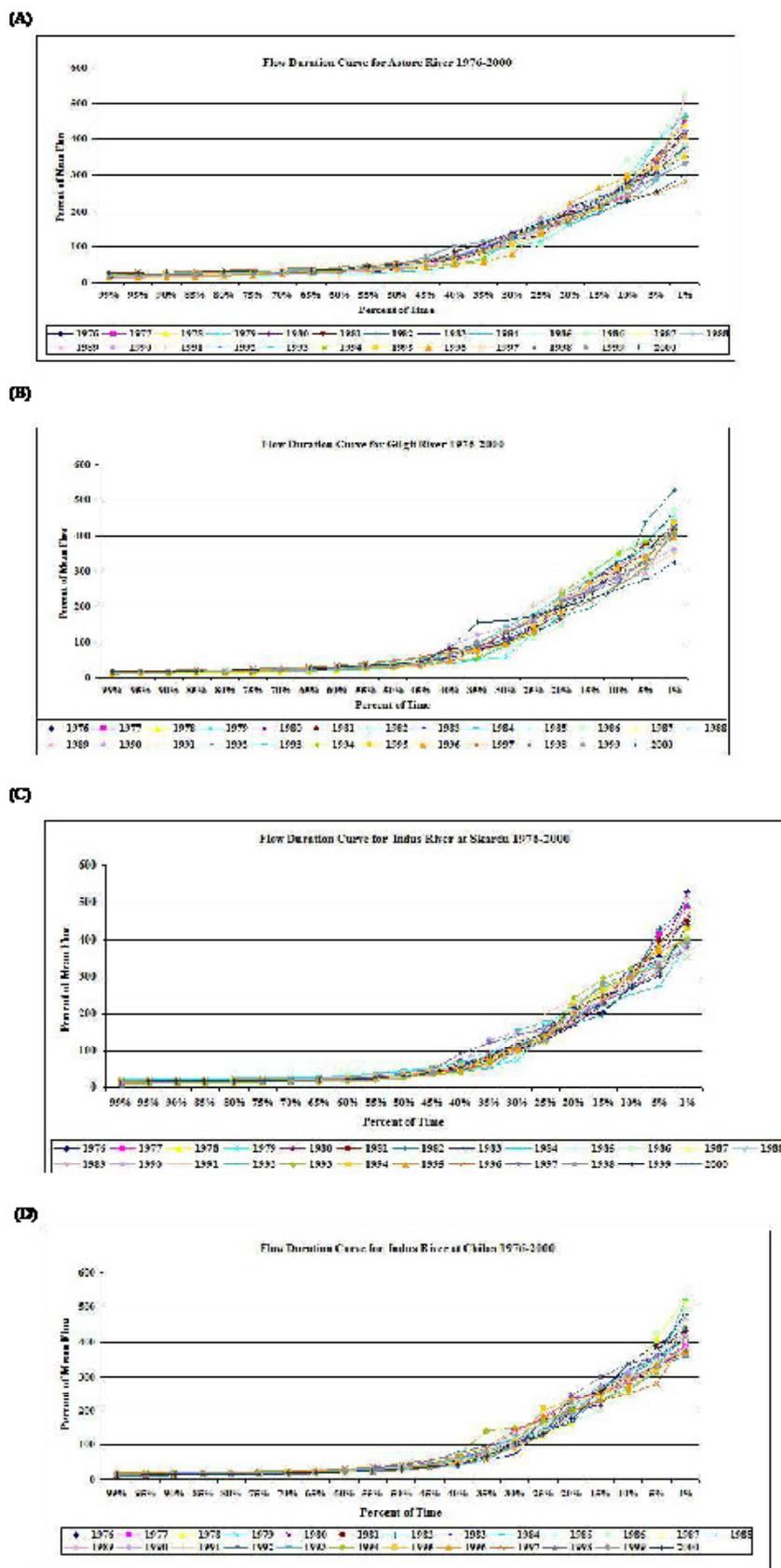


Figure 3: Flow duration curves for three rivers of extreme north at four different gauge stations. (A) Astor River (B) Gilgit River (C) Skardu River (D) Chilas River.

in pre-monsoon period. The flow duration curve (Figure 3) indicates that the discharge remains above the mean approximately 20% of the time while 65% of the time the discharge is less than the mean value. It also shows that up to 15% of the time the discharge is in excess of 200 to 500% of the mean flow. From the river basin analysis, it is clearly manifested by the data that mean monthly maximum temperature (32.14°C) has strong influence on river discharge (2250.1 m³/s) and impact of rainfall (17.2 mm) is relatively small because large bulk of river discharge occurs during monsoon season (Jul-Sep) due to snow/glacial melt. While in pre-monsoon period (April-Jun) mean monthly maximum temperature record (26.05°C) and mean monthly discharge rate is less approximately 909.2 m³/s as compare to mean monthly rainfall (32.23 mm). The present study is found most consistent with the global studies of Probst and Tardy [12,13]. They examined discharge records of 50 large rivers for influence of rainfall on flows. They observed increasing river flows over 1910-1975 in Africa and America, decreasing flow in Europe and Asia, and 3% linear increase worldwide over the study period, which they attributed to the global warming. Similarly Labat et al. [14], analyzed runoff records of 221 large rivers, for the periods 1900-1975 and 1925-1994. They observed increasing flow rates in Africa, America and Asia and decreasing flows only in Europe, a global increase of 3% over 1900-1975 and 8% over 1925-1994, because of accelerated hydrologic cycle caused by global warming. During the past two decades numerous studies have been conducted on the hydrological effects of climate change [15-23] from different regions of the world. These studies mainly focus on the effects of changes in temperature and precipitation on mean monthly, seasonal, or annual river flows. Similarly in Pakistan Rehman et al. [24] have reviewed discharge characteristics and suspended load of the northern Indus basins and concluded that most of the area show highest discharge during the July and the summer to total ratio for most of the northern rivers is >80%.

Conclusion

Variability in river flow was determined for four gauge stations of those rivers whose headwater regions lie in the extreme north of Pakistan. Influence of temperature and rainfall on river discharge and water yield per annum have been determined through hydro-meteorological characteristic of each river basin analysis. The results of the study revealed that Astor River and Indus River at Skardu contribute largest volume of water and appear considerably significant among all studied rivers in the study area. Most of the studied rivers show peak flow (19.65%) in the months of Monsoon period while lowest discharge approximately 9.25% in the months of Pre-monsoon period instead of higher value of mean monthly rainfall (32.23 mm). It means that large bulk of river discharge occurred in the months of monsoon period under the strong influence of increased temperature and relatively low impact of rainfall. Further in all studied rivers 15% of the time the discharge is in excess of 200 to 500% of the mean flow. From the present study it is concluded that a rise in temperature would enhance the glacier/snow melting on one hand and on other hand increase the discharge rate and shortened the snow fall period. All these changes will further pose severe risks to agriculture and water management sectors and require proper management and further research.

References

1. Rasul G, Chaudhry QZ (2006) Global Warming and Expected Snowline Shift along Northern Mountains of Pakistan. Proceedings of 1st Asia climatic Symposium, Yokohama, Japan.
2. Lai M, Whetton PH, Pittodi AB, Chakraborty B (1998) The greenhouse gas induced climate change over the Indian Sub-continent as projected by GCM

model experiments. *Terrestrial, Atmospheric and Oceanic Sciences*, TAO 9: 663-666.

3. Vörösmarty CJ, Green P, Salisbury J, Lammers RB (2000) Global water resources: vulnerability from climate change and population growth. *Science* 289: 284-288.
4. Bart -Nijssen G, O'Donnell M, Alan FH, Dennis P, Lettenmaier C (2001) Hydrologic sensitivity of global rivers to climate change. *Climate Change* 50: 143-175.
5. Allen MR, Ingram WJ (2002) Constraints on future changes in climate and the hydrological cycle. *Nature* 419: 224-232.
6. Akhtar M, Ahmad N, Boojij MJ (2008) The impact of climate change on the water resources of Hindukush-Karakorum-Himalaya region under different glacier coverage scenarios. *J Hydrol* 355: 148-163.
7. Shakir AS, Rehman H, Ehsan S (2010) Climate change impact on river flow in Chitral watershed. *Pak J Engg & Appl Sci* 7: 12-23.
8. Rasul G, Dahe Q, Chaudhry QZ (2008) Global Warming and Melting Glaciers along Southern Slopes of Hkh Ranges. *Pak J Met* 5: 63-76.
9. IPCC (2001) Climate change, The IPCC 3rd assessment report. In: Houghton JT, Ding Y, Griggs D, Noguet M, Vander LP, et al. (eds) Cambridge: Cambridge, University Press. UK.
10. Kundzewicz ZW, Mata LJ, Arnell NW, Döll P, Kabat P, et al. (2007) Freshwater resources and their management. In: *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.
11. Rodo X (2003) Global Climate Current Research and Uncertainties in the Climate System, University of Barcelona Climate Research Group Baldiri Rexac, Torre D, Barcelona Spain.
12. Probst JL, Tardy Y (1987) Long range stream flow and world continental runoff fluctuations since the beginning of this century. *J Hydrology* 94: 289-311.
13. Probst JL, Tardy Y (1989) Global runoff fluctuations during the last 80 years in relation to world temperature change. *Am J Sci* 289: 267-285.
14. Labat D, Godderis Y, Probst JL, Guyot JL (2004) Evidence for global runoff increase related to climate warming. *Adv Water Res* 27: 631-642.
15. Nemec J, Schaake JS (1982) Sensitivity of water resources systems to climate variation. *Hydrol Sci* 27: 327-343.
16. Mather JR, Feddema J (1986) Hydrologic consequences of increases in trace gases and CO₂ in the atmosphere. In: *Effects of changes in stratospheric ozone and global climate*, Washington DC, USA.
17. Gleick PH (1986) Methods for Evaluating the Regional Hydrological Impact of Global Climatic Changes. *J Hydrology* 88: 97-116.
18. Gleick PH (1987) Regional Hydrologic Consequences of Increases of Atmospheric CO₂ and Other Trace Gases. *Climatic Change* 110: 137-161.
19. Gleick PH (1999) Introduction: Studies from the Water Sector of the National Assessment. *Am Water Res Assoc* 35: 1297-130.
20. McCabe GJ, Ayers MA (1989) Hydrologic effects of climate change in the Delaware river basin. *Water Res Bull* 25: 1231-1242.
21. Lettenmaier DP, Gan TY (1990) Hydrologic sensitivities of the Sacramento-San Joaquin River basin. *Water Res Resid* 26: 69-86.
22. Schaake JS (1990) From climate to flow. In: Waggoner PE (ed) *Climate change and US water resources*, John Wiley, New York, USA.
23. Ayers MA, Wolock DM, McCabe GJ, Hay LE, Tasker GD (1994) Sensitivity of water resources in the Delaware River basin to climate variability and change, US Geological Survey Water Supply paper: 2422, Reston, VA, USA.
24. Rehman SS, Sabir MA, Khan J (1997) Discharge characteristics and suspended load from rivers of northern Indus basin, Pakistan. *University of Peshawar, Geology Bulletin* 30: 325-336.

Citation: Khalid S, Qasim M, Farhan D (2013) Hydro-meteorological Characteristics of Indus River Basin at Extreme North of Pakistan. *J Earth Sci Clim Change* 5: 170. doi:[10.4172/2157-7617.1000170](https://doi.org/10.4172/2157-7617.1000170)