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# Water availability, use and challenges in Pakistan

Water sector challenges in the Indus Basin  
and impact of climate change



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## Abstract

This working paper takes stock of Pakistan's water resource availability, delineating water supply system and its sources including precipitation and river flows, and the impact of increasing climatic variability on the water supply system. In particular, the paper focuses on the current water usage and requirements in the agricultural sector, and how changing climatic conditions will affect the consumption patterns. With inflows expected to become more variable in the coming years, the severity of climatic extremities will become more pronounced, driving up water demands in addition to the demand increase from a rising population and urbanization. Over extraction of groundwater resources is also disturbing the water calculus and pushing the country towards a critical demand-supply gap.

Pakistan's water sector remains vulnerable to the impacts of climate change. To ensure Pakistan is adequately prepared to deal with the changing climatic realities, it is important to understand the nexus between water availability, agricultural productivity, and climatic variability. The current paper has endeavoured to highlight the same indicating the existing availability of water based on a single river system which is Indus Basin System and its tributaries, future projections of water requirements for crops, livestock, forest, rangelands, ecological and municipal sectors, and the challenges Pakistan faces in accommodating the increasing demand for water from competing sectors. Further, limited storage capacity, a debilitated infrastructure, and poor water conservation practices that are contributing towards the degradation of water quality and loss.

In light of the analysis conducted in this paper, it is clear that due to competing pressures of water demand from different sectors and a widening demand-supply gap, there is a need to guide the shift from irrigation to water management to address the challenges that come with increasing climatic variability and water scarcity. Some key recommendations are proposed signaling the need to adopt a more holistic approach towards water management and conservation, which takes into account the available resources, its usage, challenges and projected water requirements in the future and what needs to be done to ensure Pakistan is able to boost its agricultural productivity without drying out its water resources.



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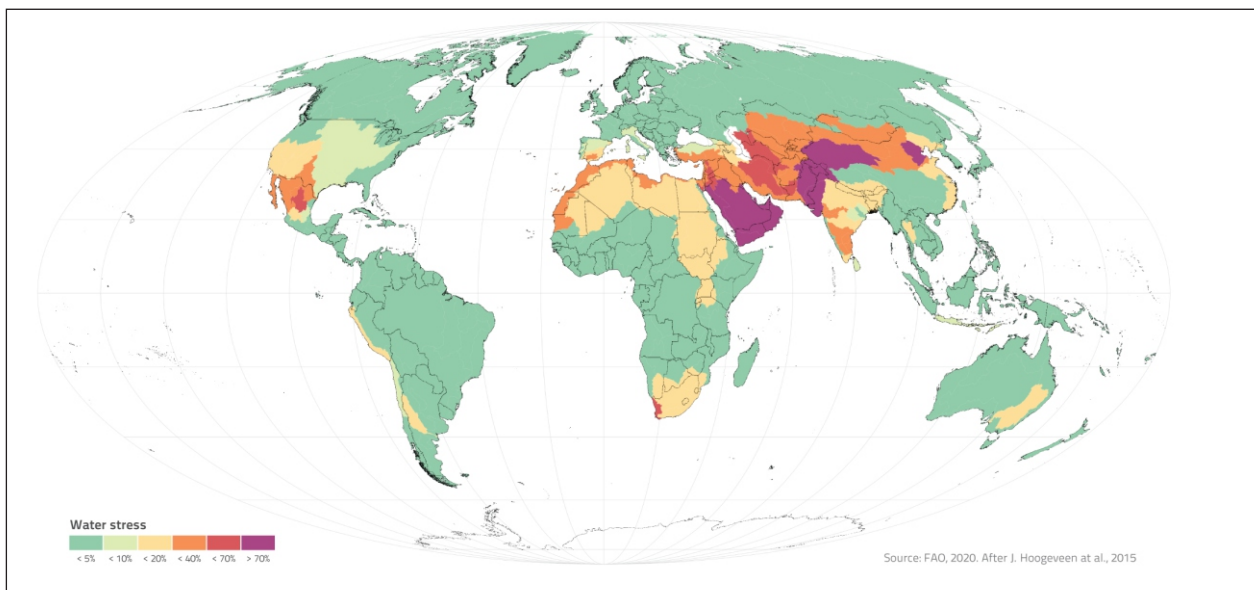


## Introduction

Pakistan is one of the 36 most water-stressed countries in the world – withdrawing over 70 percent of total renewable water resources (Map 1)- with limited quantities of surface (228 billion cubic meters: BCM<sup>1</sup>) and groundwater (about 62 BCM<sup>2</sup>). Pakistan's latest population estimates 207.78 million—of which 63.6 percent live in rural areas- making the per capita water availability reduced further to 1 188 m<sup>3</sup>/year from 5 237 m<sup>3</sup>/year in 1962 (Figure 1). The interprovincial disparity in population distribution vis-à-vis water availability makes this equation even more complex. The country's water stress is influenced by its increasing population, reliance on a single river system (Indus River Basin), and the increasing impacts of a changing climate.

Pakistan's gross freshwater withdrawal is 74.4 percent of the total renewable water resources. Pakistan withdraws around 65 BCM groundwater in the freshwater zone at a rate higher than the recharge . An excessive and extended abstraction of an aquifer is causing fusion of the fresh and saline zone and secondary salination. In addition, degraded quality of ground as well as freshwater due to contamination by agricultural residues from fertilizers and pesticides, and industrial and municipal effluents is another dimension of water scarcity being faced by Pakistan.

### Map 1: Water scarcity by major River Basin



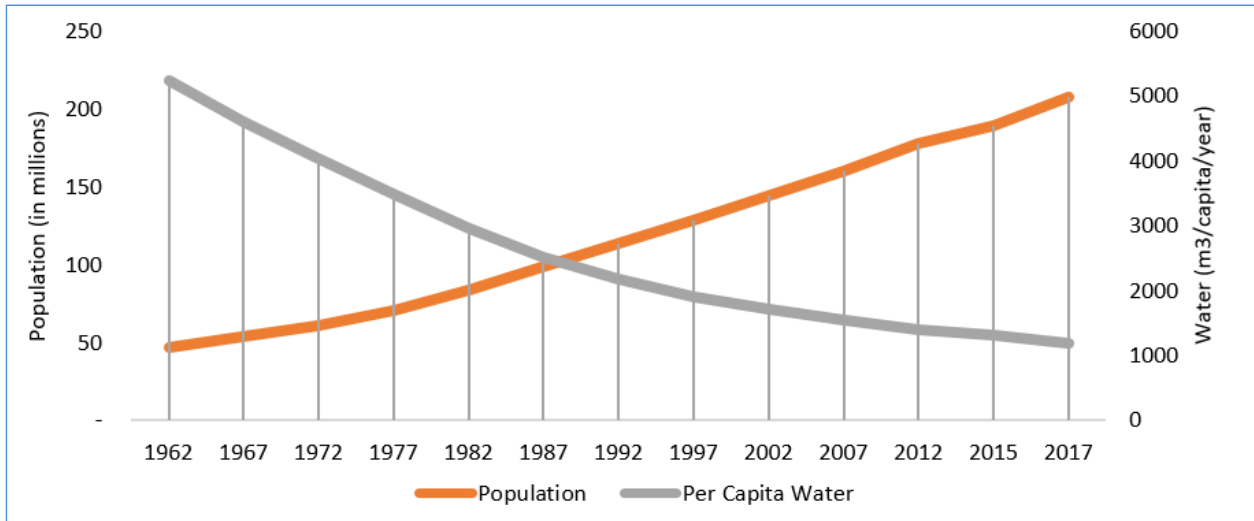
Conforms to UN Map No. 4170 Rev. 19, October 2020 and the map is taken from GlobWat – a global water balance model to assess water use in irrigated agriculture publication.

Water stress per major River Basin expressed as a percentage of incremental evaporation due to irrigation over generated groundwater and surface water resources, Mollweide Projection, FAO, 2016.

<sup>1</sup> 1 BCM = 0.81 Million Acre Feet (MAF). AQUASTAT data.

<sup>2</sup> AQUASTAT data. About 14 bcm rainfall recharge and 48 bcm recharge from river, irrigation network and other uses

Figure 1: Population vis-à-vis per capita water availability



Source: FAO. 2016. AQUASTAT Main Database. Accessed on 6 Nov 2017; and Provisional Summary Results of 6th Population and Housing Census 2017<sup>3</sup>.

Challenged by uncertainties, the farmers not only tend to grow cash crops like sugarcane and rice which require relatively more water but also over-irrigate their crops when water is available as the water supply is skewed towards five summer months when 70 percent of the surface flows are generated. The inefficient irrigation also results from poor land levelling resulting in low distribution uniformity and rather high farm losses (in the range of 30-40 percent) in the areas where the infrastructure is dilapidated. High demand-supply gap and inefficient performance of the irrigation network results in inequitable access to water—small and the tail-end landholders getting less water. All these factors contribute to the low water productivity in Pakistan (0.78 USD/m<sup>3</sup>).

Water demands of the urban, industrial and commercial sectors are locally managed and are increasingly going beyond the safe water supply limits causing local depletion of surface and groundwater resources. Deteriorating water quality of surface and groundwater resources is an increased risk for health. Despite numerous water supply and sanitation schemes, domestic and urban water supply remains a challenge. Information about the water used in the industry is sketchy, similarly, the data about commercial and business uses. These sectors are increasingly using surface water, like sugarcane and fertilizer plants, urban transport. A proper accounting of water demand and supply outside the agriculture sector is a pre-requisite to effective water management.

The water tariffs are extremely low in all water use sectors impairing sustainable operations, maintenance and modernization of the infrastructure. The low economic return from the agriculture sector are not only productivity interrelated, but agriculture and land management need to address socio-economic inequalities. The low storage capacity and high conveyance losses can be attributed to inadequate asset management and insufficient financial resources due to nominal irrigation tariff and poor cost recovery.

<sup>3</sup> Assuming constant availability of 246.8 BCM of freshwater and groundwater

Climate Change (CC) is an emerging challenge for Pakistan as it is expected to influence the freshwater supply and water demand, both. There is sufficient evidence that global warming is affecting Himalayan glaciers and Asian monsoon (various publications of IICIMOD). The climate change impact on the hydrological cycle needs to be properly understood for the management of extreme events like floods and droughts, and, protection of surface water resources. The sectoral water demands are projected to be equally affected by a rise in temperature. Increased water competition among the sectors and regions is the biggest challenge Pakistan is going to face.

Weak policy frameworks coupled with a lack of coordination among stakeholders and institutions has led to scanty ownership of reforms process and regulatory enforcement. Pakistan has launched its National Water Policy in 2018 followed by the Provincial Water policies. The eighteenth amendment and independent provincial water policies and strategies could be another challenge for coherent management and development of water resources in various sectors. The long-term and short-term implementation plans will be an important milestone.

## Water sources of Pakistan and impact of climate change

### Two small hydrological units outside Indus Basin

Balochistan province of Pakistan hosts two independent hydrological units covering about 35 percent area of the Province. The Kharan desert stretches over 48 051 sq. km barren land from the Alborz mountains (Iran) in the northern direction to the plateau in Balochistan around 1200 kilometers to the southeast. The entire area of the desert has inland drains and dry lakes. The largest dry lake of Balochistan is located in this desert called Hamun-i-Mashkel. The average rainfall in the desert is about 100 mm annually. The Mashkel and Marjen rivers are the principal sources of water in the basin. The Marjen is a minor tributary to the Mashkel. The water is discharged into the Hamun-i-Mashkel lake in the southwest, on the border with the Islamic Republic of Iran. The arid Makran coast, along the Arabian Sea, covers 17 percent of the territory in its southwestern part (Balochistan province). The Hob, Porali, Hingol, and Dasht are the principal rivers in this coastal zone.

The estimated gross runoff of these two basins is 8.4 bcm, which is usually in the form of flash floods depending upon the rainfall.

### Indus Basin

The water sources of Pakistan include surface water, rain, groundwater, and glacial melts. The surface water-resources of Pakistan are mainly from the Indus River<sup>4</sup>, which is a major

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<sup>4</sup> The Indus River is about 2 800 kilometres (km) long, with 2 682 km in Pakistan. Its alluvial plain area is about 207 200 km<sup>2</sup>, while its deltaic area is about 20 000 km<sup>2</sup>. It originates in the Tibetan tableland at Singi Kahad spring, on Kailas Parbat (mountain) near Mansarwar Lake. It then passes through the Himalayan range, and, collects runoff from the Hindu Kush and Sulaiman ranges. Its annual water runoff is about 200 cubic kilometers, and sediment discharge is approximately 200 billion kilograms yearly (Pakistan Water Gateway; accessed 29 November 2011)

trans-boundary river in Asia<sup>5</sup> with nine tributaries<sup>6</sup>. Glacier/snowmelt and precipitation in the Upper Indus Basin are the main sources of flow in the Indus river network. The Indus River has two large western tributaries (Jhelum and Chenab) and two eastern tributaries (Ravi and Sutlej) which enter into Pakistan from India. One of the western tributaries, the Kabul River is shared with Afghanistan; its watershed starts in Pakistan, traverses through the Kabul valley and then re-enters into Pakistan, close to Nowshera. Under the Indus Water Treaty, signed between Pakistan and India in 1960, the eastern rivers, Ravi and Sutlej were allocated to India; only flood runoff is discharged into Pakistan over the course of a couple of weeks after India built storages in the upper reaches of the rivers. Resultantly, there can be years of no flows in these rivers.

Based on the stream hydrology and morphology, the Indus River can be broadly divided into three segments: (i) the upstream segment, from the Singi Khahad spring down to Jinnah Barrage; (ii) the midstream segment, between Jinnah and Guddu barrages; (iii) and the downstream segment, from Guddu Barrage to the Arabian Sea. The upstream segment is largely a hilly catchment area; the midstream segment is an upper floodplains area dominated by a braided pattern of channels and tributary inflows; and the downstream segment is a lower floodplains area with flat topography, a meandering channel pattern, and deltas. The upper Indus Basin catchment is further sub-divided into four zones based on the basin's geophysical and hydro-climatic characteristics (Hewitt, 1989): zone one - more than 5 500 m above sea level (asl); zone two - 4 500–5 500 m asl; zone three, 3 000–4 000 m asl; and zone four, 1 000–3 000 m asl . The major ablation zone contributing to the seasonal runoff is between 5500 m to 3000 m.

### Indus Basin Irrigation System (IBIS)

Pakistan relies on the Indus Basin Irrigation System (IBIS) for its basic food security and water supply for all sectors of the economy. IBIS is one of the largest contiguous irrigation systems in the world and irrigates about 18 million hectares (ha) of land in Pakistan. IBIS is the backbone of the country's agricultural economy (see Figure 2). It is with three major multipurpose storage reservoirs (Mangla, Tarbela and Chashma), 19 barrages, 12 inter-river link canals, 45 major irrigation canal commands (about 56 000 km) and more than 120 000 km of watercourses in tandem with vast and growing process of groundwater extraction through private tube-wells delivering water to farms and other productive uses.

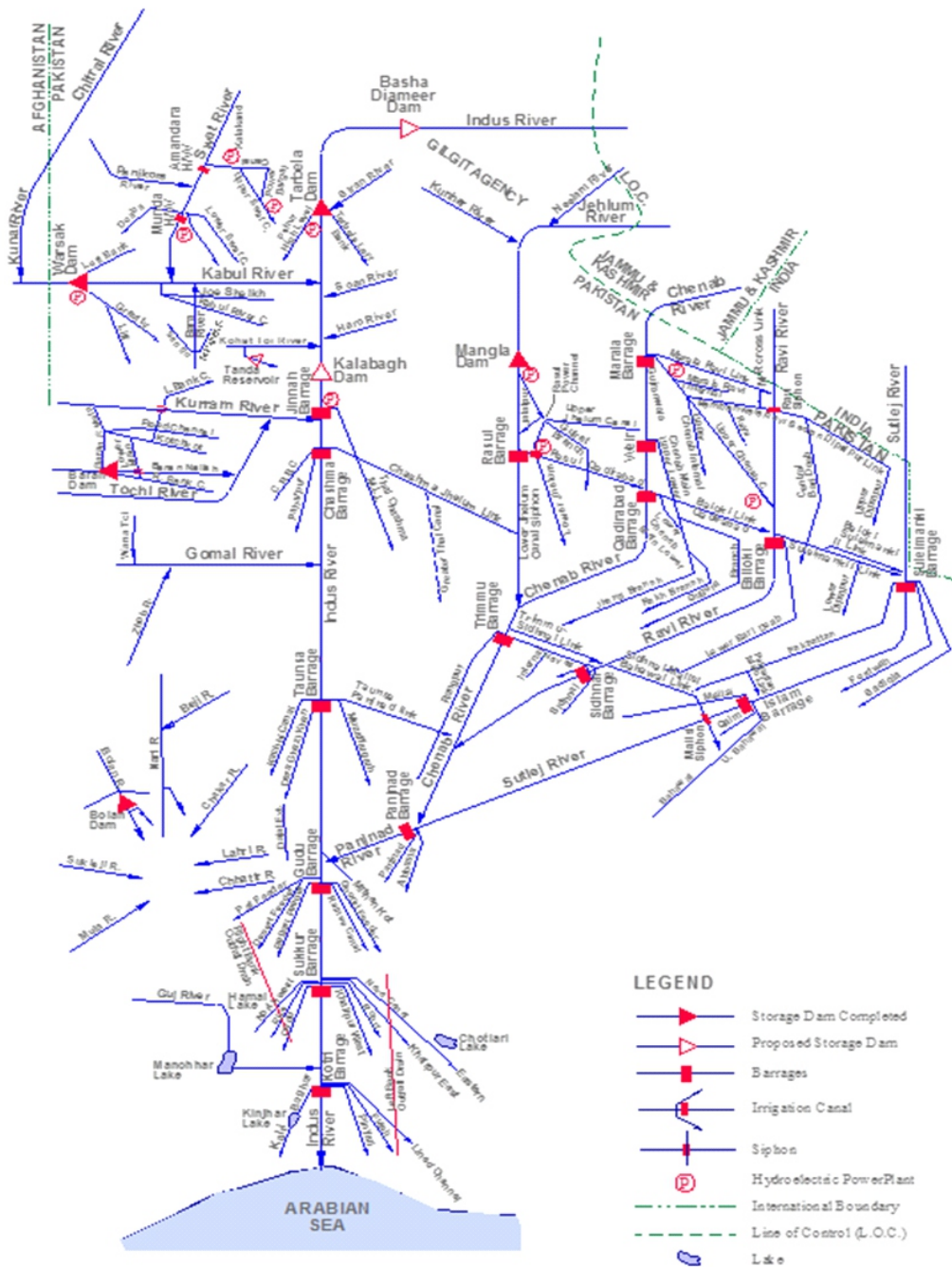
The infrastructure developed under the Indus Water Treaty of 1960 has helped improve water resource availability basin-wide increasing canal diversions from 83 BCM in 1949/50 to a maximum level of 137 BCM in 1984-87, which has declined to 130 BCM because of storage loss. The total storage capacity in the Indus Basin was 23.3 BCM, which includes

<sup>5</sup> Others include the Amu Darya (Afghanistan, Turkmenistan, and Uzbekistan), Amur (China and the Russian Federation), Brahmaputra (Bangladesh, China and India), Euphrates (Iraq, Syria, and Turkey), Ganges (Bangladesh and India), Mekong (Cambodia, China, the Lao People's Democratic Republic, Myanmar, Thailand, and Viet Nam), and the Tigris (Iraq, Syria, and Turkey).

<sup>6</sup> Five of them are on the left bank with upper catchments of Beas, Ravi, and Sutlej in India while Chenab and Jhelum are in Pakistan. The main right bank tributaries are the Gomal, Kabul, Swat and Kurram rivers.

11.9 BCM of Tarbela, 10.5 BCM of Mangla and 0.87 BCM of Chashma which is around 14 percent against the world average storage capacity 35-40 percent. But due to silting, and lack of live storage capacity it has been reduced to about 15 BCM showing a loss of 35 percent, which is for 30 days requirement.

Figure 2: Schematic diagram of the Indus Basin



## Indus glaciers

The Pakistan Water and Power Development Authority (WAPDA) began monitoring the glaciers of Northern Pakistan in the 1980s with the help of Wilfrid Laurier University, the University of British Columbia in Canada, and the University of Manchester in the UK. The measurements show that glacier runoff and snowmelt from the Himalaya Karakoram Hindukush (HKH) mountain ranges contribute a total of 50 to 80 percent of water availability in the country.

(Bocchiola, 2015) and (Akram, 2016) carried out detailed literature reviews with mention of the reports about HKH and the Upper Indus from the period between IPCC3 and IPCC5. Mountain glaciers worldwide retreated during the last one hundred years ; the glaciers in the HKH region are reported to be receding faster than those in any other part of the world. A rapid decline in glacier area is reported throughout the greater Himalayas and most of mainland Asia and is widely attributed to global warming (Ageta & Kadota, 1992); (Solomon, *et al.*, 2007).

Such a rapid decline in the glacier area means that the flows of the Indus River System may decrease up to 30-40 percent over the second half of the 21st century (World Bank Report, 2006). The glacier mass balance budget in the Karakoram positively affected the 2003–2008 specific mass balance for the entire HKH region, estimated by Kääb *et al.*, (2012) into  $-0.21 \pm 0.05$  m yr<sup>-1</sup> of water equivalent.

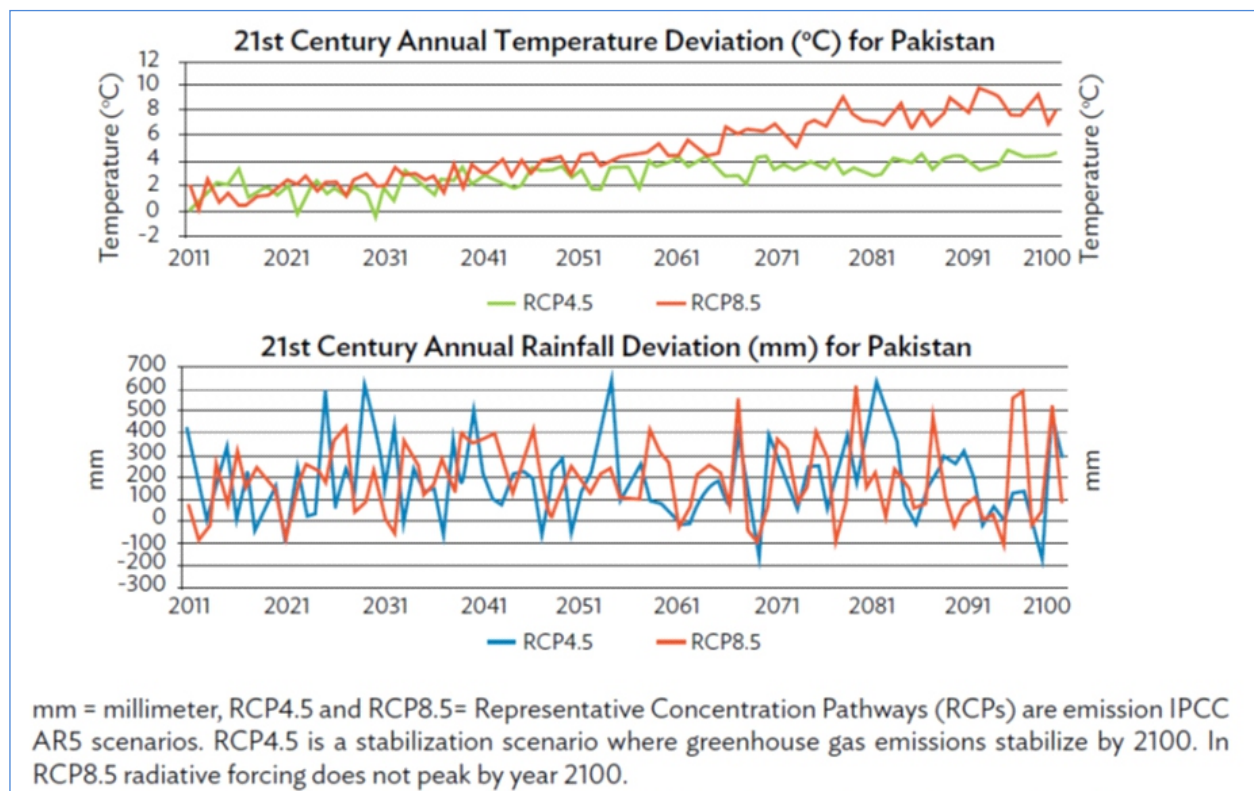
Accelerated ice melting may lead to an increased risk of floods and hazards related to glaciers (e.g., glacial lake outburst floods, icefalls, and crevasses) in the following decades. By the end of the century (2071-2100), the glacial extent is expected to have decreased significantly, reducing the contribution of glacial melt, and, therefore, total water availability across the whole Indus Basin.

Lutz *et al.*, (2016) used a fully distributed Spatial Processes in Hydrology (SPHY) model to simulate the climate change impacts on the hydrology of the Indus Basin. Two of their conclusions are important: (i) the large uncertainty in projection of climate change impacts till mid of the century, like glacier extent, precipitation; and (ii) glacier area decrease considerably during 21st century even in the wet scenarios projecting large increases in precipitation, because of an ample rise in temperature.

## Rain and precipitation

The PMD analysis of CORDEX experiments and GCISC's downscaling analysis agree that rainfall projections are highly variable in both spatial and temporal domains (Figure 3). Area average rainfall projection over Pakistan shows a large inter-annual variability. Ali (2018) reports, based on downscaled 14 GCM projections, more intense extreme rainfall events are expected in the monsoon region and northern Pakistan, suggesting increased flood risks. It is also found that consecutive dry days (CDD) will increase while consecutive wet days (CWD) will decrease.

Figure 3: Mean annual temperature and precipitation projections in Pakistan under two RCPs



Source: Pakistan Meteorological Department. 2015. High Resolution Climate Scenarios. [http://www.pmd.gov.pk/rnd/rndweb/rnd\\_new/climchange\\_ar5.php](http://www.pmd.gov.pk/rnd/rndweb/rnd_new/climchange_ar5.php)

Statistical downscaling of climate projections at the station level shows that a few distinct precipitation trends in the project areas of Punjab and Sindh provinces. In Sindh, there will be a 20 percent or more increase in total precipitation later in the 21st century. The number of days with precipitation exceeding 20mm will also increase in Sindh in the late century. On the other hand, in Punjab, the precipitation trend is not clear, indicating possible increases or decreases for different climate models and locations within the province. In Pakistan, major flooding events are associated with heavy rainfall during the summer monsoon period. The expectation of an increase in large storm events is consistent with global hydrologic dynamics (IPCC, 2012). Each 1°C rise in air temperature allows the atmosphere to hold 7 percent more moisture.

The warming of land and sea surface temperatures also leads to more moisture evaporation causing global warming. As a result, more moisture will enter the atmosphere, increasing the potential for larger storm events. Based on the research conducted on this issue suggests that such a trend is emerging in Pakistan, with an increased volume of precipitation falling on fewer rainy days (Parry *et al.*, 2017). Data from the PMD covering the years 1913–2016 indicate that the ten largest rainfall events in the recorded history in the country have all occurred since 2001.



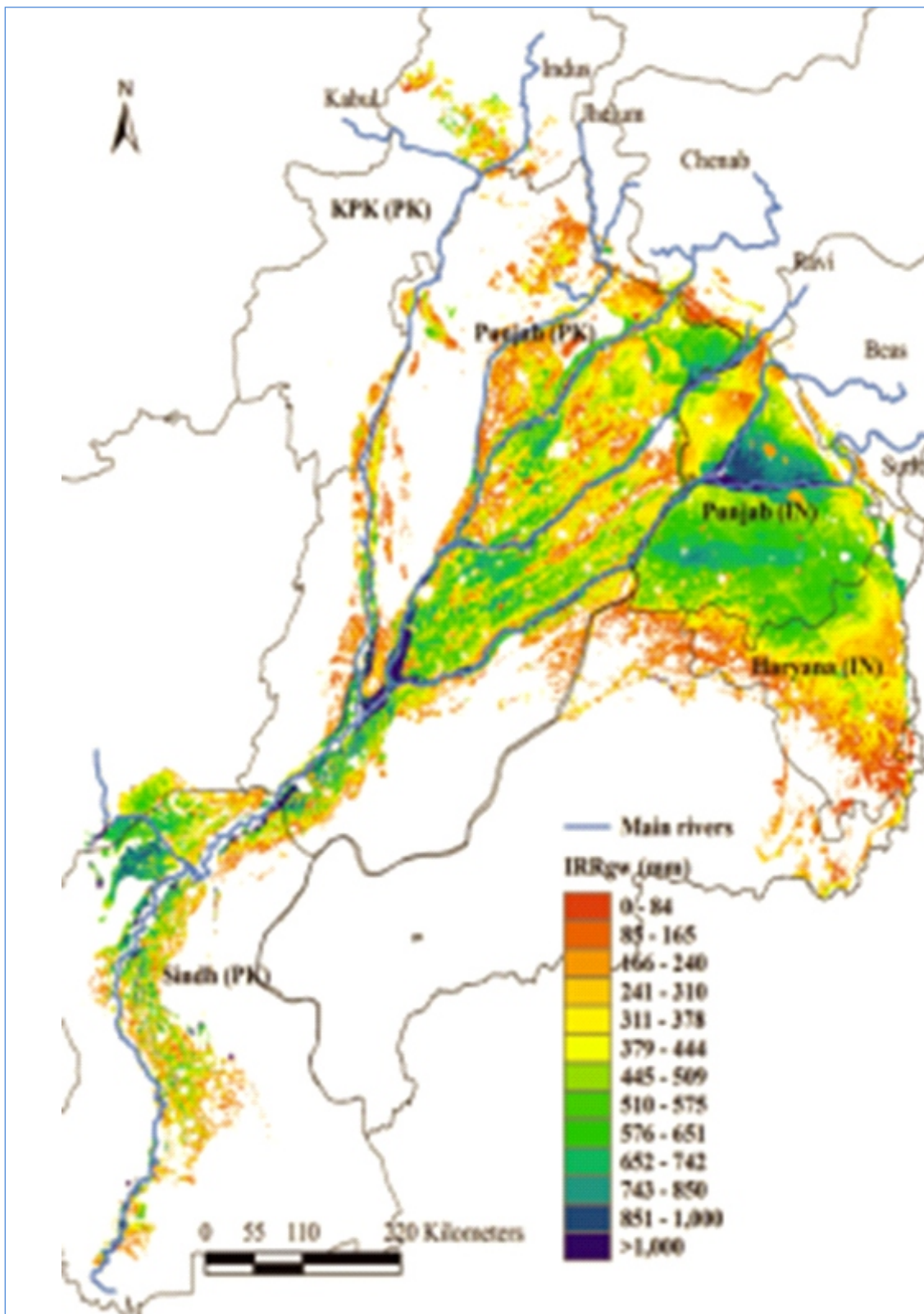
## Groundwater

Groundwater has evolved as a reliable water resource in all of Pakistan's water use sectors. Industrial and domestic supplies almost predominantly rely on groundwater pumping (sometimes through an artificially developed recharge zone adjacent to a surface waterway). In agriculture, groundwater compensates for the shortage of surface supplies. Riverine areas extensively use fresh aquifers during the dry season.

Globally, Pakistan is the fourth largest user of groundwater according to a recent report by the National Groundwater Association of the United States of America (2015). 'Facts about Global Groundwater' shows that India extracts water from aquifers at a rate of 251 km<sup>3</sup>/year, followed by China and the USA, both extracting 111 km<sup>3</sup>/year, and then by Pakistan, which extracts 65 km<sup>3</sup>/year. As a percentage of total available water resources, Pakistan has the highest reliance on groundwater.

A basin-level estimate of groundwater using hydrological modelling with the Soil and Water Assessment Tool (SWAT) was carried out by Cheema *et al.*, (2012). Spatial presentation of the model output is generated using remote sensing information and GIS data, as shown in (Figure 4). The study concludes: "Irrigation is the largest consumer of water in the Indus basin that is using both surfaces (113 km or 434 mm) and groundwater (68 km or 262 mm) to meet crop water requirements."

Figure 4: Spatial map of groundwater abstraction in irrigated Indus basin



Source: Cheema (2013)

Currently, around 1.355 million small capacity private tube-wells are operating in Pakistan, out of which 1.02 million are located in Punjab, extracting 52 BCM of groundwater (Qureshi *et al.*, 2010). These tube-wells (exclusively) and combined with canal water irrigated 19 percent and 42 percent of cultivated land, respectively. Uncontrolled and unregulated extraction of groundwater in excess of recharge in the freshwater zone is lowering the water tables making groundwater inaccessible in 5 percent, and 15 percent of the irrigated areas of Punjab and Balochistan provinces, respectively, which are likely to reach 15 and 20 percent, if the current trend continues. Declining aquifer levels force farmers towards deep electric tubewells, increasing the cost of groundwater pumping and making water inaccessible for smallholders.

## Degradation of water and land resources

The water quality of rivers, lakes, and canals has been degrading. The causes of surface water degradation include the direct discharge of city and industrial effluence into water bodies, ineffective and limited surface drainage networks and the trans-boundary inflow of polluted water. A few examples of River pollution:

Toxic industrial and domestic effluent from India and Pakistan is dumped into the Ravi river, about 10 drains of the provincial capital releasing industrial and municipal waste is also dumped into it. More than 450 industrial units are pumping untreated toxic water into the drains at different points. An estimated wastewater discharge into the river is 315 m/s daily . EPA estimated more than 594 tons per day of the organic load is discharged into the river Ravi (Pak EPA, 2010)<sup>7</sup>.

- The untreated municipal and industrial waste from the District Peshawar, Mardan, Nowshera, and Charsadda is being disposed of into different drains, which finally fall into the Kabul River (Imran, Bukhari, & Gul, 2018).
- Anthropogenic activities in agriculture and industries cause discharges of fertilizers, pesticides, chemicals, heavy metals, and pathogens that can degrade the water quality and can cause negative effects on human health. Fertilizers and pesticides used in the agricultural areas are washed off and drained into surface and groundwater aquifers.
- The waste-water systems in the urban areas contribute to water pollution by production and conveyance of untreated municipal sewerage which pollutes freshwater bodies and drinking water supply. Water affected both qualitatively and quantitatively making it hazardous for human use. the effects of deterioration are intensified as a large volume of untreated effluents from agricultural, industrial, domestic, and commercial areas enter into rivers.

The increase in temperature can be linked to bacterial growth, high turbidity, low efficiency of coagulants, and re-growth of germs, mosquitoes and other water pollutants. The

<sup>7</sup> Environment Protection Department. Environmental Monitoring of River Ravi EPA Laboratory December, 2009. 2010. Available online: <https://www.epd.punjab.gov.pk/Reports>

groundwater quality profile of Pakistan's surface water bodies has a strong north-south trend. While, over-extraction of groundwater and secondary salinization<sup>8</sup> is increasing in heavily populated area fresh-aquifer regions, especially command areas of the eastern rivers. Water pollution is expected to increase temperature and decrease rainfall in high water stress regions.

## Seasonal flows and water availability

### Indus Basin River

River flows of the Indus and its tributary rivers are measured for accounting and distribution purposes after they cross the watershed at the River Monitoring (RIM) Stations. The RIM stations are located at the first barrage system of a river, which are starting points for the water distribution system as well. More than 75 percent of total river flows generated outside Pakistan, while 25 percent of the runoff comes from the internal watersheds. The long-term average (1937–2015) flows of Pakistan's western rivers are 170.4 BCM, of which about 130 BCM are external flows. The average annual residual/flood flows in the eastern rivers are about 3 BCM, a part of it generates in India, that is externally allocated, while, a part of it is generated in Pakistan.

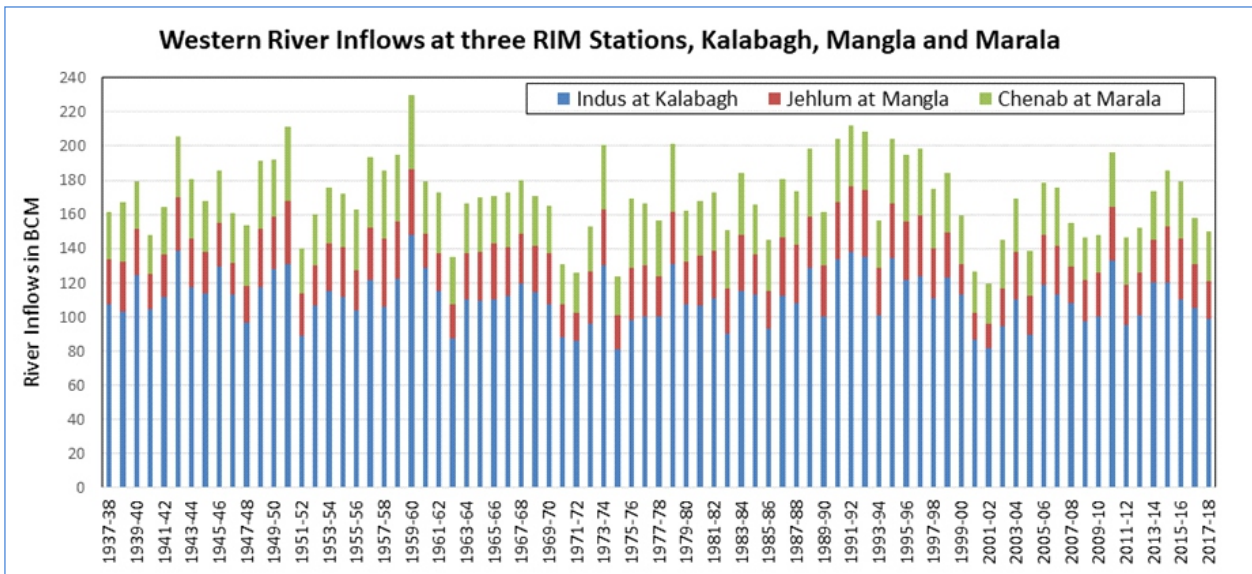
Historical seasonal flows of the western and eastern tributaries of the Indus River are summarized in Table 1 as 10-year averages from 1960 to 2015. The seasonal river flows of four western tributaries (Indus, Kabul, Jhelum, and Chenab) for about 80 years are given in Figure 5 and two eastern rivers in Figure 6. The Western rivers' RIM stations show an insignificant decrease in inflows during Kharif and largely stable behaviour during Rabi. Uneven wet and dry cycle are characterized by the smaller dry and longer wet spans. The average behaviour or trends over a short period of five to twenty years can be misleading, representing a wet, dry or transitional phase.

**Table 1: Western and eastern river inflows BCM**

Period	Western Rivers			Eastern Rivers			Total river		
	Kharif	Rabi	Annual	Kharif	Rabi	Annual	Kharif	Rabi	Annual
1961- 70	141.3	27.0	168.3	23.6	3.4	27	163.5	30.5	194
1971–80	135.5	27.1	162.7	16.8	2.4	19.2	152.3	29.5	181.8
1981–90	141.2	32.4	173	6.1	2.5	8.6	147.4	34.9	182.3
1991–00	149.9	32	182.0	8.3	1.9	20.2	158.2	33.9	192
2001–10	127.8	29.4	157.2	1.6	0.4	2.0	129.4	29.8	159.2
2011–18	130	29.6	159.3	4.6	1.4	6.0	134.4	30.9	165.3

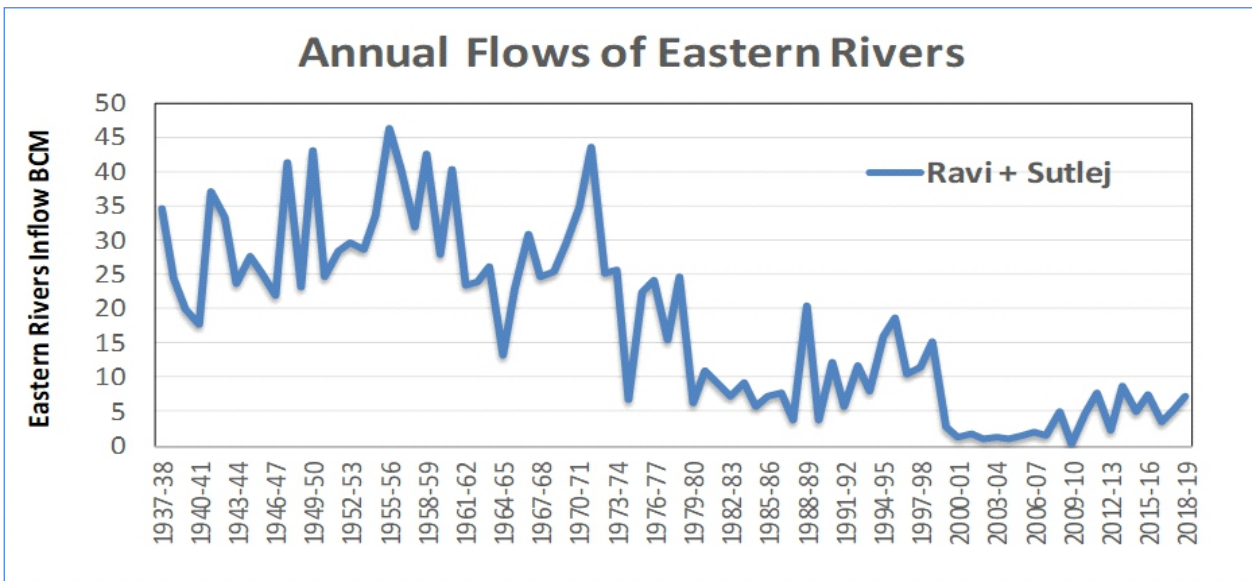
<sup>8</sup> Secondary salinization refers to salt accumulation in soils as a consequence of direct human activities, such as use of poor quality water for irrigation, water logging, and land development (Fitzpatrick *et al.*, 2000; Dehaan and Taylor, 2002).

Figure 5: Historical flow of three western rivers 1937 to 2018. Kabul river flows included in indus flows at Kalabagh



Source: Indus River System Authority

Figure 6: Eastern rivers inflows from 1937 to 2018



Source: Indus River System Authority

Combined flows of three eastern rivers, Ravi, Sutlej, and Beas are shown in Figure-6. The flows recede with time, the lower range drops from 25 BCM to less than 1 BCM and the upper range (high rainfall years) from 35 to 5 BCM. The eastern rivers are allocated to India in 1960, their water is converted by India through a series of reservoirs and canals. Residual water which enters into Pakistan is generated during heavy rainfall runoff from both sides of the border.

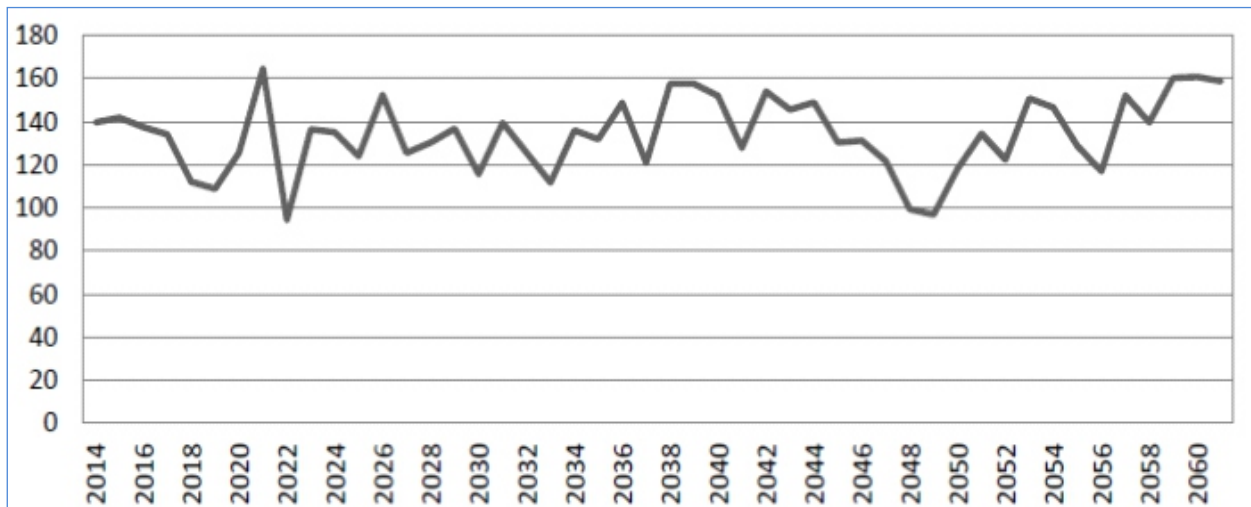
The projected changes in river inflows are influenced by precipitation projections, shifts in the monsoon period, cloudiness, and projected glacier and snowmelt patterns. The complex behaviour of river stream flows is simulated by various hydrological models. Some studies (Immerzeel, 2009; Lutz *et al.*, 2016) estimate an increase in rainfall by up to 50 percent to around 2 070 mm and a shift in the timing of river-runoff peak, which is projected to anticipate by about one month, leading to almost overall stable flows until the mid-century (near future) and eventual decrease afterwards. Projected changes in summer monsoon by different General Circulation Models have high Spatio-temporal variation across the basin and seasons. Winter simulations are more consistent, projecting an increase over the upper Indus Basin and a decrease over the lower basin (Gebre and Ludwig, 2014).

The stream flows in the near future (2021-2050) are expected to increase during autumn and spring. Upstream sub-basins (Hunza, Shigar, and Shyok) are expected to have increased water availability while lower altitude sub-basins show decreases annually, particularly during June and July and also during spring (Ali *et al.*, 2015; Lutz *et al.*, 2016). By the end of the century (2071-2100), the glacial extent is expected to decrease significantly, reducing the contribution of glacial melt and the impact on the total water availability across the whole Indus Basin. The timing of water availability depends on the Representative Concentration Pathways (RCP) scenario used, therefore, all adaptation strategies need to consider this uncertainty.

Current river inflow-patterns represent the combined impacts of glacier/snowmelt, precipitation, and upstream uses. These patterns (flow hydrograph) will continue until half of the glacier reserve is depleted or precipitation has substantially increased or decreased. The future of the upper Indus basin's water availability is highly uncertain in the long run, mainly due to the large spread in the future precipitation projections. However, a few robust changes are found. There will be the attenuation of the annual hydrograph and shift from summer peak flow towards the other seasons. There will also be an increase in intensity and frequency of extreme discharges for most of the upper Indus basin (Lutz *et al.*, 2016), increasing flood risks.

A recent study by MWH and RTI (Yves *et al.*, 2016) developed a series of projections for temperature and precipitation and river flows based on CMIP3 and CMIP5 Coupled Model Inter-Comparison Project. The historical series of inflows are used to create a series of inflows into the future to give a variable pattern to the series. These river flows were forecasted from 2014 to 2060 because of having historical flows for 48 years, see Figure 7. They selected 19 scenarios to forecast future time series of inflows to the Diamer Basha Reservoir under Future Climate Scenarios. The figure shows fairly variable annual flows, with the highest occurring in 2021 at nearly 165 MAF, which was followed in the next year by the lowest flows in the sequence, at 94 MAF, more than a 75 percent decline. Later in the series, in 2048 and 2049 a large drought is seen as well, where the flows are 99 MAF and 97 MAF. After the drought period, there is a noticeable increase in water availability. The projected flows stabilize around 2060, as a substantial part of Indus glaciers already melt.

Figure 7: Historical flows projected into the future (MAF/yr)



Source: MWH and IFPRI (2016)

### Climate change impacts on small stream flows (an example)

Shakil *et al.*, 2015, carried out a comprehensive study of the cryosphere and discharge changes in the Lidder River Basin, a key tributary of the Jhelum River. The study shows a significant downward trend for the streamflow in the Lidder basin since the mid-1990s, as a result of the substantial decrease in the overall glacial mass in the basin over the past five to six decades due to climate change (Table 2 and Figure 8).

Table 2: Change in total glacier area of Lidder watershed and Kolahoi glacier over time

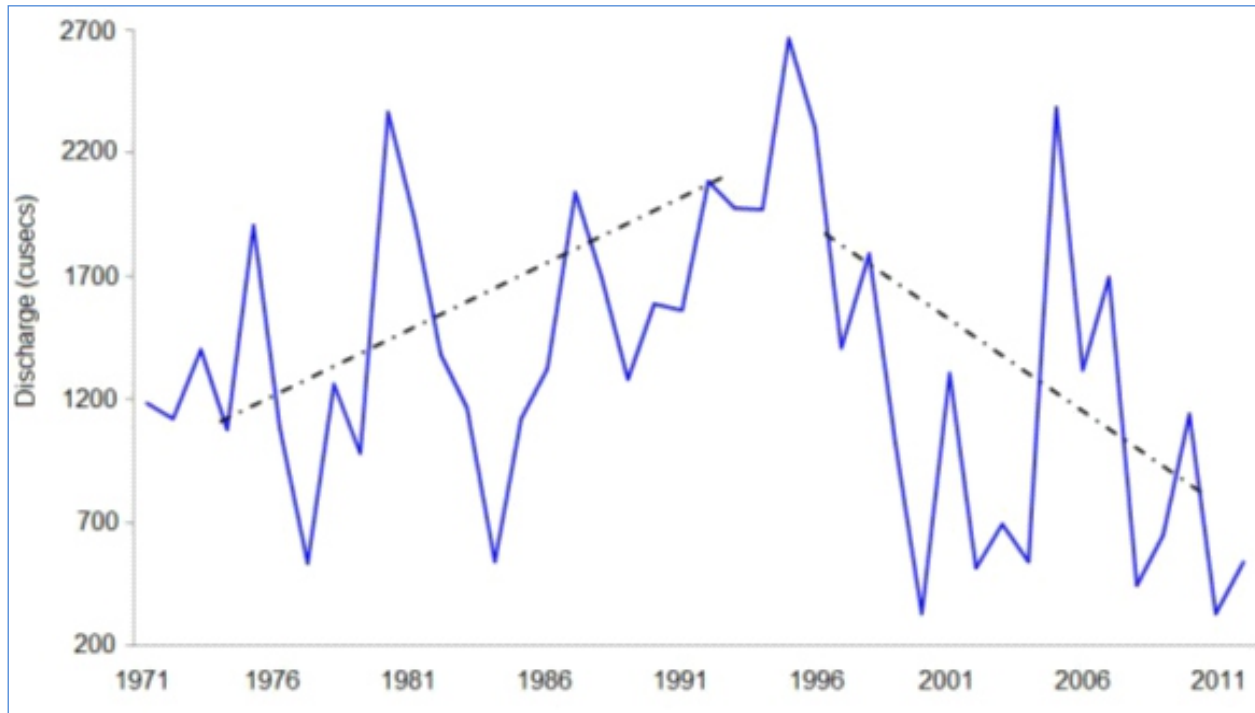
Year	Total glacier area (km <sup>2</sup> )	Kolahoi glacier area (km <sup>2</sup> )
1962	46.098	13.67
1992	41.884	13.34
2000	37.824	12.17
2013	33.433	10.92

Source: Shakil *et al.*, 2015

Sharif *et al.*, 2013 have also found a similar downward trend in a runoff in the glaciated Hunza catchment at Dainyore. However, they found a significant upward trend in the flow regime in the Nival catchment. The Lidder study shows that a short high flow period was already achieved and then a sharp decline in flows occurred despite melting.

The behaviour of these sub-catchments indicates two important factors, which could have a substantial impact on the Indus river flows. First, the glacier mass balance in some sub-catchments has already reached the level of a decrease in the overall runoff. Secondly, increased runoff from some sub-catchments are compensating for the decreased flows of some other catchments – both types of catchments have glacier and early snow melt.

Figure 8: Mean annual discharge at Aru hydrological station



Source: Shakil *et al.*, 2015

## Renewable water resources of Pakistan

Pakistan has a good network to monitor Indus Rivers at the RIM<sup>9</sup> stations and below. A long-term dataset of Indus rivers inflows is available from 1922 and 1937. While some new structures and gauges have been added with time. During the eighties, a detailed groundwater monitoring and mapping system was developed, and a sub-organization of WAPDA (SMO) was assigned the responsibility to measure and report groundwater table changes twice a year (before after monsoon rains) within the Indus Basin. The PMD and other organizations have installed about 90 rain/weather gauge-stations across the country. In recent years, multiple hydrological and glacier assessment studies have been conducted in the Upper Indus Basin, and, across the HKH (Himalaya, Karakorum, and Hindukush) ranges.

However, assessment of Pakistan water resources outside the Indus rivers regime and below the RIM stations remains incomplete. The rain-runoff below the Rim-stations and contribution of ungauged tributaries is normally not considered. The small western basins of Baluchistan are also ignored from the National Water Accounts.

The gross contribution of rainfall also has limitations in estimations; below the RIM station, rain contribution is mostly calculated by the water-balance studies as an effective water component used by crops within the canal command areas. The assessment of annual renewable groundwater aquifer also needs a proper assessment.

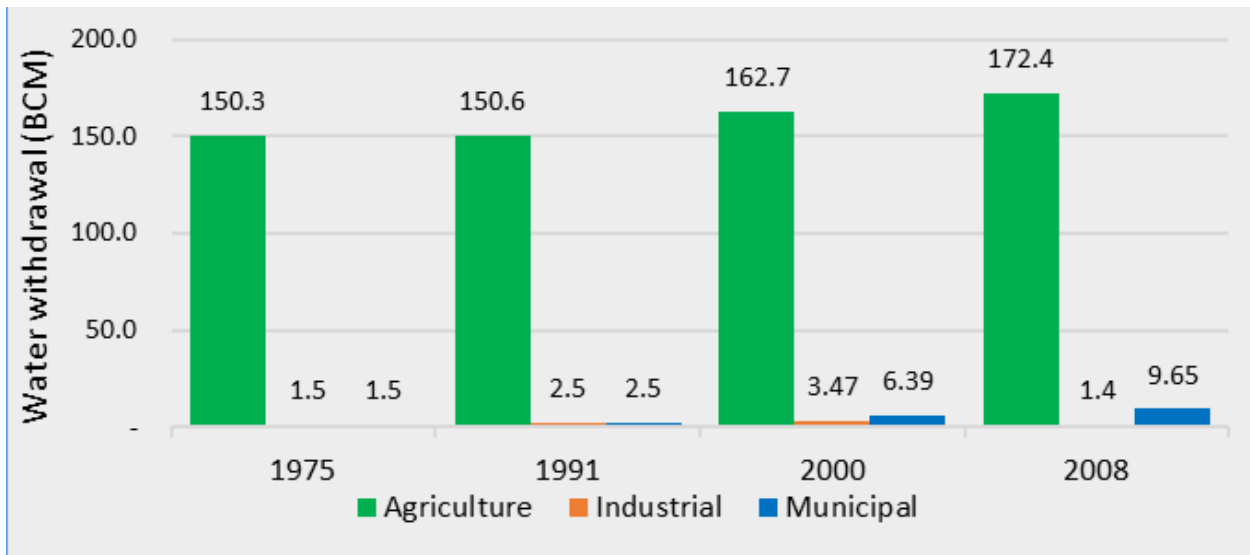
<sup>9</sup> In the context of Indus Basin, a rim station is a control structure on the river to measure discharge when the river enters into Pakistani territory or upstream of the canal-irrigated Indus Plains of Punjab and Sindh Provinces.



## Current water usage in agriculture and its requirement

The agriculture sector is the major water user consuming more than 85 percent of water, far higher than the domestic (5 percent) and industrial sector (2 percent) (Figure 9). Of the total cropped area of 23.4 million hectares (Mha), 18.63 Mha is irrigated, 77 percent of which is located in Punjab, 14 percent in Sindh, 5 percent in Khyber Pakhtunkhwa (KPK), and 4 percent in Baluchistan<sup>10</sup>. 3.8 Mha is under a spate irrigation farming system (includes Sailaba/Rod Kohi, riverine and Barani)<sup>11</sup>. The potential area under spate irrigation is estimated to be around 6.94 Mha (not included in the reported area of 18.63 Mha). Evidence also suggests that crops grown<sup>12</sup> in irrigated as well as spate farming areas are sensitive to water availability, annual rainfall, and temperature variability.

Figure 9: Sectoral water withdrawal from AQUASTAT main database



Source: FAO (2017)

## Crop water requirements

Estimated crop water requirements (CWR) and uses of the agriculture sector are provided in Table 3. Crop water demand increased by about 20 percent over the course of 24 years; canal diversions remain stagnant, while the contribution of groundwater and rainfall increased by about 25 percent. These estimates are used as the baseline for climate change scenario projections (Amir and Habib, 2015).

<sup>10</sup> Government of Pakistan, Bureau of Statistics. 2011. Agricultural Statistics of Pakistan:2010–2011. Islamabad.

<sup>11</sup> The spate irrigation farming system refers to a type of water management unique to semiarid environments. Floodwater from mountain catchments is diverted from river beds and spread over large (Ageta & Kadota, 1992) (Akram, 2016) (Bocchiola, 2015) areas.

<sup>12</sup> The major patterns of crops in Pakistan include: (i) rice–wheat, (ii) maize–wheat, (iii) cotton–wheat, (iv) sugarcane–wheat, and (v) coarse grain–wheat, and some other minor crops patterns, such as pulses, vegetables, etc.

**Table 3: Baseline agriculture water requirements (billion cubic meters –BCM)**

	1990	2000	2014
Cropped Area (official)– Million hectare	20.10	21.02	23.20
CWR Root Zone	113.81	121.79	136.79
CWR Field (75% efficiency)	158.06	166.84	182.39
Rain Contribution Field	28.45	30.03	36.48
CWR Field level (CWR Field minus Rain Contribution Field)	129.61	136.80	145.91
Gross Water Requirements Farm (CWR Field level plus Livestock Requirements)	130.71	138.25	147.65
Total surface diversions (Canal diversions plus other diversions)	127.92	124.85	132.23
Canal diversions	125.46	121.77	127.92
Other diversions	2.46	3.08	4.31
Available Farm (64% conveyance efficiency ; 48% overall efficiency)	81.87	79.90	84.62
Groundwater Contribution Farm*	48.84	58.35	63.05

Source: Amir and Habib, 2015

Note: \*Gross Water Requirements Farm minus Available Farm

Estimation of water requirements at the farm level depends upon the water balance (average rainfall or irrigation minus evaporation and crop transpiration), the type of crops grown throughout the year, water application techniques and soil moisture conditions. Groundwater aquifer levels and quality contribute to the soil condition and net root-zone water requirements. The quantity and timing of rainfall determine its effectiveness and contribution in meeting crop requirements. Pakistan has good empirical knowledge of water applied and used by crops in different agro-ecological zones.

Diverted/recommended quantities could be higher than actual water requirements due to the weekly schedule of canal supplies, flood irrigation, and low conveyance efficiencies. Table 4, shows the estimated CWR for the major crop. The CROPWAT model was used to estimate the CWR for ten main crops across the full temperature range. These values are used to estimate agricultural water uses from 1990 to 2014 in the Indus Basin. CWR increased at a rate of one percent per year (average agriculture growth was three percent) and water uses increased at almost the same rate, with partial contributions from groundwater and direct rainfall.

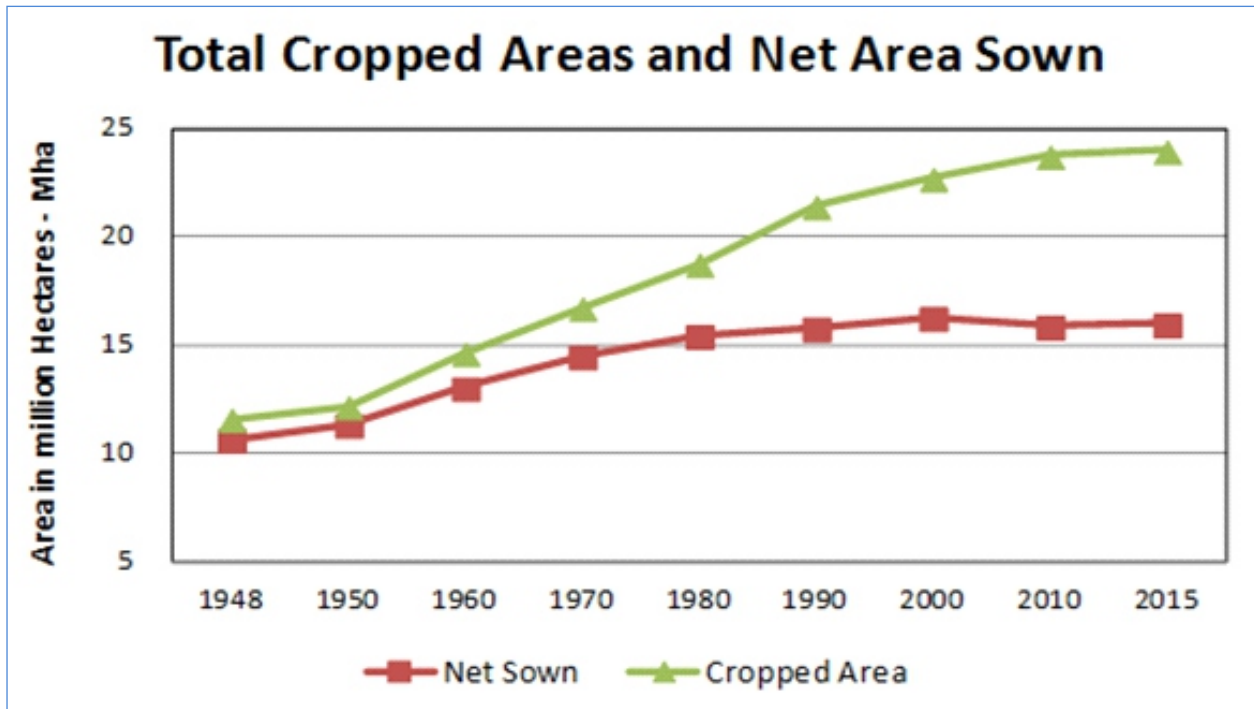
**Table 4: Potential water requirements of major crops estimated using CROPWAT**

	Crop	Crop water requirements (mm) North (temperate) – South (arid)	Average CWR (mm)
1	Wheat	290 - 520	402
2	Cotton	587 - 1000	714
3	Sugarcane	1 000 - 1 900	1 512
4	Rice	540 - 1156	931
5	Maize	244 - 450	435
8	Fruit	900 - 2 200	1 120
7	Sorghum	370 - 530	332
8	Fruit	700 - 2 200	1 120
9	Pulses/oil seed	300 - 500	332
10	Vegetable/fodder	450 - 650	530

Source: Amir and Habib (2015)

The reported net sown area of Pakistan has become almost stagnant at around 16 million hectares, while the cropped area has shown a small annual increase (Figure 10). Net sown area refers to actually cultivated land. Whereas cropped area is referred to as the total area under different crops in a year; hence also includes double cropping. Pakistan is obligated to produce grains and edible crops at a level higher than the population increase due to its food security requirements.

Figure 10: Total cropped areas and net sown area in Pakistan over time



Source: Amir and Habib (2015)

Although the agriculture system has physical potential in terms of agricultural land, the availability of water is a key constraint for the expansion of the sector. Existing divertible river flows are fully allocated among the provinces of Pakistan. All surface water diversions take place through irrigation canals, with the agriculture sector being the predominant stakeholder and user of river flows. At the planning and management level, the agriculture sector is unable to escape this inert state.

### Livestock sector water requirements

The livestock sector of Pakistan has shown a consistent growth rate of about three percent over the last two decades. Compared to the major crops, the annual growth of livestock has been more reliable with no noticeable influence from floods and other extreme events. The livelihood support role of the sector for small farmers and a lower risk factor against extreme events gives it a resilient character. The livestock sector's water intake is estimated by using animal estimates from the National Bureau of Statistics (Finance, Pakistan Economic Survey, 2014-15) and dairy guides. Within the projected

temperature variation range for Pakistan, a two-degree increase will augment the water intake of a large animal by about 5 percent, and a four-degree increase will do so by about 12 percent.

By maintaining the existing growth rate, the water needs of the livestock sector are computed for the years 2015, 2025 and 2050 (Table 5). No change in water use patterns are considered in these calculations; hence, the estimates are on the conservative side. The current estimated direct water use of livestock is 1.7 BCM, which will increase to 2.35 BCM by 2025 and 4.9 BCM by 2050.

**Table 5: Projected water requirements livestock and poultry**

	2006	2013	2015	2025	2050
Annual gross livestock water requirements (BCM)	1.26	1.65	1.75	2.348	4.916

Source: Amir and Habib (2015)

### Water used by forest, range land and ecological demands

Forest water use is dependent on the local climate, soil conditions and forest type. In dry regions, ecosystem water use (tree transpiration + interception + soil evaporation) is generally limited by water availability, provided by the precipitation and aquifer.

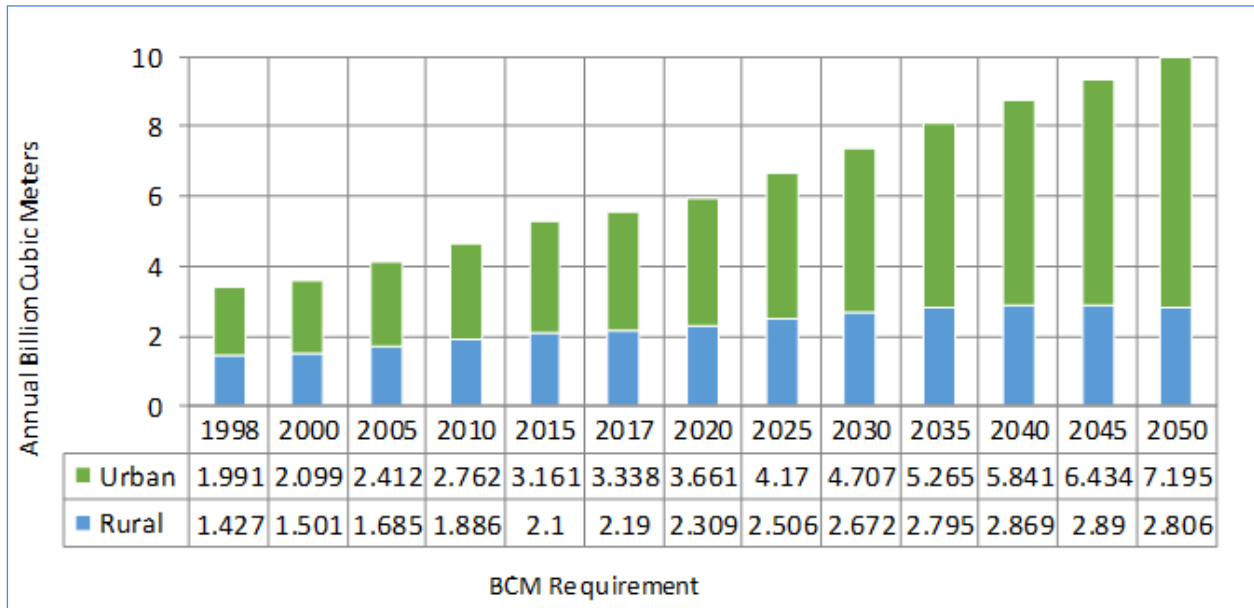
While analysing temperate grassland and forest sites, Sun *et al.*, (2011) found that forests in the warm-temperate zone require at least 400 mm of precipitation in the growing season to sustain their desired functions. Grassland and scrubland are found at sites where growing season precipitation is below 400 mm –they survive on lower evapotranspiration (UK Forestry Commission, 2010; Sheikh Saeed Ahmad, *et al.*, 2010). Forest and rangeland water requirements are estimated using conservative coefficients. Water use for 4.2 million hectares of forest and rangeland was estimated to be about 6.2 BCM for an average 150 mm evapotranspiration.

### Municipal water requirements

Urban and industrial water requirements are rarely computed based on actual water use data in Pakistan. A percentage value from 2 percent to 3 percent is used (to show some numbers); available references for these values are the National Water Strategy document prepared in the nineties and two earlier studies by WAPDA from 1976 and 1989.

The National Drinking Water Policy of Pakistan promised safe drinking water access to the entire population (Government of Pakistan, 2009). The minimum supply for drinking and domestic use is set at 45 liters per capita per day (l/c/d) for rural areas and 120 l/c/d (120 liters =32 gallons) for the urban areas. Based on this promise, Figure 11 illustrates rural and urban household supply projections (Amir and Habib, 2015).

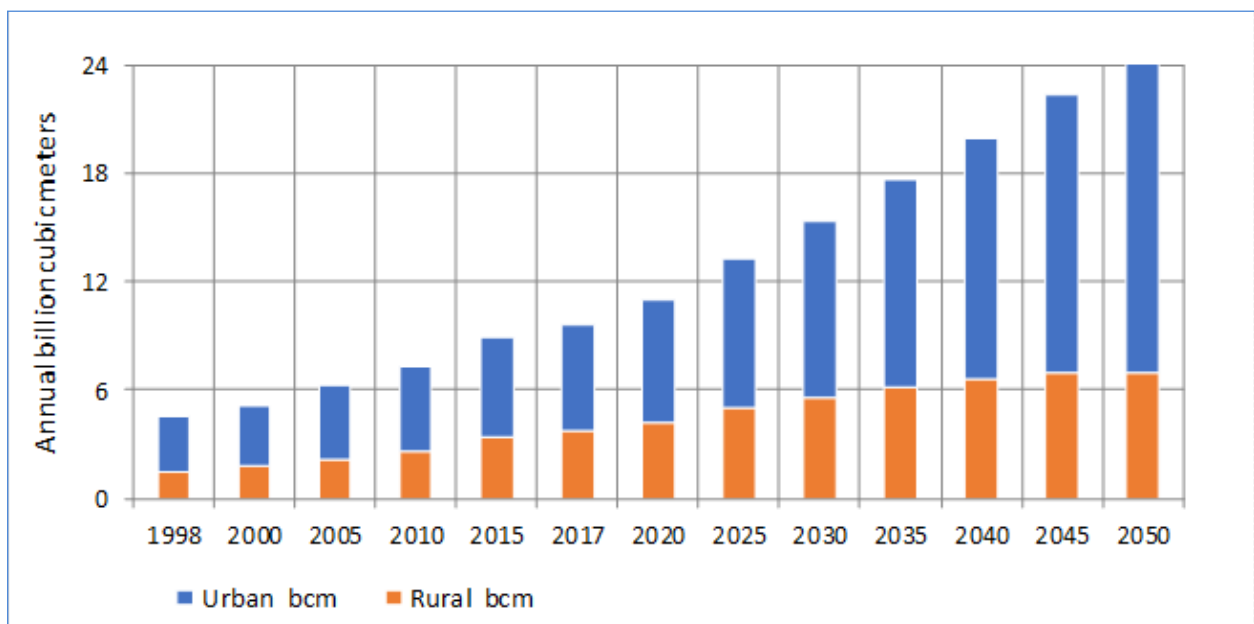
Figure 11: Rural and urban household water supply projections



Source: Amir and Habib (2015)

Amir and Habib (2015) estimated quite high values for future municipal water demands, based on the current urban water supply patterns of the municipalities (Figure 12). According to their report, urban development authorities from large and major cities plan for a supply of more than 65 gallons (300 liters) per capita per day, which in some cases goes up to 80 gallons.

Figure 12: Estimated municipal water requirements



Source: Amir and Habib (2015)

## Water loss and productivity

### Water loss in agriculture

Water losses in agriculture are considered extremely high because of the high evaporation rate, seepage from a long water conveyance and distribution network and widely spread agriculture land, which aggravates the water scarcity further. The evaporation losses are not only hard to account for, but also difficult to control.

Two recent estimates of rivers and irrigation losses tell a complicated story. An Indus Basin study estimates losses due to seepage are as high as 60 percent (Yu, *et al.*, 2013). According to this study, around 25-30 percent of available water is lost in canals and watercourses, and another 25-40 percent in the water application. Although this seepage recharges the underground aquifer (and is recoverable), a significant supply is lost to saline aquifers (Briscoe and Qamar 2005).

Young *et al.*, (2019) computes the national level water losses in two categories, induced losses, and the natural losses respectively in the range of 18 percent and 31 percent. Natural losses include evaporation and plant transpiration from the forest and rangeland including mangroves. The report argues (Young 2019) that a part of evapotranspiration occurring from the ecosystem and forest (31 percent) is strongly temperature driven and could not be managed. Other referred losses are 39 percent from the crop evapotranspiration and more than 10 percent are directly from the rivers. Hence, only a part of the evaporation losses can be managed.

According to Yu 2013, out of 130.4 BCM of irrigation water that goes into the system, only 50.4 BCM reaches crops, a loss of about 61 percent of the water delivered at the canal heads (Table 6) (Yu, *et al.*, 2013). About 30.8 BCM is lost in watercourses and 20.9 BCM in fields, most vulnerable components of the irrigation system (Yu, *et al.*, 2013) simulated various climate changes scenarios for 2020-80 and found that improving the canal efficiency system can save an additional 14.8 BCM. A relatively minor increase in infrastructure can lead to a significant increase in water use efficiency (Parry, Osman, Terton, Asad, & Ahmed, 2017).

As far as discharge into the sea is concerned, this is a function of the seasonal mismatch in water inflow and its usage; available storage; and the need to maintain a balance between sea-water and freshwater in the coastal areas. According to estimates, more than two-thirds of the annual flow of the western rivers transpires during June-August, whereas water needs remain high year-round.

However, seepage losses are highly variable, they are often directly linked to canal maintenance as shown in a study by (Wahaj, 2001) that estimated watercourse losses vary from 9 percent to 39 percent in 1000 meters length depending on the level of maintenance. (Habib, 2004) compared water losses assessed as part of different studies and programme between 1965 and 1999. The comparison shows high variability in water loss values at watercourse level ranging from 15 percent - as part of the study carried out by Punjab Irrigation

Research Institute in 1971 - to 35 percent - study by IWASRI in 1997. This makes it a more than 100 percent increase in seepage losses at the watercourse level over 26 years. Many of the studies carried out after 1972, showing higher water losses in the canals, were carried out as part of the preparation for the watercourse lining programme. Thus, the watercourses selected for measurement of seepage losses were in bad physical condition with dilapidated infrastructure, which makes these high estimates biased and non-representative of the entire basin (Habib, 2004).

## Low water productivity

Water withdrawals globally have increased as a result of rising population and economic growth. It has risen by a factor of 40, from 100 BCM in the year 1700 to 4 104 BCM in 2010, exceeding the 11-fold increase in population over the same period and far less than 144-fold increase in global GDP, surging from USD 371 billion in 1700 to USD 53 394 billion (IMF, 2015). Table 6 includes 10 countries withdrawing the most water, seven populous countries in the world, six largest economies and five countries with the most land cultivated for agriculture. In addition to irrigation practices, high water withdrawals per unit of land are influenced by the percent of irrigated areas and cropping patterns.

**Table 6: Top 10 countries' water withdrawals in 2010**

Country	Freshwater Withdrawal (BCM)	Population (In Million)	PPP GDP billions of USD)	Agricultural Land Area thousands of square kilometer)	Withdrawals (cubic meters per capita)	Withdrawals (Cubic meters per unit of GDP)	Withdrawals (Cubic meters per square kilometer)
India	760	1 206	4 130	3 287	631	18	231
China	627	1 360	10 040	9 597	461	6	65
USA	441	312	14 958	9 629	1 413	3	46
<b>Pakistan</b>	<b>183</b>	<b>179</b>	<b>487</b>	<b>796</b>	<b>1 022</b>	<b>38</b>	<b>230</b>
Indonesia	166	241	1 026	1 905	691	16	87
Iran	89	74	942	1 648	1 202	9	54
Russia	80	144	2 222	17 075	558	4	5
Mexico	80	118	1 603	1 958	676	5	41
Philippines	79	93	365	300	848	22	264
Japan	76	127	4 351	378	596	2	201
World	4 104	6 837	73 658	131 077	600	6	31

Source: World Bank Indicators Database 2015

Note: 2010 was heavy flood year in Pakistan.

Average water productivity (Table 7), calculated as a total constant 2010 USD GDP per cubic meter of annual freshwater withdrawal in Pakistan is considerably low compared to other countries (World Bank, 2018). Low crop yields, both per hectare and per cubic meter of water are attributed to excessive reliance on traditional irrigation methods like flood irrigation, leading to large water losses from excessive run-off, deep percolation, and evaporation. Flood irrigation can damage land quality (waterlogging) and reduce crop yields, as excessive water leaches nutrients out of the root zone.

At the user's level, Warabandi<sup>13</sup> and the manipulations of the water allocation system have taken place and they have persisted over time. Alterations of canal outlet sizes and timings of delivery have created inequalities, leaving some farmers – particularly poor farmers at the tail end of a canal or watercourse – with fewer allocations and less access to water. As a result, access to canal water at the farm level depends on access to land and the location of that land along the canal (Yu, *et al.*, 2013).

Another issue related to low water productivity is ineffective interventions. For example, rice and sugarcane improvement programmes failed to consider issues of water shortages, heat or salt tolerance, focusing primarily on developing high yield and disease-resistant varieties.

Average farmers are unable to access laser levelling equipment easily, which is a popular and effective method of increasing water productivity, and the private sector is not actively engaged in providing these services.

Lastly, Warabandi and the manipulations of the water allocation system have taken place, and they have persisted over time. Alterations of canal outlet sizes and timings of delivery have created inequalities, leaving some farmers – particularly poor farmers at the tail end of a canal or watercourse – with fewer allocations and less access to water. As a result, access to canal water at the farm level depends on access to land and the location of that land along the canal (Yu, *et al.*, 2013). Table 7 Comparison of Water Productivity in Agriculture.

**Table 7: Comparison of water productivity in agriculture**

Country	Tons/Hectare	Constant 2005 USD/m <sup>3</sup>	Kg/m <sup>3</sup>
<b>USA</b>	7.34	30.20	1.56
<b>Germany</b>	7.32	98.33	
<b>Egypt</b>	7.25	1.88	
<b>France</b>	7.10	74.54	
<b>Japan</b>	6.10	53.13	
<b>China</b>	5.89	8.86	0.80
<b>Vietnam</b>	5.42	1.12	
<b>Indonesia</b>	5.15	3.96	
<b>Brazil</b>	4.83	16.09	
<b>Bangladesh</b>	4.36	3.12	
<b>India</b>	2.96	1.96	0.39
<b>Kyrgyz</b>	2.90	0.44	
<b>Pakistan</b>	2.72	0.78	<u>0.13</u>

Source: World Bank Indicators Database 2015.

<sup>13</sup> Warabandi system or water timeshare system was introduced by the British administration to ensure equitable provision of water to cropped lands. As the demand for irrigation water was rather minimal due to low cropping intensity and production of primarily of low-water requirement crops like food grain (wheat, maize, sorghum, and millets), pulses, oilseeds, etc. During the last decade, however, the pressure on water has drastically increased, with more competition for quantity and quality of irrigation water within the irrigation sector, but also from other sectors of the economy.



A different set of arguments is provided by Young (2019). The economic return from irrigation water has doubled over the last three decades from around 0.03 USD/m<sup>3</sup> to 0.06 USD/m<sup>3</sup> in Sindh and from around 0.04 USD/m<sup>3</sup> to 0.08 USD/m<sup>3</sup> in Punjab. This has been achieved through expansion of the irrigated area, increased groundwater use, increased use of fertilizers, mechanization, and improvements in water management-Water productivity needs to improve markedly if Pakistan is to revitalize economic growth, and should come from better water delivery control, better on-farm management, higher input quality, and better pest control.”

Large variations in estimates and decades-old data used in some cases by the global databases suggest the need to rectify the data and methodology to estimate some key indices like water use efficiency, crop productivity and the value of water.

## Financial sustainability of the water sector

Gross revenue generated from agriculture and other water use sectors is extremely low and has a decline in its real value over time. Water rates for agriculture uses are historically linked with the irrigated land and have been considered low. A major target of Irrigation management transfer reforms was to improve the water rates and the actual revenue collection. However, total revenue from the sector decreases, as, Punjab shifted from the crop-based irrigated land revenue to the flat-rate revenue on the landholding. Sindh and other provinces could not enhance the assessment and collection procedures.

Most of the industrial water used from the surface resources are not accounted for. While under-reported allocations are nominally charged. Similarly, water rates are very low in the commercial and domestic sectors. Because of the low-income water sector depends upon national exchequer for its daily operations and maintenance of the system. water resources development and asset management fully rely on foreign funded projects. Tariffs and subsidies also benefit big producers, eventually supporting a small group of “progressive farmers”, having higher productivity of land and water but a small overall contribution.

## Future projection of water requirements

Climate change impacts on sectoral water demands estimate water requirements of agriculture and other sectors without specific interventions (Amir and Habib, 2015). The baseline scenario (no climate change) was developed based on:

- (i) a modest population growth rate (1.67 percent increase in 2015 and only 0.61 percent in 2050);
- (ii) higher conveyance efficiency of the irrigation network (64 percent );
- (iii) urban/domestic water requirements based on official targets for the safe domestic water supply and the current actual supply pattern of large and medium cities;
- (iv) expected infrastructure, industrial and social sectors' requirements; and
- (v) promised environmental flows.

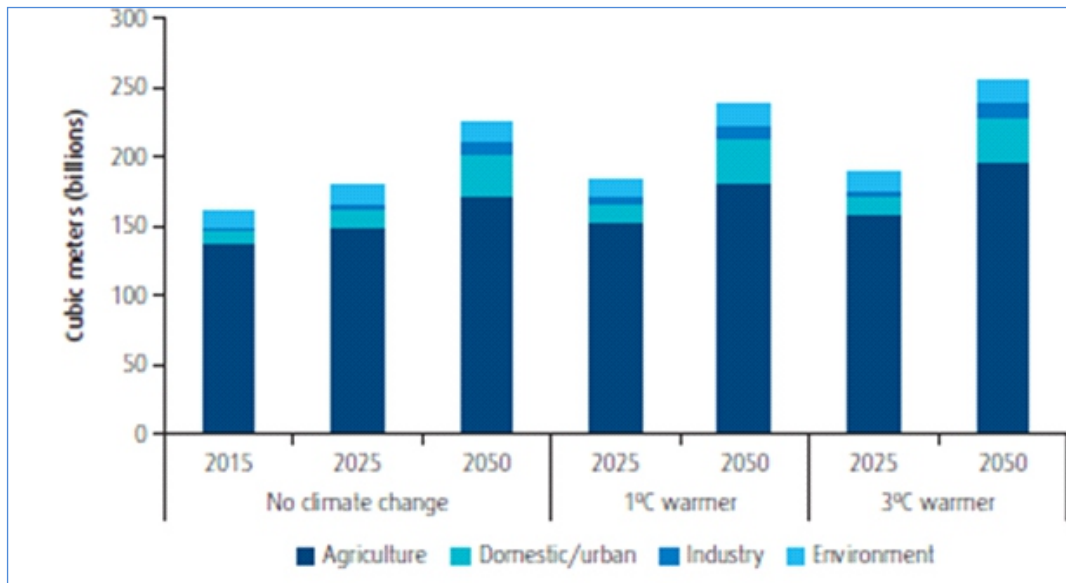
The report estimates CWR for 1oC and 3oC increase in temperature in 2020 and 2050 using the CROPWAT model for the major crops and evapotranspiration projections by PMD. It estimated that a +3°C increase in temperature by 2050 would result in agricultural water requirements increasing by 6 percent by 2025 and 12-15 percent by 2050. The study presents high water competition among various water use sectors and increased stress on the agriculture sector. For the baseline estimates, non-agriculture water demand will be around 17 percent in 2025 and 24 percent in 2050. Climate-induced warming will increase water requirements by 5 BCM in 2025 and 10 BCM in 2050. The forecast for the municipal water demand is higher compared to all other estimates, which is justified by the authors based on existing urban water supply patterns and public commitment to provide safe drinking water and sanitation access (Amir and Habib, 2015). The demand estimates by the study are provided in Table 8 and Figure 13.

**Table 8: Controlled population (1.7 percent to 0.5 percent in 2050) and reasonable economic growth – water requirements at the water use level (farm in case of agriculture)**

Year	Urban/Commercial	Industrial/Social	Agriculture	Ecology/Forest	ENV Flows	Total water demand		Agri. Share
	Billion Cubic Meters ----- BCM -----					BCM	MAF	%
Base Scenario – No systematic change in temperature and precipitation								
2015	9.3	3.3	138.5	6.3	5	162.4	132.0	85
2025	12.7	5.5	149.8	7.0	5	180.0	146.3	83
2050	30.5	10.2	171.9	8.9	5	226.6	184.2	76
Temperature Increase 1C till mid-century								
2025	12.8	5.7	154.3	7.2	5	184.9	150.4	0.83
2050	31.0	11.7	182.4	9.5	5	239.5	194.8	0.76
Temperature Increase 3C till mid-century								
2025	13.3	5.9	158.8	7.5	5	190.6	155.0	0.83
2050	32.9	15.1	196.5	10.0	5	259.6	211.0	0.76

Source: Amir and Habib (2015)

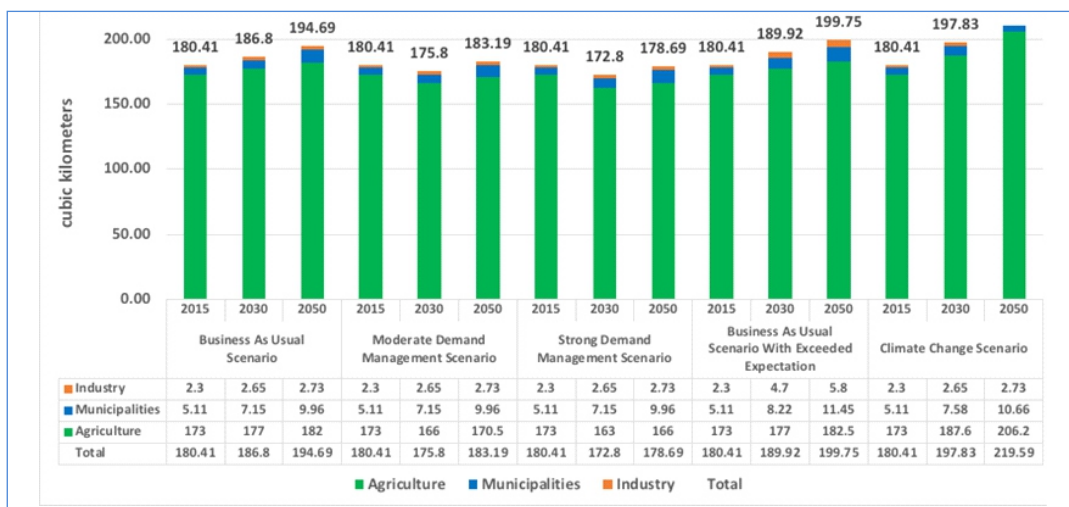
Figure 13: Climate change impacts on water demand by 1C and 3 C increase in temperature



Source: Amir and Habib (2015)

Infrastructure development, thermal and coal power plants, the sugar-industry, cement plants and cottage industry all require water at a faster pace than the agriculture sector. The allocation of surface water (from rivers and canals) for non-agriculture use is not fully accounted for at the basin level. However, local accounts of these competitors are emerging (Amir and Habib, 2015). The study estimates that non-agriculture demand in 2050 will be about 25 percent of the total demands. Total demand estimates are about 227 BCM in 2050 – in the case of no climate change, and about 260 BCM (211 MAF) with 3 oC rise in temperature. These demands (2050) are in the range of Pakistan's total renewable water resources.

Figure 14: Comparison of five water demand scenarios against baseline period of 2015



Source: UNDP, 2017

Another review study was recently carried out by UNDP and COMSAT, 'The Vulnerability of Pakistan's Water Sector to the Impacts of Climate Change: Identification of gaps and recommendations for action' (2017, see Figure 14). The study used the same data as Amir and Habib (2015) for projections on the population, temperature, rainfall and agriculture areas. However, both studies have different estimates of the current water demands (Table 8 and Figures 13 and 14). The baseline agriculture demand by UNDP is estimated as 173 bcm (same as total withdrawals from all sources in 2015). All UNDP scenarios consider a small change in industrial demand, from 2.3 bcm in 2015 to 2.73 bcm in 2050, much less than the estimation of Table 8 (3.3 bcm to 10 bcm). In addition to the climate change scenario, two demand management scenarios were adopted by the UNDP study substantially reducing agricultural demands from 2015 to 2030 and maintaining the current level in 2050. The business as usual scenario shows 15 bcm increase in total water demand in 2050 and the climate change scenario an increase of 39 bcm.

## Information and data gaps

Table 9 summarises the range of values of water variables used by various water balances and assessment studies. The rivers inflows at the RIM-stations and the surface diversions through canals are the two variables, having the same values and data sources in all studies. All other quantities are computed differently by different studies, influenced by various factors like methodology, the scale of analysis, objectives of a particular study and assumed boundary conditions. The remarks column briefly comments on each water component. Some of these limitations are also mentioned in the text of this paper.

The provincial level assessment of water and land resources and applications of remote sensing techniques are the emerging trends in Pakistan. The new water management scenario will need a more serious and systematic approach to present a correct profile of the water resources at various levels.

The factors behind and sometimes justification for a range of water numbers given in Table-9 can be summarized as:

- i. Currently, no public sector organization is responsible for the compilation of water data other than the main rivers flows and canal diversion. The responsibilities of WAPDA (particularly related to monitoring and reporting) are not taken by any other agencies, as WAPDA slowly exited.
- ii. Almost all water balance studies by donors (WB, ADB) and a big project are focussed on the Indus Basin and IBMR model or its new versions (used by WB studies of 2013 and 2019). The model further focusses on the irrigated agriculture inside the canal command areas. Hence, the water used outside the model setting is either not considered or taken from the available references.
- iii. Most of the analysis are carried out in the supply-based setting and traditional concepts about the irrigation canals prevail. That seriously influences estimations of water

demands and the actual uses, which are mostly calculated through the supply-side efficiency factors.

- iv. The emerging water use sectors do not report the actual uses and the sources of water, hence, assessments for urban, commercial and industrial remain low and erratic. Sometimes 30 years old data is still used.
- v. Some of the basin water definitions are not properly applied, like “the renewable water resources” and the “internal water resources”.
- vi. The remote sensing applications especially need ground-truthing and calibrations, in addition to the scale and resolution issues.

**Table 9 : Gaps in the estimation of the gross water resources, water availability and water uses**

Water Component	Value	Source	Remarks
Indus River and tributaries Inflows: Indus, Jhelum, Chenab, Kabul, Ravi, Sutlej	170 bcm	PIDs, IRSA, WAPDA	Historical River flows data is available
Ungauged Tributaries below RIM stations	6.4 bcm	Not in the public domain, available on request	Not updated, considered a part of River gains and Losses
Kharan and Makran Basins of Balochistan	9.8 (6.2+3.5) bcm	WAPDA 1991, Young 2019	Not updated
<b>Runoff from Watersheds Pakistan Upstream of RIM Stations</b>			
Kabul River runoff generated inside Pakistan boundary	<i>10.5 to 15 bcm</i>	Arfan, M.; Lund, J (2019). R. Ullah 2017, Khan, F. and Pilz, J. (2018).	Nine rivers shared by Pakistan and Afghanistan with an annual flow of around 22.5 BCM, Kabul River alone accounts for 21.5 bcm (Mustafa, 2011).
Upper Indus Basin (UIB) flows generated in Pakistan controlled Area	<i>about 15 bcm yield between Chalas and Alam bridge</i>	Kashif Jamal (2018)	Climate change and runoff contribution by hydrological zones of cryosphere catchment of Indus River, Pakistan
Small Dams storages and uses	<i>About 70 small dams</i>	<i>Provincial Small Dams Orgs.</i>	<i>Accumulated data of actual storage and uses not available</i>
Surface water uses upstream RIM stations	<i>4 – 6 bcm</i>	<i>Allocation of civil canals of KP by WAA 1991. Bhasha study 2011</i>	<i>Three big canals of SWAT &amp; Kabul rivers and many civil canals are formal systems monitored by the Prov. Irrigation Dept. However, most of the databases ignore them.</i>

Rainfall Contribution			
Surface Runoff & Recharge within Indus Plains below RIM stations.	In the range of 28 - 48 bcm	WAPDA 1991 Young 2019, Amir & Habib	No national-level estimate available
Rain direct uses by crops in the Indus Basin	12 bcm to 36 bcm	WAPDA 1991, Ijaz <i>et al.</i> , (2010) Habib 2004 Amir & Habib 2015	Water Accounting study 2019 FAO
Rainfall uses in Baranni areas outside Canal Commands	In the range of 9 bcm	Estimated in 1979 and 1991 by WB and WAPDA	Not Updated.
Groundwater estimates based on Water Balances			
Groundwater Aquifer: Annual withdrawal	60 bcm to 72 bcm	WB 2019, FAO & many others	balances mostly confined to the Indus Basin
Aquifer total Replenishing Potential	66 to 75 bcm		Estimates based on water balances and irrigation conveyance efficiencies
Estimations of water requirements, supply and uses in various sectors at the National, Provincial and Basins levels.			
Agriculture Water Demands and Uses	80 bcm to 136 bcm	WAPDA 1974, WAPDA 91, Habib 2004, WB 2005, Ijaz 2010, Yu <i>et al.</i> , 2013, Amir & Habib 2015, UNDP 2017, Young <i>et al.</i> , 2018 FAO AQUASTAT	Basic limitation of the given estimates: I, values computed for water balance models of the Indus basin CCAs ii, water uses calculated by applying conveyance efficiency factors iii, non-agricultural uses randomly assumed
Urban, domestic, civil & commercial water uses	5 bcm to 9.6 bcm		
Industrial water uses	1.8 bcm to 3.6 bcm		
Water used by Forest, rangeland, and ecosystems	About 4 bcm	WAPDA 1991	Not updated
Internally Generated Water Resources	55 bcm	Aquastat, WB databases	Under-estimated only considering rainfall contribution within CCAs & for the aquifer recharge

## Conclusion & recommendations

Pakistan faces daunting water resources challenges as the need for water supply from different sectors intensifies due to population growth, economic development, and impacts from climate change. The country withdraws more than 70 percent of its renewable water resources, most of which are used in agriculture. Annual river flow data over a 35-year period indicates a quantifiable decline in the annual volumes of river flows. Exacerbating the challenge is a growing demand for water, mainly stemming from rising population, rapid urbanization, the adverse impact of climate change, and the continuing degradation of water quality. Further, water demand from new emerging sectors that include environmental flows, China Pakistan Economic Corridor (CPEC) related development, afforestation needs, and social developments have neither been foreseen nor factored in future planning.

Climate change is making matters worse with erratic rainfall, temperature rise and increased variability in water availability patterns. The impact of climate change on water availability is projected to be severe with intense events of floods and droughts. While, water supply is already affected by changing climates; water demand is also projected to increase, not only in agriculture, but also in urban areas as well as in the industry.

A proper and standardized system of water accounting is not followed both at Federal or at Provincial levels. Water balances carried out by different organizations and institutions using different methodologies and data sources are providing different results for the same physical boundaries. Also, the Remote sensing and GIS based water accounting carried out in the country often lacks proper (re)calibration of the model(s) used. Part of the reason for this is the limitations of available data and information, which sometimes is incomplete, especially seasonal cropping patterns and crop yields.

Groundwater has a critical role in managing the demand-supply gap at the user level in all sectors of the national economy. Across the freshwater zone active recharge and abstraction of groundwater provide a unique recycling opportunity to the rain and irrigation runoff. However, consistent aquifer mining is causing secondary salinization and depletion of a critical resource in high water stress areas. In the saline aquifer zone, about 30 percent of the Indus plains, excessive effluent, and insufficient drainage result in waterlogging, salinity and pollution of fresh surface water bodies. The groundwater monitoring mechanism developed in the eighties has faded with time. New provincial initiatives have limited spatio-temporal coverage and still not able to generate annual groundwater profiles. Deterioration of groundwater quality is directly linked with the marginalization of drinking water quality and health issues.

To check the emerging unaccounted water uses, there is a need to strictly follow and extend surface water allocation procedures to all water use sectors. Pakistan needs to improve its water and land data reporting systems at the national and global levels. There is a severe lack of understanding of some new terms and variables, like the renewable and internal water resources, productivity of water, and, local and global water use efficiencies.

## Recommendations

In light of the review and analysis of the water situation in the country, some key recommendations have been proposed as follows, which can be applied to overcome the problems faced by Pakistan's water sector and its impact on agriculture due to climate change.

1. Institutional coordination between federal and provincial levels as well as across the sectors is a key challenge, which should be addressed through permanent institutional mechanisms. Instead of launching new institutes, Pakistan needs to revisit existing institutional responsibilities, overlaps and gaps.
2. Pakistan must maintain and extend surface water allocation procedures to all water use sectors in addition to the irrigation sector. The surface water resources, which are increasingly used for the municipal and industrial supplies should have a clear allocation to these sectors.
3. A paradigm shift **from irrigation to water management** is key in meeting water challenges, especially in changing climate and addressing the increasing needs of a growing population and other sectors including industries and municipalities. Although by 2050 agriculture will account for the highest increase, water demand for domestic uses (urban and rural) will rise sharply with the highest rate.
4. Strategic long-term water management necessitates employing a standardized **water accounting system** that can provide comprehensive information on water use and availability and is especially resourceful for resolving tensions and gaps between water supply and demand. Water accounting provides critical information about the hydrological cycle, assesses spatial and seasonal rainfall variations with water extremities – information that can inform water infrastructural investments such as pumping, storage, and planning for climate change.
5. Remote-sensing and GIS technology, in a combination of ground data, can be used to **measure and monitor the evapotranspiration** from basin, sub-basin, administrative units and agro-climatic zones) in the agriculture sector to determine actual crop water consumption and water productivity (production and income per unit of water consumed).
6. **Demand management** needs to be at the center of current and future water policies and strategies in order to sustainably manage water resources. As the gap between water supply and demand increases managing demand in agriculture and other sectors become more important. Strategies need to focus on improvements in water productivity, reduction in non-beneficial evapotranspiration, and reduction in source and non-source water contaminating practices. The safe use of non-conventional water resources in agriculture and non-agriculture sectors needs to be encouraged.
7. **Sustainable management of groundwater aquifers** must be considered in order to



optimize the development of water resources, management, and conservation within a basin. Recharge in the areas with sweet groundwater zones should be encouraged, whereas, reduction in seepage in the areas with marginal groundwater quality (and with saline groundwater zones) should be reduced. Artificial recharge of aquifers is certainly one of the tools that can help in the sustainable use of groundwater resources, especially in areas with good quality groundwater.

#### 8. Irrigation system modernization; rehabilitation and maintenance of irrigation systems.

Irrigation Systems in the Provinces requires not only proper maintenance but also modern techniques and technologies for improved management and water delivery services. This will allow farmers to make timely on-farm decisions resulting in higher productivities and incomes. High-efficiency water application techniques such as trickle/drip sprinkle, bubbler irrigation, furrow bed irrigation need to be introduced and upscaled for improved water use, the ratio between beneficial and non-beneficial evapotranspiration, and water productivity.

9. **Climate-smart agriculture and on-farm water management.** The provincial extension services need to provide information and reorient farmers to planting resilient crop varieties, changing planting dates, and adapting farming practices to a shorter growing season. Drought-tolerant varieties of wheat and cotton, and heat-tolerant varieties for cotton, which are being practiced in some parts of Pakistan, need to be upscaled. Additionally, practices such as laser and gradient land-leveling need to be promoted to prevent water losses due to poor field design and surface unevenness causing water accumulation or leave dry pockets. Resultantly, germination is often inconsistent and uneven growth of crops. The use of a laser beam allows farmers to achieve uniformity in field preparation for uniform water and moisture distribution. Zero-tillage (rice-wheat crops) can help with seed germination, minimizing the soil disturbance and maximizing carbon storage. Soil ripping can help conserve water. The government in collaboration with the private sector can help to facilitate climate-resilient agricultural systems by establishing demonstration plants and moving towards high-value agriculture. Additionally, the extension staff in coordination with the irrigation department may train the farmers in soil and water conservation techniques, such as dry seeding or rice, furrow irrigation, and drip irrigation, which can boost land productivity and conserve scarce water resources.

10. **Water tariff and subsidies.** Water subsidies generally benefit upper-income groups in developing economies, as the poor often have limited or no water access. Current water tariffs in Pakistan and agricultural input and crop subsidies (fertilizer, pests, sugarcane) promote water-intensive cropping (sugarcane and rice). Similarly, subsidized electric supply for tube-wells encourages the over-abstraction of groundwater and poor irrigation practices. The federal and provincial governments may have a deeper look at the current subsidies regime and water pricing to align with the challenges caused by climate change. It requires gradual phasing out of current subsidies and diverts a part of these subsidies to promote climate-smart agriculture and water management. Water tariffs must be set to recover the full cost of maintenance of the irrigation system and groundwater needs to be licensed and priced.

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