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Indus Basin Dependency on Mountain Waters: Assessment of Future Water Availability and Its Effect on Large Reservoirs Proposed Under Pakistan Water Vision 2025.

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Abstract: The mountainous region of Upper Indus Basin is critical water supply source for Indus River System and thus for Pakistan. The future water availability scene for proposed reservoirs are investigated through the potential impacts of climatic change on flow regime of Hunza basin under hypothetically generated climate change scenarios simulated through the application of the semi-distributed hydrological model PREVAH over a period of 10 years and consequent impact upon flow regime of main Indus River. The adopted climate scenarios ranging from 1 to 4°C temperature change are based on ensemble of 9 global model predictions for the studied region in 21st century. Under all adopted scenarios, total stream flow produces an early response along with a change in their runoff distribution. The early and extended ablation period for snow and ice melt have significantly enhanced water availability in main Indus River. The flow pattern of Indus River and its tributary Hunza shows identical percentage change in their monthly contribution to respective annual flow volumes, as major contribution in both rivers comes from snow and ice melt runoff. The regression coefficient was above 90%. The relationship was used to estimate the water availability in main Indus River. An increase of 1 to 4°C have resulted in net increase of about 2.35 to 11.84 BCM in winter flows and 15.51 to 58.71 BCM in summer flows, while 17.86 to 70.56 BCM increase were recorded in mean annual flows. The mean annual figure of Indus River, even at 1°C shows sufficient water availability for proposed reservoirs. Based on current Indus River data analysis and future water availability scene under warmed scenarios, the government's decision to develop new reservoirs as to meet future demands through tapping part of 42 BCM unutilized water flowing to Arabian Sea, seems justifiable and also viable in changing climate. In nutshell, the increased snow and glacier melt runoff and resulting massive increase in summer flows justifies the construction of new reservoirs, as it will not only reduce the threat of floods but enhance the present capacity of regulating and utilizing surpluses water for crop irrigation in much needed times particularly during low flow period of the winter and early and late summer season.

Keywords: Climate change; mountain hydrology, future water resources

1. INTRODUCTION

Irrigated agriculture is the backbone of Pakistan's economy, which is heavily dependent on an annual influx of water from mighty Indus River and its tributaries originate in the northern and northwestern parts of the country commonly known as Hindukush-Himalaya (HKH) region. Therefore, the Indus water system is the lifeline for Pakistan's agriculture economy. The flow regime is highly erratic and seasonal. The average annual water available in the river system is 172 BCM; of which 130 BCM is diverted into irrigation systems and 42 BCM escapages to the sea. Out of the total annual flows; about 84% are available in Khareef season and 16% in Rabi season. The crop water requirements in Kharif and Rabi season is about 95 and 35 BCM respectively. The additional Rabi crop water requirements are met through large reservoirs constructed over Indus River and its tributaries. The three reservoirs with total capacity of 19 BCM, provides continuous supply in low flow periods (Rabi season). Since, development of last reservoir in 1976, three reservoirs have lost 26% of their total storage capacity due to siltation. It is estimated that by the year 2025, this loss would increase to almost 75% of the original combined storage capacity of three reservoirs. The decreasing capacity of existing reservoirs due to siltation on one hand and lesser rainfall than the normal on other hand are all resulting in sever short falls in canal water supplies. Over recent years, water supply shortages are identical. Many authors have reported shortages of the order of 15 to 50 per cent in Rabi from October to March, and early Khareef in April and May (Javaid and Yamin 2003). Due to severe water shortages, Pakistan's annual GDP growth rate, which is directly linked with agricultural development, has drastically fallen to 3.5%, once consistently growing at 5-7 % in last one decade. On the basis of current water shortages and rapidly increasing future demands, the experts have foreseen that this situation would simply be unsustainable for the agriculture, thus Pakistan could soon become one of the food deficit countries in the near future. The damming of unutilized Indus water; with sizeable surplus of about 42 BCM still going out to sea, and 30,000 MW of economically developable hydropower potential provides the only left over opportunity to bridge the widening inter-seasonal supply-demand gap and to harness and regulate all available river surpluses. Therefore, in context of

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current water shortages, future water needs, food security as well as hydropower and flood control requirements, the Pakistan Water and Power Development Authority (WAPDA) have devised a 25 year gigantic National Water Resources and Hydropower Development Program—Vision 2025. The vision encompasses the development of additional reservoirs, introduction of water efficient techniques, reduction in conveyance losses, lining of water canals and distributaries and institutional strengthening etc. However, the prominent feature of this report is its focuses on development of 23 BCM new storage reservoirs in next 25 years. However, many experts and organizations have raised serious concerns and doubts over future water availability for proposed reservoirs on Indus River and its tributaries. The latest IPCC assessment report (2007) clearly indicated that the mountain river basins are inherently the most sensitive to climate change, and this sensitivity will particularly be crucial for snow/ice melt dominated runoffs. Due to substantial contribution from snow and glaciers, the flow regime of Indus river system is expected to be extremely vulnerable to climate change and can have serious implications on downstream water resources development and management programs. In such uncertainty, a review of historical flow data analysis and understanding of possible changes in future water resources are the key before successful commissioning of such mega projects. The objective of this study is to assess the viability of this project- current water availability for proposed large reservoirs through available historical data analysis and to scrutinize the future water availability scene under different warmer climate change scenarios. This study will provide analysis to make informed, robust decisions on adaptation and mitigation strategies to cope with any expected future changes in water availability scenarios for proposed project.

2. MATERIAL AND METHODS

Current Water Availability Scene for Proposed New Reservoirs

The flow regime of Indus river system i.e. the Indus river and its tributaries are highly seasonal and erratic **(Fig 1 and 2)**; with the highest flows occurring between June and September, when ice and snowmelt on the mountains cause a combined peak discharge, while minimum flows occur during winter months, e.g., November to February, when the mean monthly flows are less than one fifth of those in summer. Based on 78 years (1931-2008) annual data; 172 BCM average annual water is available in river system, of which 130 BCM is diverted into irrigation systems and 42 BCM escapages to the Arabian Sea. This escapages level exceeds 110 BCM in wet years **(Fig 2)**. The highest maximum flow in the recorded 78 years history was 231 BCM in 1959-60 as against the minimum of 120 BCM

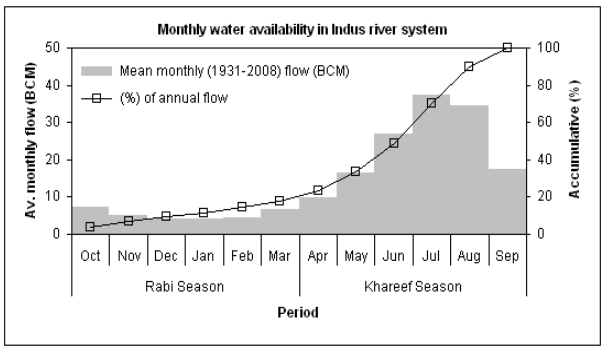


Fig. 1 Mean monthly percent of accumulated flow and average monthly volume in Indus river system for period of 1931-2008.

in the year 2001-02. The recorded average Kharif flow is about 144 BCM, while in Rabi season it is around 28 BCM. Out of the total annual flows; about 84% are in Kharif season and 16% in Rabi season. During Kharif season the maximum flow of 191 BCM was recorded in the year 1959-60 as against minimum of 98.6 BCM in the year 2001-02, while in Rabi season the highest flow was about 43.4 BCM in 1990-91 as against minimum of 19.43 BCM in 1971-72 **(Fig. 2)**. The monthly figure

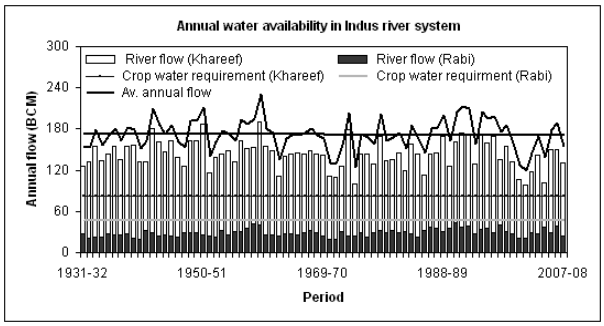


Fig. 2 Mean annual & seasonal flow in Indus river system for period of 1931-2008 and present seasonal crop water requirements.

shows that more than 65% of annual water flows in Indus, is available over very short span of 8-10 weeks from June to August, while the remaining nine months period only constitutes 34% of total flow. The variability in river flows is a major limitation in the development of run of river type irrigated agriculture, particularly to meet crop irrigation requirements in low flow period of Rabi season and early and late Kharif season. The construction of three reservoirs, Chashma (0.89 BCM) in 1967, Mangla (6.59 BCM) in 1967 and Tarbela (11.9 BCM) in 1976 have provided a great control and capability to store surplus water available in flood season and utilize in low flow periods i.e. low periods of Rabi from October to March, and the sowing Kharif period in April and May. After construction of these dams, the severe shortages in Rabi season have been eased to great extent and the area under cultivation is increased from 23 million acres in mid 60s to 36 million acres today. The annual canal diversion of 91.3

BCM in 1966 now has been reached to 130 BCM today. The water supply contribution in critical Rabi season is jumped from 27.3 BCM of pre dam period (1931-67) to 39.3 BCM of post dam period (1976-08) **(Fig 3, 4)**. The river contribution in Kharif period is also increased from 64 BCM in pre dam period to 83 BCM of 34 year post dam period. The average post dam (1976-08) discharge has been increased by 44% in Rabi and 30% in Kharif, where as annual withdrawals have been improved by 30%. Since last 34 years, after development of last reservoir in 1976, three reservoirs have lost almost about 5.0 BCM or 26% of their storage capacity due to siltation (Fig 4).

It is estimated that by the year 2025, (**Fig. 3)** this loss would increase to 14.5 BCM, almost 75% of the original combined storage capacity of three reservoirs. With a large arable land, Pakistan still has the potential of bringing several million acres of virgin land under irrigation. Although river flows are fully utilized, large chunk of flood water in Kharif period is still unexploited and escapages to Arabian Sea. After adjustment of current 85 BCM Kharif crop water requirements, 45 BCM Rabi crop water requirements and 12 BCM release for Indus deltaic region allocated under Indus water distribution accord 1991, still 30 BCM water remain unexploited.

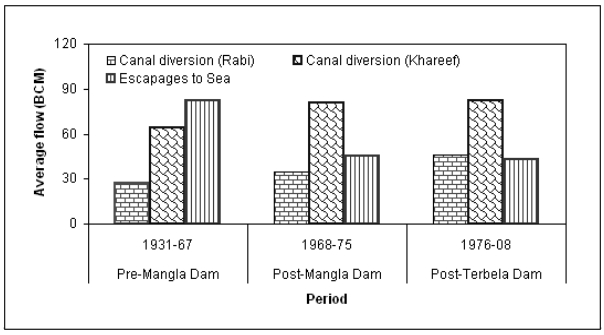


Fig. 3 Pre and post dam impact over canal water diversions and escapages to Sea.

Whereas, in 34 year's post Tarbela period (1976-2008), the unexploited water figure also remains over 42 BCM. Therefore, as per historical data analysis, sufficient amount of water is available for proposed reservoirs. Our existing live storage capacity is hardly 14 BCM or less than 10 per cent of average annual flows, while the world's average storage capacity for appropriate control is 25-40 per cent. Our grossly inadequate regulatory storage capacity does not enable us to make optimum use of surpluses river resources. Even a modest target level of 20 per cent would indicate need of over 30 BCM new storages. The additional storage capacity will provide the flexibility in system to shift from a supply-based operation towards a demand-based system.

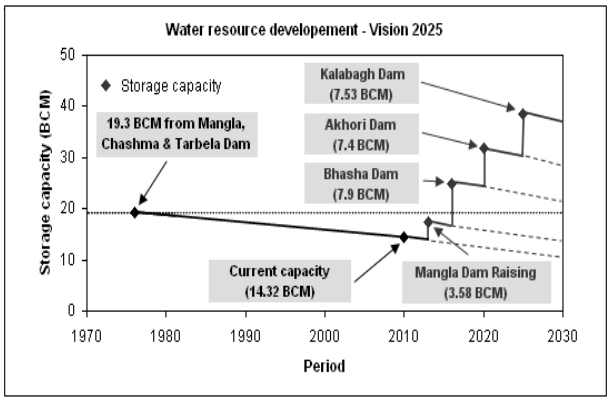


Fig. 4 Water resource development plan – vision 2025, with current storage losses and addition per vision 2025.

Due to improved regulatory capability, reservoirs will provide great flexibility in controlled inter seasonal and inter-year transfer of river flows to substantially increase water supply for agricultural production, generate cheap hydropower and reduce flood losses. All above facts and figures clearly supports the additional water availability in river system and favors' the construction of proposed dams.

3. RESULTS

Study Area Characteristics

The Hunza tributary with catchment area of about 14746 km^2 is located in upper Indus basin within western Karakorum ranges of Pakistan. It is an important tributary of Indus River System. It is high altitude basin with elevation ranges from 968 m to over 7500 m a.s.l **(Fig 5).** The Hunza basin consists of alpine climatic conditions, where annual precipitation ranges between 1400 to 1500 mm while mean monthly temperature varies between -20°C in winters to +28°C in summers **(Fig 6)**. The westerly weather disturbances deposit nearly all the precipitation during the winter months and most of precipitation falls in the form of snow in this season. The monsoon rains have very little influence in this particular basin, as compared to the main Himalayan ranges.

Valleys receives less than one fifth of total annual precipitation, while most of precipitation is deposited between middle and upper part of the basin. The maximum snow cover area exists in March and extends till the melting process starts in May/June. About 35% of the total basin area is perennial glacial ice field with about 808.79 km^3 ice reserves **(Fig 5,6)**. The flow regime is highly seasonal; with the highest flows occurring in Khareef season, e.g., between June and September, when snow and ice melt on the mountains cause a peak discharge, while minimum flows occur in Rabi season, e.g., November to February, when most of the precipitation falls in form of snow.

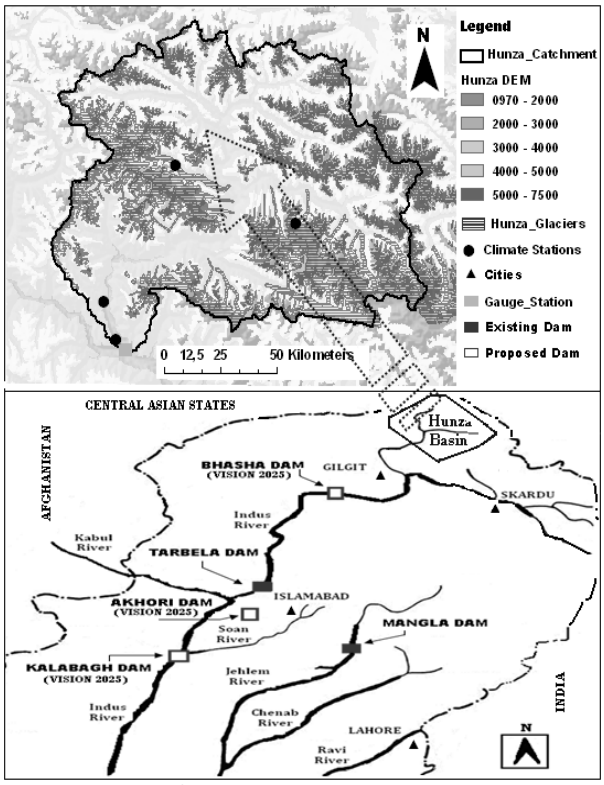


Fig 5 Location of study area catchment with digital elevation model (DEM)

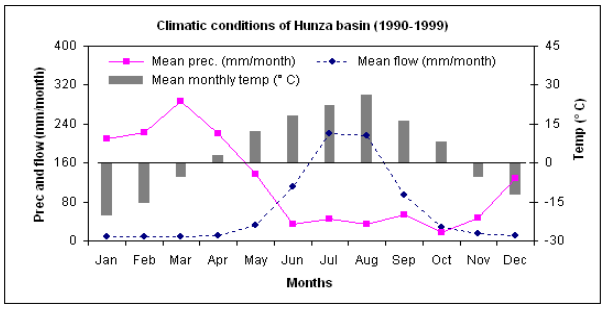


Fig 6 the 10 year (1990-1999) mean monthly temperature, precipitation and stream flow measured at gauge station (Dainyor Bridge) for the study catchment (Hunza Basin) located in the Greater Karakorum range.

Model Application and Calibration

The quality of a hydrological simulation in mountainous regions depends on its ability to consider the very heterogeneous physical (topography, land use, land cover, soil) and meteorological variables typical of such a region. The distributed hydrological modeling system PREVAH (Precipitation-Runoff-Evapotranspiration Hydrotope Model) has been developed to suit such conditions present in mountainous catchments (Viviroli *et al.*, 2009). Since its development it has been successfully applied to various hydrological and/or climatological studies in mountainous catchments (Gurtz *et al.*, 2003; Zappa *et al.*, 2003; Verbunt *et al.*, 2006; Vanham *et al.*, 2008a; Vanham *et al.*, 2008b). The details about model can be seen in (Viviroli *et al.*, 2009). For this particular study, the 10 year time series of daily flow from the gauge station Dainyor Bridge on the Hunza River have been used for calibration and validation purposes. The first 3 years have been used for calibration, while the whole period (1990-1999) was used for validation processes. The mean annual efficiency for the calibration and validation period is above 80%, while the measured and simulated mean annual stream flow difference amounts to less than 5%. The calibration/validation results indicate that the basin characteristics are well reproduced by the model. The simulated mean annual water balance components (1990-1999) are shown in **(Table 1)** respectively.

Table 1 Mean simulated annual water balance of the Hunza basin for the period 1990-1999 (mm year^{-1})

Water balance components	PREVAH Model
Observed runoff (mm)	686
Simulated runoff (mm)	659
Precipitation (mm)	1434
Evapotranspiration (mm)	117
Storage change (mm)	+652
Volume deviation (mm)	-27

The change in water storage could be explained by an increase in glacier mass. The mass balance measurements are not available. Therefore the calculated change in glacier mass can not be checked against measurements. However, the positive change in mass balance is in good agreement with the studies conducted by (Hewitt 2005 and Fowler and Archer 2006), which indicated glacier surges particularly in this Hunza basin. The calibrated model was then used to investigate the hydrological behavior of the basin under a future warmed climate. The detailed study about model structure, parameterization or calibration/ validation processes can be referred to (Verbunt *et al.* 2006 and Viviroli *et al.* 2009).

Hydrological Modeling of Hunza basin

In this study attempts are made to investigate the climate change impact on total stream flow for a highly glacerized high altitude Hunza river catchment which is one of the major tributary of main Indus River. The adopted climate scenarios ranging from 1 to 4°C temperature change were based on ensemble of 9 global model predictions for the studied region in 21st century. **(Fig 7)** illustrates the effect of temperature on monthly stream flow volume. It is clearly seen that the increase in temperature systematically increased monthly flows. The findings are quite in contrast to earlier findings in high altitude basin that mean annual water availability in generally and summer in particularly will be reduced under warmer climate (Singh and Bengtsson, 2004).

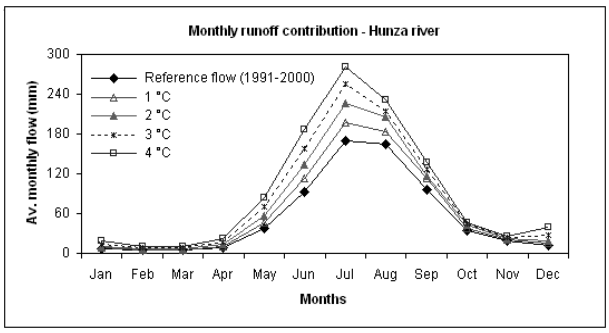


Fig. 7 Effect of selected temperature scenarios on mean monthly total flow volume for period of 1990-1999.

However, for this specific very low temperature regime basin, where 31% of the total basin area remains under ice cover and more than 85% precipitation fall as in snow, the increase of 1 to 4 °C thus results in more melting runoff. The timing of peak stream flow is not affected; however, the magnitude of peak stream flow is changes as temperature increases. The maximum change in monthly flows is observed from May to August. A large increase in these months is due to higher amounts of snow melt runoff and earlier glacier melt contribution due to warmer climate. The resulting shift in monthly flows has significant effect on magnitude of seasonal and annual flow regime of basin. The increase in temperature from 1 to 4 °C will change seasonal flow from current reference contribution (24%) to (34.4-45.6%) and (67.7%) to (74.8-81.5%) in total flow for winter (Oct-Mar) and summer (Apr-Sep) flows respectively. As contrary to some hypothesis (Vanham *et al.*, 2008b and 2009), that increases in temperature result in a conversion of much of the winter precipitation to rainfall and early snowpack decline produce higher winter flows, the winter flow regime of this specific basin is not affected significantly. As the temperature regime of this particular basin in winter months is below freezing point, therefore the increase of 1 to 4°C have no any influence over form of precipitation or melting process. However, the higher increase in monthly flows from April to August are in good agreement of an earlier findings (Laghari *et al.*, 2009) that temperature sensitivity seems to be confined to spring and summer months. The maximum effect of increased temperature is found on glacier melt runoff as compared to snow melt runoff. However, snow melt contribution in total flow is still dominating than to ice melt contribution. This high altitude basin, which contains snow fields/glaciers throughout the ablation period, more melt is generated under a warmer climate. On a basin scale, reduction in snowmelt from lower part is compensated through the increase in from middle part i.e. 3500-5500 m a.s.l. The glacier melt contribution comes only through middle zone. However, the increase in air temperature for a longer time will reduce snow cover in shorter time, thus expose glacier area early to warmer climate and hence glaciers will retreat because of their depletion under these conditions.

Future Water Availability Scene for Main Indus River

The Hunza River is a major tributary of main Indus River which forms an important part of the Indus river system. Both rivers receive substantial contributions from snow and glacier melt runoff to annual stream flows. The flow pattern of both rivers shows identical percentage changes in their monthly volumes. The 25 year (1976-2000) monthly flow (percent of annual flow) data of both rivers clearly indicates that any changes observed in Hunza tributary is proportionally reflected in main Indus River. This could be seen in Fig 8, which shows co-relationship between Main Indus River and its tributary Hunza River. The value of coefficient of determination R^2 shows good agreement between monthly flows and thus any % changes in future water availability in Hunza tributary could be adopted for main Indus River. The value of (%) change in water availability in Hunza River is therefore applied to regression equation given in **(Fig 8)** to quantify the % change in future water availability in main Indus River. Under all adopted scenarios, the rise in temperature from 1 to 4 °C have substantially increased mean annual and seasonal water availability in main Indus River. The mean annual figure of Indus River, even at 1°C shows sufficient water availability for proposed reservoirs **(Table 2).**

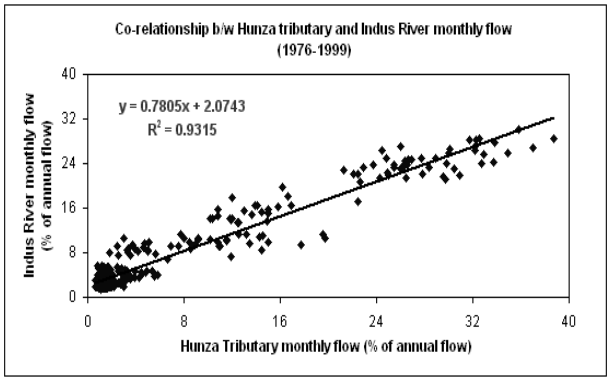


Fig. 8 Scatter plot with regression equation of the monthly flows (percent of annual flow) between Hunza and Indus flows.

An increase of 1 to 4°C have resulted in an increase of about 2.35 to 11.84 BCM in winter flows, 15.51 to 58.71 BCM in summer flows and 17.86 to 70.56 BCM in mean annual flows respectively. However, the increase in water availability in winter flows are still below to required volume for winter crops, hence additional quantity can only be provided through reservoirs filled during surplus season. The highly erratic nature of flows, particularly the increased snow and glacier melt runoff and resulting massive increase in summer volume justifies the construction of new

reservoirs, as it will not only reduce the threat of floods but enhance the present capacity of regulating and utilizing surpluses water for crop irrigation in much needed times particularly during low flow period of the winter season and early and late summer season.

Table 2 Main Indus River water availability scene under adopted warmer scenarios

Climate scenarios	Water availability (BCM)		
	Winter (Oct–Mar)	Summer (Apr–Sep)	Mean annual
Reference value (1976-2000)	***16.42***	***98.71***	***115.13***
1 °C	18.77	114.22	132.99
2 °C	21.55	127.85	149.40
3 °C	25.10	141.68	166.77
4 °C	28.26	157.42	185.69

4. CONCLUSION

The objective of this study is to provide an overview of potential implications of climatic variability on the flow regime of the Hunza basin and consequent changes upon flow regime of main Indus River and subsequent future water availability for proposed reservoirs. The temperature increase of 1 to 4°C have resulted in an increase of about 16.6%, 33.08%, 49.66% and 68.57% respectively in current mean annual total flow volume of Hunza basin. The major contribution comes from summer months, while flow situation in other months remain same. In this high altitude basin, the climatic sensitivity is seems limited to summer season, particularly to lower and middle part of the basin, while upper part of the basin remains unaffected. The other main finding of this study is identical percentage change in monthly contribution to total flow volumes of Indus River and its tributary Hunza, as major contribution in both rivers comes from snow and ice melt runoff. The regression coefficient was above 90%. The relationship was used to estimate the water availability in main Indus River. An increase of 1 to 4°C have resulted in an increase of about 2.35 to 11.84 BCM in winter flows and 15.51 to 58.71 BCM in summer flows, while 17.86 to 70.56 BCM increase were recorded in mean annual flows. It is quite clear that massive increase in annual flows justifies the construction of new reservoirs, as it will not only reduce the threat of floods but enhance the present capacity of regulating and utilizing surpluses water for crop irrigation in much needed times particularly during low flow period of the winter and early and late summer season. However, the above conclusion is based on one basin study; it is therefore recommended that similar studies should be carried out in other catchments of Indus basin, having seasonal snow cover and permanent ice fields, so as to assess any influence over basin hydrology and water resources.

REFERENCES:

Fowler, H. J., andD. R. Archer (2006) Conflicting signals of climatic change in the Upper Indus Basin. Journal of Climate 19 **(17)**: 4276–4293.

Gurtz, J., M. Zappa, K. Jasper, H. Lang, M. Verbunt, A. Badoux, and T. Vitvar, (2003) A Comparative Study of Modelling Runoff and its Components in Two Mountainous Catchments. Hydrological Processes, **(17):** 297-311.

Hewitt, K., (2005) The Karakoram anomaly? Glacier Expansion and the elevation effects, Karakoram Himalaya'. In Mountain Research and Development, 25 **(4)**: 332-340

Javaid, M. A. and T. Yamin. (2003) Water crises and crop production gaps in Punjab: Identification, risk analysis and mitigation measures. Science International Publication, Lahore.

Singh, P., M. Arora1 and N. K. Goel, (2006) Effect of climate change on runoff of a glacerized Himalayan basin. Hydrological Processes **(20):** 1979–1992.

Singh, P. and L. Bengtsson, (2004) Hydrological sensitivity of a large Himalayan basin to climate change. Hydrological Processes **(18)**: 2363–2385.

Singh, P. and N. Kumar (1997) Impact assessment of climate change on the hydrological response of a snow and glacier melt runoff dominated Himalayan river. Journal of Hydrology **(193)**: 316-350.

Vanham, D., E. Fleischhacker, and W. Rauch, (2008a) Impact of an extreme dry and hot summer on water supply security in an alpine region, 11th international specialized conference on watershed and river basin management, Budapest, Hungary.

Vanham, D., E. Fleischhacker and W. Rauch, (2008b) Impact of snowmaking on alpine water resources management under present and climate change conditions, 4th Biennial International Young Water Professionals Conference, Berkeley, USA.

Vanham, D., E. Fleischhacker and W. Rauch (2008c) Technical Note: Seasonality in alpine water resources management – a regional assessment. Hydrology and Earth System Sciences, 12 **(1)**: 91-100.

Viviroli, D., M. Zappa, J. Gurtz and R. Weingartner (2009) An introduction to the hydrological modelling system PREVAH and its pre- and post-processing-tools. Environmental Modelling and Software, **(24)**: 1209–1222.

Zappa, M., F. Pos, U. Strasser J. Gurtz (2003) Seasonal water balance of an alpine catchment as evaluated by different methods for spatially distributed snow melt modeling. Nordic Hydrology, **(34)**: 179-202.