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Indus Basin Irrigation System and Climatic Trends Regarding Glacial Regimes and Water Runoff

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Abstract: Glaciers, rivers and other water resources are important to sustainability of life. Pakistan have world's most precious irrigation network. This review explains the evidences, inconsistent changes, factors of glacier changes in Himalaya and Karakorum. Deviations in seasonal temperature shifts, snow cover elevations and snowfall trends are most effective factors in this regard. These are directly influencing flow rate in Indus delta. Climate change is affecting entire system very significantly. This study evaluates different aspects of these issues with economic and social influence. Understanding the importance of all these factors requires investigated situations at upper elevations with advanced monitoring system and modern technological tools. This will mark glacier regimes, water requirements, irrigation network, river flow, irrigation requirements and irrigation efficiency from glacier bodies to the end use. Water security is defined with respect to agricultural water use efficiency. Irrigation needs for agriculture are key defining points of water use efficiency. Irrigation efficiency needs to be enhanced for better agricultural productivity. Pattern of recent floods and droughts is also studied in this review. Energy shortage affects water resources and water usages. In conclusion, the extensive study was conducted to evaluate the irrigation network, water resources, natural extremes, droughts and water security under present scenario.

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1. Historical perspective

Pakistan is an ethnically and linguistically diverse country, with a wide range of variations in geography, climate and wildlife. Pakistan is divided in three major geographic zones; the northern highlands, the Baluchistan plateau and the Indus River plain. Indus river and its tributaries are as much important for Pakistan as the Herodotus described about Egypt as "the gift of the Nile" and as "a land won by the Egyptians and given them by the Nile".

The Indus River and its tributaries, Kabul, Jhelum, Chenab, Ravi and Sutlej rivers originating from Karakoram, Hindu Kush and the Himalayan regions collectively form Indus Basin. Among the total area of the basin 528,156 km2 lies in Pakistan out of the entire area of 900,930 square kilometers of this Basin. Flow of this Basin varies as in summer discharge is 20 times of winter. On the basis of hydrological features, Pakistan is divided into three major regions; (i) Indus Bain, (ii) The Karan Desert and (iii) The arid Makran Coast (Akhtar, et al., 2008; Abukhater, 2013).

Pakistan's Indus River Basin System comprises of five main rivers i.e. Indus, Jhelum, Chenab, Ravi and Sutlej. Origin of these rivers is higher altitudes and they derive their flows mainly from snow-melt and monsoon rains. Climate is not uniform over the whole Indus Basin. It varies from sub-tropical arid and semi-arid to temperate sub-humid on the plains of Sindh and Punjab provinces to alpine in the mountainous highlands of the north (Archer, D. 2003; Ahmad, S. et al., 2004).

The Indus Basin Irrigation System (IBIS), world's largest gravity-fed irrigation system. Most of the water comes from monsoon rains and glacier melting. (comprises 3 dams/reservoirs, 2 head works and 19 barrages, 12 inter-river link canals, 45 main canals and over 120,000 watercourses delivering water to farms and for other productive uses (Xu, et al., 2009). It covers 16.68 M ha, out of 21 M ha of agricultural land through its large scale irrigation systems (Eriksson, et al., 2009).

IBIS irrigates 45 million acres farm land on which different crops are being cultivated, e.g. wheat, rice, sugarcane, vegetables, fruits etc. for local use as well as for the export. Indus River contributes more than half of the total flow of the IBIS.

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Pakistan's economy mainly depends upon agriculture as agriculture share in GDP is 22% and water is a critical resource in agricultural production. Water availability depends upon the area or flow of water from Indus Basin Irrigation System in Pakistan (Siddiqui, 2010; Abukhater, 2013).

After partition in 1947, Sir Cyril Radcliffe, Chairman of boundary commission, awarded control barrages (which are near to boundary) to India while 90% of the farm land lay in Pakistan (Shirazi and Hussain, 2009). Due to this irrational partition, water dispute arises and in 1948 war was started between Pakistan and India. Than with the facility of World Bank, in 1960 Indus Water Treaty was signed between Pakistan and India (Siddiqui, 2010; Alcamo, et al., 2003; Ammad, 2011). According to this treaty, three eastern rivers, i.e., Ravi, Sutlej and Beas were given to India and western rivers, i.e., Indus, Jhelum and Chenab were under Pakistan (Raskin, et al., 1997; Siddiqui, 2010).

2. Irrigation Network

Pakistan marks the largest irrigation system with 13.96 million ha (34.5 million acres) of adjacent cultivated area. Major feeding sources for irrigated areas are Indus and its tributaries. Significant contribution in this system is from three major dams, namely, Chashma and Tarbela on Indus, Mangla of Jhelum, having a live storage of 15.4 $BM^3$12.5 MAF), 19 well established barrages, and 12 inter link canals and forty three (43) irrigation canals(Sharma, et al., 2010; Raskin, et al., 1997). Main canals comprise on an area of 58,500 km. Water courses are extended to about 1,621,000 kms. Barrages play the role for water diversion. On an average, 106 MAF of surface water is drawn from the system each year (Cheema and Pawar, 2015; Cogley, 2009).

2.1. Changes in available water supply

Water demand continues to rise with rising population. The "Sobering fact" that "there is no feasible intervention which would enable Pakistan to mobilize appreciably more water than it now uses" (Agro-Dev, 2000; Sharma, et al., 2010). But reduces irrigation water availability is also possible due to reduction in available irrigation water and reduction in flow. Some factors that indicate these problems are:

i. Declining storage capacity of reservoirs due to the sedimentation
ii. Increase d industrial and domestic demand
iii. Enhancement in environmental flows
iv. Reduction in groundwater resources
v. Climatic impact on mountain and glacial sources.

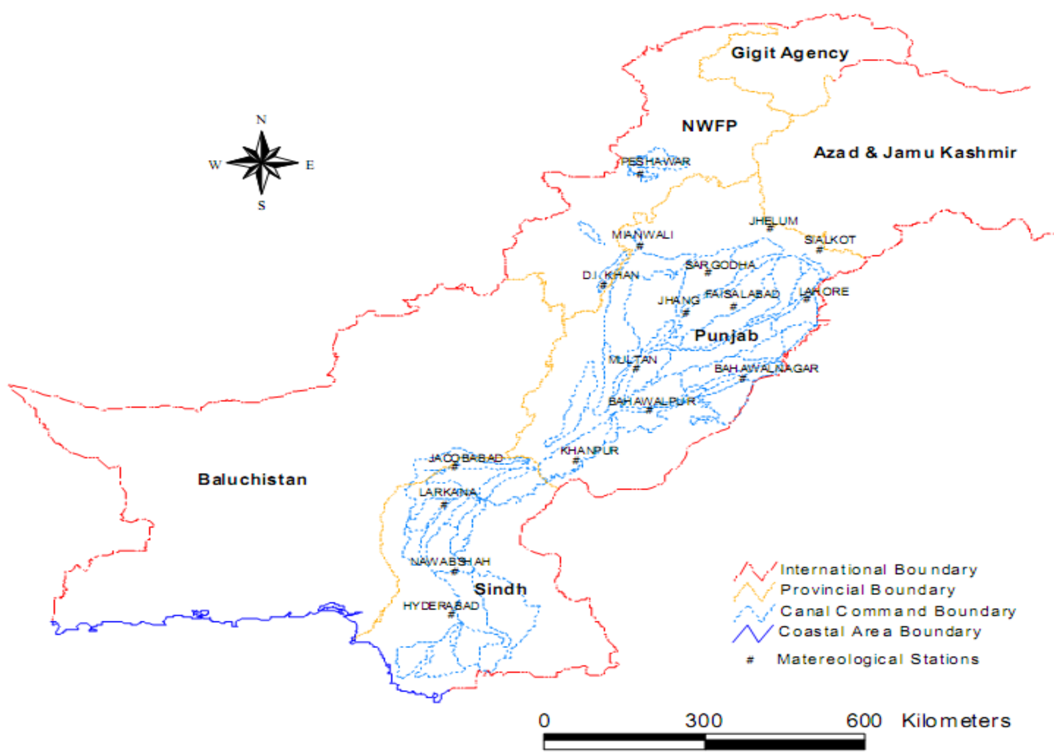

Fig. 1. Location of canal command of Indus Basin Irrigation System with meteorological stations (Source Flood Forecasting Division, Lahore).

Indus basin irrigation network carries a remarkable load of sediments. A reduction of 28% to the initial capacity of Tarbela has occurred with an estimated life age of 85 years more (Akhtar, et al., 2008; Fowler and Archer, 2006). Not many measures have been made to manage these sedimentation problems. This also has limited the applicability for Mangla and Terbela (Kaser et al., 2010).

2.2. Water management and irrigation issues

This concept is acquiring new directions in the country. Irrigation performance is facing multi-dimensional constraints. The most common and demanding constraints in irrigation management are financial insufficiency (lack of funds, high maintenance expenditures, intensifying expenses on establishment, huge gap between expenditures and cost recovery), physical limitations (structure design capabilities, irrigation water scarcity, less storage, continuing deterioration of system, overstressing and aging) , official issues (Institutional setup changes, lack of planning, provincial misunderstandings) and ecological problems (water logging, sodicity, salinity, imbalance of salts and continuous pollution in water bodies) (Fowler and Archer, 2006; Akhrat et al., 2008).

Indus basin system is about a hundred year old so its efficiency has decreased up to 50% regarding storage, water losses and accuracy of system. Water losses during transit and applications are now considerable. Significant losses and wastage of valuable water is causing limitations in expansion of irrigated land (Sharma, et al., 2010; Qureshi, 2008). Benefits per unit of land are also reduced. This is also promoting the issue of salinity and water-logging. Because of this continuing pressure on irrigation system, water conservation is very much important for future food security with reference to the increasing population of the country. So, urgent need by mean time is to secure every drop of water; in irrigation system, in transportation of water, at farm level and during application. This demands energetic contribution of end users along with government sector, irrigation department and policy makers (Fowler and Archer, 2006; Akhtar et al., 2008).

Water is very much important for Pakistan and its importance can never be underestimated for agricultural use in the country. The area under cultivation is about 16.2 million hectare which is 74% to the total area which is 22 million hectare. Ninety seven percent of total water is used for agriculture (Rodell et al., 2009; Archer, 2010). Agriculture then contributes 25% to the country's GDP with export revenue return of 70%, employment rate (labor force) of 50% directly and 20% indirectly.

Under these conditions perfection and improvement to the system are becoming authoritative. Over last few decades, floods have caused hazardous damages comprising water stowage in large areas with abundant economic losses. Present surveys revealed that most of country's hydraulic edifices are in hazardous condition. Moreover, these students needs to be rehabilitated urgently along with overall perfections for effectual operations and boosted water distribution (Archer and Fowler, 2004; Akhtar et al., 2008).

2.3. Western Rivers of Indus and Pakistan

Indus River System is major water source for Pakistan and backbone of agricultural sector. Its dependence is mostly on glacier melting and seasonal rainfall. Climatic changes and infrastructural reserves are causing challenges to water management including hydrological changes (Rodell, et al., 2009; Rees and Collins, 2006). Under rising prices of electricity tariffs and high diesel prices scenario, farmers are tending to avoid groundwater mining. Therefore, for promotion of better utilization of surface and groundwater the current canal infrastructure needs to be improved for better water use efficiency in agriculture.

Current water system have capacity to generate much more energy than required but this demands investments in infrastructure and improved application of technologies. Presently, country's major challenge is to boost up hydraulic sector adeptness at private level rather initiating new projects.

Following section briefly describes about characteristic (achievements and failures) of the country in managing water of Indus Basin Irrigation System for hydropower production and irrigation purpose.

2.4. Achievements

Growth rate was promoted up to 6.3% during green revolution of 1960s, with enhanced canal supply with construction of Mangla Dam and IBP works. This era is also considered the most pulsating and result-oriented era for agriculture. Green revolution resulted interest in surface water investments and the resulted irrigation assistances from Tarbela were 25% higher in 1975 to 1998 than the considered estimates and appraisals. Land salinization is also a major problem faced in this system. The government initiated groundwater pumps during 1960s and 16,700 tube-wells were installed for supplying water covering 2.6 million hectares of land. This project was given the name of "Salinity Control and Reclamation Projects (SCARPs). This not only worked for salinity reduction but also improved irrigation supply system through groundwater emancipation. With cooperation of "National Drainage Programme (NDP)" and "On-farm water management (OFWM) programme" various water conserving technologies have been introduced that include bed or furrow sowing, raised bed cropping, zero tillage techniques, dry seeding of rice crop, and accurate laser land leveling. But the facts with these technologies are their limitations to small area, expenses, labor requirements and various scientific questions regarding production.

2.5. Challenges:

The Government of Pakistan faces challenges to achieve and overcome some issues and problems which are assigned below:

Soon after Indus Water Treaty, main efforts of government were focused on engineering aspects of irrigation network. Water conservation and management were not given much importance. IBIS receives only 250mm rainfall annually which is much less than the global average. Pakistan's water requirements (for irrigation and other purposes) are totally dependent on IBIS. Due to less management policies regarding adaptation to seasonal variations, water crisis are causing severe damages (Wichelns and Drechsel, 2011; Vörösmarty, et al., 2000). Irregular and uncertain withdrawal of water from IBIS by India further exacerbates this problem for Pakistan. Floods of 2008, 2010 and 2014 were combined effect of seasonal changes and Indian release of excess water in Eastern Rivers. India started storage of water from Chenab in Baglihar hydroelectric dam since September 4, 2008 (Cheema et al., 2015). This withdrawal reduced the river flow up to 25,000 cusecs. Our current irrigation system is supplying reduced amount (11%) of water than actual crop need. In 1947, Pakistan had 67MAF available water for diversion but this amount of water increased to 85 MAF during 1960s.But the storage capacity of major reservoirs (Tarbela, Mangla and Chashma) is reduced to 12.6 MAF already. Irrigation efficiency of system is estimated 45%.

Rate of total water available in Indus Basin is increasing by past decades but the average water availability is constantly decreasing in country. This problem is due to limited water storage availability and water losses from canals. Government wants to promote cultivated area by establishing more reservoirs. The estimated target for 2025 is to establish the cropped area to 31.83 million hectares. But the dire need of time is to promote increased water productivity per unit irrigated area (Thayyen and Gergan, 2010; Singh, 2007).

Another serious issue with Pakistan's irrigation system is water losses due to insufficient maintenance of canal system, siltation problem in reservoirs, salinity problem and traditional cropping system (Qureshi et al., 2008; Winiger, 2005). Water seepage is considered the serious contributing factor to low crop yields regarding per unit of water withdrawal. Some problems including degradation of groundwater quality, less yields and decline in water tables are overcoming the system due to over-mistreatment of water sources because of the less efficient management.

2.6. Water Productivity restrictions:

Productivity of Indus region is affected by certain geographical and seasonal variations. India is gaining many benefits by enhancing water productivity by developing infrastructure and investing massive amount. India is producing 35% of the live storage capacity of its average annual flow but this figure in case of Pakistan is only 9%. Pakistan is investing to enhance live storage capacity than to invest for cheap hydropower generation. This demands sustainable institutional support in hydro-generation sector for encouraged boosted development of electricity. Present situation requires sustainable utilization of available water (World Bank. 2005; Alcamo et al., 2003; Sharif, M. 2013).

2.7. Water resource management under changing climatic and socio economic condition

Pakistan's water resources originate from mountains of upper Indus. These resources are mainstay of country's economy. So any deviation in resources can cause thoughtful influence to food security and future environment (Ageta, 2003). These resources can be discussed regarding climate change for three hydrological systems. Navigational system dependence is on winter snow melting, a glacial system, and rainfall system depending on synchronized rainfall. Fluctuations in precipitation and temperature affect the mountain resources of flow. Because melting of seasonal snow from glaciers determine the runoff (Winiger et al., 2005; Archer, 2003; Khan and Tingsanchali, 2009; Johnston, 2014).

Due to uneven climate changes (temperature and precipitation) the snow accumulation and glacier ablation in catchment areas may seriously affect the livelihoods of people and economic resources (Molle et al., 2010). With various assessments about the climatic conditions and their impact on Indus that what might happen in future, with great concern to temperature, most expectations support the melodramatic reduction in river flow (Rees and Collins, 2006; Akhtar et al., 2008; Berthier, 2007). Some reports also indicate same situations regarding Himalaya, Karakoram and Hindukush (HKH) (Eriksson et al., 2009; Berthier, 2007; Randhawa et al., 2011). With all these facts the climatic effects on western HKH (on glaciers and river flow) are yet to be described. Most scientist predict although there is a rise in mean annual summer temperatures globally from July to September, the main subject to glacial melting, have been falling at many valley stations in the Karakoram during 1961 to 2000 (Fowler and Archer, 2006). Analogous temperature falls are also indicated by Hewitt, K. (2007) for both pre monsoon and monsoon period about "high mountain region". During summer and winter the precipitation is increased in Upper Indus during 1961 to 1999 (Hewitt, K. 2005). Hewitt's (Hewitt, 1998; Hewitt, 2005) reports on ice (glacial mass balance) after his broad experience of numerous decades also indicate shrinking of glaciers. There was a prevalent indication of glacial spreading out predominantly in elevated glaciers in central Karakoram. Under this conflicting scenario about climatic changes and glacial zones of Upper Indus Pakistan needs to plan serious future implications for water management. This management strategy will enhance sustainability of water sources, including resulting impact to the downstream flow advancing to irrigated plains of the country (Punjab and Sindh). This impact makes climate changes and water management the primary anxiety to the society.

2.8. Potential impact of climate change

Two assumptions are very important when considering climate change and water resources: that the glacial melting is primarily due to rising temperature; and that temperature is expected to rise in line with global climate change estimates (Laghari, 2012; Rees and Collins, 2005; Raina and Sangewar, 2007). However, these suppositions are still dubious. Often occurring droughts, on a large scale are also a major impact of climate change. Drought recurrence period is estimated sixteen years with some spectral analysis. Three major drought periods are classified as late 1960s-early 1970s, 1980s and 1990s-2000s. Integrated water management and integrated energy utilization can help to plan sustainable ways to overcome these droughts. With population of about 195 million (as of 2011), Pakistan is facing momentous water scarcity. Arid and semi-arid climate covers two-third of country's total area (Chaudhry and Rasul, 2004). Increasing industrialization and population is demanding more quantity of water. Therefore stern water dearth is expected in coming years (World Bank, 2005). With same circumstances, the drought scenario may intensify water stress in country. Droughts with climatic extremes can impose far reaching effects on socio-economic sustainability (Ahmad, S. et al., 2004). Researchers indicate that droughts occur simultaneously in these regions with a serious impact on country. During previous drought periods, more than 90% area of Pakistan was affected. As Pakistan is already under water scarcity, drought aggravates the waters scarcity problems significantly.

3. Hydrological background:

Indus basically originates from "The Tibetan Plateau". Basin is denoted to as "Third Pole". Its basin contains a great part of perennial glaciers outside the "Polar Regions" (more than 20,000 km^2). Components of climate of the Upper Indus are highest mountain ranges and monsoon rains. These monsoon rains carry substantial rain on southern sideline. Snowfall, during winter and spring, is basic source of precipitation in trans-HKH ranges (Cosgrove and Rijsberman, 2014; Dyurgerov and Meier, 2005). Climate models showed that rainfall in areas under IBIS is highly unpredictable and vary greatly at spatiotemporal scales (Amin et al., 2016). With limited precipitation at low elevation, seasonal melting of snow befalls at elevations above 4000m and is key contributor concerning river runoff on or after March to September. A combined yearly average for discharge in major rivers of Indus plain is about 175 x 10^9 m^3. Maximum summer monsoon occur in southern ranges of Himalaya with a remarkable contribution from winter rainfall totals up to 1800 mm (Singh, 2007; Sharif, 2013).

4. Water stress

Water stress generally can be defined as a ratio of withdrawals to long-term average annual runoff (Alcamo et al., 2003) or in term of per capita water availability (Majeed et al., 2009).

4.1. Withdrawal and runoff ratio

In term of this ratio the stress is considered to occur when ratio exceeds above 0.4, a marked threshold determined by a syndicate of the World Water Council (Alcamo et al., 2003; Cosgrove and Rijsberman, 2014), by Vorosmarty et al., (2000) and by United Nation Organizations (Raskin et al., 1997) as approximate verge of "high" or "severe" water stress. Maximum annual escapes to the sea was noticed during 1995 and maximum annual withdrawal was recorded during 1983 during data analysis from 1976 to 2004 (Matsuo and Heki, 2010). For Pakistan's scenario, flow rate abstracted from Indus to canal system is indicated as 73%. This value indicates a much stressed level. Moreover, during drought years from 2000 to 2003, almost the all-inclusive flow was abstracted parting only a dribble to sustain the ecology and to reduce salt water interruption on the lower river (Ramirez, 2001; Akhtar et al., 2008). According to United Nations, population growth in Pakistan from 40 million in 1950 to 185 million in 2010 (Matsuo and Heki, 2010) and per capita water availability indicates that country is already dipping below, with a water scarcity level of 1000 m^3/capita. If the situation remains same for 2025 and 2050, that would result per capita estimation of only 711 and 522 respectively (Lopez, et al., 2010). Actual demand for managing these sediments to accumulate is increasing and seems to be feasible if evacuation is possible (Khan and Tingsanchali, 2009).According to Archer, (2003) glacier melting is not only the reason of river flow in Indus. Seasonal snow melting and rainfall also affect the runoff and flow. Vital part to river flow is contributed by naval regime. Seasonal snow covers more area and contributes to more magnitude than perennial ice and snow. Winter precipitation produce more trends for significant impact on runoff (Franken, 2012; Gloor, 2012). Westerly disturbances cause more impact on these winter precipitation trends.

There are not any strong evidences against climate change in Upper Indus Basin with glaciological observations. Some evidences are there that describe field measurement of glacial cover but these are not comprehensive gauges of situations over the complete elevation range (Kaser, et al., 2010; Akhtar et al., 2008). It's estimated that significant trends may also not continue in future. Glaciers also play a vital role in determining river flow. At different valley stations summer temperature and runoff show an important correlation (Archer, 2010; Fowler and Archer, 2006). The negative mass balance evaluation of Himalaya indicates a reduction in glacial regime (Berthier, et al., 2007). According to Hewitt (2007) up to mid-nineties there has been a slump in glaciers of Karakoram. He also explained that after 20th century thinking and advancement of various non-surging glaciers have been observed for specific regions of highest watersheds in Karakoram. In his survey report of 1997 to 2002 Hewitt (2005) signposted that thirteen glaciers of moderate size and sixteen detached tributaries of large glaciers were found to be evolving. However glaciers at lower elevations were observed declining. In upper Siachen glacial zone there has been no remarkable retreat in last five decades (Raina and Sangewar, 2007). Observations from satellite gravimetry during 2003 to 2009 settle that glacial losses are shriveled in Karakoram while compared with Himalaya and Pamir mountains (Matsuo and Heki, 2010). Increasing temperature in summer and lack in Karakoram reported universally (Dyugerov and Meier, 2014; Cogley, 2009) and in elsewhere mountain regions (Ramirez et al., 2001; Lopez et al., 2010) propose a fairly diverse reaction to climatic changes.

4.2. Water resources and climate change

Uneven and ambiguous uncertainties in climatic trends are impacting link between glacial accruals, climate and runoff in Indus Basin Irrigation System. This raises a question that why catchments of Indus would vary in these responses and changes than other mountainous regions of the globe. When discussing water resources, very limited operational dimensions are taken in IBIS (Ageta et al., 2003).Flow regulation, volumetric delivery and compensations of seasonal flow forecasts are significantly affected by limited measurements (Archer and Flower, 2010; Majeed et al., 2009).

5. Conclusion

Pakistan is bounded to a network with various intertwined challenges among them water resource management is playing a vital role. Limited availability of quality water for drinking and irrigation may produce alarming situations for future food security. With increasing population and fatal economy this aspect may cause serious demands in future. The diligent use of water is necessary for better food production. Providing the water to agriculture, increasing population and industrial needs is to be harmed if water resources are not given proper importance. Our previous reservoirs are diminished (and are onward) with sediments and now available water, especially spring water will be difficult to manage if large reservoirs are not constructed. Hydropower production ability will also decrease if same amount of sedimentation is accumulated with same rate. And growing needs of hydropower for industrial and domestic purpose will be difficult to meet. These conditions will also affect water supply for spring crops with falling water table and fair pumping. Under present conditions high investment in water management is required to fulfill the countrywide demands for health, food and security from uncertain damages. The leading threat may be due to uncertain climate change. Countless efforts are still demanded to elaborate the relationship among runoff, climate and glaciology. Main management practices required are sophisticated and sustainable water (surface and groundwater) use, rebuilding and reintegration of surviving frame, enhancing water use efficiency for agriculture, cropping system modification and scheduling, monetary instrumentation and enhancing post-harvest technology.

During recent five decades IBIS achieved the considerable development in Pakistan and India. Hydropower and irrigation sector is improved. Enormous investments were made to build infrastructure for surface water and groundwater development in both countries. This also produced higher production rates than past. However, presently various challenges are questionable representing cumulative population compressions, climatic impact on water flow, depletion of groundwater and incompetent setup for surface water stream. This mounting water insecurity in constituency, demands attainments in water administration to make it justifiable.

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