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Impacts of Climate Change on Agricultural Water Management and Adaptation- A Case of Pakistan

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Abstract: Climate change is now an undeniable reality. It is vital for all of us to work together to tackle this issue. The meteorological data analysis clearly presented that Pakistan climate is getting warmer with increase in mean annual temperature. The rate of change is 0.74°C for the period 1961–2018 with highest increase in southern part (+0.32°C to +0.50°C per decade) than northern part (+0.02°C to + 0.10°C per decade). There is a 19% increase in mean annual rainfall since 1961 for the period 1961–89, while the rainfall pattern showed decline rate after 1990. There is a decreasing trend (-0.54 mm/day) in annual precipitation under RCP4.5 while increasing trend (0.9 mm/day) in precipitation under RCP8.5 for 2011 to 2100. A 1°C increase in mean annual temperature may increase 5% crop water demand by 2050, while a 3+°C change in temperature increases 6% and 12–15% agricultural water requirements by 2025 and 2050, respectively. The research findings emphasis that the scope of policy related to climate change adaptation should focus on the strategies at community and farm level for significant development outcomes. While analysis has identified some of the broad changes underway in Pakistan's climate, the findings also point with potential climate change adaptations and mitigation strategies to be developed and adopted at local and regional levels.

Keywords: observed climate changes; future projections; temperature; rainfall; flow; adaptation

1. Introduction

According to IPCC AR5 report, the global temperature will be likely to increase 1.5°C between 2030 and 2052 under business as usual scenario while the Asia outlook is particularly troubling [1]. Pakistan is in water stressed to water scarcity situation showed its vulnerability to changing climate. During the 20th century, rainfall trends increased significantly (25 percent, or 63 mm) while temperature also showed warming pattern (+0.6°C) over the country [2]. According to literature study, there is a declining trend in mean annual inflows such as Indus River from 1937-2011 [3]. Different studies also indicated the decrease in crop yield with the increase in temperature. For example, the wheat yield decrease 5% to 7% with a 1°C rise in temperature [4]. Ahmad et al., findings indicated that if the rise in temperature remains as usual, the rice yield in semi-arid areas of Pakistan could be decreased by 15% from 2012 to 2039, 25% from 2040 to 2069 and 36% from 2070 to 2099 [5]. Similarly, the decrease in rainfall affect crop production as presented that 6% decrease in rainfall could increase 29% more irrigation water requirement in Pakistan [6].

Different findings indicated that under business as usual scenarios the observed temperature of Pakistan will continue to increase up to the end of this century and also the models upshots suggested the same. According to Climate Service Center report, Pakistan average temperature is projected to rise by 3.8°C (from 2.1°C to 5.1°C) by 2100 [7]. The same has been indemnified in other study i.e. the increase of 1.4°C to 3.7°C by the 2060s [8]. However these changes vary spatially and seasonally across the country i.e. northern regions and winter season is getting warmer compared to other regions and seasons [9, 10].

Consequently, the adverse impact of climate change on water resources of Pakistan can be minimized with the implementation of adaptation and mitigation approaches simultaneously. Salient features of these approaches are integrated water resources management (IWRM). This study outlines the newsworthy knowledge to understand the impact of climate change on agricultural water management and water resources of Pakistan, and presents certain agricultural adaptation strategies that are determined in the literature studies.

2. Materials and Methods

In this study, the long-term (1961–2018) climatic data (rainfall and temperature) of 55 observing stations has been used to assess climatic changes of Pakistan. The yearly data of rainfall and mean temperature was acquired from Pakistan Meteorological Department (PMD). Key climate change trends (temporal and spatial) are identified at the national level. The spatial patterns were plotted using IDW interpolation method in GIS environment. We use 30-year averages, computed for the period 1961–90, termed "reference normal," as the benchmark for observed climate change assessment [11]. The river inflows data of five major rivers (Indus, Jhelum, Chenab, Ravi and Sutlej) was acquired from Surface Water Hydrology Project-Water and Power Development Authority (SWHP-WAPDA) for 1961-2016 on yearly basis. The linear trend analysis was adopted to identify the increasing or decreasing trends of river inflows.

For the future projections of temperature, rainfall and river flows, this paper is primarily based on literature studies [12-17] and the dependence was given to the secondary data sources. The reports and documents were obtained from government agencies such as PMD; Ministry of Environment and Climate Change; WAPDA and Pakistan Agriculture Research Council. Moreover, the other documents such as reports and policy briefs were also obtained from different NGOs (IWMI, ICIMOD, ICARDA) working in Pakistan. The literature cited was selected based on a critical review of publications of greatest relevance to Pakistan using Web of Science, Science Direct, Scopus and Google Scholar [18].

3. Results and Discussion

3.1 Present Climate and Observed Changes based on Temperature, Rainfall and River Flows

Figure 1 indicating warming trends since 1960s. The rate of change is 0.74°C for the period 1961–2018. The rise is protuberant (0.67°C) in the last half of this period. The highest increase is in southern cities i.e. Quetta in Balochistan (+0.50°C per decade) followed by Karachi in Sindh (+0.32°C per decade) and the least increase in northernmost cities i.e. Muzaffarabad in AJK (+0.02°C per decade) and Gilgit in GB (+ 0.10°C per decade). Warming is ostensive over entire country and greater over major parts of Balochistan, in southeastern and southwestern Sindh, and in eastern parts of Punjab.

The average annual rainfall showed 19% increase over the period 1961–2018 in whole country. The earlier period showed the increase in average annual rainfall but the latter half shows a decreasing trend (Figure 2). The tendency of rainfall on regional level is somewhat mixed. The most increase in total annual rainfall is in Peshawar (+39 mm/decade), followed by Islamabad (+37 mm/decade) and Lahore (+26 mm/decade), while the most decline is observed in Muzaffarabad (–19 mm/decade) and Karachi (–17 mm/decade).

The Indus annual inflows indicates a significant decreasing trend over the period of record (Figure 3). The Jhelum average annual inflow is about 23 MAF while Chenab delivers about 25 MAF per year at the Marala Headworks. There is a significant decreasing rate of discharge on the Ravi and Sutlej (Figure 4). Ravi inflows parade a step function at Balloki Barrage the average annual inflow was 8 MAF in the 1970s, dropped to 4 MAF until 1999, and less than 2 MAF thereafter. Sutlej River inflows also declined dramatically in the 1970s at Sulemanki Barrage but with different pattern (higher variability) than the Ravi. Generally, annual inflows look comparatively stable over the period of observed data. In contrast the Chenab's recent decade of flows are most often below the mean, which raises water concerns downstream.

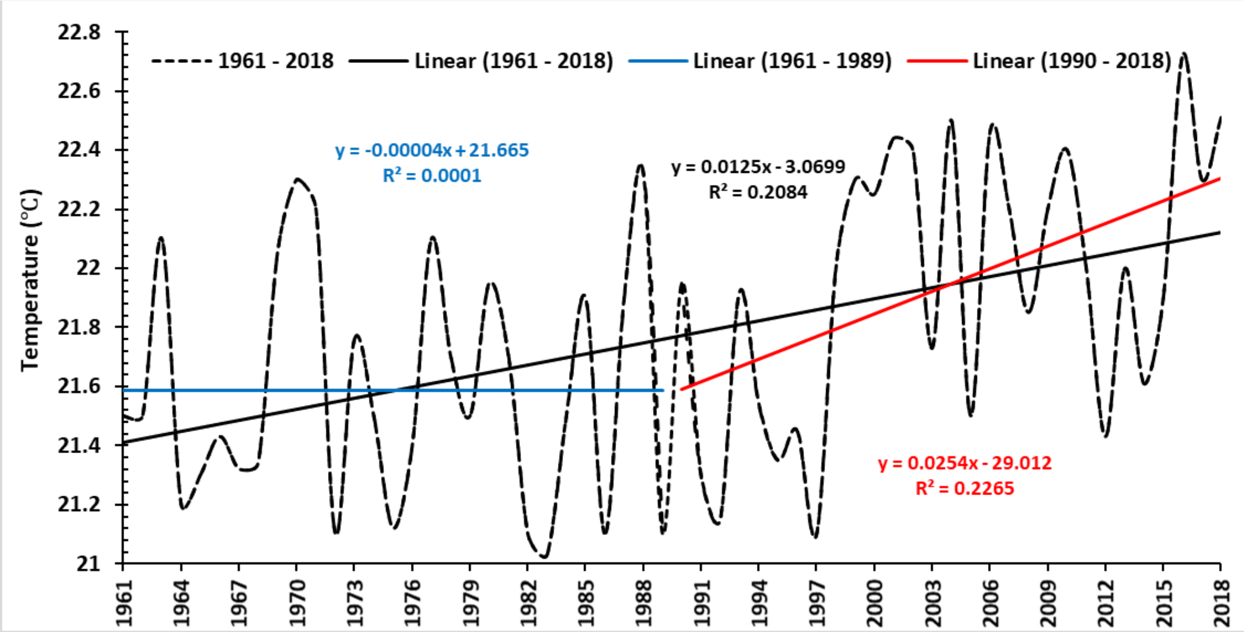

Figure 1: Annual mean temperature trends for 1961–2018, 1961–89, and 1990–2018 in Pakistan

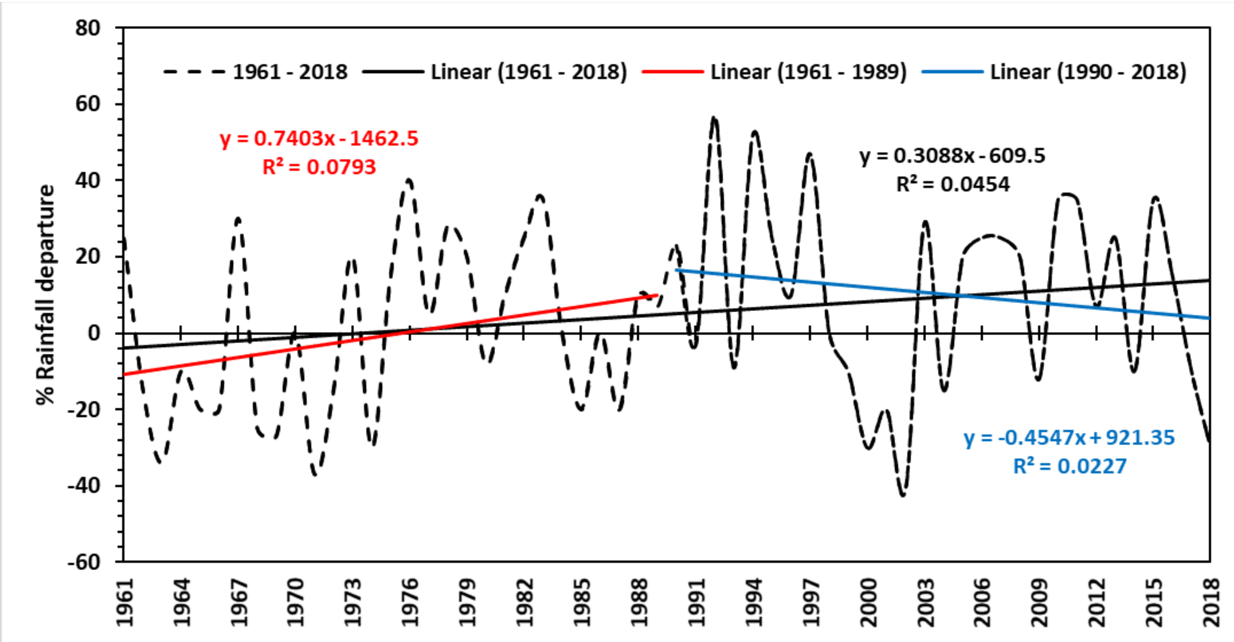

Figure 2: Annual precipitation trends in Pakistan, 1961–2018, 1961–89, and 1990–2018

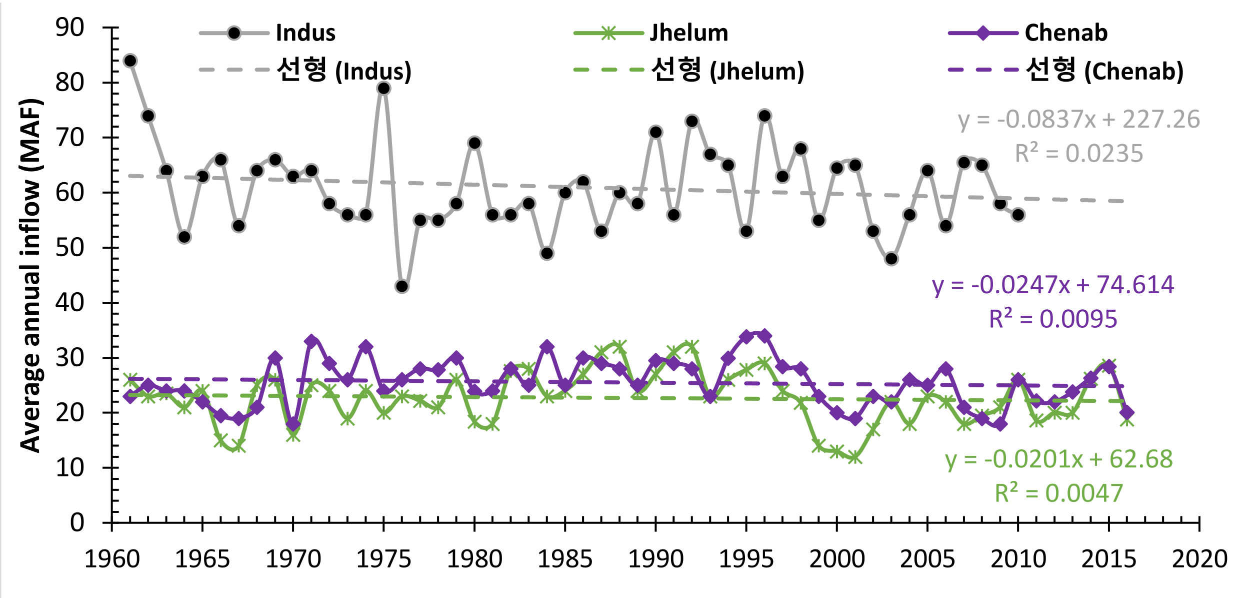

Figure 3: Indus, Jhelum, and Chenab Rivers average annual inflows trend plotted from WAPDA data

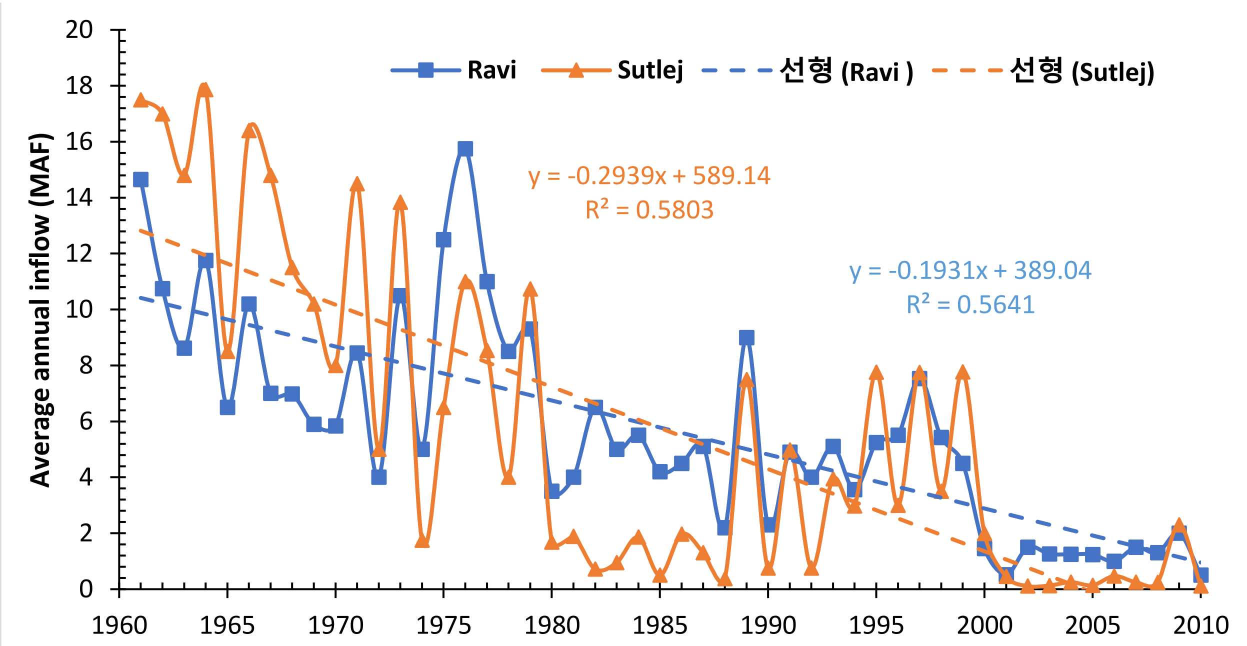

Figure 4: Ravi and Sutlej Rivers average annual inflows trend plotted from WAPDA data

3.2 Future Trends of Temperature and Precipitation under RCPs Scenarios

According to Pakistan Meteorological Department (PMD) data for the four different General Circulation Models using the World Climate Research Program-Coupled Model InterComparison Project Phase-5 (CMIP5), there is a significant increasing trend (3°C to 3.5°C) of mean annual temperature under RCP4.5 scenario for the period 2011 to 2100 while this increase is up to 8.3°C under the RCP8.5. There is a decreasing trend (-0.54 mm/day) in annual precipitation under RCP4.5 while increasing trend (0.9 mm/day) in precipitation under RCP8.5 (Figure 5). The precipitation is highly variable at spatial and temporal scales. Northern areas (i.e. northern part of KPK, GB and Kashmir) are getting higher impact of warming (i.e. 3°C to 4°C) compared to southern parts (2°C to 3°C) of the county under RCP 4.5 scenarios. In southern parts Balochistan showed slightly higher warming rate (not shown here). RCP scenarios (4.5 and 8.5) showed increasing change (2 mm/day to 3 mm/day) in average annual rainfall over the country.

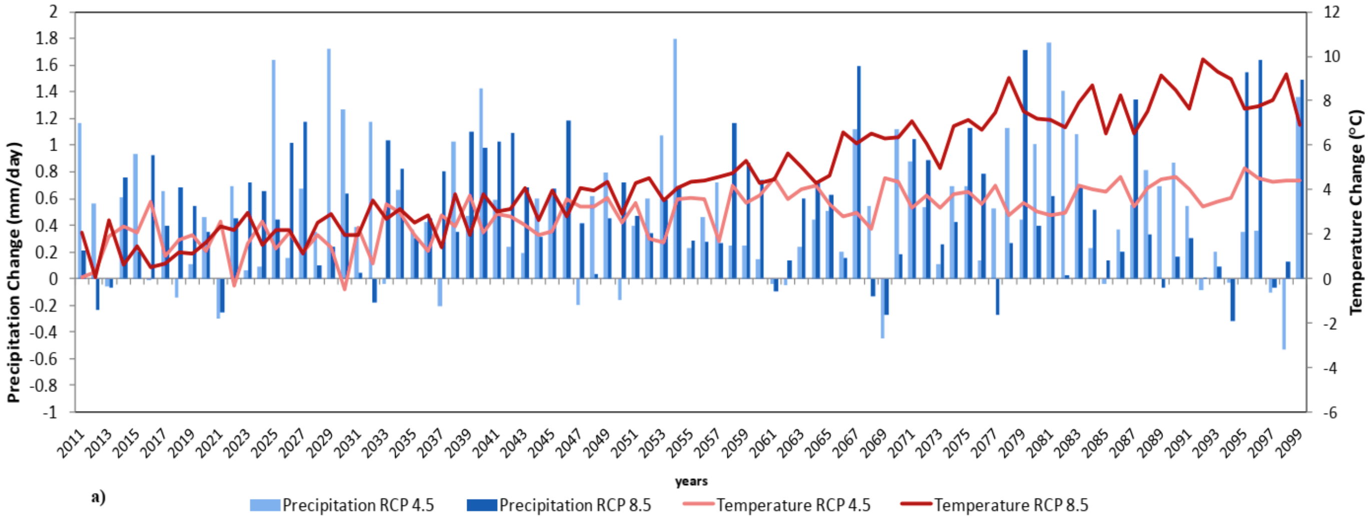

Figure 5: Annual mean Temperature and rainfall projections during 21st century under RCP4.5 and RCP8.5 Emission Scenarios of Pakistan

3.3 Future Runoff and River Flows under RCPs Scenarios

The impact of climate change on river flows was assessed from previous research studies published during 2015 to 2020. Most of these studies were conducted in the sub catchments of Upper Indus Basin (UIB) and future climate impact were assessed using hydrological models (SWAT, SRM, UBC model and HBV) under RCP 4.5 and RCP8.5 scenarios for 2011-2040, 2041-2070 and 2071-2100 periods [19-25]. The brief analysis and findings of these studies is summarized in Figure 6. According to literature studies, it is projected that total water flows of Indus Basin will remain relatively unchanging before 2050, whereas the warming temperature may shift the time to peak and produce higher runoff that could increase flows to earlier in the year [26]. RCP 4.5 and RCP 8.5 results portrayed an overall increase in annual mean flows until 2100. Mean annual discharge was projected to increase 30.43% (RCP 4.5) and 41.87% (RCP 8.5) and 35.79% (RCP 4.5) and 50.15% (RCP 8.5) for (2011-2040) and (2041-2070), respectively. For 2071-2100 period, the increase in flow is 42.03% and 66.47% during RCP4.5 and RCP 8.5, respectively. Likewise, the anticipated changes in precipitation ranges from 1.2% to 2.5% for RCP4.5 and 3.1% to 6% under RCP8.5 (from mid-century to late century).

4. Climate change mitigation and adaptation options for Pakistan

The agricultural water use share is 92% accounts 111.21 MAF is likely to decline due to climate change. Based on current study related to temperature and rainfall projections, the agricultural water demand is increasing for sustainable crop growth while present water availability is reducing. The projected agricultural water demand is 119.85 MAF in 2025 and 135.76 MAF for 2050. The balance gap between present and future water availability has clear implications for sustainable agriculture such as changing cropping patterns, crop rotations and water requirements using smart water saving irrigation techniques such as drip, sprinkler and raised bed farming. There should be marked investment in irrigation efficiency improvement and water conservation technologies which is the need of time, if continuing with business as usual level, the agriculture system will be in difficulty [27].

There are two approaches available to for tackling climate change: (upstream) mitigation or abatement, and (downstream) adaptation. Pakistani farmers are adapting various practices to counter the adverse impacts of climate change. Ali and Erenstein [28], conducted a study related to farmer use of climate change adaptation practices in Pakistan using regression models based on structured questionnaire. In term of adaptation farmers typically adjusted the crop sowing time according to the changing conditions and also adopted heat tolerant crop varieties. Some farmers shifted to new crops due to changing climatic conditions. Adjustment in sowing time, use of drought tolerant varieties and shifting to new crops can be major adaptation practices. It was observed that the farmers who adapted more practices had higher food security levels (8-13%) than those who did not.

Intercropping is also a well known technique to improve water productivity for example the case study results of intercropping of sugarcane in wheat indicated is equivalent to 3 irrigations compared to sowing of sugarcane with traditional method. Another potential option is rainwater harvesting and according to PCRWR study, there is a great rainwater harvesting potential in Pakistan such as from rainfed areas (6.0 MAF), deserts areas (0.34 MAF), coastal areas (0.53 MAF) and hill torrents (18.0 MAF).

There are some recommendations for protecting water resources and improving agricultural yield for climate change adaptation [29-32].

- Adopt the concept of climate smart agriculture
- Assessment of water sector vulnerability to climate change in terms of water availability.
- Re-modeling and up-grading of irrigation infrastructures according to projected extreme events.
- Introduce water harvesting and conservation schemes in rural and urban areas
- Improve irrigation technology and promote compost organic fertilizers to reduce water requirements in agriculture
- Construct small dams/detention ponds to capture flash floods water
- Promote reforestation and forestation to increase water catchments
- Promote judicious/equitable use of water by implementing water metering and budgeting systems and by consumer awareness
- Establish systems to monitor ground and surface water resources
- Bring crop patterns (planting) in line with shifting weather patterns and adopt farming practices suited to the climate
- Introduce drought and heat resistant crop varieties and reduce dependency on traditional agricultural staples
- Introduce high yielding and less water intensive varieties of crops
- Apply integrated nutrient management techniques to reduce on-site emissions by reducing leaching and volatile losses
- Improve agro-forestry systems by developing shelter belts and riparian zones/ buffer strips with woody species
- Up-scale land leveling to save 30% water with enhanced water and agricultural productivity
- Modify the local market to absorb the change in cropping patterns in rainfed areas due to climate change
- Set climate change units/ centers in agricultural organizations to establish agricultural production surveillance system in vulnerable areas to categorize according to extreme climate events and vulnerability
- Awareness raising and capacity building of local level organizations in using sustainable farming techniques, water efficiency and climate
- Enhance capacity of academia and private sector to develop indigenously low cost agricultural water management techniques
- Undertake extensive review of existing research about mitigation options and prepare digital simulation models of climate change impacts on agricultural water to assess the value of investment in this program

5. Conclusions

The analysis of meteorological data (rainfall and temperature) presented in this study indicated the clear picture of changing climate of Pakistan i.e. it is getting warmer with some regions facing a faster rise in annual mean temperature. The rate of change is 0.74°C for the period 1961–2018 with highest increase in southern part (+0.32°C to +0.50°C per decade) than northern part (+0.02°C to + 0.10°C per decade). Since 1961, average annual rainfall has increased 19% during 1961–89 but after 1990, rainfall patterns generally showed declining trend. The regional level rainfall tendency is somewhat mixed. Total annual rainfall increase rate is the most in Peshawar (+39 mm/decade), followed by Islamabad (+37 mm/decade) and Lahore (+26 mm/decade), while the decline rate is more in Muzaffarabad (–19 mm/decade) and Karachi (–17 mm/decade). The plotting of river inflows indicating declining rate of discharge on Indus, Jhelum, Chenab, Ravi, and Sutlej over the period 1961-2016. According to CMIP5 model, there is a significant increasing trend in average annual temperature (3°C to 3.5°C) under RCP4.5 for 2011-2100 period while under the RCP8.5 scenario, the increase in annual mean temperature is 8.3°C. The changes in annual mean precipitation under both RCPs scenarios showed an increase in rainfall of 2 mm/day to 3 mm/day over entire country. Results depicted an overall increase in average annual flows under RCP 4.5 and RCP 8.5 up until 2100. Mean annual discharge was projected to increase 30.43% (RCP 4.5) and 41.87% (RCP 8.5) and 35.79% (RCP 4.5) and 50.15% (RCP 8.5) for (2011-2040) and (2041-2070), respectively. A 1°C increase in average temperature may increase agricultural water demands by about 5% by 2050. The research studies emphasis that the scope of policy related to climate change adaptation should focus on the strategies at community and farm level for significant development outcomes. Whereas this study analysis has acknowledged some of the broad changes ongoing in Pakistan's climate with a point to critical need to take into account the regional and local trends that may greatly diverge from country level trends. There is a needs to develop programs and policies that stimulate economy and society resilience to climate change.

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