Paper No. 814

CLIMATE CHANGE IMPACT ON SNOW-CUM-GLACIAL MELT FLOWS OF WESTERN RIVERS IN EARLY KHARIF AND ITS MITIGATION

Riaz Nazir Tarar

CLIMATE CHANGE IMPACT ON SNOW-CUM-GLACIAL MELT FLOWS OF WESTERN RIVERS IN EARLY KHARIF AND ITS MITIGATION

By:

Riaz Nazir Tarar[1]

1. Introduction

1.1 Indus River System

1.1.1 Lay of Land

Indus River System (IRS), primarily nourished by precipitation and snow/glacier melt in the high-mountain ranges of Tibet-China, northwest India, northeast Afghanistan and north Pakistan, supports one of the largest irrigation systems in the world with drainage area of about 112 million ha and irrigated command area of over 26 million ha.

Water flowing through IRS is a vital source of existing hydropower projects with massive untapped potential across its headwater tributaries and for agricultural production in valleys and downstream arable lands. Thus, IRS water plays a crucial role in prosperity and growth of national economies and livelihoods of over 300 million inhabitants in Afghanistan, India and Pakistan. However, water, food and energy securities in this region are inextricably linked with sustainable water supplies in the IRS, which are prone to alteration by: future climate change and/or variability including cross-border aggression; and stressed by increasing demands for rapidly growing population, socioeconomic development and ecosystem services.

High-mountain watersheds of the IRS, gauged at many locations along its main course and at the confluence of major tributaries, are shown in (Figure-1).

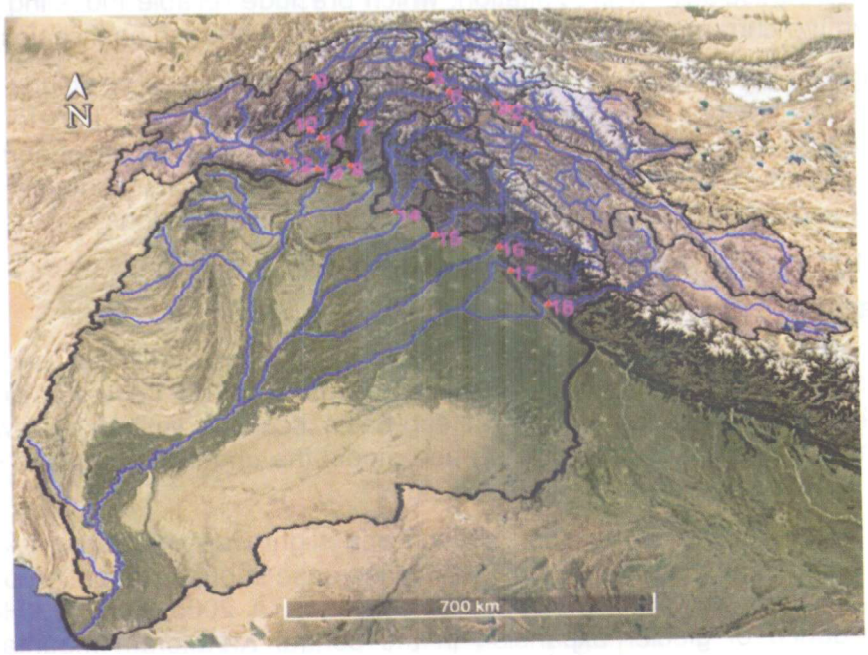


Figure-1: Indus Basin and its High-mountain Watersheds.

[1] General Manager (R) WAPDA & Associate, National Development Consultants (NDC)

Black line in Figure-1 show basin boundaries and blue lines represent river network. Pink-colored numbers indicate discharge measuring river gauges installed at: 1) Indus-Kharmong, 2) Shyok-Yogo, 3) Shigar-Shigar, 4) Hunza-Dainyor, 5) Gilgit-Gilgit, 6) Astore-Doyian, 7) Indus-Besham, 8) Indus-Tarbela, 9) Chitral-Chitral, 10) Panjkora-Zulam Bridge, 11) Swat-Chakdara, 12) Kabul-Warsak, 13) Kabul-Nowshera, 14) Jhelum-Mangla, 15) Chenab-Marala, 16) Ravi-Thein Dam, 17) Beas-Pong Dam, and 18) Sutlej-Bhakra Dam. River gauges numbered 1–7 and 9–12 are outlets of the tributaries of Indus at Tarbela and Kabul at Nowshera respectively.

1.1.2 Climate Change Context

Global warming and consequently the climate change, resulting from increasing concentrations of GHGs in the atmosphere, is now an established phenomenon. Its effects have been observed in most parts of the world including Pakistan. Past temperature trends over Pakistan are seen almost tallying with global trends, whereas future projections show that the rate of increase of average temperature over Pakistan could be higher than globally. As Pakistan is located in sub-tropics, a temperate region with warm climate, its predominantly agrarian economy is highly climate sensitive. It is presently adjudged that Pakistan is 8th country prone to adverse impacts of climate change.

IRS has been lifeline for Indus Valley Civilization since time immemorial. Pre-historic wiping out of this ancient civilization is attributed to drying-up of the rivers due to prolonged drought for about 900 years during 2330–1430 BC.

Even in the modern era of technological innovations, climate change is considered to be one of the major drivers of demographic changes and expansion or weakening of national economies across the globe. Climate change is also alleged to impede nations' abilities to achieve sustainable development goals. Evidence of the impacts and risks associated with climate change is strongest for natural systems. Yet, there are considerable uncertainties in the observed and modelled climate particularly for precipitation, which preclude reliable modeling of the changes and variability in the current and future water cycles at global and regional scales.

Hindukush-Karakoram-Himalayan (HKH) region and concomitant high-altitude Indus Basin is recognized as a 'hotspot' of climate change due to significant transformations in its hydrometeorological regime. However, an authentic assessment of climate change and variability and its underlying impacts on hydrological regime in the Basin are seriously constrained by paucity of observed data and delicate hydrometeorological investigations.

1.2 Climate Change Research / Studies in Indus Basin

1.2.1 Research

Climate change research in the Indus Basin is a recent campaign and still at its infancy. As such, there are significant data, information and knowledge gaps. Thus, our understanding of the basin's hydrometeorological regimes particularly at sub-basin scale is limited. A few studies have attempted to analyze recent climate change and model the underlying impacts on hydrological regime and/or water availability in the Indus Basin.

Some studies noted cooling of monsoon season and slight warming during winter and spring months, while some other detected a considerable increase in precipitation throughout the year. In contrast to a worldwide decline of mountain glaciers, a 2005 study by Hewitt observed widespread evidence of glacier expansion in the central Karakoram mountain range. This anomalous behaviour of glacier surge in the Karakoram mountain range was supported by another study which detected regional-scale increases in humidity, cloud cover and precipitation along with decreased net radiation, near-surface wind speed, potential evapotranspiration and

river flows and termed the high-mountain watersheds of the Indus Basin as moisture surplus and energy deficient.

Generally, summer runoff in higher-mountain catchments of Indus Basin is strongly correlated with the preceding winter snowpack and prevailing summer temperatures. Nevertheless, significant uncertainties still exist in precise representation of the basin's hydrometeorological regime due to lack of observed meteorological data and extremely complex orography interacting with synoptic-scale atmospheric circulations. Greatest uncertainties are associated with the spatio-temporal distribution of precipitation and dynamics of glacial ice mass in the higher-altitude areas, which are the dominant source of stream flows in IRS.

1.2.2 Studies of Glacier Behaviour in Upper Indus Basin Due to Climate Change

Glaciers all over the world are found to be receding over the past and early 21st century including those in UIB. Notwithstanding this, there is an uncertainty about temporal behavior of Karakoram Glaciers which have not been studied in detail so far. Based on the studies conducted since start of 21st century utilizing scanty data, limited investigation have thrown up somewhat conflicting information as shown in Table-1.

Table-1: Comparative Results of Studies Conducted Since Start of 21st Century Regarding Glacier Retreat in Upper Indus Basin Due to Climate Change

Sr. No.	Entity	Year of Conducting	Basis of Study	Finding Regarding Mean River Inflow
1.	Wallingford	2004	100-year time horizon starting 1991	Initial increase between 14-90% followed by decrease between 30-90% by the last decade of 21st century
2.	World Bank	2005	Till end of 21st century under scenario of 0.015°c annual temperature rise	Initial increase in flows by about 50% with decrease of over 60% by the end of 21st century (Graphical representation in Annex-01)
3.	Global Change Impact Studies Center (Islamabad)	2009	Average annual temperature rise of 0.03°C in upper Indus Basin	Flow reduction by about 15% showing considerable change in monthly flow pattern with more water in spring and early summer and less water in late summer (Graphical representation in Annex-02)
4.	WAPDA Using data collected from automatic high-altitude meteorological network established	2012	Positive degree day data from 1995-2009 for snowmelt period (May-June) and glacier melt period (July-Sept) covering upper Indus	Flows from western Himalayan part of Indus from India / China showed a remarkable rising trend in summer mean monthly flows a phenomena

Sr. No.	Entity	Year of Conducting	Basis of Study	Finding Regarding Mean River Inflow
	in 1995 (location map in Annex-03)		sub-basins Shyok, Shingo, Astore, Hunza and Gilgit	attributed to receding glaciers. On the other hand, Karakorum tributaries from Pakistan part of Upper Indus Basin showed a falling trend in corresponding period attributable to expanding glaciers.
5.	Joint Study by Researchers from Pakistan / Nepal and USA, titled 'Modeling of Future Discharge Estimation from Glacierized Hunza River Basin'	2013	Model calibration from Hunza River discharge data from 1995-2001 and validated for 2002-13	No drastic changes in future discharge except higher discharges in few years that may cause flooding and contribution from a combination of 2°C temperature rise and 20% increase in precipitation which may increase the discharge by about 10%.
6.	Climate change and Hydrological Regime of the High-Altitude Indus Basin Under Extreme Climate Scenarios (paper published in Science of the Total Environment Journal by International Researchers (M/s Zakir Hussain Dahri, Fulco Ludwig, Eddy Moors, Shakil Ahmad, Bashir Ahmad, Sarfraz Ahmad, Muhammad Riaz, Pavel Kabat)	2021	i. Investigations of historic and future hydrometerologic regimes ii. Modest increase in temperature and precipitation observed during the last 40 years iii. Anticipated unprecedented and highly contrasting future hydromet signals.	i. Substantial increase in magnitudes of peak flows and one-month earlier attainment on all rivers. ii. Anticipated high flow increases and low flow decreases in Jhelum, Chenab and Kabul River Basins. iii. Hydrological extremes likely to be intensified. iv. Critical modifications in strategies and action plan required for: irrigation withdrawals; construction and operation of storage reservoirs; flood controls and drought management; and hydropower generation.

1.2.3 Modeling Future Hydrometeorological Projections Through General Circulation Model

Accuracy of future hydrometeorological projections is constrained by a high variability and large spread of the available General Circulation Model (GCM), structural limitations of climate and hydrological modeling frameworks and lack of reliable and representative observations. Despite improvements in climate models to better represent climate processes, significant uncertainties in precisely reproducing the current and projected climates still remain the subject of ample concern. All GCMs project consistent but slightly varying increases in temperature, whereas their precipitation projections are highly variable ranging from considerably drier to moderately wetter precipitation regimes. Most GCMs have difficulties in simulating the South-Asian monsoon and its variability on a range of timescales. Even greater changes and uncertainties are estimated with regard to snow/glacier dynamics under different climate change scenarios. "Paris Agreement" signed in 2015 urged the 195 signatory nations to limit the global temperature increase well below 2 °C relative to pre-industrial (1861–1890) level and stabilize it at 1.5 °C by 2100. However, the road to realize such an ambitious goal would require unprecedented efforts to increase the current levels of nationally determined contributions (NDCs) by many times.

With 1.5° and 2° C warmer world, the temperature in HKH region may rise to 2.1 and 2.7 °C, respectively. Relatively accelerated rise in temperature of high-altitude regions is attributed to elevation dependent warming. Anticipated impacts of 1.5 and 2 °C global warming on basin-scale water balance project 34 and 43% increase in river runoff from upper Indus Basin (upstream of Besham Qila), Jhelum and Kabul. Similarly, the projected loss of present-day glacial ice mass in high mountain Asia by 2100 is 26 ± 7% under 1.5 °C global warming, which may increase to 49 ± 7 for 2.7 °C. Hence, significant and somewhat accelerated transformations in the basin's hydrometeorological regime can be anticipated under various climate change scenarios. Under such circumstances, precision of the baseline meteorological forcing and energy input data and application of appropriate hydrological models play a vital role in the accurate assessment of catchment scale water budgets.

It is now well-recognized that actual precipitation in the high altitude Indus Basin is much higher than what had been previously thought and used in the earlier studies. In hydrological modeling frameworks, the underestimated precipitation is often compensated through suboptimal alteration of other parameters (e.g. evapotranspiration, soil properties, snow/glacier melt factors, etc.) during model calibration and validation. Therefore, the inferences regarding the dynamics and underlying impacts of these sub-optimally altered parameters may be uncertain and inaccurately adjudicated. Moreover, since the Indus is predominantly a snow/glacier-fed basin, the degree-day or temperature-index based hydrological models often inadequately represent the prevailing energy balance, which is the key driving force for melting of glacial ice mass in the snow/glacier-fed systems.

Therefore, the overarching goal of recent 2021 study (refer S. No. 6 in Table 1) is to reduce uncertainty in hydrometeorological regime of UIB by developing higher-quality meteorological forcing datasets and use of improved hydrological modelling framework. For this purpose, much-improved and high-resolution meteorological forcing datasets of precipitation and temperature have been developed for historical period and various scenarios of future climate change through statistical downscaling and bias correction of better performing gridded datasets and GCM outcomes. These improved datasets are used to force a fully-distributed physically-based energy-balance Variable Infiltration Capacity (VIC) hydrological model to simulate the hydrological regimes at regional and sub-basin scale. Climate change analyses and hydrological model executions are attained for a baseline historical period and a set of six scenarios of future climate representing extreme scenarios of warm-wet and cold-dry climates. The study further determines

the changes and variability in overall water availability and examines the shifts in the timings and peaks of hydrological extremes. Further improvements in results of this study will curtail the uncertainties to understand the current and future hydrometeorological regime of the high-mountain Indus Basin and help take informed policy decisions for hydropower development, climate change adaptation and optimal management of the Indus river water resources.

2. Western Rivers Flow Sources and Their Utilization

2.1 Flow Sources

Mainstay of irrigated agriculture in Pakistan is surface water resource of Western Rivers of Indus Basin. Average annual rim-station flows of Western Rives (Indus / Kabul, Jhelum and Chenab) over Post-Tarbela record period of 1977-2003 were about 141-million-acre feet (MAF) or 174 billion cubic meters (BCM). These varied between a low of 97 MAF (120 BCM) in 2002 to high of 172 MAF (212 BCM) in 1992.

Annual flow contribution of Western Rivers is about 82% in Kharif (April to September) and 18% in Rabi (October) respectively. Seasonal distribution of water in Western Rivers is shown in Annex-04.

Between 50-80% average flows of Western Rivers are derived from snow and glacier melt in Western Himalayas, Karakorum and parts of Hindukush mountain ranges.

Dominant seasonal water source of individual rivers is also detailed in Annex-04 and is summarised in Table-2.

Table-2: Dominant Seasonal Water Source of Western Rivers

Sr. No.	River	Dominant Source of Water	
		Kharif (Summer)	Rabi (Winter)
1.	Indus	Snow / Glacier melt	Winter Rainfall + Baseflow
2.	Kabul	Snow / Glacier melt	Winter Rainfall + Baseflow
3.	Jhelum	Mainly Snow melt + Monsoon	Winter Rainfall + Baseflow
4.	Chenab	Mainly Snow melt + Monsoon	Winter Rainfall + Baseflow

Early Kharif runoff, particularly on Jhelum is mainly generated through snow melt due to lower elevation catchment.

2.2 Utilization of Flows For irrigated agriculture

Kharif runoff of these rivers can be further split up into early (April – June) and late (July – September). Early Kharif runoff (April to June) normally provides for sowing of major Kharif crops (cotton / sugarcane / partly rice) including initiation of storage in reservoirs particularly Mangla, subject to surplus water availability. Late Kharif runoff (July to September) after meeting crop water requirements is used for filling of storages (particularly Tarbela) and escapages below Kotri.

Rabi crop water requirements are met from flows supplemented by storage releases from Mangla, Tarbela and Chashma reservoirs.

3. Upper Indus Basin Hydrology and Glaciers

3.1 Hydrology

While it is generally agreed that a significant percentage of the Indus River flow originates in the mountain headwaters of the Karakoram Himalaya. Western Himalaya, and Hindu Kush Mountains, there is no consensus regarding the role or importance of this runoff for the complex

hydrometeorological environments that characterize the mountain catchments. In particular, there has been considerable speculation concerning the importance of glaciers in the flow volume and timing of the Indus River and its tributaries, as well as on the potential impact of climate change on this water supply. Although these concerns are recognized, few analyses so far have described the role of glaciers in hydrologic regime of these mountains, in large part due to inaccessibility and altitude (4,000–7,000 meters) of Himalayan glaciers.

3.2 Regional Distribution of Glaciers in Upper Indus Basin (UIB)

Bulk of glacial melt contribution to Upper Indus flows is confined to catchment area of 142,700 km^2 at the gauging station of Partab / Bunji Bridges. This results from the regional distribution of glaciers in UIB as per break-up in Table-3.

Table-3: Regional Distribution of Glaciers in Upper Indus River Basin

Sr. No.	Region	Approximate Distribution of Glaciers (%)
1.	China Xizang Plateau	22
2.	Great Himalayas	31
3.	Karakoram	19
4.	Pamir	11
5.	Hindukush	17
6.	Total	100

3.3 Extent of Upper Indus Basin Glaciers in Pakistan

This is summarized in Table-4.

Table-4: Extent of Upper Indus Basin Glaciers in Pakistan

Number	11000
Size	Small, Medium and Large
Aerial Extent	15000 km^2
Large Sized Glaciers: -	
Siachin	1181 km^2
Baltoro	756 km^2
Biafo	627 km^2
Hispar	622 km^2
Panmah	410 km^2
Batura	290 km^2

3.4 Generation of Glacial Runoff

Estimates of potential impact of a continued retreat of the glaciers are premised on the basis of use of disaggregated low-altitude databases, topography derived from satellite imagery and simple process models of water and energy exchange in mountain regions. Surface area of UIB is approximately 220,000 km^2. Of this surface area, more than 60,000 km^2 is above 5000 m, estimated mean altitude of summer season freezing level. It is assumed that significant melt of glaciers does not occur over most of this upper zone. Glaciers of the region flowing outward from this zone have been estimated to have a surface area of approximately 20,000 km^2, of which 7,000–8,000 km^2 is below the summer-season freezing level. It is this 7,000–8,000 km^2 area, in

the ablation zone, that is the source of the bulk of the annual glacier melt water flowing onto the Indus River tributaries.

3.5 Sources of UIB Runoff

3.5.1 Principle Sources

Two principal sources of runoff are winter precipitation, as snow that melts the following summer and glacier melt. Winter precipitation is most important to the seasonal snow runoff volume, while summer temperature contributes most to glacier melt volume. Drawing a clear distinction between the runoff volumes resulting from snow melt and glacier melt is difficult. Primary zone of melt water from both sources is maximized at around 4,000–5,000 m, as a result of a combination of maximum terrain surface area, maximum glacier surface area and maximum snow water equivalent deposition occurring there. This is the altitudinal zone generally reached by the upward migration of the freezing level during the months of July and August, which is also the time of maximum runoff.

3.5.2 Glacial Contribution

This is estimated from the inventory in UIB as shown in Table-5.

Table-5: Glacier Inventory in Upper Indus Basin

Basin	No. of Glaciers	Glaciated Area (km^2)	Estimated Ice Reserve (km^3)
Swat	233	223.55	12.22
Chitral	542	1903.67	258.82
Gilgit	585	968.10	83.35
Hunza	1050	4677.34	808.79
Shigar	194	2240.08	581.27
Shyok	372	3547.84	891.8
Indus (upstream of Kharmong)	1098	688.00	46.38
Shingo	172	36.91	1.01
Astor	588	607.03	47.93
Jhelum	384	148.18	6.94
Total	**5218**	**15040.7**	**2738.51**

Ice reserves of over 2700 km^3 (2190 MAF) as shown in Table-5 are equivalent to over 15 years of average flows of Indus River system (IRS) comprising Indus, Jhelum and Chenab rivers assigned to Pakistan under Indus Waters Treaty, 1960. Therefore, their current and future status with changing climate is of vital concern to Pakistan, particularly in the context of water security. Additionally, energy output from existing / proposed hydropower projects may be affected.

'Mountain Catchments of Upper Indus Basin' are shown in Figure-2.

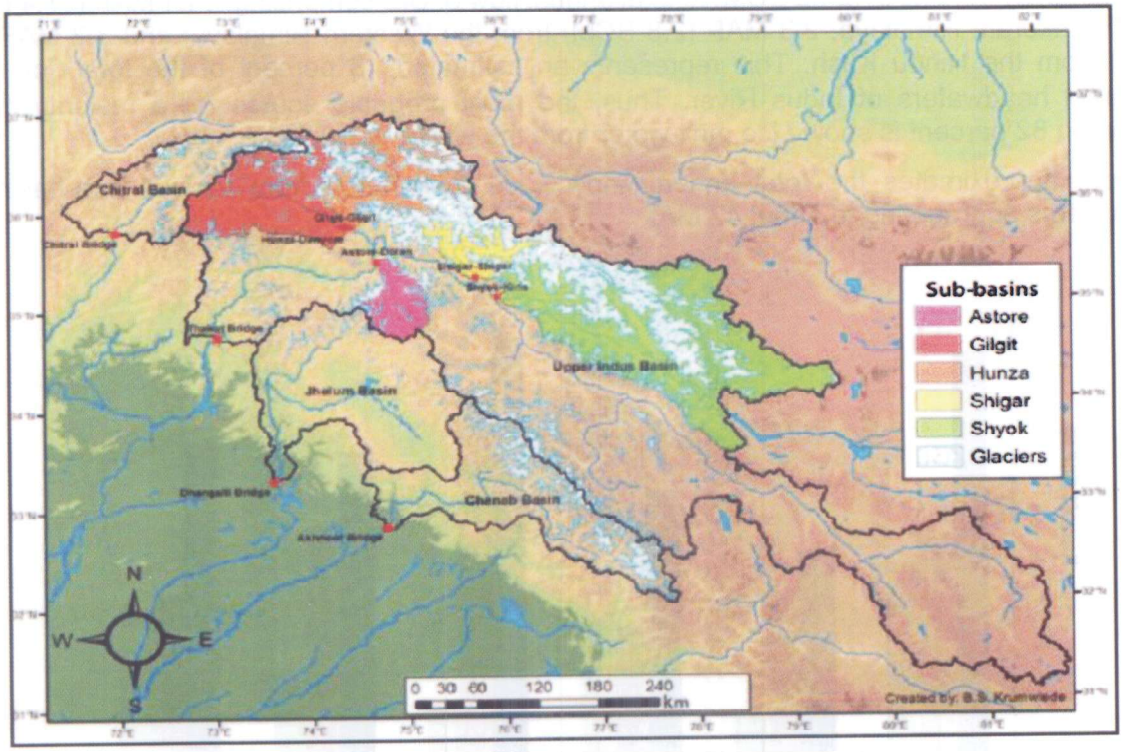


Figure-2: Mountain Catchments of Upper Indus Basin

'Glaciers and Drainage Area in Upper Indus Basin, Pakistan' are shown in Figure-3.

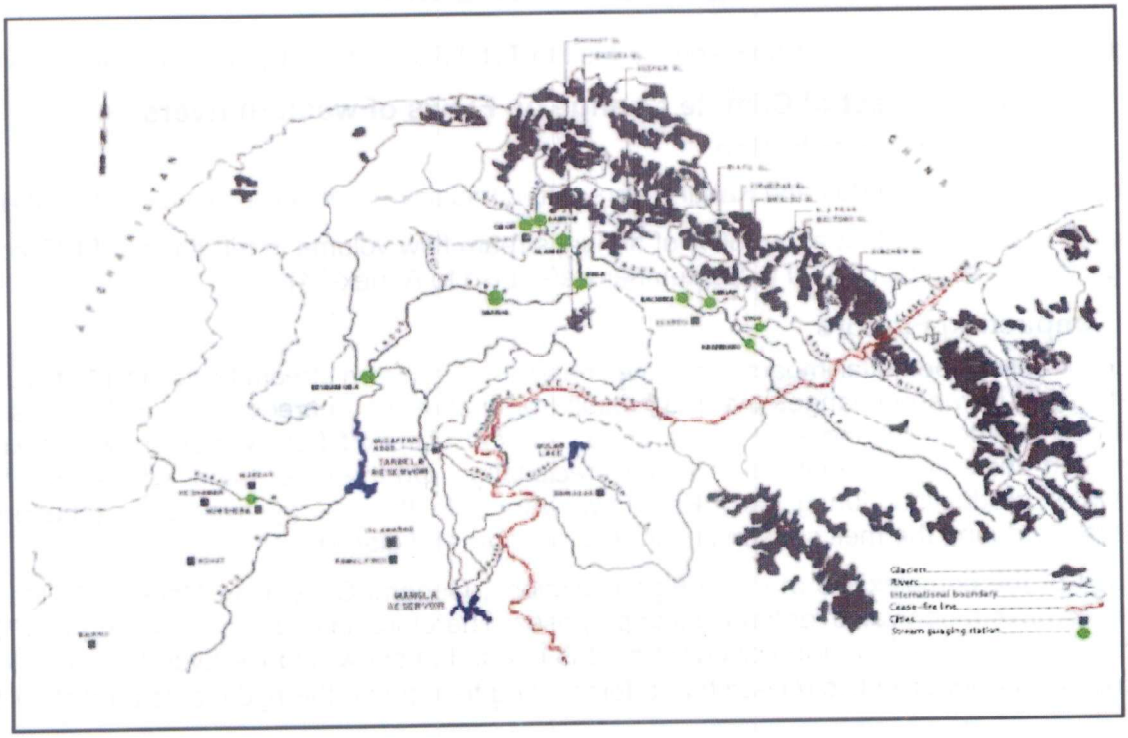


Figure-3: Glaciers and Drainage Area in upper Indus Basin, Pakistan

Using a simple model of these dynamics, it is estimated that glacier runoff contributes approximately 19.6 MAF (24.2 BCM) to total annual flow of UIB comprising: 14.1 MAF (17.4 BCM) from Karakoram Himalaya; 2.3 MAF (2.8 BCM) from the Western Himalaya; and 3.2 MAF (3.9 BCM) from the Hindu Kush. This represents an estimated 18 percent of the total flow from mountain headwaters of Indus River. Thus, the most probable source for a majority of the remaining 82 percent is snow / ice melt water from the winter snowpack

Figure-4 approximates the total annual snow / ice melt runoff from various sub-basins of Karakorams aggregating to about 42 MAF.

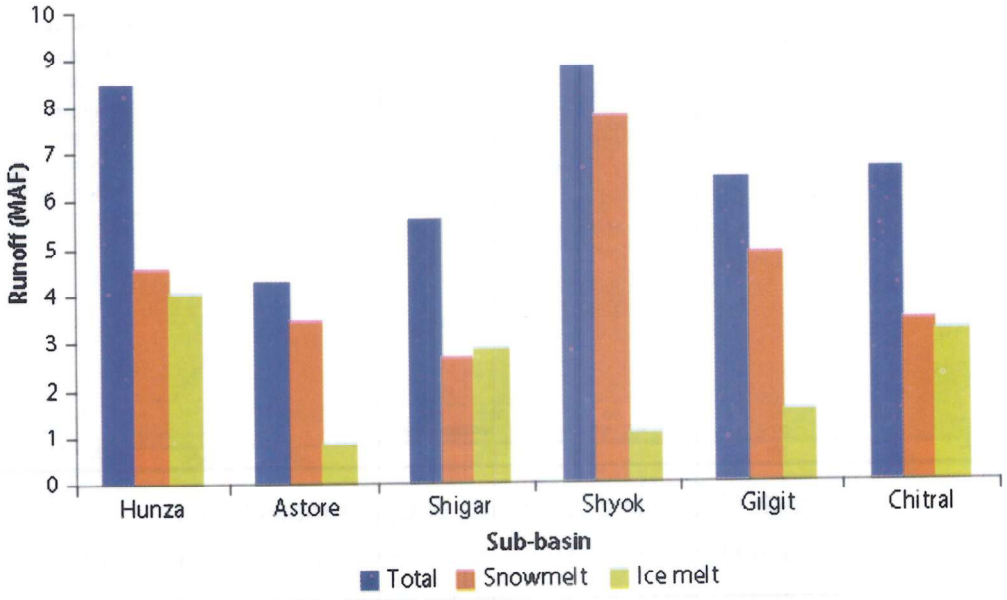


Figure-4: Contributions of Snow and Ice Melt to Total Runoff from Upper Indus Sub-Basins

4. Potential Impact of Climate Change on Flows of western rivers

4.1 Annual flow contribution

Major contributors are Indus and Kabul Rivers with cumulative flow of 60% (refer Annex-04).

Further, it is estimated that about 86% of annual stream flow volume in tributaries of UIB occurs during summer months of April to September (refer also to Annex-04).

4.2 Impacting Factors

In order to assess potential impact of climate change scenarios on stream flows in UIB, it is useful to distinguish between changes that may result from variations in precipitation including snows and those related to changes in temperature. Volume of runoff from winter snowmelt will be determined primarily by variations in winter precipitation. On the other hand, snow-cum-glacier melt water production during early Kharif will vary with the energy availability (changes in temperature during the melt season at surfaces of snow and glaciers).

Because of the complexities at these high elevations, General Circulation Models (GCMs) are unlikely to have much value for forecasting purposes. Therefore, in addition to existing WAPDA's Network (refer Annex-03), a major investment is needed in snow and ice hydrology monitoring stations, for further scientific research and forecasting to improve the hydrologic predictability of UIB.

Reportedly, Pakistan Metrological Department (PMD) has also initiated pilot efforts to monitor behaviour of some large glaciers in UIB. This may also compliment the efforts for projecting Climate Change Impact on the flows of Western Rivers.

So far, the definite research efforts regarding impact on river flows are reflected in Studies at SNo. 3 and 6 of Table-1.

5. Synthesis of recent early kharif river flows

5.1 Scope

As already mentioned, early Kharif river flows are critical for sowing of crops, particularly cotton, sugarcane and rice. This was manifested during early Kharif 2021 when a dip in flow of Western Rivers created an alarming situation regarding canal supplies, particularly in Sindh and Punjab provinces. Therefore, this case study synthesises early Kharif river flow behaviour over the last 12 years of 2010-2021 in the context of climate change impact.

The parameters selected for this study are: -

i. Historic flows on Western Rivers.
ii. Impact on provincial irrigation uses.
iii. Correlation between actual river flow variations and the basic influencing factors of: -
    a) Catchment snow cover ending preceding March.
    b) Average 10-daily temperatures in upper catchment (only at Skardu for Tarbela, for which the data is available).

5.2 Historic Early Kharif Flows on Western Rivers

During the study period of 2010-21, total early Kharif rim-station flows varied between 32.7 and 49.5 MAF with an average of 40.7 MAF as shown in Table-2.

Table-6: Western Rivers Rim-Station Inflows During April-June From 2010-2021

Year	Flows (MAF)				
	Indus at Tarbela	Kabul at Nowshera	Jhelum at Mangla	Chenab at Marala	Total
2010	15.0	7.5	9.6	6.0	38.1
2011	18.0	7.9	10.3	7.9	44.1
2012	11.8	7.6	8.0	5.3	32.7
2013	17.1	12.1	8.7	6.4	44.3
2014	12.5	11.1	10.1	7.3	41.0
2015	15.2	10.4	12.4	9.6	47.6
2016	21.1	11.3	9.8	7.3	49.5
2017	19.4	8.3	10.9	8.4	47.0
2018	12.0	7.0	6.0	5.0	30.0
2019	11.6	10.5	9.4	6.4	37.9
2020	13.7	10.4	9.6	6.4	40.1
2021	13.3	6.9	9.2	5.0	34.4
Average	15.1	9.3	9.5	6.8	40.7

5.3 Provincial Irrigation Shortages

It is a known fact that due to non-construction of any major reservoir since 1977 and rapid sedimentation of on-line reservoirs, it is not possible to ever sustain Post-Tarbela Average (1977-82) canal withdrawals which formed the basis of 12 MAF additional allocations to the provinces under Water Apportionment Accord, 1991.

As a result of above situation, the provinces have been experiencing irrigation shortages in meeting the bench-mark withdrawals in almost all Post-Accord period.

Actual year-wise average provincial irrigation shortages from 2010-21 are detailed in Annex-05 and summarized in Table-6.

Table-7: Western Rivers Rim-Station Early Kharif Flows and Corresponding Province-Wise Irrigation Shortages from 2012-2021 In Meeting Post-Tarbela Average Uses

Year	Western Rivers Rim-Station Flows (MAF)	Irrigation Water Shortages (%)				
		Punjab	Sindh	Balochistan	Khyber Pakhtunkhwa	System [a)]
2010	38	20	30	0	0	27
2011	44	0	8	0	7	2
2012	33	27	35	0	1	38
2013	44	5	17	0	1	9
2014	41	0	0	0	1	3
2015	48	0	0	0	0	0
2016	50	0	0	0	0	0
2017	47	4	0	0	1	1
2018	30	31	36	0	7	35
2019	38	10	20	0	1	14
2020	40	0	0	0	0	0
2021	34	15	17	0	12	16
Average	41	10	11	0	5	10

a) As per supporting details in Annex-06

5.4 Correlation Between river flows and Variations

5.4.1 Causative Factors

As already mentioned, the following two are basic causative factors for variation in early Kharif snow-cum-glacial runoff on Western Rivers: -

i. Catchment snow cover ending preceding March.

ii. Average 10-daily temperature in the upper catchment from April 1 to June 3.

5.4.2 Catchment Snow Coverage Ending Previous March and Early Kharif Runoff

This is an important causative factor of river flows during the following early Kharif period. Related information for Indus, Kabul, Jhelum and Chenab catchments from 2010-21 is detailed in Annex-06, while river-wise annual variation is summarized in Table-8.

Table-8: River-Wise Yearly Catchment Snow Coverage Ending March and Runoff During Following Early Kharif

Year	Indus at Tarbela		Kabul at Nowshera		Jhelum at Mangla		Chenab at Marala	
	Early Kharif Runoff (MAF)	Snow Coverage Ending Preceding March (%)	Early Kharif Runoff (MAF)	Snow Coverage Ending Preceding March (%)	Early Kharif Runoff (MAF)	Snow Coverage Ending Preceding March (%)	Early Kharif Runoff (MAF)	Snow Coverage Ending Preceding March (%)
2010	15	54	8	29	10	32	6	47
2011	18	60	8	33	10	41	8	55
2012	12	57	8	36	8	36	5	52
2013	17	59	12	39	9	37	6	53
2014	13	60	11	45	10	44	7	58
2015	15	62	10	38	12	43	10	58
2016	21	54	11	36	10	38	7	55
2017	19	61	8	36	11	38	8	54
2018	12	48	7	28	6	27	5	47
2019	12	67	11	45	9	42	6	58
2020	14	61	10	41	10	40	6	56
2021	13	52	7	33	9	36	5	51
Average	15	58	9	37	10	38	7	54

Table-8 and Annex-06 show river-wise correlation between snow coverage ending preceding March and following early Kharif runoff, which is highlighted as below: -

i. Indus at Tarbela

On the average, about 58% of the catchment area is covered by glaciers and snow with average flow of 15 MAF. Inter-year variations of coverage and runoff are between 48% to 67% or 12 to 21 MAF, respectively. Comparative plots of both these parameters (refer page 1 of 4 of Annex-06) show random variation without any trend. However, the best fit line of the plots show that: snow coverage is almost constant; while runoff has a slight reducing tendency. These are apparently contradictory and exhibit no trend over the study period.

ii. Kabul at Nowshera

On the average, about 37% of the catchment area is covered mostly by snow. Inter-year variations of coverage runoff and are between 29% to 45% or 7 to 12 MAF. Comparative plots of both these parameters (refer page 2 of 4 of Annex-06) show random variation without any trend. However, the best fit lines of the plots show that: snow coverage is almost constant; and runoff has a rising tendency. These are apparently contradictory and exhibit no trend over the study period.

iii. Jhelum at Mangla

On the average about 38% of the catchment area is covered mostly by snow. Inter-year variations of snow coverage and runoff are between 32% to 44% or 8 to 11 MAF. Comparative plots of both these parameters (refer page 3 of 4 of Annex-06) show random variation without any trend. However, the best fit lines of the plots show that snow coverage is slightly increasing; and runoff has a little declining tendency. These are also somewhat contradictory and exhibit no trend over the study period.

iv. Chenab at Marala

On the average, about 54% of the catchment is covered mostly with snow. Inter-year variations of snow coverage and runoff are 47% to 55% or 5 to 10 MAF. Comparative plots of both these parameters (refer page 4 of 4 Annex-06) show random variations without any trend. However, the best fit lines show that: snow coverage is almost constant; and runoff has an increasing tendency. These are also contradictory and exhibit no trend over the study period.

5.4.3 Average 10-Daily Temperatures in Upper Indus Catchment During Early Kharif and Corresponding Runoff

Upper snow covered catchments of Western Rivers are outside Pakistan. However, a substantial part of Upper Indus catchment lies within Pakistan and form dominant source of early snow-cum-glacial runoff on Indus River. According to standard operating procedure (SoP) for Tarbela Dam, temperatures at Skardu provide the basic yardstick for the purpose of forecasting 10-daily reservoir inflows. For this study, year-wise data has been collected for 10-daily mean temperatures at Skardu for early Kharif period of April 1 to June 3. These are listed in Annex-07 along with corresponding early Kharif runoff at Tarbela.

It can be seen from Annex-07, that year-wise average Skardu temperatures over early Kharif period of April 1 to June 3, varied between 13.7 to 18.9 °C. Corresponding runoff at Tarbela varied between 11.6 to 21.1 MAF.

Comparative plots of these two parameters are also show in Annex-07. Best fit lines of plots show that there was: slightly decreasing tendency in Skardu temperatures; and Tarbela runoff was almost constant. This was also contradictory and did not exhibit any trend.

5.5 Statistical Trend Analysis of Rim-Station flow Variations

Mann-Kendall Test Statistics was used for this purpose. This test is non-parametric test for identifying trends in time series data. It compares magnitudes of sample data rather than the data values themselves. One benefit of this test is that the data need not conform to any particular distribution. Also, the data reported as non-deducts (outliers) can be included by assigning them a common value that is smaller than the smallest measured value in the data set.

Foregoing correlation analyses has shown no trend between periodic variations in river flows over the study period of 2010-21. To further probe into this random flow behaviour, Mann-Kendall Analysis has been carried out for the rim-station flows of the four Western Rivers covering:

i. Cumulative entire early Kharif period of April to June.

ii. April to May

iii. Individual months of April, May and June.

Rim-station flow, catchment snow coverage and temperature in upper catchments data series used for conducting Mann – Kendall analysis for four Western Rivers are listed in Table-9.

Table-9: Western River Early Kharif Rim-Station Flow Data, Catchment Snow Coverage and Temperature in Upper Catchments

Series Used for Mann – Kendall Analyses

Sr. No.	River / Site	Data Services used for Mann – Kendall Test						
		Inter-Year River Flow			Catchment Snow Cover Ending Preceding March			Average 10-daily Temperature in Upper Catchment
		From	To	Years	From	To	Years	
1.	Indus / Tarbela	i. 1961 ii. 2000	2021 2021	61 22	2000	2021	22	2000-2021 (22 Years) at Skardu
2.	Kabul / Nowshera	i. 1961 ii. 2000	2021 2021	61 22	2000	2021	22	No Data
3.	Jhelum / Mangla	i. 1922 ii. 2000	2021 2021	100 22	2000	2021	22	No Data
4.	Chenab Marala	i. 1922 ii. 2000	2021 2021	100 22	2000	2021	22	No Data

Mann- Kendall Test Results for Parametric Trend Analyses of Western Rivers are listed Annex-08. Results of these analyses for the study period of 2010-21 are summarized in Table-10.

Table-10: Trend Analysis of Early Kharif (April to June) Rim-Station Flows on Western Rivers Based on Mann-Kendall Test Statistics

Sr. No.	Data Period	Parameter	Inflow Trend [a]			
			Indus at Tarbela	Kabul at Nowshera	Jhelum at Mangla	Chenab at Marala
1	2000-21 (April-June)	Inter-Year Flow	None	None	None	None
2	2000-21 (April-June)	Catchment Snow Cover Ending Preceding March V/S Flow	None	None	None	None
3	2000-21 (April-June)	Average 10-Daily Temperature In Upper Catchment V/S Flow	Temperature at Skardu-None Except Decreasing Trend in April-10	No Data	No Data	No Data

a) Based on Mann-Kendall Test Statistics

6. Mitigation of climate change impact on river flows

6.1 Lessons learnt from 2021 River flows

Before preparing any mitigation measures it seems pertinent to examine variations in monthly flows of the Western Rivers over the study period of 2010-21. These are then compared with actual 2021 flows to assess their probability of occurrence. Details are contained in Annex-09 and summarized in Table-11.

Table-11: Summary of Average Month-Wise Early Kharif Flow Variations on Western Rivers and Actual Experience of 2021

Month	Average (2010-21) Flow (MAF)					Actual 2021 Flow (MAF)					2021 Occurrence Probability (%)
	Indus at Tarbela	Kabul at Nowshera	Jhelum at Mangla	Chenab at Marala	Total	Indus at Tarbela	Kabul at Nowshera	Jhelum at Mangla	Chenab at Marala	Total	
April	2.0	2.1	2.9	1.4	8.4	1.4	1.0	2.5	0.9	5.8	± 80
May	4.3	3.2	3.4	2.1	11.0	3.7	2.5	3.3	1.5	11.0	± 50
June	8.8	3.9	3.2	3.2	19.1	8.2	3.4	3.4	2.6	17.6	±60
Total	**15.1**	**9.2**	**9.5**	**6.7**	**38.5**	**13.3**	**6.9**	**9.2**	**5.0**	**34.4**	**±75**

It can be seen form Annex-09 and Table-10 that:-

i. Occurrence probability of ± 80% during April 2021 caused anxiety among the main co-sharing provinces of Sindh and Punjab particularly with regard to early Kharif season of cotton sowing. In case, carry over storage of about 2 MAF was available from the preceding Rabi, this situation could have been managed satisfactorily.

ii. Occurrence probability of ± 50% during May 2021 was almost normal and hence irrigation system shortages significantly reduced.

iii. Occurrence probability of ± 60% during June 2021 was below normal and could have somewhat impacted rice transplantation.

6.2 Managing System Irrigation Shortages During Substantial Dips During Early Kharif flows

It is anticipated that climate change, though still in transition, can significantly impact early Kharif river flows, basically contributed by snowmelt, through large random variations. Therefore, to cope with situations like 2021, which may recur frequently, carry-over storage of about 2-MAF should be available from preceding Rabi. However, this is not available as the current (2021) total on-line live storage capacity including Raised Mangla is about 12.3 MAF against original capacity of 15.7 MAF in 1977 (refer Annex-10).

To cope with the above situation, it is imperative that additional storages be constructed on the Western Rivers wherever feasible. Jhelum River has been already over-exploited through construction of Raised Mangla. All of Chenab River upper catchment lies in India and thus there is no possibility of constructing any storage under control of Pakistan. This basically leaves Indus / Kabul where four storages (Dasu, Mohmand, Kurram Tangi, Diamer Basha) are under construction with an aggregate live capacity of 8.7 MAF. These are scheduled for commissioning between 2024 and 2029. Even after induction of these storages, the projected aggregate capacity by 2030 could approach 19.7 MAF (refer Annex-10). Even then, Indus Basin Irrigation System (IBIS) might face vagaries of climate change on rim-station flows of Western Rivers and consequential irrigation shortages in sustaining even the bench mark post-Tarbela average (1977-82) canal uses.

Furthermore, to provide for about 12 MAF additional uses allocated under Para-2 of Water Apportionment Accord (WAA), it is high time that construction of additional storages on the Indus River be given highest priority. In this regard, the candidate dam projects could be Kalabagh, Akhori, and Yugo / Khaplu. Out of these, the first two dams are already engineered while third

one is entering the stage of feasibility updation, engineering design and contract documentation to pave the way for its implementation.

It is considered necessary that construction of at least one major storage project be taken up soon after completion of Dasu and Mohmand Dams by mid-2025.

7. Conclusions and recommendations

7.1 Conclusions

i. Impact of climate change, though still in transition, has started taking its toll in the form of large random variations in early Kharif snow-cum-glacial melt flows of Western Rivers. In turn, it is causing severe irrigation water shortages in the crucial early Kharif season of April to June.

ii. A case study based on hydrometeorological data of Western Rivers for the recent 12 years (2010-12) shows that: -

   a. This situation is already being experienced in low flow years due to by about 1/3rd loss in capacity of on-line storages.

   b. The situation has been further accentuated by climate change impact on the snow-cum-glacial melt flows of Wester Rivers during April to June which is crucial for early Kharif crop sowing season.

   c. Indus Basin Irrigation System (IBIS) shortages over the study period have gone upto 35% with an average of 10%.

   d. To mitigate the above adverse impact on irrigated agriculture in Indus Basin, a carry-over storage of about 2 MAF may be required from preceding Rabi to the following early Kharif, which is presently unavailable.

iv. a. A trend analyses of early Kharif flow has been carried out for the two basic change causative factors of: catchment snow coverage ending preceding March: and early Kharif temperature in the upper catchments.

   b. These analyses do not yield any visible trends in river flow variations of all the Western Rivers.

   c. On the other hand, river flows exhibit very large ± random variation with consequent adverse impact on irrigated agriculture:

v. a. To mitigate the randomness of river flows being caused by climate change, it is imperative to have additional carry-over storages on the Western Rivers.

   b. Three dams (Dasu, Mohmand and Diamer Basha) to be completed during the current decade, will barely provide for prevailing irrigation shortages for sustaining the bench-mark withdrawals of WAA 1991.

   c. Creation of this storage capacity, besides providing additional water for sustaining irrigation uses, will improve river regulation, flood control and provide affordable clean energy in the form of hydropower.

7.2 Recommendations

i. After commissioning of Dasu and Mohmand Dam Projects by mid-2020s, another major dam project (Kalabagh / Akhori / Khaplu) should be taken up for priority construction.

ii. To improve the capability of reliable river flow forecasting of concerned national agencies of PMD and WAPDA: -

a. Upper catchment hydrometeorological data collection network be substantially augmented.

b. Analytical capabilities of modelling including application know how in these agencies be enhanced through standing collaboration with international researching / funding institutions (ADB / World bank).

c. Global Change Impact Studies Center at Islamabad, should assume a pro-active role including interaction with the concerned line agencies to advance the research efforts for reliable forecasting as well as mitigation of the impacts of this phenomenon on the national economy.

8. Acknowledgement

Special thanks are due to Mr. Zeeshan Riaz Tarar, System Analyst, Indus River System Authority (IRSA), who collected and collated all relevant hydrometeorological data required for this study. In addition, he carried out all the analyses including Mann-Kendell Test for trend analysis of the causative factors of catchment snow cover and temperatures.

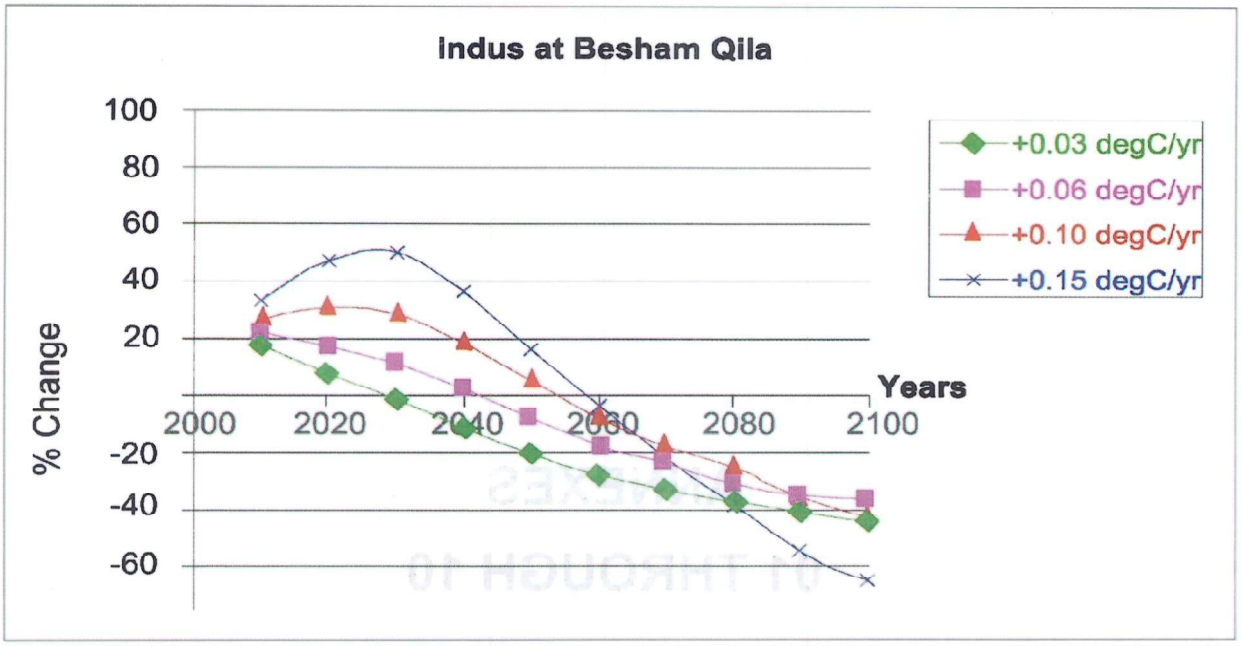
9. References

1. Pakistan Water Economy – Running Dry, World Bank, 2005.
2. Climate Profile and Past Climate Changes in Pakistan, Global Change Impact Studies Centre (GCISC), Islamabad, 2009.
3. Impact of Climate Change on Pakistan Rivers – A Case for Cooperative Research By Riaz Nazir Tarar: Paper Contributed for 2013 World Water Day of Pakistan Engineering Congress.
4. The Indus Basin of Pakistan – The Impacts of Climate Risks on Water and Agriculture, World Bank, 2020.
5. Climate Change and Hydrological Regime of the High – Altitude Indus Basin Under Extreme Climate Scenarios – Science of the Total Environment, January 2021.
6. Climate Change 2021 – The Physical Science Basis, Intergovernmental Panel on Climate Change (IPCC), 2021.

ANNEXES
01 THROUGH 10

ANNEX-01

PROJECTED EFFECTS OF DEGLACIATION ON INDUS RIVER FLOWS AT BESHAM DURING 21ST CENTURY

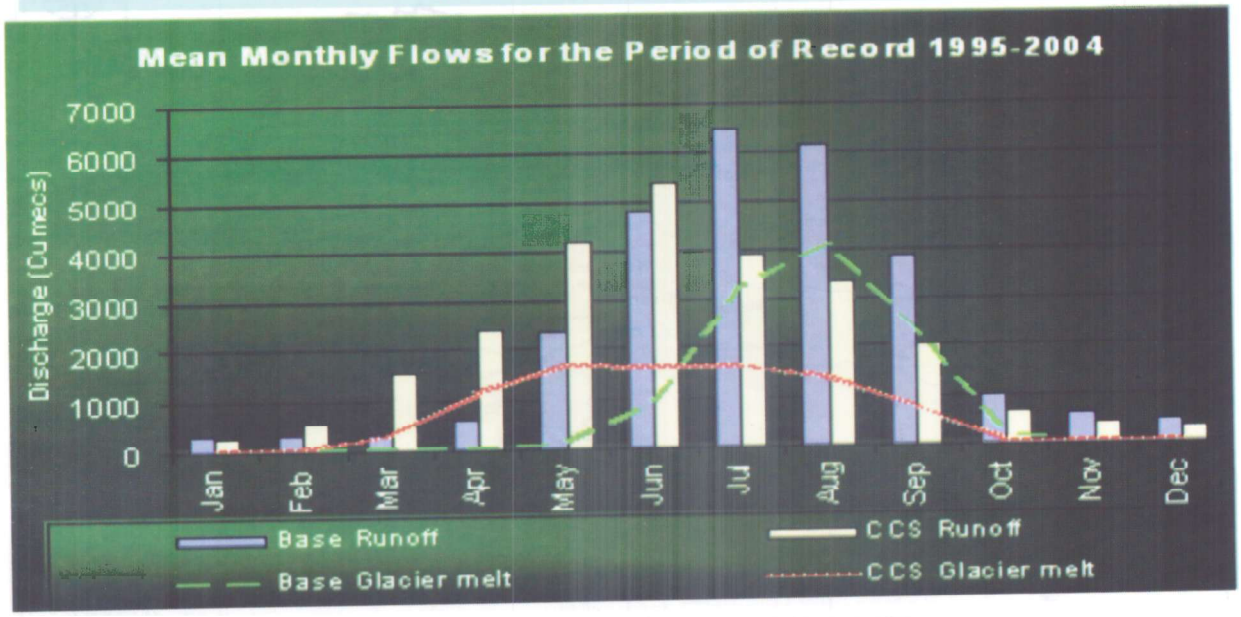


Source: World Bank (2005)

ANNEX-02

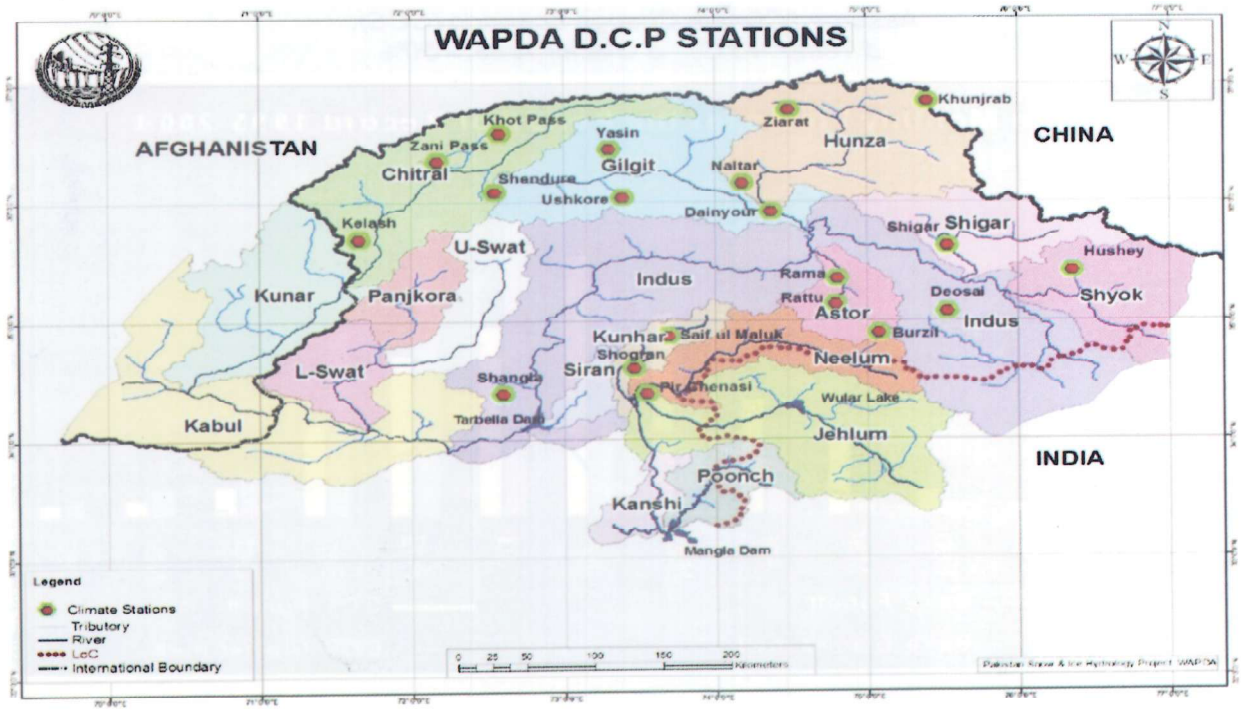
IMPACT OF CLIMATE CHANGE AND GLACIER RETREAT ON UPPER INDUS BASIN FLOWS

Assumed Climate Change Scenario (CCS):
Δ Temp: +3°C, Δ Glacier Area: - 50%



ANNEX-03

WAPDA'S HIGH ALTITUDE DATA COLLECTION PLATFORM NETWORK IN UPPER INDUS BASIN



ANNEX-04

DISTRIBUTION OF WATER IN MAIN RIVERS OF PAKISTAN

River	Flow Contribution (%)	Seasonal Distribution (%)		Dominant Source of Water	
		Summer (Apr-Sep)	Winter (Oct-Mar)	Summer	Winter
Indus	44	86	14	Snow/Glacier melt	Winter Rainfall + Baseflow
Kabul	16	82	18	Snow/Glacier melt	Winter Rainfall + Baseflow
Jhelum	16	78	22	Mainly Snow melt + Monsoon	Winter Rainfall + Baseflow
Chenab	19	83	17	Mainly Snow melt + Monsoon	Winter Rainfall + Baseflow
Others	5*	100	0	Uncontrolled floods	
Total / Average	100	86	14		

* Unaccounted flows including uncontrolled floods from Eastern Rivers of Ravi and Sutlej.

ANNEX-05

Western Rivers Rim-Station Early Kharif (April – June) Flows and Corresponding Province-Wise Canal Withdrawals and Shortages From 2010-2021

Year	Western River Rim-Station Inflows from April-June (MAF)					Canal Withdrawals											
						Punjab			Sindh			Balochistan			Khyber Pakhtunkhwa		
	Indus at Tarbela	Kabul at Nowshera	Jhelum at Mangla	Chenab at Marala	Total	Post-Tarbela Average 1977-82 (MAF)	Actual (MAF)	Shortage (%)	Post-Tarbela Average 1977-82 (MAF)	Actual (MAF)	Shortage (%)	Post-Tarbela Average 1977-82 (MAF)	Actual (MAF)	Shortage (%)	Post-Tarbela Average 1977-82 (MAF)	Actual (MAF)	Shortage (%)
2010	15.0	7.5	9.6	6.0	38.1	15.9	12.7	20.1	11.3	7.9	30.1	0.21	0.50	-138.10	1.82	1.90	-4.40
2011	18.0	7.9	10.3	7.9	44.1	15.9	16.1	-1.3	11.3	10.4	8.0	0.21	0.50	-138.10	1.82	1.70	6.59
2012	11.8	7.6	8.0	5.3	32.7	15.9	11.6	27.0	11.3	7.3	35.4	0.21	0.40	-90.48	1.82	1.80	1.10
2013	17.1	12.1	8.7	6.4	44.3	15.9	15.1	5.0	11.3	9.4	16.8	0.21	0.50	-138.10	1.82	1.80	1.10
2014	12.5	11.1	10.1	7.3	41.0	15.9	15.5	2.5	11.3	10.5	7.1	0.21	0.50	-138.10	1.82	1.80	1.10
2015	15.2	10.4	12.4	9.6	47.6	15.9	15.4	3.1	11.3	12.7	-12.4	0.21	0.40	-90.48	1.82	1.70	6.59
2016	21.1	11.3	9.8	7.3	49.5	15.9	16.4	-3.1	11.3	13.2	-16.8	0.21	0.50	-138.10	1.82	1.60	12.09
2017	19.4	8.3	10.9	8.4	47.0	15.9	15.3	3.8	11.3	11.4	-0.9	0.21	0.50	-138.10	1.82	1.80	1.10
2018	12.0	7.0	6.0	5.0	30.0	15.9	10.3	35.2	11.3	6.6	41.6	0.21	0.30	-42.86	1.82	1.70	6.59
2019	11.6	10.5	9.4	6.4	37.9	15.9	14.3	10.1	11.3	9.1	19.5	0.21	0.30	-42.86	1.82	1.80	1.10
2020	13.7	10.4	9.6	6.4	40.1	15.9	14.7	7.5	11.3	12.7	-12.4	0.21	0.70	-233.33	1.82	1.60	12.09
2021	13.3	6.9	9.2	5.0	34.4	15.9	13.6	14.5	11.3	9.4	16.8	0.21	0.50	-138.10	1.82	1.60	12.09
Average	15.1	9.3	9.5	6.8	40.7	15.9	14.3	10.1	11.3	10.1	10.6	0.21	0.50	-138.10	1.82	1.73	4.95

Note: Minus figures indicate surplus

ANNEX-06

Table-1 Indus at Tarbela

Early Kharif Flows From 2010 to 2021
And Catchment Snow Covered Area Ending Preceding March

Sr. No.	Year	Inflow From April 1 to June 3 (MAF)	Catchment Snow Cover Ending Preceding March (%)
1	2010	15.0	54.0
2	2011	18.0	60.0
3	2012	11.8	57.0
4	2013	17.1	59.0
5	2014	12.5	60.0
6	2015	15.2	62.0
7	2016	21.1	54.0
8	2017	19.4	61.0
9	2018	12.0	48.0
10	2019	11.6	67.0
11	2020	13.7	61.0
12	2021	13.3	52.0
13	Average	15.1	58.0

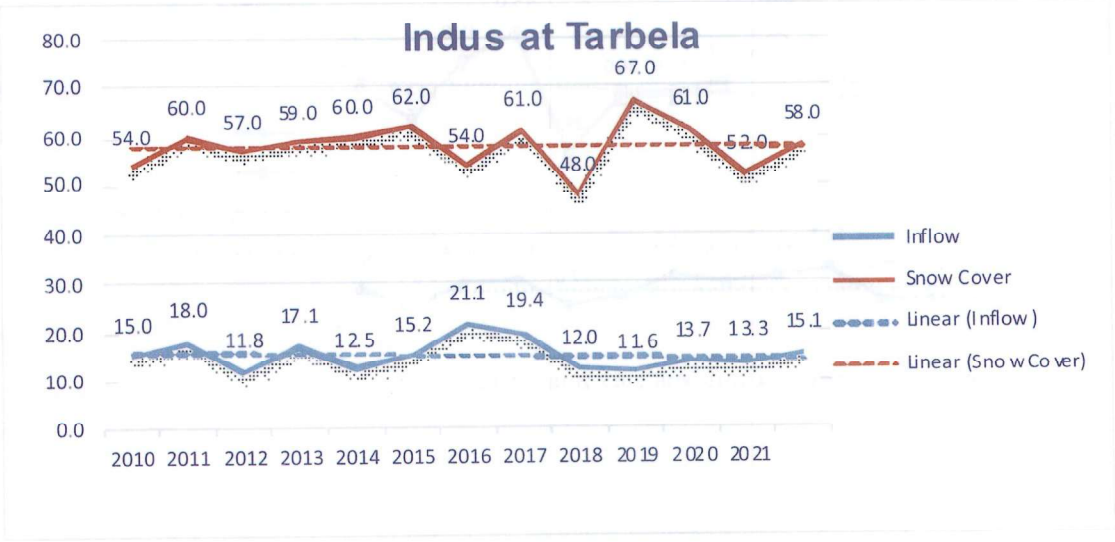


Table-2 Kabul at Nowshera

Early Kharif Flows From 2010 to 2021
And Catchment Snow Covered Area Ending Preceding March

Sr. No.	Year	Inflow From April 1 to June 3 (MAF)	Catchment Snow Cover Ending Preceding March (%)
1	2010	7.5	29.0
2	2011	7.9	33.0
3	2012	7.6	36.0
4	2013	12.1	39.0
5	2014	11.1	45.0
6	2015	10.4	38.0
7	2016	11.3	36.0
8	2017	8.3	36.0
9	2018	7.0	28.0
10	2019	10.5	45.0
11	2020	10.4	41.0
12	2021	6.9	33.0
13	Average	9.3	37.0

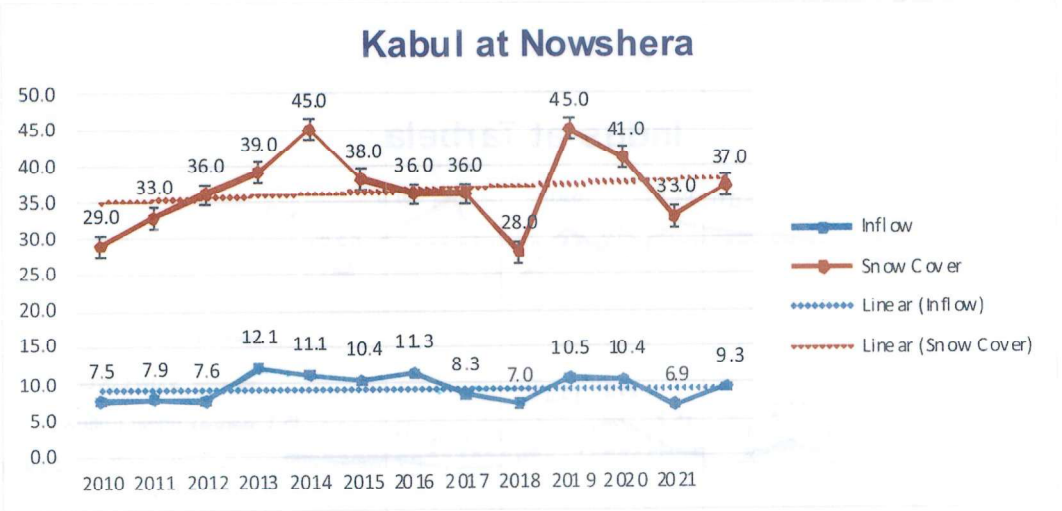


Table-3 Jhelum at Mangla

Early Kharif Flows From 2010 to 2021
And Catchment Snow Covered Area Ending Preceding March

Sr. No.	Year	Inflow From April 1 to June 3 (MAF)	Catchment Snow Cover Ending Preceding March (%)
1	2010	9.6	32.0
2	2011	10.3	41.0
3	2012	8.0	36.0
4	2013	8.7	37.0
5	2014	10.1	44.0
6	2015	12.4	43.0
7	2016	9.8	38.0
8	2017	10.9	38.0
9	2018	6.0	27.0
10	2019	9.4	42.0
11	2020	9.6	40.0
12	2021	9.2	36.0
13	Average	9.5	38.0

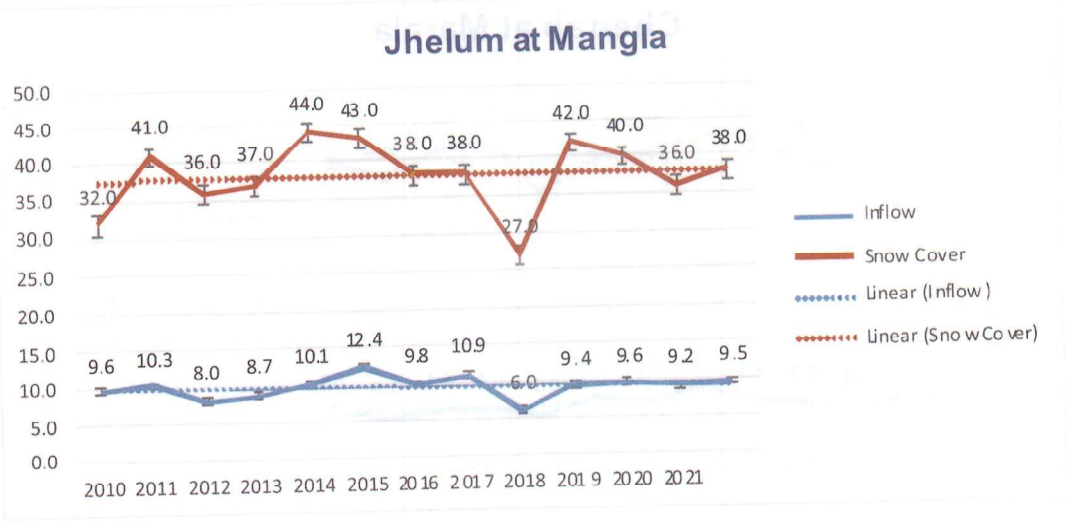
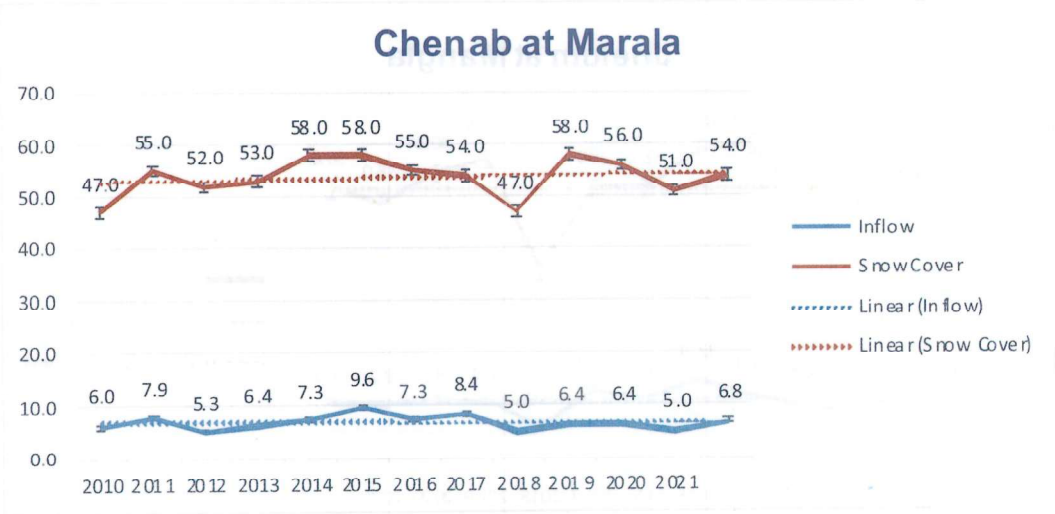


Table-4 Chenab at Marala

Early Kharif Flows From 2010 to 2021
And Catchment Snow Covered Area Ending Preceding March

Sr. No.	Year	Inflow From April 1 to June 3 (MAF)	Catchment Snow Cover Ending Preceding March (%)
1	2010	6.0	47.0
2	2011	7.9	55.0
3	2012	5.3	52.0
4	2013	6.4	53.0
5	2014	7.3	58.0
6	2015	9.6	58.0
7	2016	7.3	55.0
8	2017	8.4	54.0
9	2018	5.0	47.0
10	2019	6.4	58.0
11	2020	6.4	56.0
12	2021	5.0	51.0
13	Average	6.8	54.0

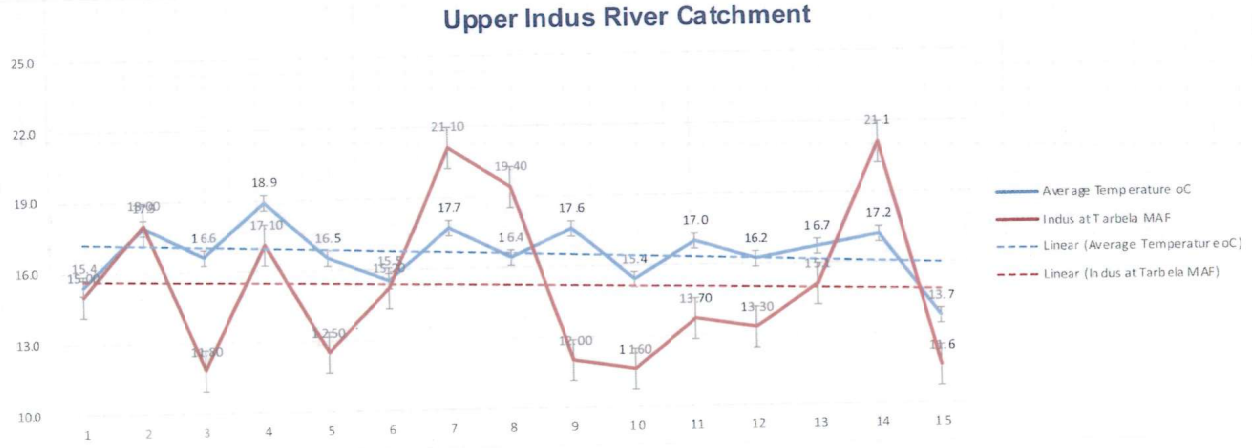


Upper Indus River Catchment

Average 10-Daily Temperatures at Skardu From 2010 to 2021 During Early Kharif Period of April to June and Corresponding Flows at Tarbela

℃

10-Daily Period	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Average	Maximum	Minimum
APR 1	11.5	9.4	13.7	11.6	11.4	10.2	9.1	8.0	15.8	10.9	9.0	7.4	10.7	15.8	7.4
2	12.8	12.1	11.5	14.4	10.8	14.0	12.2	11.7	13.7	14.2	12.4	10.9	12.6	14.4	10.8
3	13.8	15.2	15.9	14.9	14.7	14.0	13.6	13.8	15.5	16.1	16.4	13.1	14.8	16.4	13.1
MAY 1	16.3	18.7	16.3	13.9	19.0	15.3	17.7	15.4	16.4	15.0	16.2	17.2	16.5	19.0	15.0
2	14.5	19.4	17.1	17.4	16.0	17.8	17.9	17.9	16.6	16.7	17.4	15.7	17.0	19.4	14.5
3	15.2	18.7	17.4	17.1	17.1	14.4	19.7	19.5	17.7	16.5	20.1	18.1	17.6	20.1	14.4
JUN 1	16.4	20.5	18.6	21.2	18.6	17.7	22.0	20.1	22.5	17.0	20.3	22.4	19.8	22.5	16.4
2	18.0	22.6	18.1	19.9	20.2	18.5	22.2	18.9	21.7	14.2	19.6	19.5	19.5	22.6	14.2
3	20.3	24.8	20.5	23.4	20.9	17.7	24.6	22.4	18.8	18.1	21.9	21.3	21.5	24.8	17.7
Average Temperature	15.4	17.9	16.6	18.9	16.5	15.5	17.7	16.4	17.6	15.4	17.0	16.2	16.7	17.2	13.7
Indus at Tarbela (Apr. to June-MAF)	15.00	18.00	11.80	17.10	12.50	15.20	21.10	19.40	12.00	11.60	13.70	13.30	15.1	21.1	11.6



ANNEX-07

ANNEX-08

Mann-Kendall Test Results For Flow Trend Analysis of Wester Rivers

Sr. No.	Data Period	No. of Years	River / Station	Unit	Normalized Test Statistic (Z)	Probabailit y	Trend / Significance %
1	April to June: 1961-2021	61	Indus / Tarbela	MAF	-0.40	0.6571	No Trend
2	April to May: 1961-2021	61	Indus / Tarbela	MAF	2.20	0.9860	Increasing / 95%
3	April :1961-2021	61	Indus / Tarbela	MAF	0.63	0.7352	No Trend
4	May: 1961-2021	61	Indus / Tarbela	MAF	2.45	0.9928	Increasing / 95%
5	June : 1961-2021	61	Indus / Tarbela	MAF	-1.97	0.9757	Decreasing / 95%
6	May: 2000-2021	22	Indus / Tarbela	MAF	-1.75	0.9598	Decreasing / 90%
7	June : 2000-2021	22	Indus / Tarbela	MAF	-0.73	0.7683	No Trend
8	Stand. Dev. of DailyFlow (April-June): 2000-2021	22	Indus / Tarbela	cfs	-1.52	0.9361	No Trend
9	Stand. Dev. of DailyFlow (April): 2000-2021	22	Indus / Tarbela	cfs	-0.51	0.6941	No Trend
10	Stand. Dev. of DailyFlow (May): 2000-2021	22	Indus / Tarbela	cfs	-1.69	0.9547	Decreasing / 90%
11	Stand. Dev. of DailyFlow (June): 2000-2021	22	Indus / Tarbela	cfs	-1.24	0.8926	No Trend
12	Snow Covered Area Ending March	22	Indus / Tarbela	%	0.20	0.5783	No Trend
13	Glacier Exposed Area Ending March	22	Indus / Tarbela	%	-1.33	0.9081	No Trend
14	April to June: 1961-2021	61	Kabul / Nowshera	MAF	-1.15	0.8752	No Trend
15	April to May: 1961-2021	61	Kabul / Nowshera	MAF	-0.44	0.6707	No Trend
16	April :1961-2021	61	Kabul / Nowshera	MAF	-0.35	0.6386	No Trend
17	May: 1961-2021	61	Kabul / Nowshera	MAF	-0.49	0.6885	No Trend
18	June : 1961-2021	61	Kabul / Nowshera	MAF	-1.67	0.9523	Decreasing / 90%
19	June: 2000-2021	22	Kabul / Nowshera	MAF	2.09	0.9815	Increasing / 95%
20	June : 2010-2021	22	Kabul / Nowshera	MAF	0.62	0.7314	No Trend
21	Stand. Dev. of DailyFlow (April-June): 2000-2021	22	Kabul / Nowshera	cfs	1.86	0.9686	Increasing / 90%
22	Stand. Dev. of DailyFlow (April): 2000-2021	22	Kabul / Nowshera	cfs	1.41	0.9207	No Trend
23	Stand. Dev. of DailyFlow (May): 2000-2021	22	Kabul / Nowshera	cfs	1.69	0.9547	Increasing / 90%
24	Stand. Dev. of DailyFlow (June): 2000-2021	22	Kabul / Nowshera	cfs	0.34	0.6325	No Trend
25	Snow Covered Area Ending March	22	Kabul / Nowshera	%	0.97	0.8328	No Trend
26	April to June: 1922-2021	100	Jhelum / Mangla	MAF	-0.86	0.8053	No Trend
27	April to May: 1922-2021	100	Jhelum / Mangla	MAF	0.48	0.6842	No Trend
28	April :1922-2021	100	Jhelum / Mangla	MAF	1.56	0.9410	No Trend / Almost near 90%
29	May: 1922-2021	100	Jhelum / Mangla	MAF	-0.56	0.7112	No Trend
30	June : 1922-2021	100	Jhelum / Mangla	MAF	-2.92	0.9983	Decreasing / 99%
31	June: 2000-2021	22	Jhelum / Mangla	MAF	1.47	0.9287	No Trend
32	June : 2010-2021	22	Jhelum / Mangla	MAF	-0.21	0.5815	No Trend
33	Stand. Dev. of DailyFlow (April-June): 2000-2021	22	Jhelum / Mangla	cfs	-0.17	0.5672	No Trend
34	Stand. Dev. of DailyFlow (April): 2000-2021	22	Jhelum / Mangla	cfs	1.02	0.8450	No Trend
35	Stand. Dev. of DailyFlow (May): 2000-2021	22	Jhelum / Mangla	cfs	-1.92	0.9724	Decreasing / 90%
36	Stand. Dev. of DailyFlow (June): 2000-2021	22	Jhelum / Mangla	cfs	0.23	0.5892	No Trend
37	Snow Covered Area Ending March	22	Jhelum / Mangla	%	0.62	0.7334	No Trend
38	April to June: 1922-2021	100	Chenab / Marala	MAF	0.65	0.7409	No Trend
39	April to May: 1922-2021	100	Chenab / Marala	MAF	1.44	0.9248	No Trend
40	April :1922-2021	100	Chenab / Marala	MAF	1.60	0.9451	No Trend / Almost near 90%
41	May: 1922-2021	100	Chenab / Marala	MAF	1.13	0.8717	No Trend
42	June : 1922-2021	100	Chenab / Marala	MAF	-0.86	0.8053	No Trend
43	April:2000-2021	22	Chenab / Marala	MAF	0.62	0.7327	No Trend
45	Stand. Dev. of DailyFlow (April-June): 2000-2021	22	Chenab / Marala	cfs	-1.02	0.8450	No Trend
46	Stand. Dev. of DailyFlow (April): 2000-2021	22	Chenab / Marala	cfs	0.68	0.7507	No Trend
47	Stand. Dev. of DailyFlow (May): 2000-2021	22	Chenab / Marala	cfs	-2.93	0.9983	Decreasing / 99%
48	Stand. Dev. of DailyFlow (June): 2000-2021	22	Chenab / Marala	cfs	-0.62	0.7325	No Trend
49	Snow Covered Area Ending March	22	Chenab / Marala	%	0.94	0.8261	No Trend
50	Apr-1: Av. Temp: 2010-2021	12	Skardu	Centigrade	-1.85	0.9679	Decreasing / 90%
51	Apr-2 : Av. Temp: 2010-2021	12	Skardu	Centigrade	0.07	0.5273	No Trend
52	Apr-3 : Av. Temp: 2010-2021	12	Skardu	Centigrade	0	-	No Trend
53	May-1 : Av. Temp: 2010-2021	12	Skardu	Centigrade	-0.27	0.6083	No Trend
54	May-2 : Av. Temp: 2010-2021	12	Skardu	Centigrade	-0.21	0.5819	No Trend
55	May-3 : Av. Temp: 2010-2021	12	Skardu	Centigrade	0.96	0.832	No Trend
56	Jun-1 : Av. Temp: 2010-2021	12	Skardu	Centigrade	1.24	0.892	No Trend
57	Jun-2 : Av. Temp: 2010-2021	12	Skardu	Centigrade	0	-	No Trend
58	Jun-3 : Av. Temp: 2010-2021	12	Skardu	Centigrade	-0.48	0.6844	No Trend

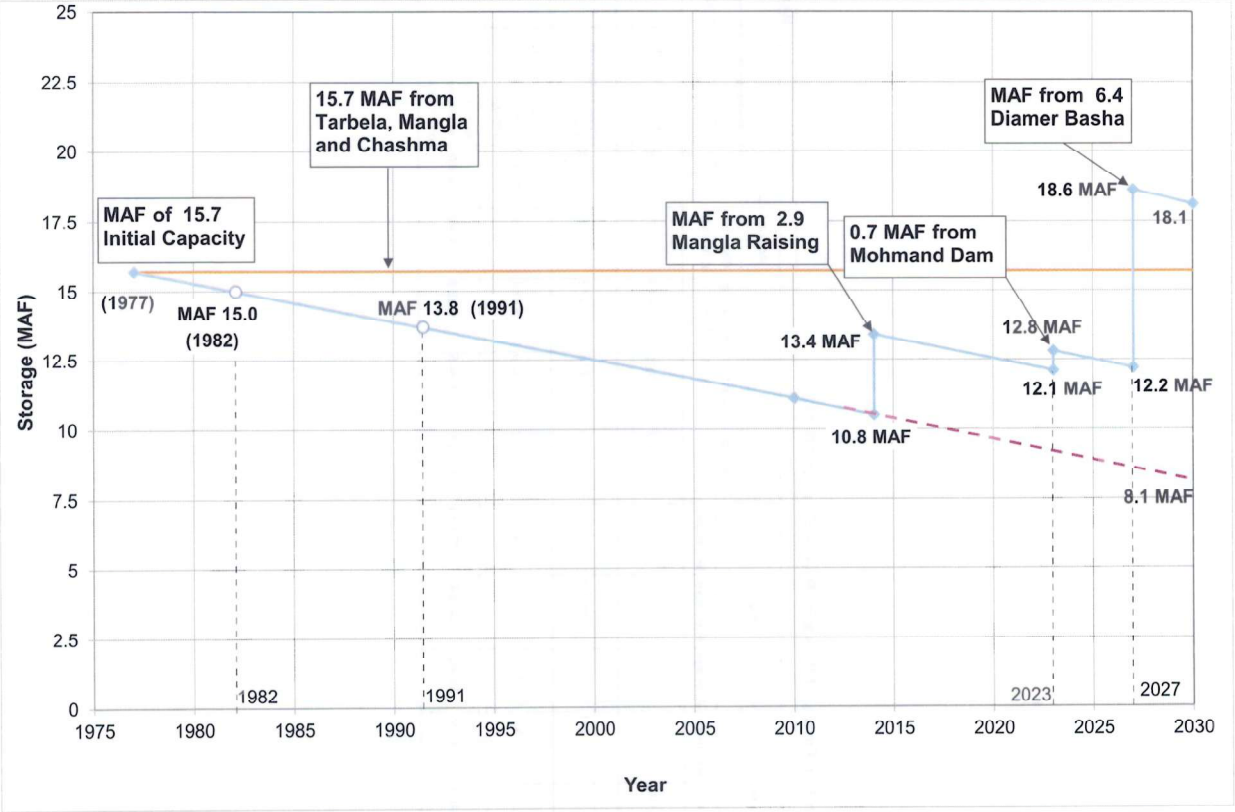
ANNEX-09

Month-Wise Early Kharif (April - June) Variation For Flows of Western Rivers Over 2010-2021

MAF

Month	Indus at Tarbela			Kabul at Nowshera			Jhelum at Mangla			Chenab at Marala			Total			Actual 2021					Remarks Regarding 2021 Inflow	
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Indus at Tarbela	Kabul at Nowshera	Jhelum at Mangla	Chenab at Marala	Total	Pattern	Probability (%)
April	1.975	2.940	1.452	2.119	4.096	0.962	2.889	4.495	1.668	1.468	3.013	0.877	8.451	14.544	4.959	1.452	0.962	2.539	0.877	5.830	Close to historic minimum	±60
May	4.328	6.818	2.606	3.153	4.027	1.707	3.423	4.436	2.192	2.083	3.095	1.241	10.904	18.376	7.746	3.656	2.474	3.276	1.474	10.880	Close to historic average	±50
June	8.766	12.337	7.006	3.965	5.944	2.686	3.189	3.695	2.120	3.193	3.745	2.537	19.113	25.721	14.349	8.22	3.429	3.414	2.634	17.697	Somwhat lower than historic average	±60
Total	15.069	22.095	11.064	9.237	14.067	5.355	9.501	12.626	5.980	6.744	9.853	4.655	38.468	58.641	27.054	13.328	6.865	9.229	4.985	34.407	Almost median of historic average and minimum	±75

ANNEX-10


MAF of 15.7
Initial Capacity
15.7 MAF from
Tarbela, Mangla
and Chashma
MAF from 2.9
Mangla Raising
0.7 MAF from
Mohmand Dam
MAF from 6.4
Diamer Basha
(1977)
MAF 15.0
(1982)
MAF 13.8 (1991)
13.4 MAF
12.8 MAF
12.1 MAF
18.6 MAF
18.1
12.2 MAF
10.8 MAF
8.1 MAF
1982
1991
2023
2027
Storage (MAF)
Year
25
22.5
20
17.5
15
12.5
10
7.5
5
2.5
0
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030