PAKISTAN COUNCIL OF RESEARCH IN WATER RESOURCES

Technical Studies on “Adaptation Strategies to Cope with Climate Change Impacts on Pakistan’s Water Resources”

Technical Progress Report

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Executive Summary

1. Introduction

1.1. Objectives

i. Coping with the reducing water availability in the Indus Basin of Pakistan through changes in cropping pattern
ii. Reallocation of water allowance in the irrigated areas of Indus basin under changing cropping pattern and climate

1.2. Research Questions

i. What are the impacts of climate change on crop water requirements in canal irrigated zones?
ii. How existing canal water allocations are being utilized?

2. Review of Literature

IPCC (2001) concluded that to adapt with the changes caused by water scarcity, one way is to change cropping patterns and make adjustment for available water resources. Another way might be to change farming practices by adjusting cultivation period, applying appropriate crop rotations and/or developing and adopting new varieties that are resilient to future climate variability. The recent development in climate change forecast using global circulation models and regional climate models (GCM and RCM) made it possible to provide more detailed information on future changes in regional precipitation, temperature and other climatic variables in face of global warming.

Yang, Y. H. *et al*.,(2006) stated that no irrigation can supply water for crop growth without some waste or losses because the cost to prevent all losses is prohibitive. Irrigation water waste mainly takes place in the following ways: canal seepage, leakage from defective pipe connections, evaporation in canal or leakage in an irrigation distribution system, soil evaporation, less efficient use of crop transpiration, and percolation below the root zone. Water loss in agricultural field mainly occurs in soil evaporation, luxury transpiration during less water- requiring growth stages, and water leakage. Water leaking is not considered as water loss, since most water lost from irrigation can recharge groundwater.

Cao, H. X. *et al*., (2009) concluded that intensive research was carried out at molecular and single plant level from physiological and genetic aspects to see difference in traits of water use efficiency of different wheat cultivars. By testing cultivars of winter wheat and corn generated in different decades from the 1960s to the 2000s under different irrigation conditions, experiments show that, while annual ET increased slightly along with improvement in crop varieties, crops can produce much higher yields. Meanwhile water use efficiency of 26 wheat cultivars was clarified. Results showed that WUE increased substantially from 1.0–1.2kg m^3 for cultivars from the early 1970s to 1.4–1.5kg m^3 for recently released cultivars. Using molecular linkage genetic maps and quantitative trait loci (QTLs) mapping technology, the locations of a series of QTLs controlling water use efficiency of wheat was identified. Up to now, those QTLs relevant to high water use efficiency have been used in breeding of new wheat cultivars. Several high water efficient wheat cultivars and drought-resistant wheat cultivars have been successful bred.

Rawabdeh et al (2010) stated that achieving balance between water demand and supply is crucial for sustainable agriculture in semi-arid countries. Many agronomic options and socio-economic measures can be applied to reduce water demand in agriculture sector without compromising its performance. This work investigated some specific management options for the improvement of the performances of the irrigated agricultural systems in Northern and Southern parts of the Jordan Valley under normal and dry year's conditions. An economic model was developed, calibrated and applied to evaluate farmer's income, water supply/demand balance and economic water productivity under different policy and water management scenarios. The overall results indicated that water productivity was lower in Southern than in Northern part of the Valley and that the improvement of the irrigated agriculture performance in the region can be achieved through the modification of cropping pattern (cultivating date palms and tomatoes instead of banana in the South) and the introduction of regulated deficit irrigation (for citrus in the North and for barley in the South).

Hao, Xiaoling and Vijay (2018) stated that in arid and semi-arid areas, the profitability of irrigated agriculture mainly depends on the availability of water resources and optimal cropping patterns of irrigation districts. In this study, an integrated agricultural cropping pattern optimization model was developed with considering the uncertainty of water availability and water saving potential in the future, aiming to maximize agricultural net benefit per unit of irrigation water. The available water which was based on the uncertainty of runoff was divided into five scenarios. The irrigation water-saving potential in the future was quantified by assuming an increase in the rate irrigation water-saving of 10% and 20%. The model was applied to the middle reaches of Heihe River basin, in Gansu Province, China. Results showed that if the irrigation water-saving rate was assumed to increase by 10%, then the net water-saving quantity would increase by 21.5-22.5 million m3 and the gross water-saving quantity would increase by 275.7-303.0 million m3. Similarly, if the irrigation water-saving rate increased by 20%, then the net water-saving quantity would increase by 43.0-45.1 million m3 and the gross water-saving quantity would increase by 331.7-383.2 million m3. If the agricultural cropping pattern was optimized, the optimal water and cultivated area allocation for maize would be greater than those for other crops. Under the premise that similar volume of irrigation water quantity was available in different scenarios, results showed differences in system benefit and net benefit per unit of irrigation water, for the distribution of available irrigation water was diverse in different irrigation districts.

Niu et al (2016) in their study developed an interactive two-stage fuzzy stochastic programming (ITFSP) method for supporting crop planning and water resource allocation under uncertainty. ITFSP can effectively address uncertainties expressed as probability distributions and fuzzy-boundary intervals. It can also be utilized for in-depth analyzing different policy scenarios that are integrated with various economic implications since penalties are executed with recourse actions. ITFSP enables decision makers to identify a tradeoff between higher objective values and feasibility of constraints. The ITFSP method is applied to a real case of Hetao irrigation district, one of the largest irrigation districts for food production in China. Different scenarios for crop planning targets which reflect the attitudes of local authority to the available water resources are examined. Results discover that different scenarios lead to changed irrigation patterns, water shortages, penalties, as well as system benefits. Results also reveal that decision makers would be more positive to water allocation to crops of wheat and oil than maize; oil crop always possesses the priority of water allocation and would be partly satisfied even under the low flow. Solutions are useful for determining optimized cropland use and water allocation patterns in such an agricultural system in the arid region, which could hedge appropriately against future available water levels in more profitable and sustainable ways.

Asres (2016) evaluated irrigation water management of Koga large scale irrigation scheme located in the Blue Nile basin of Ethiopia. Disturbed and undisturbed Soil samples were collected from selected irrigation blocks within the irrigation system. Soil moisture, texture, field capacity, permanent wilting point and bulk density data were obtained from laboratory analysis of the samples. Results of demand versus supply analysis of the scheme showed that there was excess supply at the beginning of reservoir release and upto 7.13 MCM of excess flow water was estimated in year 2015. Results also showed that crop water requirement value varied for each block and for different crops in the same block, assuming the climatic conditions of the site constant. The crop water requirement variations were caused by differences in soil water holding capacity of each block. Based on crop water demand analysis result with appropriate crop water provision of 50% efficiency, the maximum irrigable area which could be accommodated by the reservoir storage was 5635.8ha as compared to the design command of 7000 ha. The paper also investigated the status of reservoir water availability as compared to the demand and annual release. The findings of this research will have greater implications in creating awareness to the water user associations, farmers and gate operators of Koga irrigation scheme on how to measure the amount of water they are using during the whole crop growth so that optimum irrigation water shall be delivered to a crop for maintaining water management.

Zhang and Ping (2016) studied the quantification of agriculture water savings under water integrated optimal management and analyzed the economic increment of agriculture water savings. Optimal solutions of planting structure and corresponding water resources allocation scheme indicate that water demand and supply are more reasonable after assembling crop water demand to flood seasons. Water saving could be realized in the premise of maximum economic benefit after integrated optimization management. Next, active water saving and passive water saving scenario have been set to analyze the correlativity between water saving quantity and maximum economic benefit through adopting integrated agriculture water management optimization model. The results show that water saving potential and agriculture benefit demonstrate a negative correlation. The interval linear function of water saving-effect comprised of two scenarios is used to represent this negative correlation. Consequently, approximately 10% of surface water could be saved in Fenhe Region under current planting scale. Finally, an optimization model for agricultural water transfer are formulated to the further study on agriculture water savings reallocation by maximizing incremental benefit of water resources. The interval linear function of agriculture water saving-effect and water production function of the second industry and tertiary industry have been introduced to obtain agriculture water transfer trend under various circumstances. For Fenhe Region, agriculture water transferring to the second industry (533×104m3) and tertiary industry (235×104m3) could bring an incremental benefit about 8.66–8.94 billion RMB, and 90.2–93.1 RMB for 1m3 of irrigation water, which exhibits a huge potential of economic benefit of agriculture water savings. The results indicate that optimization model for agricultural water transfer is an efficient way to analyze economic value of irrigation water and provide agriculture water transfer strategies.

Kyle et al (2018) taking the case of cereal production in India, used a process-based crop water model and government data on food production and nutrient content to assess the implications of various crop shifting scenarios on consumptive water demand and nutrient production. They found that historical growth in wheat production during the rabi (non-monsoon) season has been the main driver of the country's increased consumptive irrigation water demand and that rice is the least water-efficient cereal for the production of key nutrients, especially for iron, zinc, and fiber. By replacing rice areas in each district with the alternative cereal (maize, finger millet, pearl millet, or sorghum) with the lowest irrigation (blue) water footprint (WFP), they show that it is possible to reduce irrigation water demand by 33% and improve the production of protein (+1%), iron (+27%), and zinc (+13%) with only a modest reduction in calories. Replacing rice areas with the lowest total (rainfall + irrigation) WFP alternative cereal or the cereal with the highest nutritional yield (metric tons of protein per hectare or kilograms of iron per hectare) yielded similar benefits. By adopting a similar multidimensional framework, India and other nations can identify food security solutions that can achieve multiple sustainability goals simultaneously.

Boustani and Mohammadi (2010) stated that determination of optimal cropping pattern is essential for arid and semiarid regions with deficit water resources. Fars province is located in the southern part of I.R. of Iran with mean annual precipitation from 50 to 1000 mm and in most parts of this province water resources for agriculture are deficit. Jahrom region with semi-arid climate is located in Fars province with mean annual rainfall of 373 mm. In this study optimal cropping pattern was determined for this region based on water deficit condition. For this purpose, multi-objective programming approach was applied in order to reduce water consumption use. The results of this study showed that, there was trade offs among reduce water use, reduce risk and getting a specific gross margin. Also, the results showed that, wheat tended to increase, causing from price supporting program, indicating the government intervention trace in farmers cropping pattern. Therefore, sustainable use of resources is affected by output condition in market. Furthermore, the area of maize and vegetables were increased in all of selected solutions as compared to their current area. Also, the findings of this study performed intended polices in crop markets may alter the water usage.

Kumar and Khepar (1980) demonstrated the usefulness of alternative levels of water use over the fixed yield approach when there was a constraint on water in India and modified a fixed yield model to incorporate the stepwise water production functions using a separable programming technique, which applied to determine optimal cropping patterns.

Chartzoulakis stated that under scarcity conditions considerable effort has been devoted over time to introduce policies aiming to increase water efficiency based on the assertion that more can be achieved with less water through better management. Better management usually refers to improvement of allocative and/or irrigation water efficiency. The former is closely related to adequate pricing, while the latter depends on the type of irrigation technology, environmental conditions and the scheduling of water application. Agricultural practices, such as soil management, irrigation and fertilizer application and disease and pest control are related with the sustainable water management in agriculture and protection of the environment. They not only provide the soil moisture and nutrients necessary for plant growth, but they also contribute to control erosion, soil and groundwater degradation. Socio-economic pressures and climate change impose restrictions to water allocated to agriculture.

Abidi (2013) stated that on the inflow side canal water in the canal command area of Mirwah is mismanaged by irrigation officials and head-end and influential farmers. Farmers in Sindh generally and Khairpur particularly irrigate their land without scientific techniques and there is no economic pricing of water that might encourage conservation. This, together with the lack of any adequate substitute in the form of administrative control of water and cropping patterns, has been responsible for the excessive water-coefficient of output, and the unequal distribution of water, which have been at the heart of the problem of mismanagement water on the inflow side. The need for restructuring the irrigation system in Sindh is urgent not only because of both allocation and distribution, because, over the years, the province has suffered from unequal distribution of water between big and small farmers, and between head-end and tail-end farmers.

Asad claimed that the Indus River basin supplies water to the largest contiguous irrigation system in the world, providing water for 90% of the food production in Pakistan, which contributes 25% of the country’s gross domestic product. But Pakistan could face severe food shortages intimately linked to water scarcity. It is projected that, by 2025, the shortfall of water requirements will be 32%, which will result in a food shortage of 70 million tons. Recent estimates suggest that climate change and siltation of main reservoirs will reduce the surface water storage capacity by 30% by 2025. The per capita water storage capacity in Pakistan is only 150 m3, compared with more than 5000 m3 in the United States and Australia and 2200 m3 in China. This reduction in surface supplies and consequent decreases in groundwater abstraction will have a serious effect on irrigated agriculture. Supply-side solutions aimed at providing more water will not be available as in the past. Current low productivity in comparison with what has been achieved in other countries under virtually similar conditions points to the enormous potential that exists. To harness this potential, Pakistan needs to invest soon in increasing storage capacity, improving water-use efficiency, and managing surface-water and groundwater resources in a sustainable way to avoid problems of soil salinization and waterlogging. Building capacity between individuals and organizations, and strengthening institutions are key elements for sustaining irrigated agriculture in the Indus Basin.

Mahsud and Shahid () stated that the problems associated with irrigation system are the main cause for low productivity in agriculture because of water scarcity, in-efficiency, inequity and sustainability issues. There have been advances in improving cropping patterns by adding high value horticultural crops. The area under these crops has increased significantly during the last 50 years. The paper highlighted the achievements made during the last 50 years while addressing these issues. The major unresolved issues were identified which still require technological development, managerial and institutional reforms and mechanisms to attain sustainability of irrigated agriculture. There is a need to initiate comprehensive planning and integrated development and management of irrigated agriculture in the country. The information of predicted crop water requirements, rainfall probability and forecasting of extreme events like droughts and floods should be printed daily in the newspapers or forecasted on radio and television to meet seasonal and weekly requirements of the farmers.

Ghumman A.R. (2011**)** depicted in his research, performance of an irrigation system in Punjab Pakistan. The data regarding cost of cost and total production cost including the cost of irrigation, seed, fertilizer, pesticide, labour, etc. were collected by field survey, farmer's interviews, and survey of markets. The analysis shows that irrigated agriculture in Pakistan is potentially not cost-effective. There are only 77.7% cost is recovered in the form of abiana against the total distribution cost of the system due to which the system is not self-sustainable. Irrigation in Punjab is profitable and its profitability may further be increased by decreasing on farm irrigation cost. He concluded that it was the recovery cost ratio and relative water costs of the system are 0.777 and 0.311 respectively. Low value of delivery performance ratio indicates inequitable distribution.

Aherrao D.Y. (1987) studied an impact of irrigation on Agricultural and socio-economic change- A case study of Ahmednagar District (MH.). In his research he pays attention on the cropping pattern, multi-cropping patterns, techniques used in farm of 14 Tahsils of the Ahmednagar. He also focused on the changes in cropping patterns, agricultural production, crop frequency, economic and social changes etc. this shows irrigation and its good effects on agricultural occupation.

Alekzander K.C. (1982) studied 'Agricultural Development and Social Transformation'. In it, he focused on A comparative study of irrigated and nonirrigated area of Ganganagar District in Rajasthan. He says that in the irrigated area we get development in agriculture. The demands of peasants, fertilizers, insecticides, hybrid seeds are increased. The results are per acre production and income and saving are raised. Markets and business flourished due to irrigation facility.

Dangat and Yadav (1997) deliberately studied the irrigation potential created and its utilization during the last 35 years in Maharashtra state. Then results of the study revealed that the proportion of net irrigated area to net sown area increased from 6 percent during the year 1960-61 to 15 percent during the year 1994-95. The increased irrigation facilities had favored the increased share of the crops like sugarcane and wheat. Though, the proportion of irrigated area under food grain crops increased in relation with total cropped area during the period under study.

Gadgil D.R. (1948) has studied the impact of irrigation on Economic development. He focused on the direct and the indirect benefits of Godavari and Pravara canals and also comparatively studied the irrigated and non-irrigated areas. He has noticed that their cropping patterns are changed, production is increased and total production is too increased. Then the farmers provided much attention on transportation and food processing. The result is total production increased and business flowered. There is increase in railway and road transportation, market etc. due to this, peasants are needed, they got jobs, salary increased and many got chances. The status labors are increased. She made an observation that due to project building and administration made good effect on economic lives. It also effect on neighboring society.

Hussain Tariq (2003) in article discloses an experiment to the effect of different irrigation levels on the yield of cotton under two showing methods was conducted at the Agronomic research area, university of agriculture, Faisalabad. The treatments were consisting of flat and ridge showing methods. It is concluded that irrigation at all stages and ridge showing appeared to be the most suitable for obtaining higher seed cotton yield under Faisalabad conditions.

Karatekin and Bibercigdem (2008) has studied Irrigation Frequencies and Corn Yield Relation in Northern Turkey, according to research results, the maximum corn grain yield was obtained when the corn plants were irrigated at 15% of available soil water capacity to field capacity. The above reviews have clearly indicated that there have been changes in crop mix over a period of time because of change in availability of irrigation water at different locations. Different cropping patterns have been observed in different regions. On availability of irrigation the cropping pattern had been diversified towards commercial crops like sugarcane and cotton in western Maharashtra. In Marathwada, jowar contributed highest share in irrigated area. While in Konkan, it was under rice. Contribution of irrigation resulted in diversification.

3. Research Methodology

3.1. Thematic Area

This research is focused upon exploring the grounds of climate change impact on crop water requirements and limitation of existing canal water allocations in this regard. To draw some purposeful conclusion, multidisciplinary data collection is required for this study. Therefore, the qualitative research methodology encompassing following thematic areas was adopted;

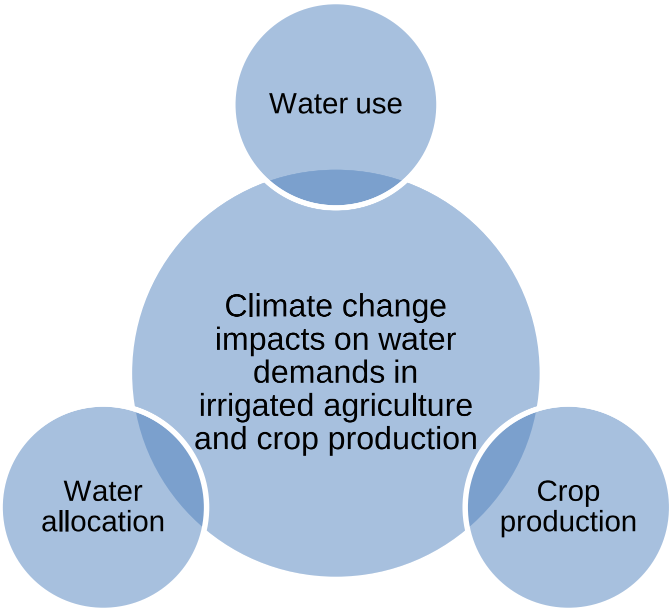


Figure 1: Thematic areas of Research

3.2. Collection and Assessment of Data

Following datasets have been acquired for this study:

- Agro-met data of Irrigated areas: Pakistan Meteorological Department (PMD)
- Canal Water withdrawal data of irrigated areas: provincial Irrigation Department
- Crop consumption data: Lysimeteric stations of PCRWR
- Cropped area: Agricultural Statistics

4. Results and Discussion

4.1. Crop cultivation pattern in irrigated areas

4.1.1. Balochsitan Province- (Rice-Wheat Zone)

Balochistan province constitutes the largest landmass of Pakistan and least cultivated. Out of 3.77 million acres of net sown area, only 0.94 MA falls under the command of canals fed by Indus Basin Irrigation system (I&P Department, 2016). Rest of the irrigated land is sourced from private canals, karez, groundwater and hill torrents and dug wells. The canal network from these canals irrigates agricultural land lying in Naseerabad, Jafarabad and Kachhi (previously known as Bolan) districts. Now, diversion from Kachhi Canal (6000 cusecs) is also available to irrigate 72,000 acres of rich agriculture land in Naseerabad, Dera Bugti and Kachhi districts. The actual flow and agricultural impact data for this canal is not yet available. However, a brief overview of canals in Balochistan, command area and crops is shown in Table 1.

Table 1: Cropping pattern in commands of different canals in IBIS

<table>
<tr><th>Canal Name</th><th>CCA (MA)</th><th>Type</th><th>Command Districts</th><th>Kharif Crops</th><th>Rabi Crops</th></tr>
<tr><td>Patfeeder</td><td>0.508</td><td>perennial</td><td rowspan="5">Naseerabad, Jafarabad and Kachhi (Bolan) districts</td><td rowspan="5">Rice, Cotton, Vegetable, fodder, Sugarcane, Jowar (Sorghum), Sesame Onion, pulses, chillies</td><td rowspan="5">Rapeseed Mustard including canola, vegetable, fodder, Wheat, pulses, Gram</td></tr>
<tr><td>Kirthar</td><td>0.266</td><td>perennial</td></tr>
<tr><td>Uch</td><td>0.068</td><td>Flood</td></tr>
<tr><td>Mithuri</td><td>0.028</td><td>Flood</td></tr>
<tr><td>Kachhi</td><td>0.072</td><td>Flood & Perennial</td></tr>
<tr><td>Total</td><td>0.942</td><td></td><td></td><td></td><td></td></tr>
</table>

Source: Agricultural Statistics of Balochistan, Government of Balochistan (2002-16)

Like rest of Pakistan, there are mainly two cropping seasons in canal irrigated plains of Balochistan; Kharif and Rabi season. Wheat crop (0.336 MA) is the major crop of Rabi season followed by Rapseed Mustard (0.048 MA) crop. Fodder (0.018 MA) and vegetable are also priority crops due to their cash value and demand focus. During Kharif season, rice crop (0.416 MA) is the major crop in all three canal irrigated districts which is preceded by Sorghum (0.20 MA) and Onion crops (0.041 MA). Sugarcane (0.08 thousand acres) and cotton (0.018 MA) crops are lesser popular crops compared to Fodder (0.013 MA) and pulses crops. Due to higher availability of water during Kharif season, land use intensity is higher compared to Rabi season (Balochistan Agricultural statistics, 2002-2017).

4.1.2. Punjab Province

The total irrigated area of Punjab province is 19.4 million acres that comes under the command of 25 main canals sourced from 2 reservoirs, 7 barrages/ headwork’s and 25 main canals. This vast network of canals is spread across a diversity of cropping zones ranging from cotton-wheat to cotton-wheat-rice and sugarcane zone. According to the statistics, all canals of Punjab supplies 33.16 MAF of irrigation water in Kharif season and 17.16 MAF in Rabi season to the command of this irrigation system (PDS, 2015-16). Salient feature of 25 canals and their water allowances are detailed in Table 2.

Table 2: Salient features of Canal Irrigation system in Punjab Province

Irrigation Zone	Canal Name	Cultivable command Area (MA)	Water Allowance (cusec/1000 acres)	Water Allowance (mm/day)	Cropping Pattern
Sargodha	Thal Canal	0.535	3.180	1.9226	Wheat-Sugarcane zone
	Upper Jhelum	1.453	2.860	1.7292	
	Lower Jhelum	2.123	3.040	1.8380	
Faisalabad	LCC (gugera+Jhang)	3.770	3.170	1.9166	Wheat – Rice-Sugarcane zone
Lahore	Main link lower UCC	1.210	7.270	4.3954	Rice-Wheat zone, Maize, increasingly sugarcane
	Central bari doab	1.219	9.010	5.4474	
	Upper Dipalpur	0.345	4.950	2.9928	
	Lower Dipalpur	0.450	6.520	3.9420	
DG Khan	DG Khan	0.440	8.610	5.2056	Rice-Wheat-Cotton zone
	CRBC	0.770	9.010	5.4400	
	Muzzafargarh	0.323	8.140	4.9214	
Multan	Pakpattan Lower	0.309	3.120	1.8864	Cotton-Wheat zone
	Pakpattan Upper	0.974	3.120	1.8864	
	Rangpur (non-perenial)	0.230	4.800	2.9021	
	Mailsi (Non-perennial)	0.707	5.500	3.3253	
	Haveli	1.024	3.000	1.8138	
Bahawalpur	Fordwah	0.531	6.410	3.8755	Cotton-Wheat zone, increasingly sugarcane
	DG Khan	1.086	8.610	5.2056	
	SadqiA	1.151	4.260	2.5756	
	Bahawal	0.802	6.850	4.1415	
	Abbasia	0.160	6.900	4.1717	
	Panjnud	1.477	6.090	3.6820	
LBDC	Lower bari doab canal	1.880	3.330	2.0133	Cotton-Wheat zone

Punjab province is dominantly a cotton-wheat and rice-wheat cropping zone. Sugarcane is becoming a popular crop among many cropping zones due to its immediate cash value. Sugarcane is a perennial high delta crop and its cultivation jeopardizes water availability for both Rabi and Kharif crops. Irrigation zones in Punjab are distributed according to canal water distribution and withdrawal system. Sargodha zone includes Layyah, Khushab, Bhakkar and Sargodha districts.

Faisalabad Irrigation zone includes Faisalabad, Toba Tek Singh, Jhang and Chiniot districts. Lahore irrigation zone includes a large number of districts including; Sialkot, Gujranwala, Gujrat, Sheikhupura, Hafizabad, Mandi Bahauddin, Lahore, Kasur, Nankana Sahib. Multan Irrigation zone includes canal that irrigate; Multan, Muzzafargarh, Lodhran, Vehari, Sahiwal, Pakpattan and Khanewal districts. DG Khan Zone is also irrigated by hill torrents including districts D.G.Khan, parts of Muzzafargarh, Taunsa and Ranjan Pur Districts. Lower Bari Doab Canal provide irrigation water to Multan and Bahawalpur irrigation zone. Bahawalpur Canal Zone include; Bahawalpur, Bahawalnagar and Rahim yar Khan Districts.

4.1.3. Sindh Province

Canal commands of Sindh province are divided in two ways; command of barrages and sides of Indus River. Sukkur Barrage forms the largest diversion of the province with a system of 7 left and right bank canals including; Nara Canal, Rohri Canal, Khairpur Feeder (East) at the left bank whereas Dadu, Rice Canal, Khairpur Feeder (West) and North West canal at the right bank. The diversion of Guddu Barrage consists of a network of 3 canals, Ghotki canal irrigates left bank of Indus Basin in Upper Sindh, Begari Feeder and Desert canals have the command area on right bank. Desert canal enters into Balochistan province to irrigate Naseerabad district. All four canals of Kotri Barrage (K.B. Feeder, Fuleli Canal, Pinyari Canal and Akram Wah) irrigate lower Sindh province. Guddu Barrage command area on left and right bank side of Indus River is dominantly a cotton-wheat zone. Right bank of the Sukkur barrage is Rice-Wheat zone and left bank is cotton wheat zone with higher number of command districts practicing mixed cropping such as; cotton, wheat, sugarcane, chillies, banana and vegetables. Command areas of Kotri barrage are Rice, Sugar and wheat zone all high delta crops. Further details of salient features of Canals and their command area are given in Table 3.

Table 3: Salient feature of irrigation system and its command areas in Sindh

Sr#	Canal/Barrage Name	Command Area (MA)	Canal Water Availability (mm) over CCA		Major Crops
			Kharif	Rabi	
A	**Guddu Barrage**				
1	Ghotki Feeder	1.09	581.5	297	Rice-Wheat-Cotton zone on both sides of Indus
2	Begari Feeder	1.15	704.04	61.65	
3	Desert Pat Feeder	0.94	321	55.77	
B	**Sukkur Barrage**				
4	Nara Canal	1.08	1175.77	794.65	Left bank of Indus River: Cotton Wheat Zone and Banana crop Right Bank: Rice- Wheat Zone
5	Rohri Canal	0.56	2498	1636.7	
6	Khairpur Feeder (West)	0.58	285.42	179.65	
7	Khairpur Feeder (East)	2.58	80.57	51.23	
8	Dadu Canal	0.51	653.71	510	
9	Rice Canal	2.85	2315	190	
10	North West Canal	0.30	169.06	80.84	
C	**Kotri Barrage**				
11	K.B. Feeder	0.67	656	411	Lower Indus, Rice, Wheat and Sugar cane Zone and Banana crop
12	Fuleli Canal	1.00	897	228.75	
13	Pinyari Canal	1.09	1198.42	301.81	
14	Akram Wah Canal	0.46	366.32	272.04	

Source: (Sindh Development Statistics 1998-2017)

Sukkur Barrage forms the largest diversion of the province with a system of 7 left and right bank canals including; Nara Canal, Rohri Canal, Khairpur Feeder (East) at the left bank whereas Dadu, Rice Canal, Khairpur Feeder (West) and North West canal at the right bank. The diversion of Guddu Barrage consists of a network of 3 canals, Ghotki canal irrigates left bank of Indus Basin in Upper Sindh, Begari Feeder and Desert canals have the command area on right bank. Desert canal enters into Balochistan province to irrigate Naseerabad district. All four canals of Kotri Barrage (K.B. Feeder, Fuleli Canal, Pinyari Canal and Akram Wah) irrigate lower Sindh province. Command areas of all these canals have distinct cropping patterns therefore, their water allowances are designed accordingly. A linear comparison of water depth over CCA of all of these canals shows lesser water availability during Rabi season. However according to development estimates, these canals are not irrigating their entire command areas; command areas coverage of Sukkur Barrage is 80%, Guddu Barrage is 75% and Kotri Barrage is 25% (Sindh Development Statistics, 2017). A completed diagram of these canals and their commands are given Annexure-I. The command area coverage is also reducing due to choice of high delta crops in most parts of Sindh and over irrigation practices is also leading to excessive exploitation of groundwater.

Upper Sindh Cropping Zones- Rice-Wheat-Cotton zone

District Names: Larkana, Shikarpur, Sukkur, Khairpur and Jacobabad are suitable for growing rice as main crop, matter, rape and mustard and safflower/sunflower as dobari crops.

Agro-met stations: Larakna-Shikarpur-Jacoabad, Rohri-Sukkur-Khairpur.

Main crops: Cotton, Rice, Wheat, Sunflower and Mustard. Sukkur & Khairpur districts are best suited for dry crops viz: cotton, wheat, rape and mustard and sunflower.

Middle Sindh- Cotton Zone

Districts: Nawabshaha, Dadu, Noushehro feroz
Agromet stations: Dadu, Sakrand, Padidan

Lower Sindh- Cotton Wheat Rice zone

Districts: Tandojam, Hyderabad, Hala, Sanghar, Mirpurkhas

Cotton-Wheat Zone

Upper part of Hyderabad (Hala, Hyderabad & Tando Allayar Sub Division), Sanghar & Mirpurkhas district are suitable for cotton, wheat, sunflower, soybean, rape and mustard and groundnut (in Sanghar only).

Sugarcane-Rice Zone

Tando Mohammad Khan sub division of Hyderabad district, Badin and Thatta districts are suitable for sugarcane and rice crops. In addition to the said crops; sunflower, and rape and mustard are also grown as dobari. Mash and masoor pulses are also suitably grown in Thatta & Badin districts.

Agro-met: Tandojam

4.2. Water Allocation and Consumption Comparison

4.2.1. Canal Water Allocation

Balochistan Irrigated zone (Rice-Wheat Zone)

According to Indus Water Accord, the canal water share of Balochistan Province is 8.490 MAF (perennial and flood combined) out which 3.052 MAF is being supplied to the province through remodeling of Kirthar and Patfeeder canal whereas the provincial share is going to improve by the construction of Kachhi canal (I&P Department). Water allowance for 4 canals is shown in Table 2, in comparison to the actual discharge in these canals as recorded by Irrigation and Power department, Government of Balochistan during 2009-2017. Water allowance is amount of discharge that is measured at the head of distributary and allowed to flow into watercourse to supply a designed volume of water to a unit area. It is generally measured as cusec per unit of command area and for ease of estimation it has been further calculated into mm/day. For instance, a water allowance of 8.7 mm/day is the amount of water allocated of a unit of land. The estimation of actual water supply is driven from 10 year average flows into these 4 canals. This general estimation of actual canal water availability points rightly points towards lower land use intensity in commands of these canals that is 58% (Balochistan Agricultural Statistics, 2016).

Table 4: Canal water allocation vs actual water supplied

Canal Name	Water Allowance (cusec/1000 acres)	Water Allowance (mm/day)	Actual Water Delivered	
			Kharif (mm/day)	Rabi (mm/day)
Patfeeder	14.4	8.7	4.62	2.69
Kirthar	12.9	7.8	2.53	0.88
Uch	10.2	6.16	2.161	0
Mithuri	21.1	12.7	4.199	0
Kachhi	8.41	5.08	Data not available yet	

(Source: Irrigation and Power Department, Government of Balochistan 2016)

Less canal water availability may be ascribed as a reason for reducing cropping intensity in the command districts, particularly Naseerabad. This district falls under the complex command network of Kirthar, Patfeeder, Uch, Mithuri canals and a part will also be irrigated by Kachhi canal. Despite a higher availability of canal water, total cropped area has been reduced by 50% during 2002-17. On the contrary, canal water discharge trends during 2009 to 2017 depict rising trends in flows of Pat feeder and Kirthar canals (Figure 2).

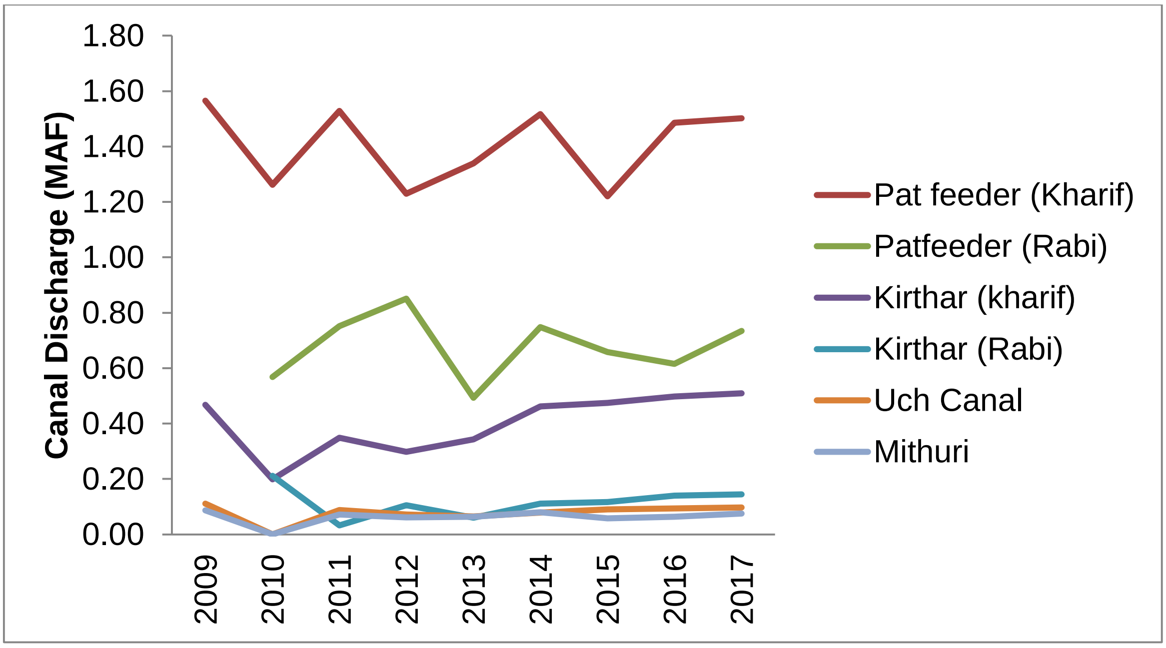


Figure 2: Variations in canal water withdrawal in Balochistan 2009-17
(Data Source: I&P Department, Government of Balochistan)

The supply of canal water does not point towards changes in reducing cropping intensity due to reducing canal discharge. The actual reasons might be; increase in crop water requirements due variations in agro-met situation or economic choices of farmers based upon their needs and yield of crops.

Punjab Irrigated Zone

Total irrigated land of Punjab province 19.4 Million acres comes under the command of 25 main canals that are sourced from a complex network of 7 barrages and 6 headwork including a system of 5 major link canals. However, the irrigation land is categorized according to their command districts. CRBC (Chasma Right Bank Canal) is diverted from Chashma barrage at river Indus to irrigate districts of Dera Ghazi Khan and Taunsa Sharif. Two more canals to irrigate areas lying in Punjab are diverted from Taunsa Barrage, namely; D.G Khan Canal and Muzzafargarh canal to irrigate Rajanpur, Muzzaffargarh and D.G.Khan. Thal Canals is a network of Upper Jhelum and Lower Jehlum Canals including Thal Canal itself. As the area curve under Figure 3 indicates, Sutlej valley canals has a vast command area in Bahawalpur, Multan and Bahawalnagar districts under the canal names of Bahawal Canal, Qaim Canal, Fordwah Canal, Eastern Sadquia canal. Haveli canals include main canals irrigating command area in Sahiwal irrigation zone, MR Link canal is a link canal in Lahore Irrigation zone, five linked canals include area irrigated by upper Punjab Irrigation zone that forms the highest flow for Punjab irrigated areas.

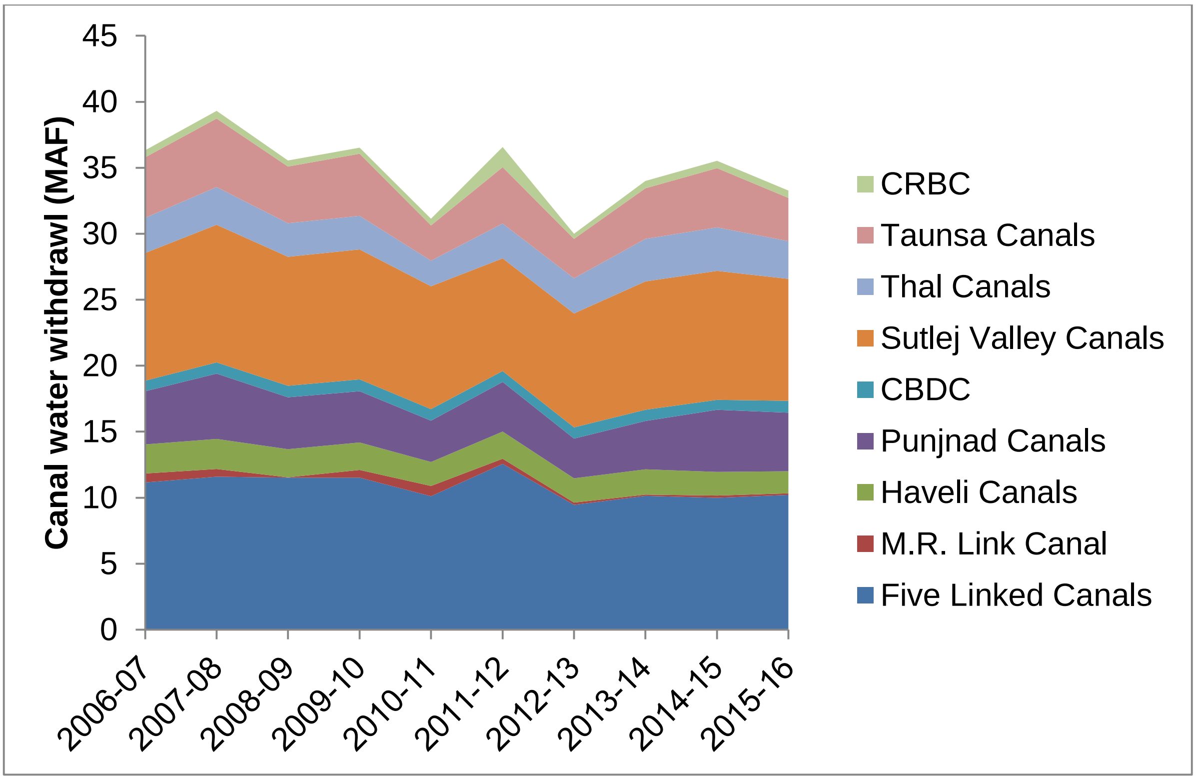


Figure 3: Kharif Season Water withdrawal in Punjab Canals (2006-16)

Source (Punjab Development Statistics, 2017)

Designed discharge for link canals has remained same over the decade because these canals are designed to carry water to rivers, barrages and headworks. The average annual discharge in these canals over a decade has remained 34.8 MAF indicating; a peak in all canal discharge during 2012-13, increased flow in Panjnad canal because of remodelling of Abbasia canals, Sutlej valley canal discharge has remained the same whereas discharge in Thal canals also increased due to remodelling of Thal main canal. During Rabi season withdrawal in these canals reduced by 47% in comparison to Kharif month of the same year (Figure 4). Average withdrawal in canals remained the same during the studies period; however, a sharp rise in withdrawal of Marala-Ravi Link canal was observed during year 2013-14. Average annual withdrawal in Punjab canals over the 10 years study period has remained 19.9 MAF.

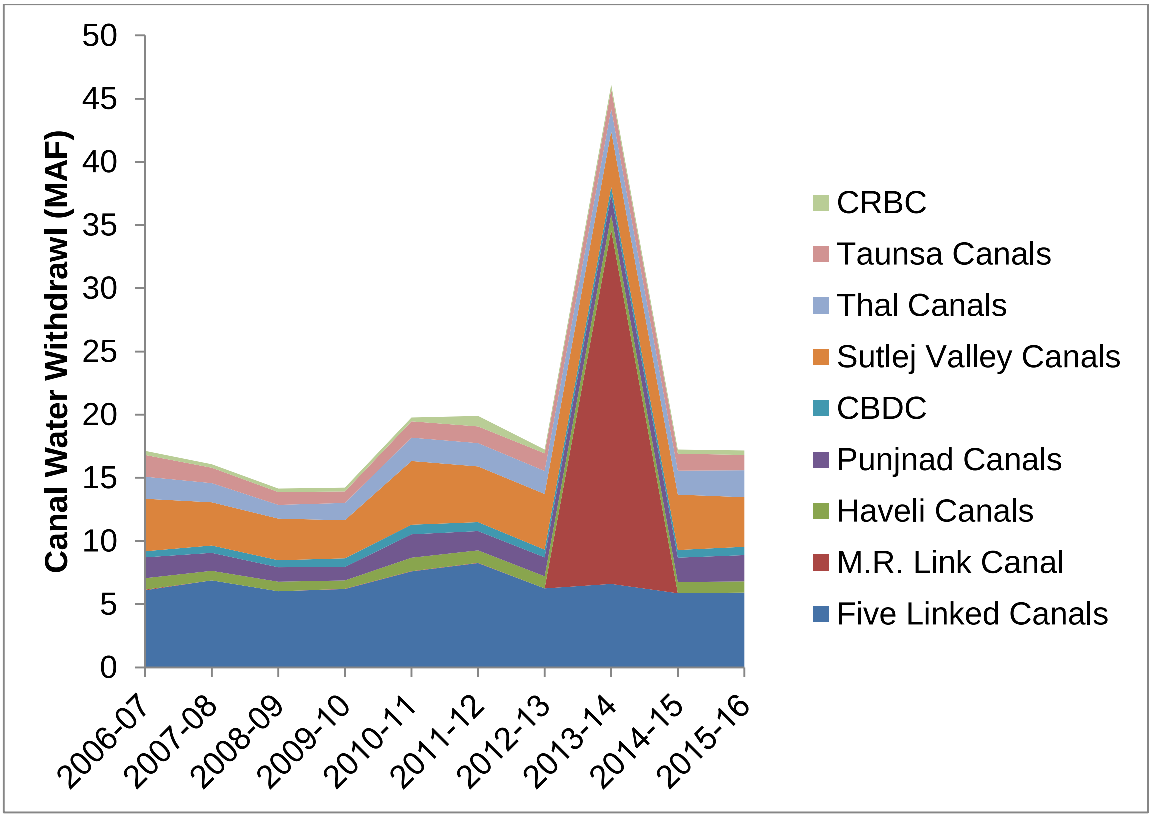


Figure 4: Rabi Season canal withdrawal (2006-16) Punjab Province
Source (Punjab Development Statistics, 2017)

Sindh Irrigated Zone

Like Punjab province, a wide network of 3 barrages and 15 canals exist to irrigate cultivable command area of 12.6 MA. Depending upon flow variations in the system, the average irrigated area of Sindh Irrigated zone is 9.34 MA. Water availability in this canal system varies on seasonal basis subject to the availability of water for storage and specific crop requirements during Rabi and Kharif Season (Figure 5).

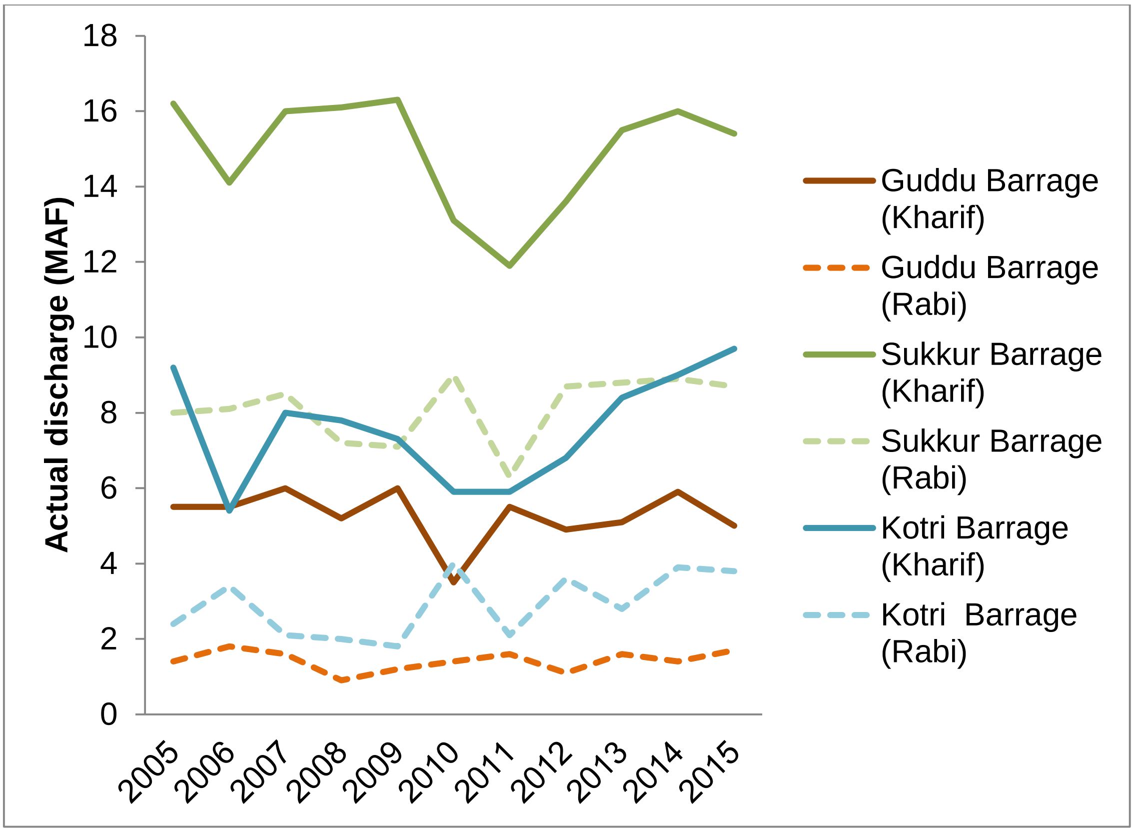


Figure 5: Flow variations in canals in Sindh
(Source: Sindh Development Statistics, 2017)

The figure shows that flows in canals varies considerably in two seasons; for Sukkur Barrage water flows during Rabi season are almost half of Kharif season, whereas Kotri and Guddu barrage canals delivers one third flow in Rabi season compared to Kharif season. A comparison of 10 years since 2005, diversion from Kotri barrage remained at 6 MAF or above during Kharif season and at 2 MAF during Rabi season. A peak in flow during Rabi season was witnessed during 2010 followed by low flow in 2011 whereas flows in Guddu barrage remained stable during Rabi season. Flows during Kharif season have shown variable trends during 10 year observation period. Guddu barrage is showing decreasing trends, Kotri barrage diversions are showing increasing trends and Sukkur barrage is showing a slight decrease returning to normal flow trends in 2015 compared to year 2005. All of these canals have a combined command area of 9.35 MA where is Sukkur Barrage has the largest contribution on both sides of the Indus River.

4.2.2. Crop water consumption

4.2.2.1. Variation attributed to changes in Agro-met scenario

Balochistan Province

To assess the impact of climatic variations on crop water requirements in canal irrigated plains of Balochistan, data from PMD agro met station based in Usta Mohammad was acquired for the duration of 2007-2017. Data from this station was considered representative for Jaffarabad, Naseerabad and Bolan (Kacchi) districts as this is the only agro-met station located in this zone. Temperature the main driver of climate change, any increase in it increases wind velocity, relative humidity and evapotranspiration (ETo). Mean value of average monthly temperature over 10 years is plotted to observe the difference across years (Figure 6).

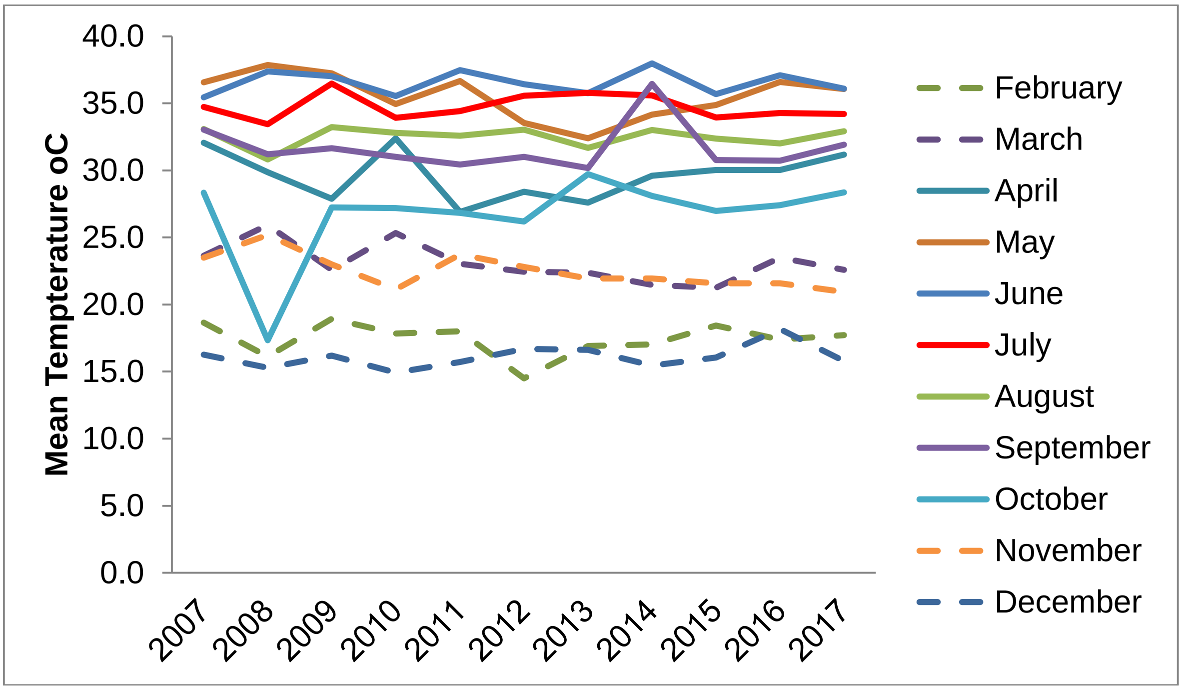


Figure 6: Mean temperature variations in Usta Mohammad (2007-17)
(Source: PMD)

In 2008, the temperature during month of October showed a sharp decline whereas only changes of 2-3 degree C were observed in months of September and August during the same year. This followed by a peak of same degree in July during year 2009, in August 2010 and June 2014, however, September 2014 was warmest compared to other years. The cross examination of data during 2007-2017 showed a linear trend in mean monthly temperature. However, it is possible that a sharp temperature rise may have driven farmers to make alternate crop choices the next year. Similarly, linear trend in temperatures was also observed during winter months. In 2008, temperature rise by 1 degree C was observed during months of March and November, however, in 2009 a decline was also observed. No prominent changes in temperature were observed despite a decline in February 2012. Impact of this temperature rise may be observed through variations in the value of ETo, as shown in Figure 7. Likewise, in September 2014 highest ETo was recorded compared to other years. In 2008, March and October months shown a slight rise in the value of ETo.

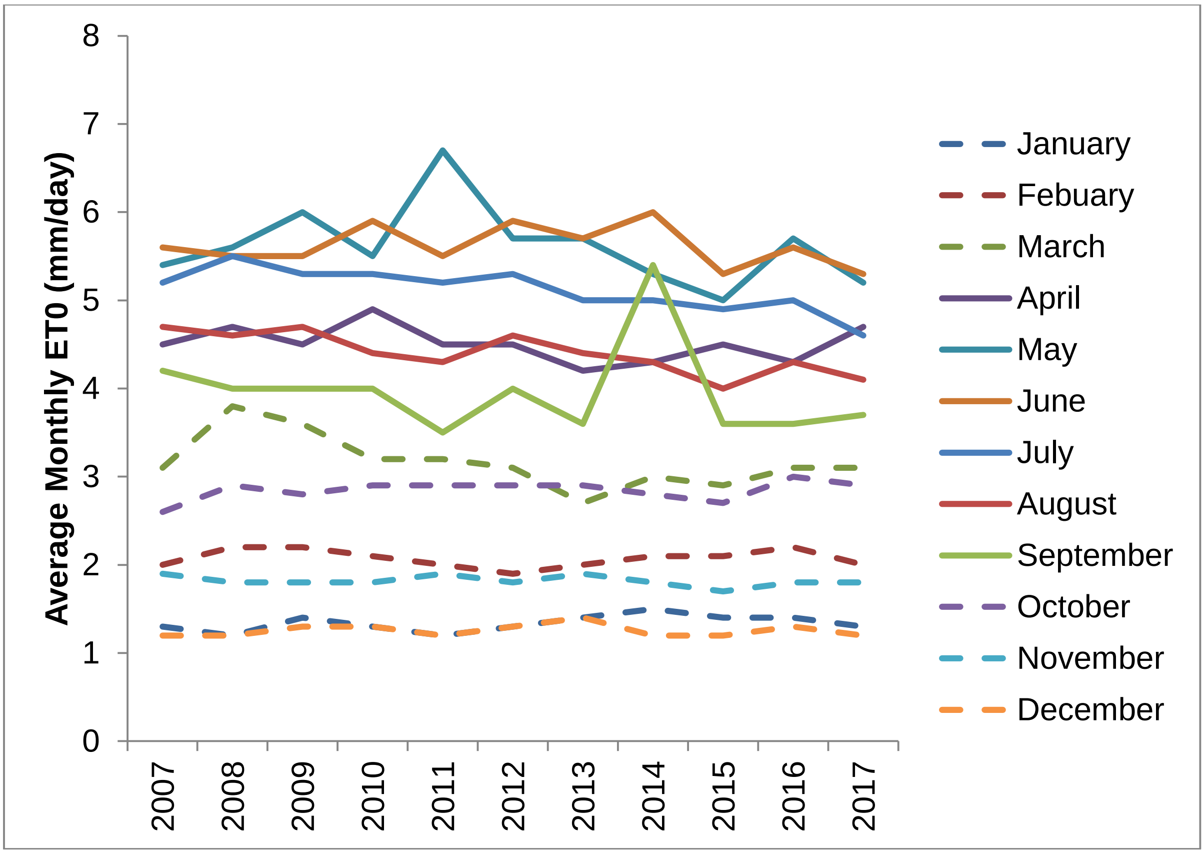


Figure 7: Variations in ETo values at Usta Mohammad (2007-17)
(Source: PMD)

The overall trend of ETo remained linear during 2007-17 except of rise and decline during some aforementioned months. Dependence on canal water is also impacted by precipitation, another climatic factor that supplements crop water requirements while acting as a balancing agent with temperature and evapotranspiration. A precipitation variation graph (Figure 8), shows high average precipitation during all months of the year 2009 except for November and December. A rainfall peak of 204 mm was also observed during July 2010 which was the historical flood year for Indus Basin Irrigation system (IBIS). In 2008, the highest rainfall during the decade was recorded in December, whereas it remained nominal in rest of the years. In 2013, rainfall above 50 mm was recorded during May, February and August. By the end of decade, rainfall events became more recurring in years 2016 and 2017 during summer months but nominal in winter months. In comparison to peak recorded rainfall in 2009, precipitation has shown a declining trend with less or no rainfall during winters and limited span over summer months. Crop choices in irrigated plains of Balochistan may be driven by the socio-economic factors; such as yield per acre and specific demands relating to a crop. This scenario will be further explored by observing general cropping trends in Balochistan province.

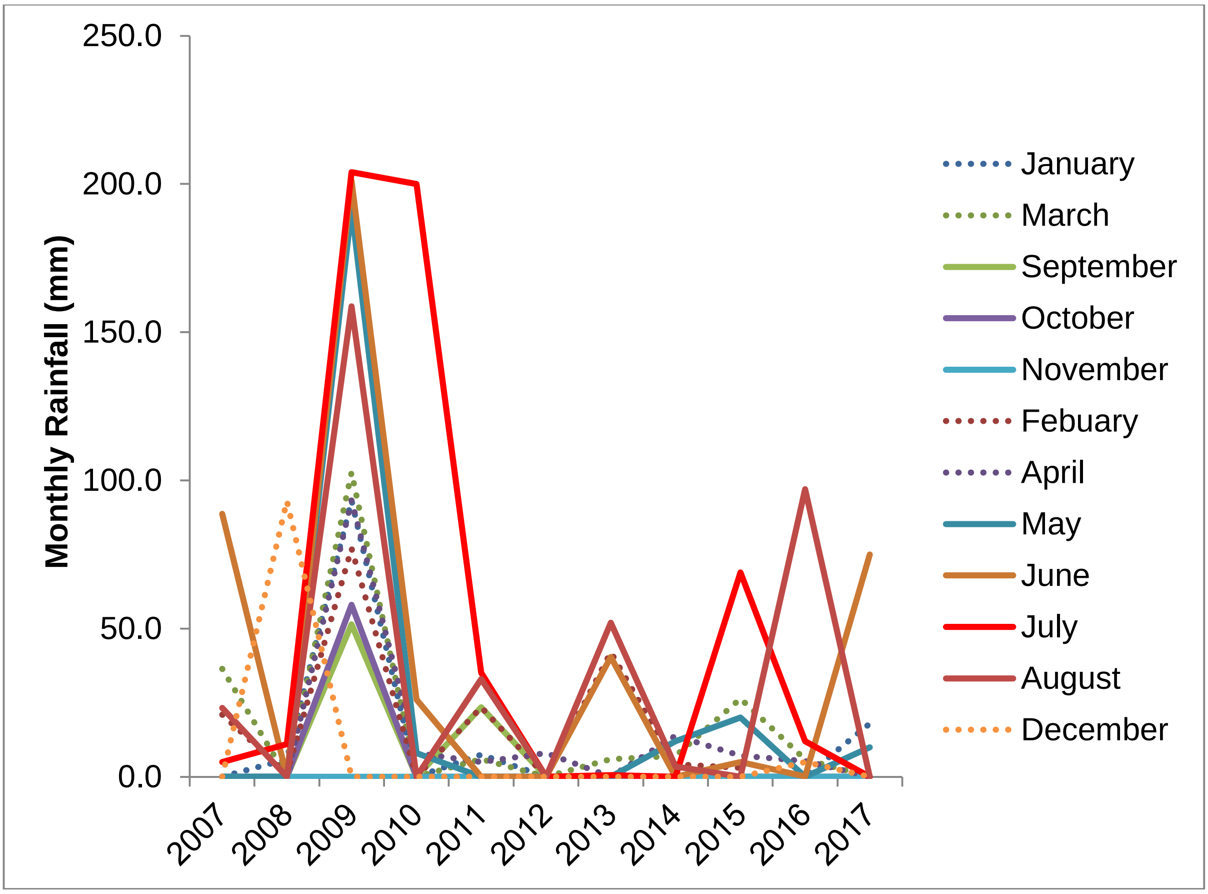


Figure 8: Variations in rainfall at Usta Muhammad (2007-17)
(Source: PMD)

An estimation of water crop water requirements according to agro-met scenario of this particular cropping zone for wheat crop is shown in Figure 9. This general estimation of water requirement is derived on the bases of crop coefficient values without contribution from groundwater and precipitation. This water requirement of wheat crop did not go higher than 2 mm/day. This shows that water canal water allocation for wheat crop is higher in areas irrigated by Patfeeder canal.

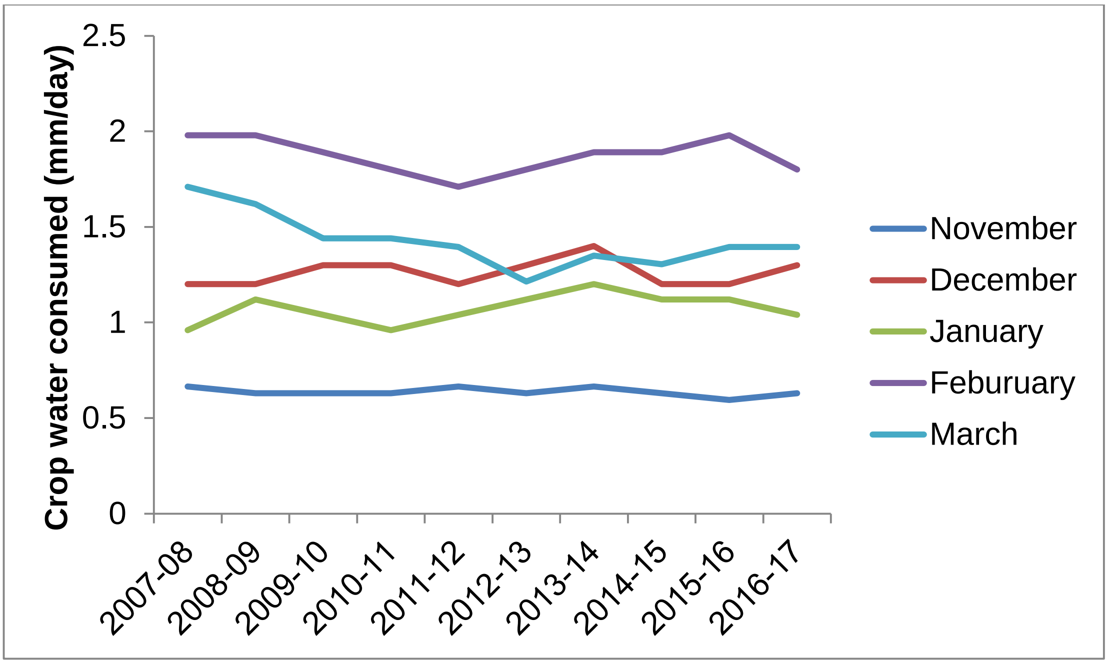


Figure 9: Actual water consumed by Wheat crop (2007-17)

These estimations of water consumed by wheat crop are made by using crop coefficient values calculated at PCRWR's Lysimeter stations. The designed water allowance is still high compared to actual water requirements of Wheat crop. As per estimates of actual water allowance (Table 2), more water is available to Kharif crops. Rice is the major crop of the region therefore; actual canal water consumed by the rice crop during 2007-2017 is shown in Figure 10 without contribution from groundwater and rainfall.

Figure 10: Water consumed by Rice crop (2007-17)

In this graph, only a slight rise in water consumption of rice crop occurred during September 2014, where evapotranspiration had increased owning to the prevailing dry spell. The per day crop water requirement of rice crop does not exceed 6 mm/day and remain as low as 3.3 mm/day during months of October and July. It is pertinent to mention here that, most of the annual rainfall is received during Kharif season therefore dependence on canal water supplies may be reduced further. Now referring back to Table 2, which shows that canal water allowances during Kharif season also exceeds 8 mm/day, moreover, water from Uch and Mithuri canal also become available. This situation shows very high water allowance to the canal command even beyond the evapotranspiration potential of this region. A wise allocation of water and shift to lower delta higher value crops may bring more of canal command area under cultivation.

Sindh Province

The irrigated zones of Sindh province have 7 agro met stations located in Rohri, Larkana, Dadu, Tando Jam, Sakrand, Padidan and Mirpur Khas. In this study, Rohri station is taken as the representative of upper Sindh Cotton-Wheat zone that include Ghotki, Sukkur and Khairpur districts. A comparison of temperature and precipitation variations during 2007-2017 are given in the Figure 11.

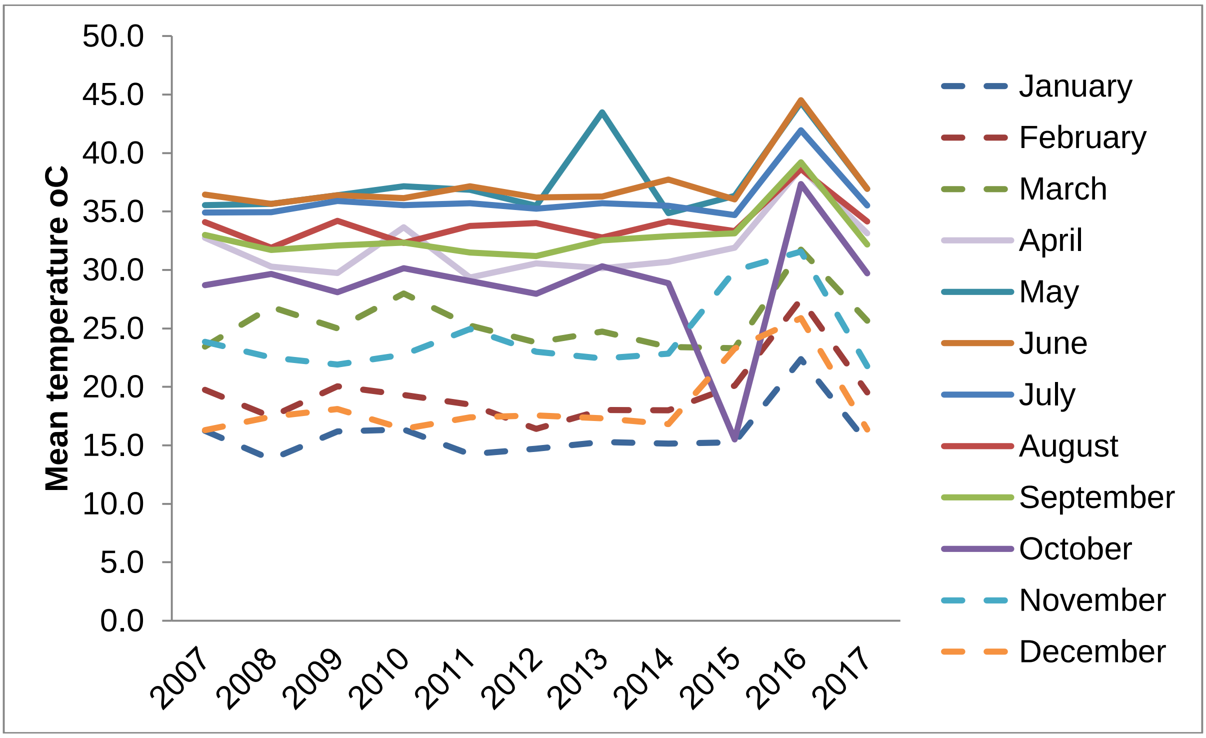


Figure 2: Temperature variations recorded at Rohri Agro-met Station

In 10 years of observation, temperature has followed a normal trend during Rabi and Kharif months of the year. A peak rise in temperature by 5°C was observed in summer months whereas temperature fallen to normal in 2017. A peak of 5°C was also observed in May 2013 but in the following year, weather returned to normal. In 2015, a sharp decline in mean temperature was observed 15°C to normal in month of October followed by a rise of 20°C in year 2016. These temperature variations may also have impacted crop water consumed by the major crops sown in that area.

Before discussing changes in crop water consumption by major crops, the precipitation contribution must be taken into account (Figure 12).

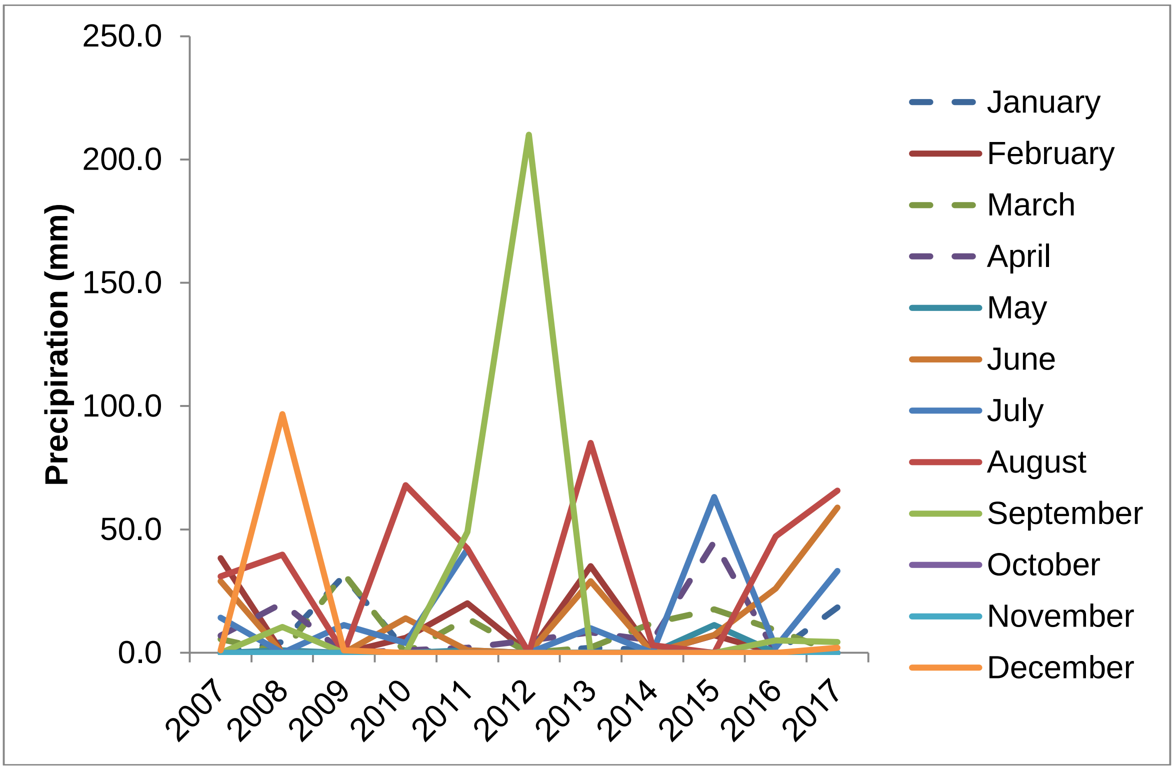


Figure 3: Precipitation variations recorded at Agro-met station Rohri

In year 2008, month of December was wettest during the observation years, likewise the highest rainfall was observed in September 2012. The data observation show precipitation increase in August which is also a critical month for Cotton crop. A single event of high rainfall was recorded in April 2015 which might only have contributed into pre-sowing of cotton crop. These trends indicate a high dependency of cotton crop on canal supply or fresh groundwater resources. This situation justified high water allocation in Rohri Canal (Table 4). Upper Sindh and Left Bank of Indus River is commonly recognized a Cotton-Wheat zone, however, Sugarcane and Rice crops are also cultivated in these districts. An estimation of water consumption of these crops is given in Figure 13.

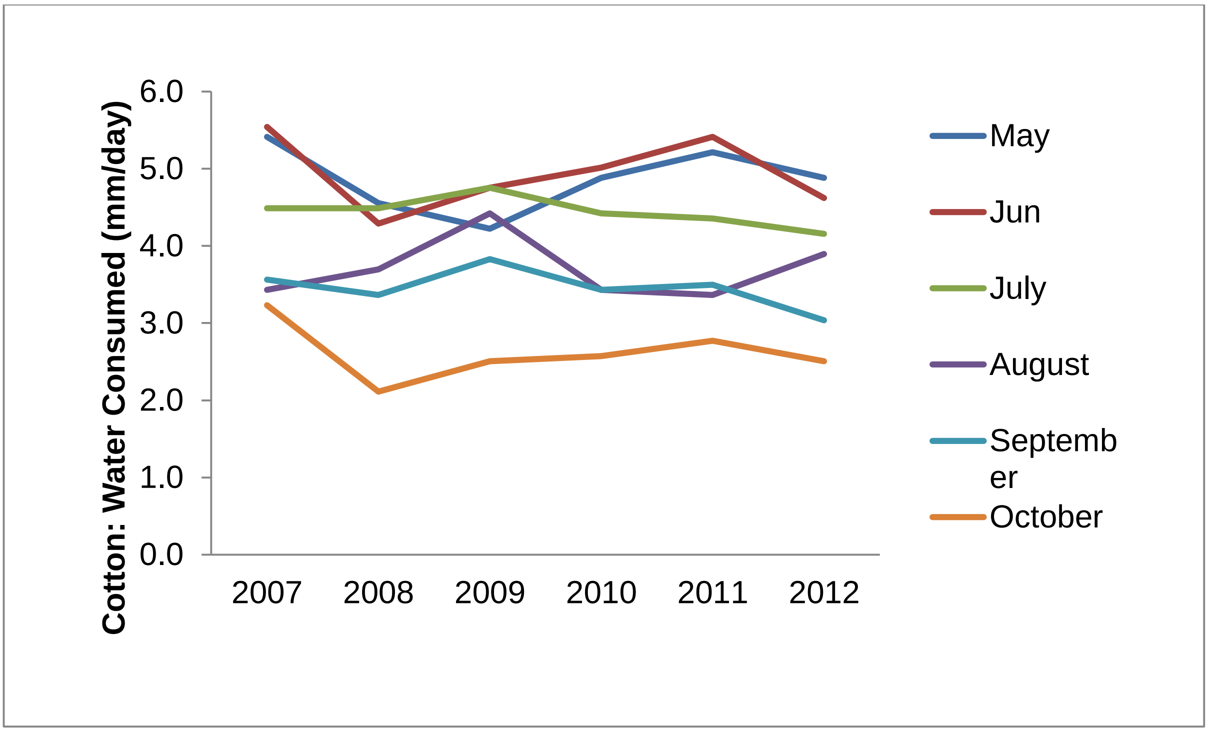


Figure 4: Water Consumed by Cotton crop in Rohri Agro-Met Station

During the observation period (2007-12) water consumption by cotton crop vary between 2.1-5.4 mm/day. Crop water consumed is generally dependent upon temperature and the crop stage whereas wind speed and relative humidity play allied roles. A tend of high water consumption by the crop prevail during June and May months of the year followed by July and August. During August, availability of rainwater reduces the need for canal irrigation. A high water consumption trend was also observed in Wheat crop during winter season (Figure 14).

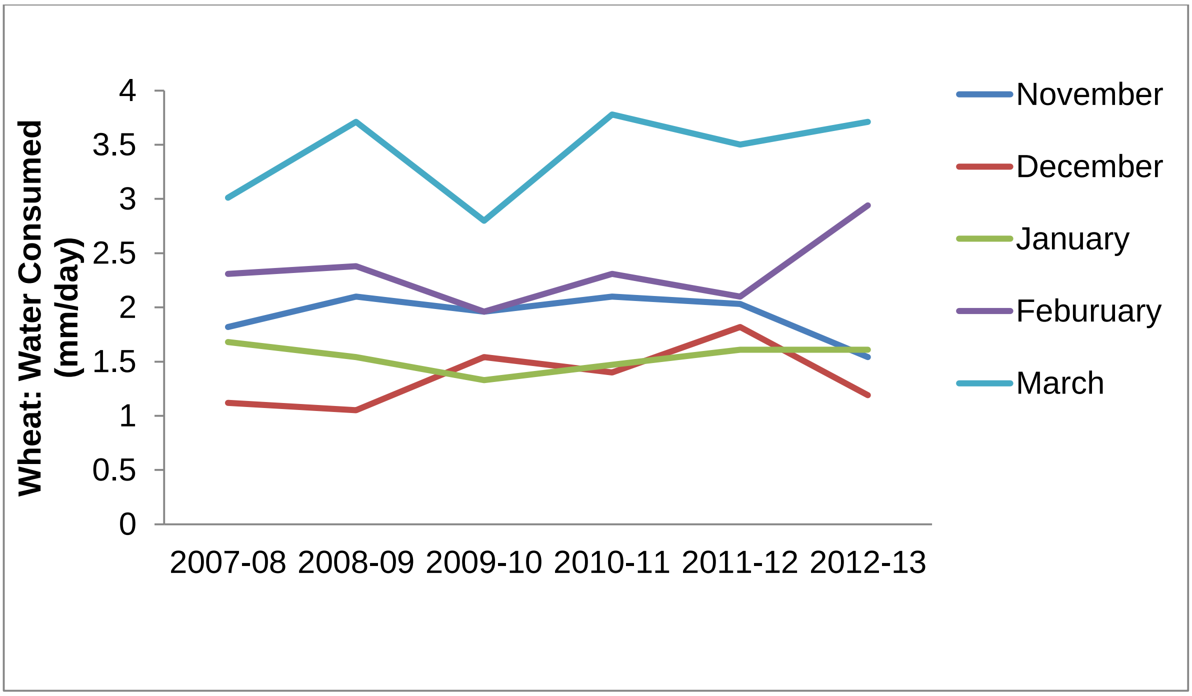


Figure 5: Water Consumption by Wheat crop at Rohri Ago-met Station

Water consumption by wheat crop varies between 1.0-3.7 mm/day, lowest in December and peak in March. The general observation over 2007-2012 shows that water requirement of the wheat crop is increasing for months of March and February whereas in November and December it is decreasing. The increasing temperature is causing more water requirement followed by early ripening of crops making a way for additional Kharif crops. In this context, in the wheat-rice cultivation zone, the trend for Sugarcane and Rice crops is also seen increasing during the observation period. Sugarcane is an annual crop whereas Rice is a Kharif crop. Crop water consumption of Sugarcane crop is depicted in Figure 15.

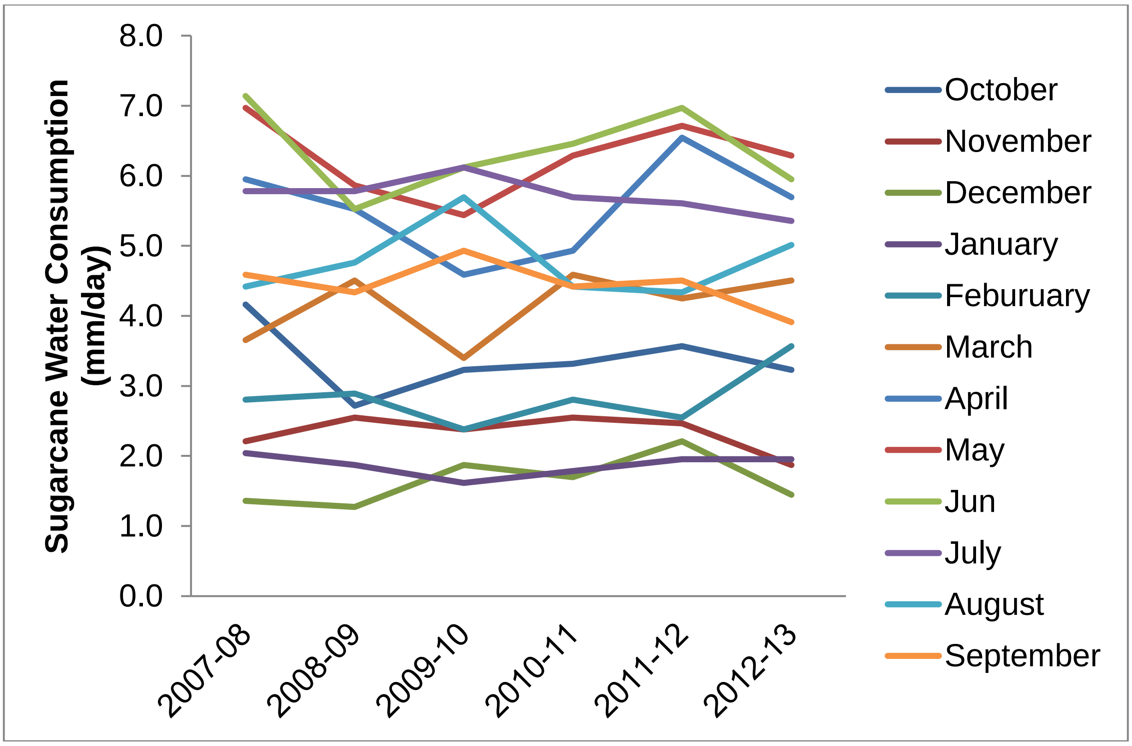


Figure 6: Water consumption by Sugarcane crop-Rohri Station

Sugarcane is a perennial crop that consumes water allocation during Rabi and Kharif season. Any increase in sugarcane sowing trend in upper Sindh is the possibility of abundant freshwater to sustain a perennial crop such as sugarcane. Likewise, rice is a Kharif crop having very high water consumption rate is also grown in parts of upper Indus Basin. An assessment of water consumption by rice crop is depicted in Figure 16.

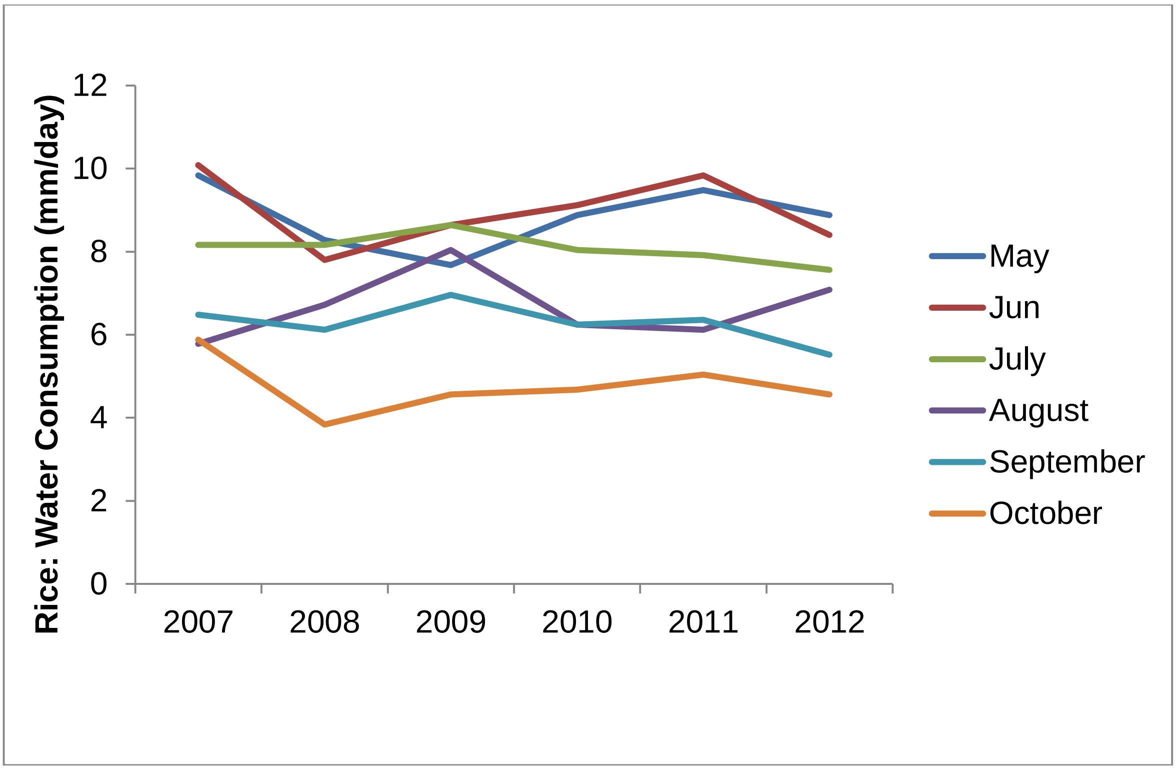


Figure 7: Water Consumption by rice crop- Rohri Station

Estimation of water consumed by crops is estimated on the basis of evapotranspiration which shows an increase in water consumed by the crop with rising temperature. Figure 17 shows a decline in average monthly temperature during Kharif months of year 2008 similarly water consumed by the rice crop flowed by a rise in year 2009.

The right bank of Upper Indus Basin is represented by agro-met station of Larkana forms rice-wheat zone of Guddu Barrage command including Larkana, Kashmore and Jacobabad. The observation of mean temperature data over a decade shows slight changes in temperature.

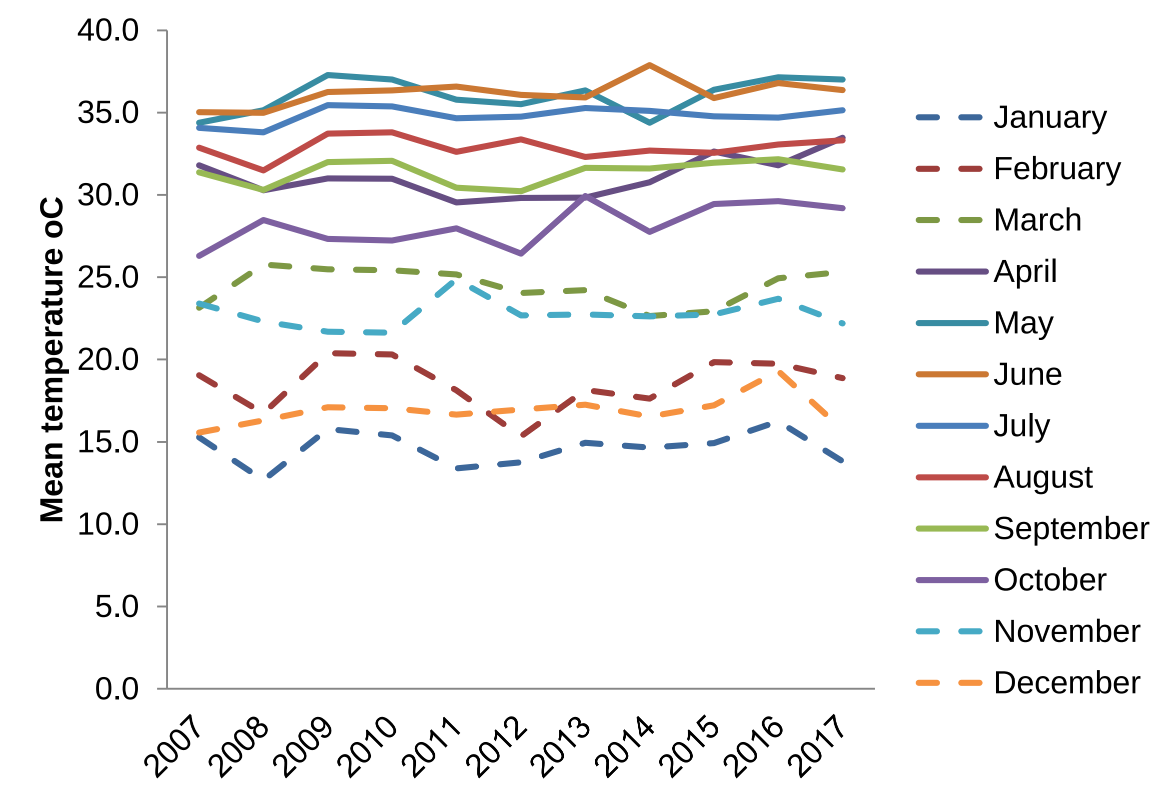


Figure 8: Temperature variations (2007-17)- Larkana Station

The Figure 18 shows a change a range of temperature variant over 10 year observation period ranging from 0.1-2.9ºC in Kharif months. However, Rabi months showed a declining trend ranging from 0.1-1.8ºC. This temperature variation over a decade indicates a possible increase in crop water requirement during Kharif month.

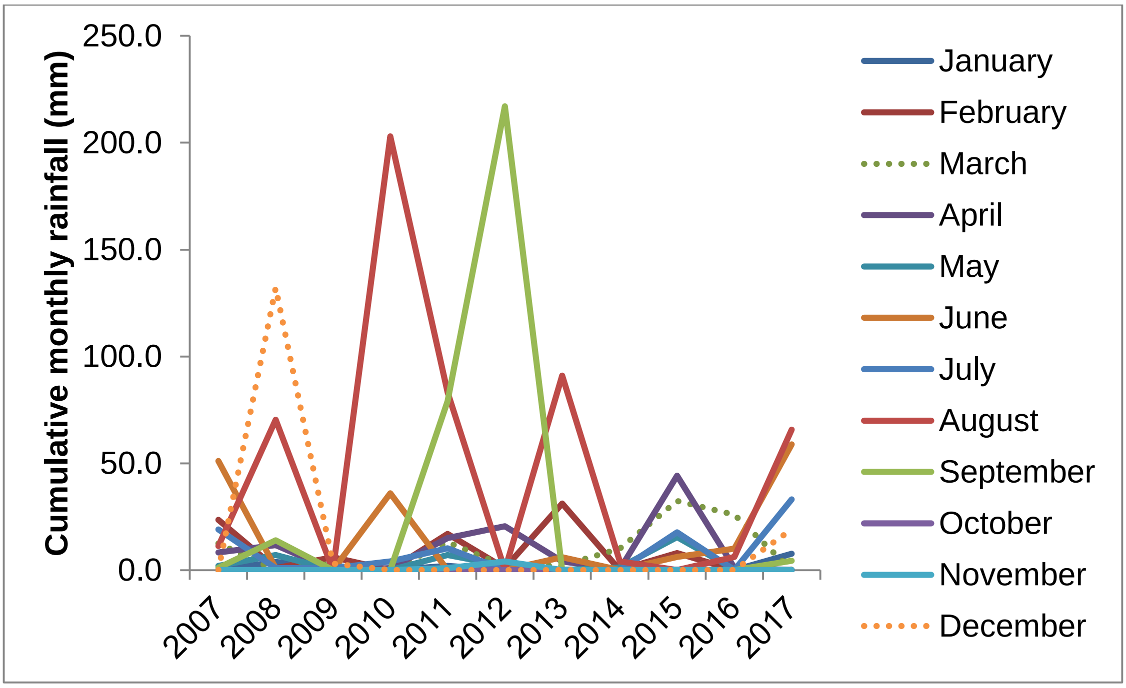


Figure 9: Cumulative monthly rainfall (mm)- Larkana Station

The precipitation in Larkana station is somewhat in harmony with Rohri station due to geographic proximity. In year 2008, month of December received highest recorded rainfall in 10 year observation period, September 2012 received peak rainfall observed and April 2015 also received higher rainfall compared to other studies years in same month. Overall, higher rainfall trend prevailed during month of August, showing 4 high rainfall events during 2007-17. In August 2010, highest rainfall during this particular month, year 2010 also mark the year of historical flood in Indus Basin. Month of August and September are critical months for cotton crop, high rainfall event during this month may be harmful for the early sown cotton crop. On the contrary, a good rainfall spell during December is beneficial for Wheat crop preserving canal water from irrigation and lower temperature also reduces crop water requirement (Figure 19).

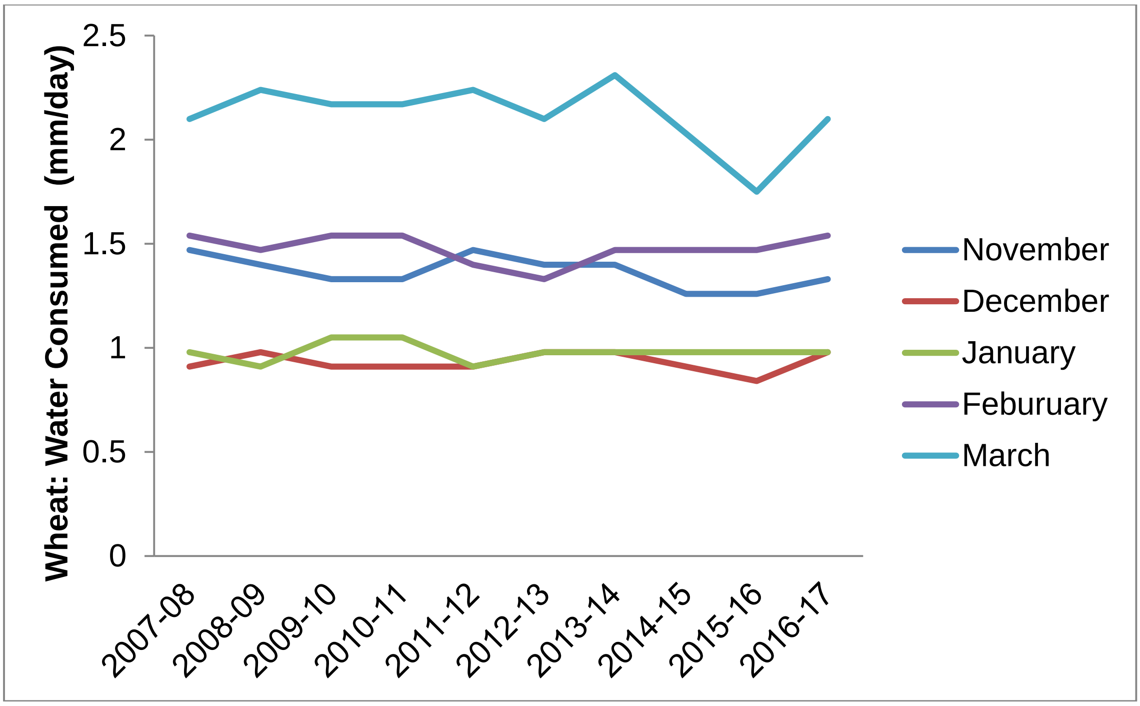


Figure 10: Water consumed by wheat crop- Larkana Station

During data observation period, water consumed by the wheat crop during Rabi months remained the same after experiencing some highs and lows during the decade. This no change scenario is attributed to less variation or decline in recorded temperature during winter months of Larkana stations. The difference in crop water consumption attributed to climate variations may be more prominent during Kharif crop, i.e. Cotton (Figure 20).

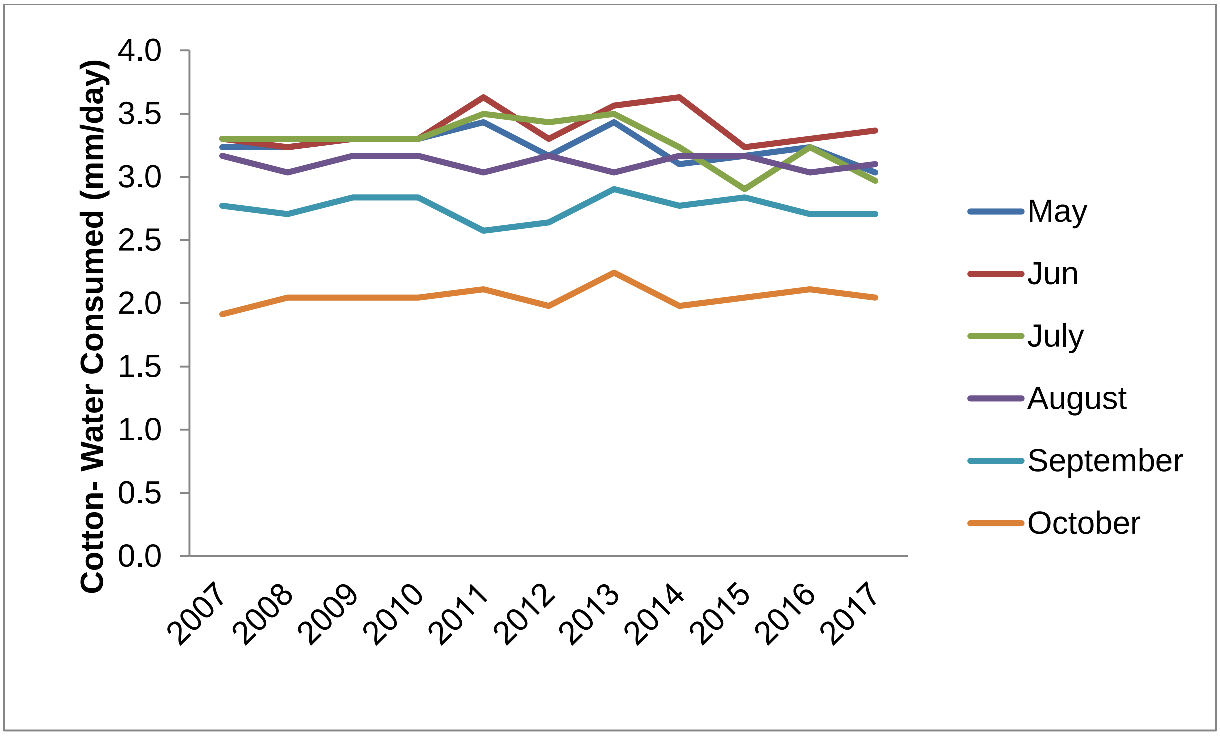


Figure 11: Water Consumed by Cotton crop- Larkana Station

In Figure 19, a variation of water consumed by the cotton crop in Larkana and allied referenced districts is depicted. The water consumption trends by the crop remained the same, however from dry months of May, June and October an increase of 0.1-0.2 mm/day was observed. Any further increase in temperature, as shown by temperature variation graph is likely to increase crop water requirement during summer months. However, the present increase in temperature is within the threshold of cotton crop for Larkana, Kashmore and Jacobabad districts.

Dadu, Shikar pur and Shahdadkot districts forms the right bank irrigation zone of Indus basin in the command of Sukkur Barrage. Therefore, Agro-met station of Dadu represents Rice-Wheat zone districts; Dadu, Shikarpur and Shahdad Kot. Temperature variations during studies period (2007-17) are shown in Figure 21.

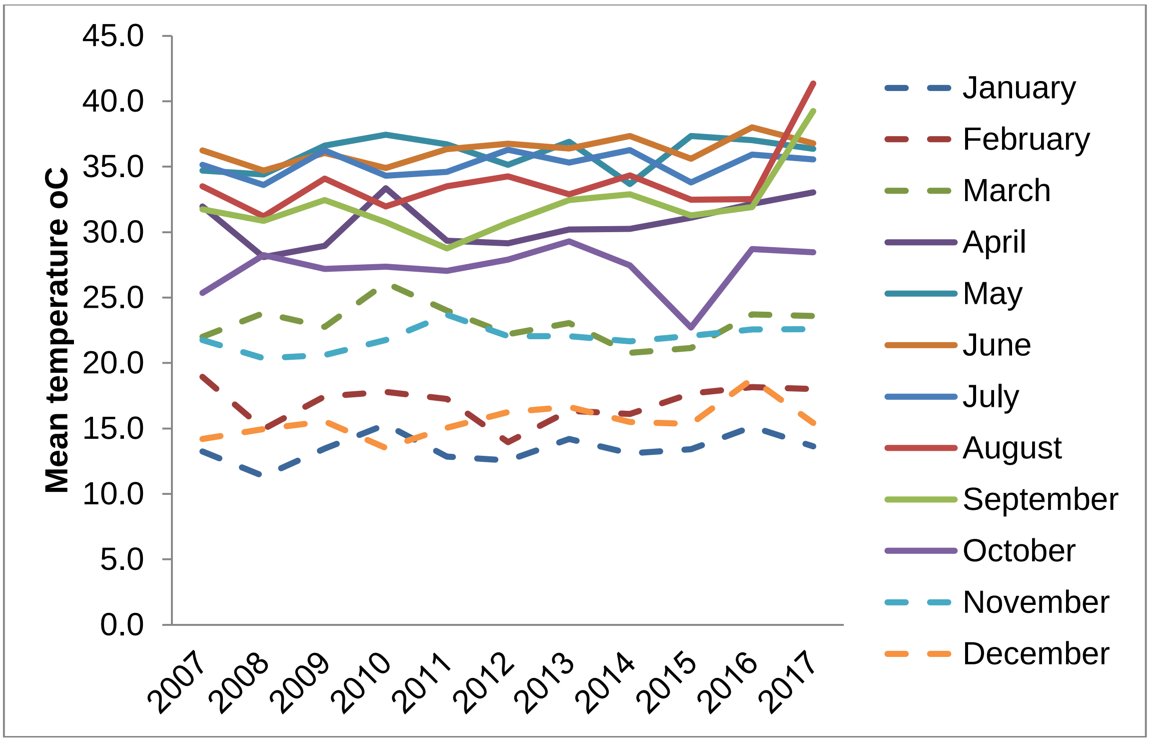


Figure 12: Mean Temperature variations (2007-17)- Dadu Station

Over the decade of observation, lowest temperature variation over a decade is 0.2ºC in October to 7.8ºC in August during Kharif period. During winter months, January and November has shown increasing temperature trend whereas rest of the Rabi months has shown no change or reduction in temperature over a decade (Figure 22).

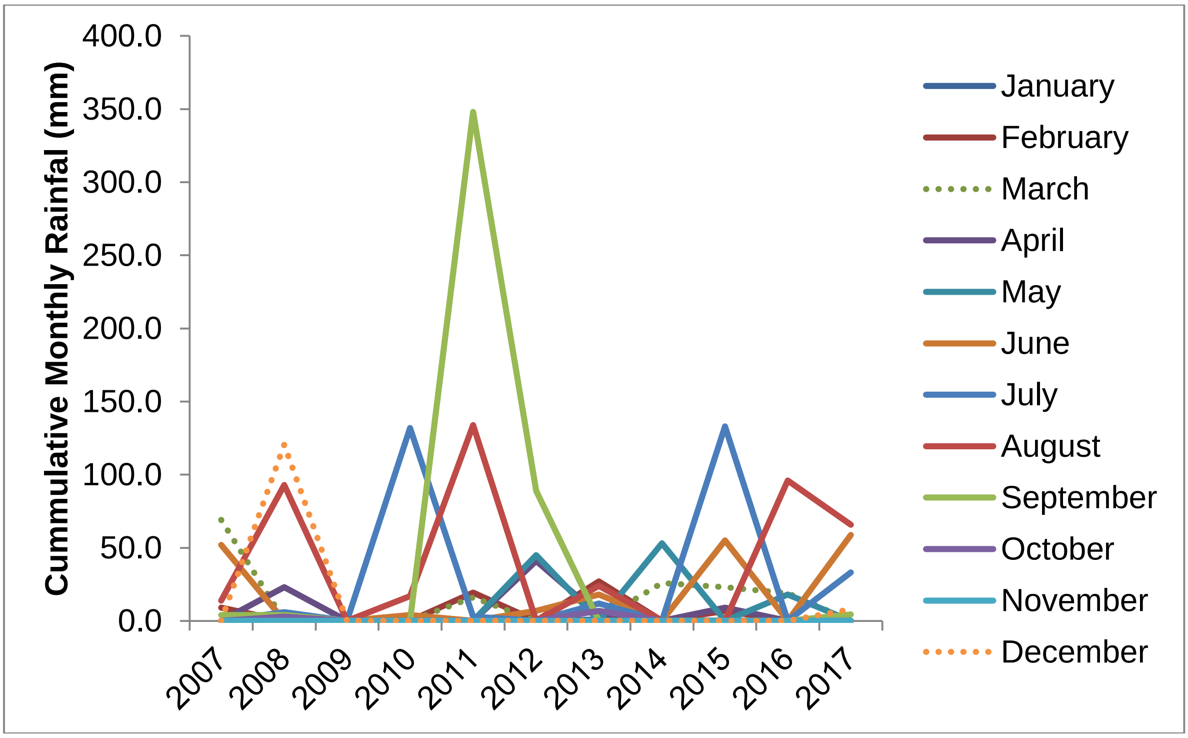


Figure 13: Cumulative Monthly precipitation- Dadu Station

Sakrand district agro-met station is representative of Shaheed Benazirabad district forming cotton-wheat zone which has high tendency of growing Banana and Sugarcane crops (Figure 23).

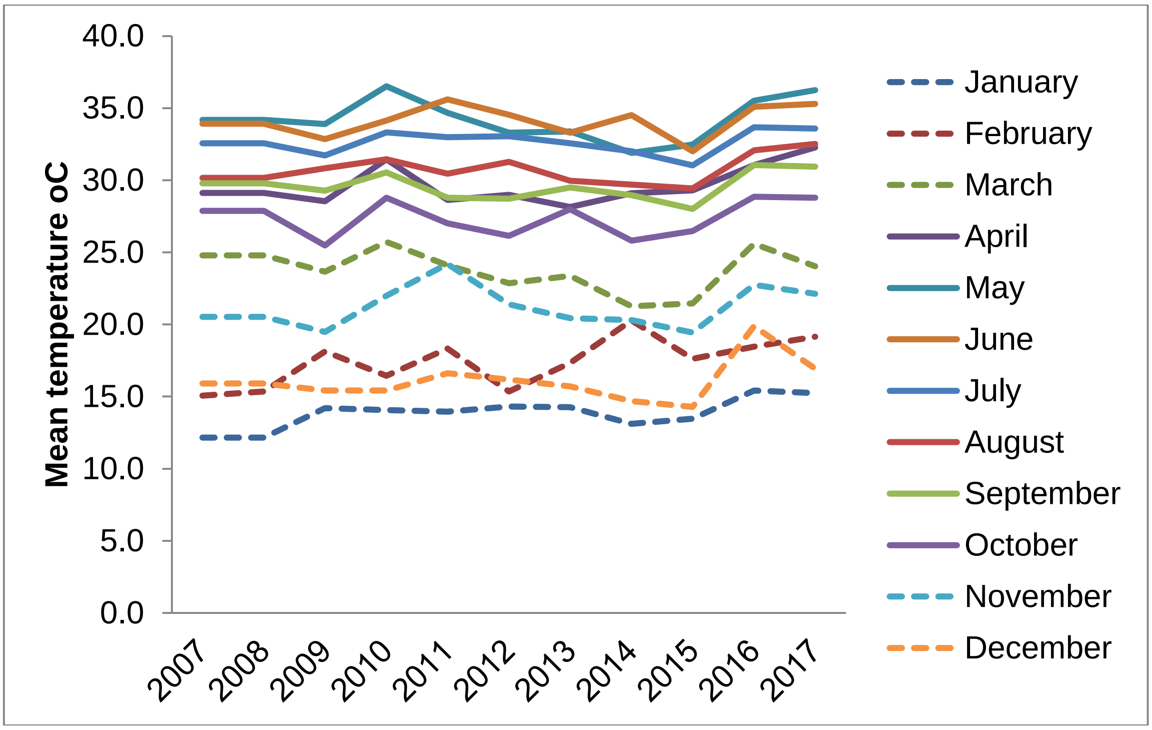


Figure 14: Temperature variations (2007-2017)-Sakrand Station

The average temperature of the observation period has increased during 2007-2017. An individual comparison of months in 2007 to 2017 also reveals a considerable increase ranging from 1-3^{o}C (April and January). During summer months, sudden temperature rise was recorded during December 2016, November 2014 and most months of year 2010. In Kharif period, temperature is showing a rising trend whereas temperature in Rabi season has impacted wheat crop considerably. Like temperature, rainfall peaks were also recorded scattered over a decade (Figure 24).

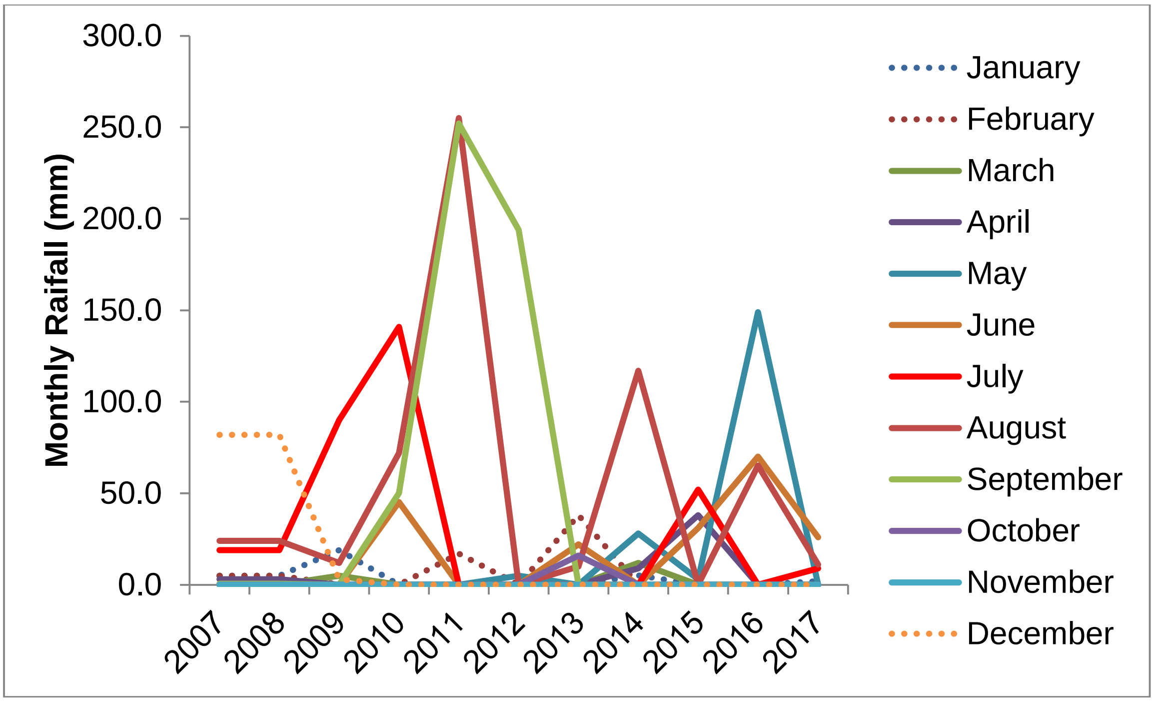


Figure 15: Monthly rainfall in Sakrand (2007-17)

During first three year of the decade, precipitation during Rabi months was considerable which provide an additional benefit to wheat crop sowing, however, in remaining 7 years this rainfall was negligible. During 2009-2012, peak rainfall events were recorded in July, August and September which reduced to approximately 60 mm rainfall during these months whereas no substantial rainfall was recorded in September. An unusual rainfall trend in May appeared in 2014 that peaked in 2016 must have provided additional water to the early stage cotton crop. Considering the temperature and Precipitation trends of Sakrand station, there is a considerable variation over a decade. Canal water supply and good quality groundwater has prevented crop from loss during dry period. The impact of seasonal variation on crop water requirement is shown in Figure 25.

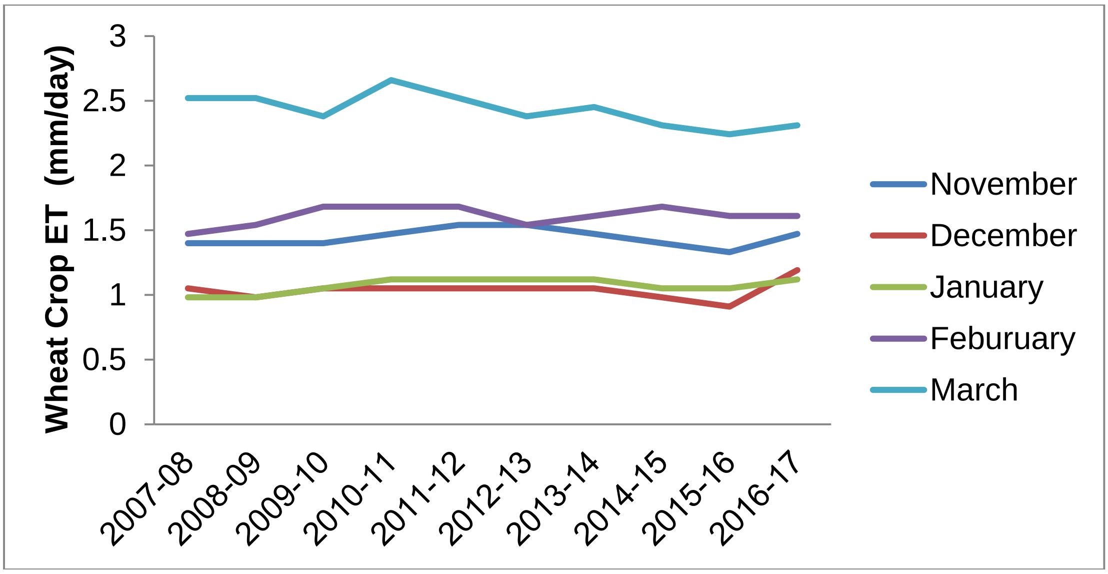


Figure 16: Water requirement (ET) of Wheat crop at Sakrand Station

During the study period, wheat crop water requirement fluctuated the most during its tillering and maturity, starting from February to March. However, crop water requirement during early months of wheat season has also increased that is a water management challenge for farmers in the absence of substantial rainfall since 2008 (Figure 26).

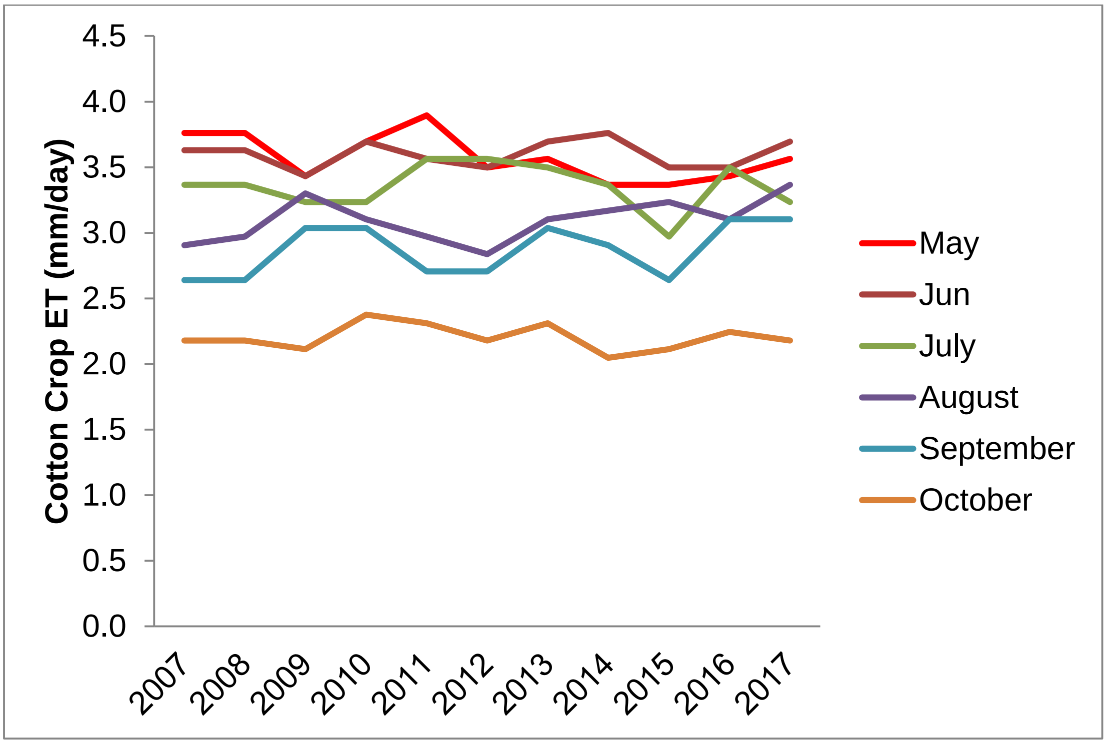


Figure 17: Water requirement of cotton crop- Sakrand Station

Water requirement of cotton crop during October is not much variable because during this month represents the picking stage of Cotton crop when most of the leaves are shed and no further irrigation is applied. Crop water requirement for cotton crop has fluctuated during summer months but the average result of the entire decade showed no considerable changes. Moreover, during Kharif month's substantial rainfall also contributes into water balance lowering irrigation requirement of crops at various stages. The excess ability of crops has derived farmers to shift to high delta crops such as sugarcane and Banana in Shaheed Benzirabad district and rural area under its constituency.

Tandojam station is representative of Hyderabad, Mitiari, Tando Allah yar and Jamshoro districts are a mixed cropping zone and high cultivation percentage of vegetable, intercropping, banana and mango crop.

Mirpurkhas station is representative of Mirpurkhas and Sanghar districts. District Mirpurkhas is considered as a mix cropping zone whereas Sanghar is a big agricultural hub irrigated by Nara Canal forms a cotton wheat zone. In this absence of any agro-met station in Sanghar District, the agro-met station at Mirpurkhas is considered reference observing climate variations for this district. Over the observation period, temperature in Mirpurkhas has shown high variations and homogenously across all month, in 2012 a temperature decline between 1-5^{o}C was recorded. A high decline in temperature was also observed during January and

February 2008 and a marginal difference during summer months. Moreover, across 10 years study period an alternate increase and decrease in temperature was recorded (Figures 27 and 28).

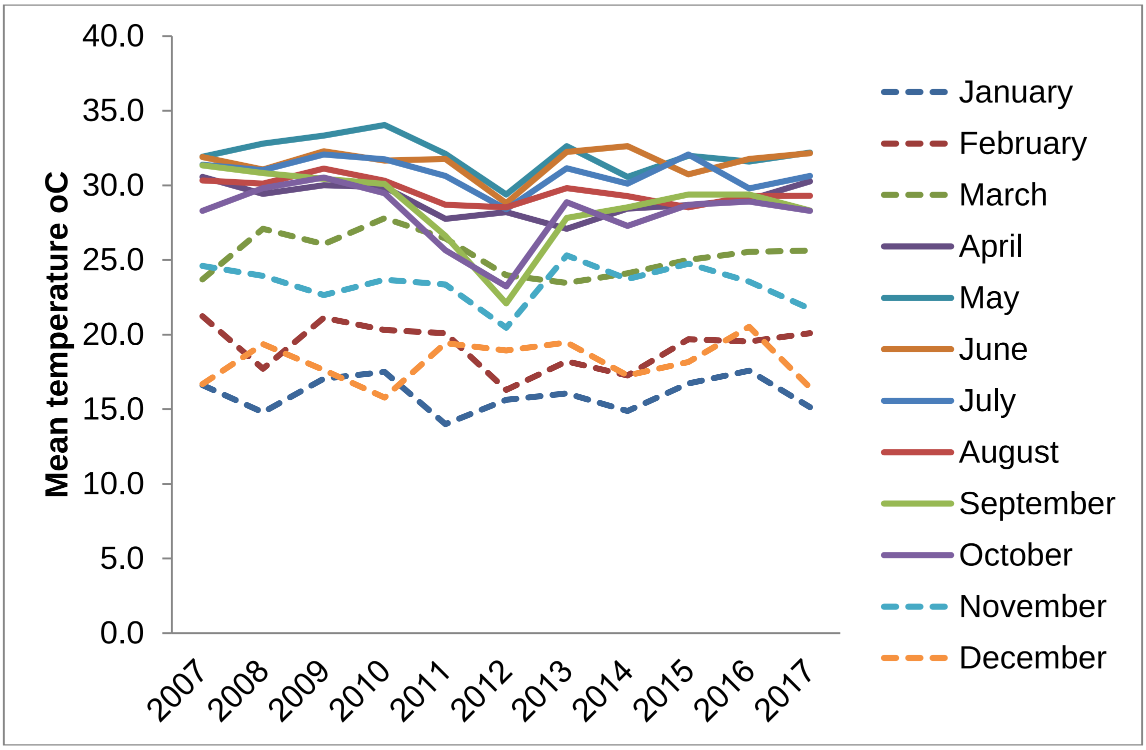


Figure 18: Mean temperature variations (2007-17)- Khairpur station

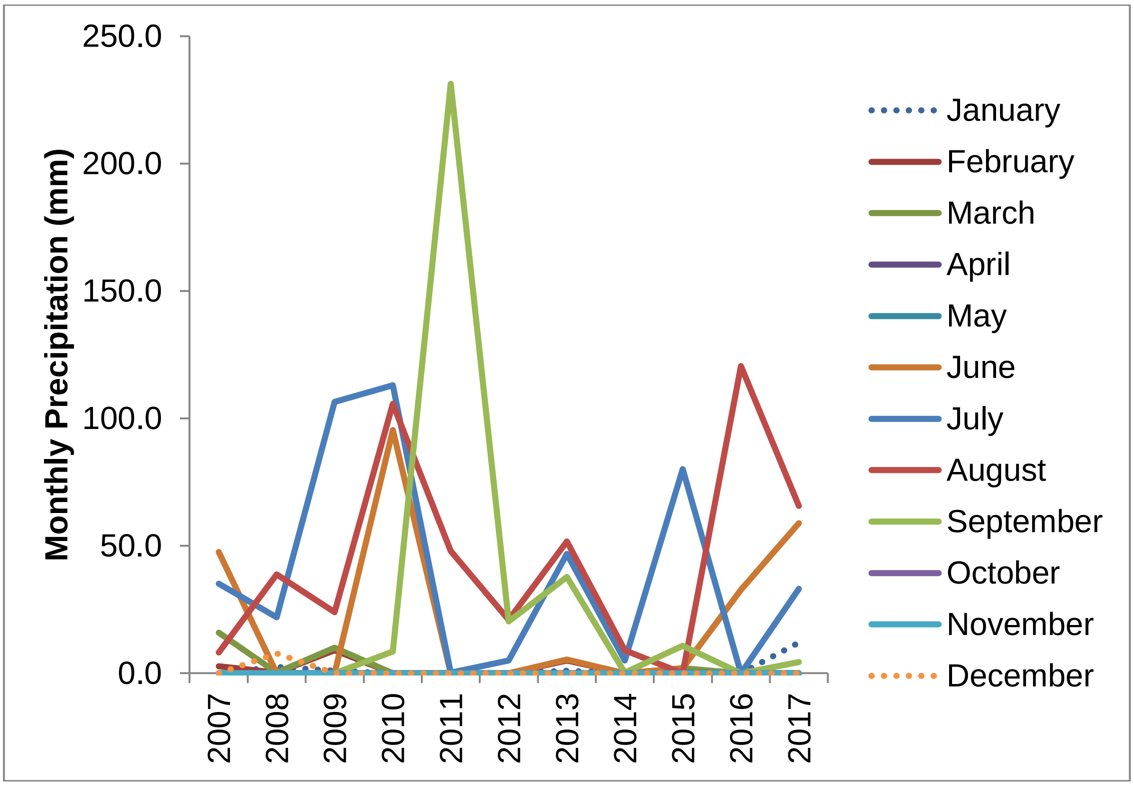


Figure 19: Monthly rainfall (mm)- Mirpurkhas Station

The rainfall pattern shows only 7.8 mm rainfall in December 2008, despite this specific period was considered a wet period for most parts of upper Sindh. January 2017 depicted a rainfall of 12 mm which is in contrast with other districts of the province. Mirpurkhas station also recorded two high rainfall events in June, in 2007 and 2017. July and August has remained wet months during half of the decade following alternate year pattern. In contrast to other districts of the country, peak rainfall event was recorded in Mirpur Khas during Septermber 2011 instead of September 2010. Like Sanghar, Mirpur Khas district is dominantly a Cotton-wheat zone; however tendency for Sugarcane crop kept rising alternatively. The crop water requirement trend over the study period was (Figure 29).

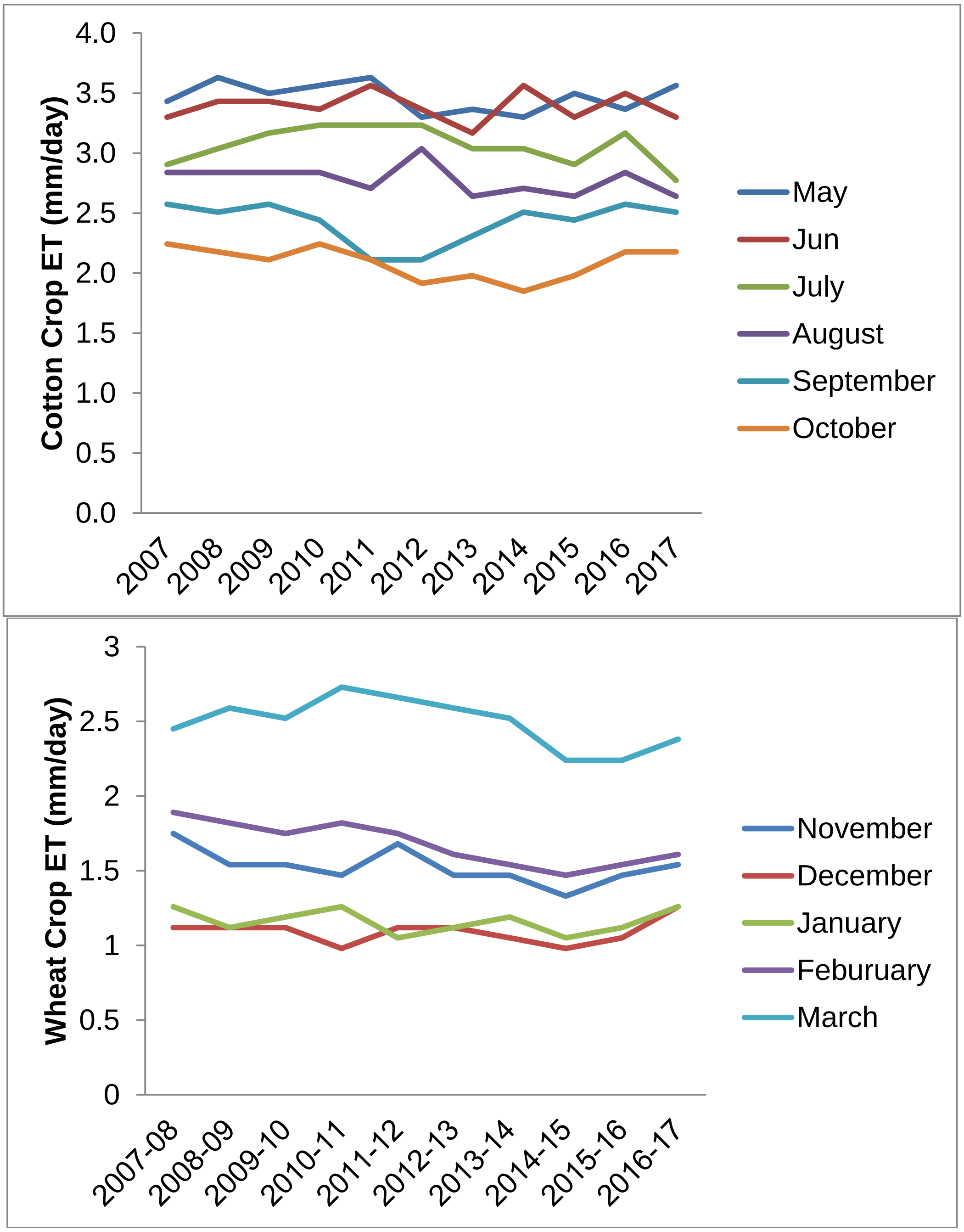


Figure 20: Water Requirement (ET) of Cotton- Wheat Crops- Mirpur Khas station

There is a high variation in crop water requirement of two principal crop giving similar to variations in temperature that were more frequent during summer months. For cotton crop, during dry month of May representing crop vegetative growth phase, water requirement by the cotton crop remained highest and showing increasing trend compared to June, July and August months. For wheat crop, in winter months, crop water requirement is showing an increasing trend. These water requirement variations are met by perennial supply of irrigation water which is providing popularity to sugarcane crop, a high delta perennial crop and its water requirement is equivalent to the combined requirement of cotton and wheat crops. The ET of sugarcane crop varies between 1-4.5 mm/day starting from November to October next year. In the joint case of cotton and wheat, crop water requirement fluctuates between 1-3.5 mm/day starting from November to October next year. Monthly trend lines are showing increasing tendency of water requirement for sugarcane crops during 2007-2017, therefore, water requirement for sugarcane crop is going to increase over in case of further increase in annual temperature (Figure 30).

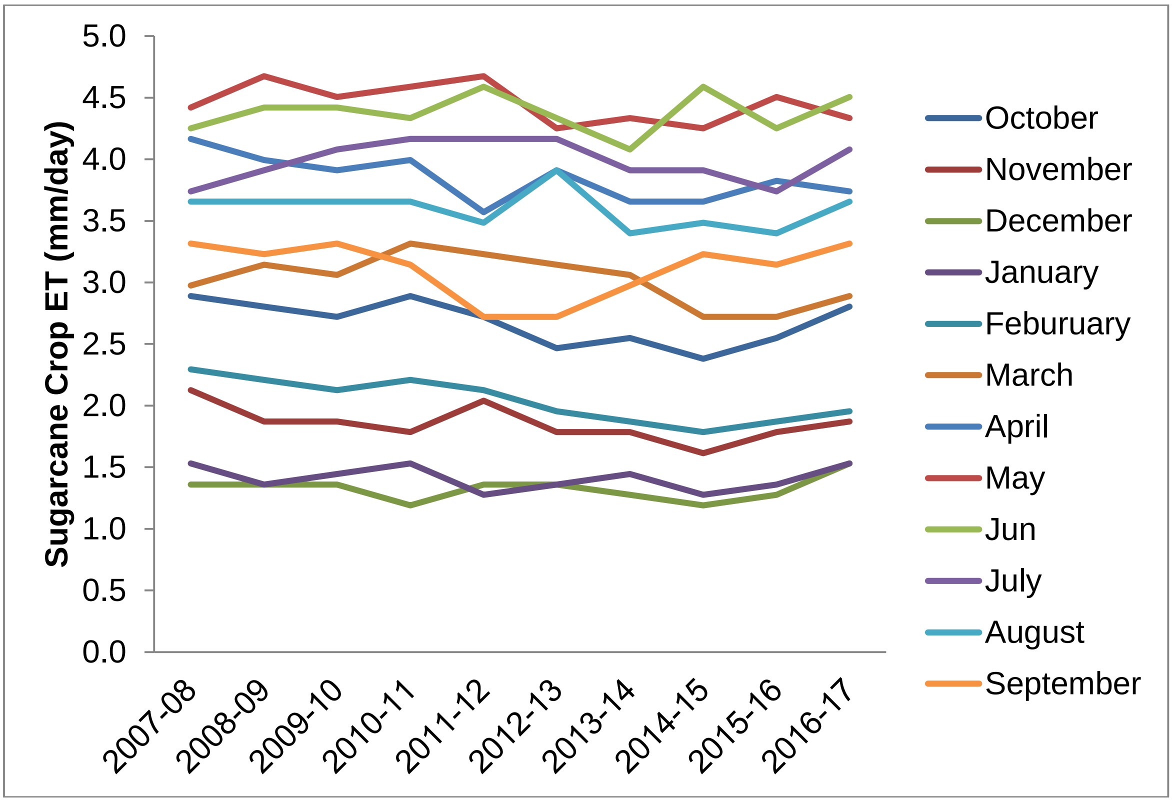


Figure 21: Sugarcane water requirement (ET)- Mir Pur Khas Station

Padidan station is representative of Nushehroferoze district containing mainly; Sugarcane, Cotton and Wheat crops. Sugarcane is not a principle crop but given the perennial supply of water through Rohri canal across the year, sugarcane is becoming a popular crop in this district. Farmers also experiment cultivation of rice crop subject to factors other than water availability.

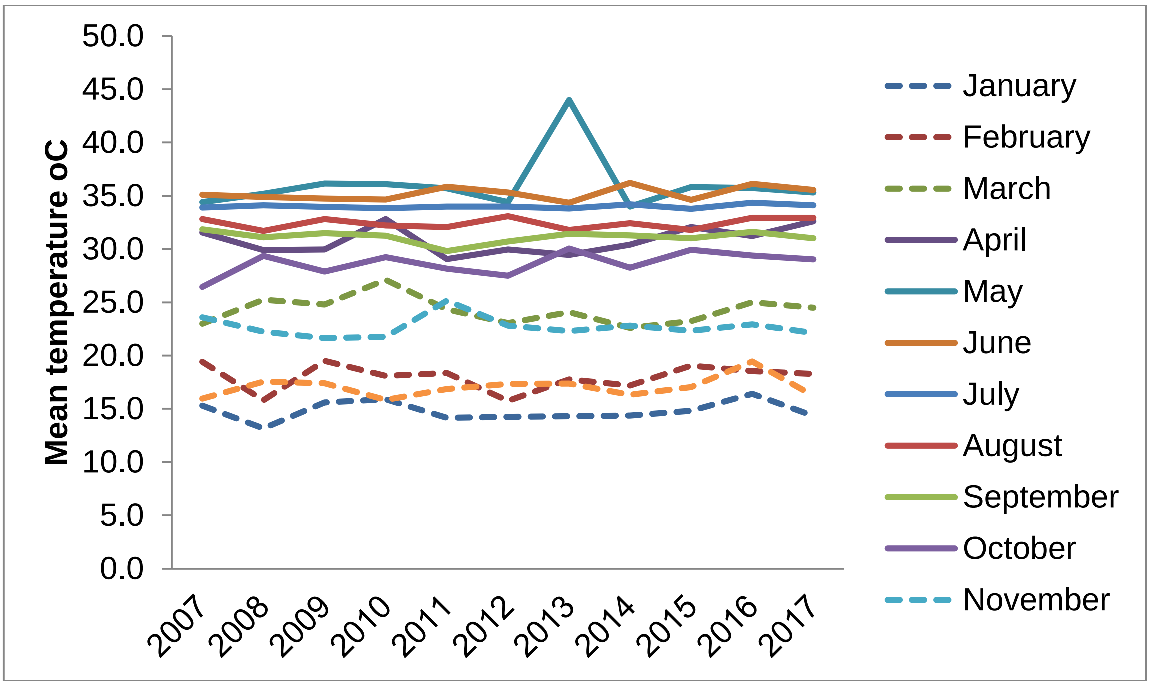


Figure 22: Mean temperature variations (2007-17)-Paddidan

Paddidan is the first station in Sindh that has recorded heat wave during May, 2013 with a 44^{o}C mean temperature (Figure 31). Rest of the months showed linear temperature trend with little or no increase over a decade. March and November months have also shown increasing temperature trends in comparison to the summer months. The precipitation trend also shows a relatively dry month of May during 2013. December 2008 represents a correlation with districts of upper Sindh, only recorded rainfall event during this period of the year. August and September months 2011 received peak rainfalls over the studied period. Rainfall in Kharif months have not followed a continuous trend; in the month of July only three substantial rainfall events were recorded, 04 in August, and 03 in June whereas rest of the year remained mostly dry (Figure 32).

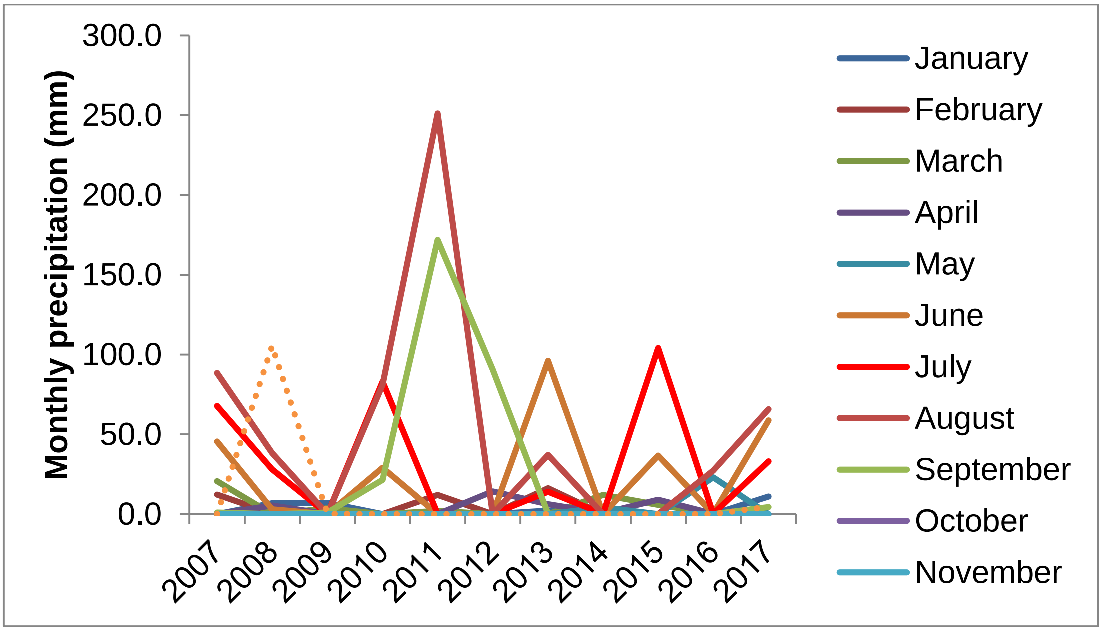


Figure 23: Precipitation variations at Padidan station

The climate of Naushehroferoze district justifies the perennial high water allowance for the districts of Rohri Canal, however, some significant rainfall events may cause more harm to crops compared to benefit. A continuous supply of canal water in additional to a 24 hour rainfall event equalling 50 mm and above may become detrimental to cash crops such as Cotton. The wheat crop on the other hand has remain in safe zone from untimely rainfall, increasing temperature during winter months may have certain impact on early maturity of wheat crop (Figure 33).

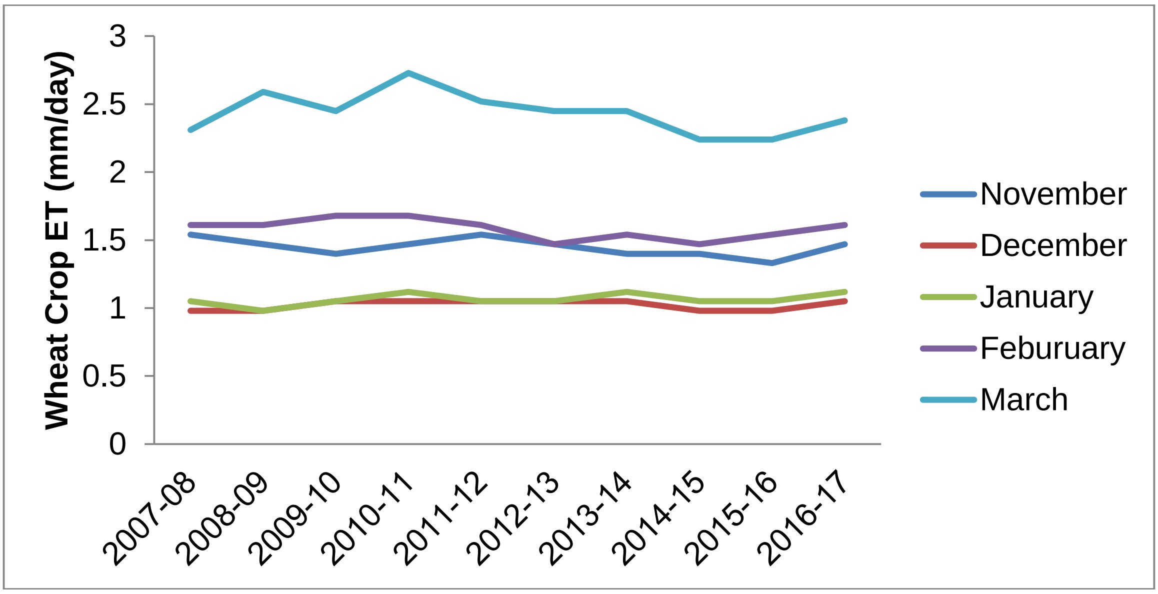


Figure 24: Wheat crop water requirement (ET)- Padidan

Water requirement for wheat crop followed a linear trend except for the month of March, which is indicating an increasing trend. The crop water consumption was peaked in 2010-11 March and then lowered during 2015-16 showing no variation on average. Sugarcane and cotton crop being high delta crop and falling in Kharif months show more variability of water requirement over the year. During heat wave May 2013, crop water requirement of both crops increased, but in May 2011 ET was 0.2 mm/day for Cotton crop and 0.1 mm/day for sugarcane crop compared to year 2013. This rise in ET was preceded and followed by a decline in water requirements during the consecutive years. Due to the abundant supply of canal water, these temperature variations are not a shock for the crop. In fact a high amount of per acre water allocation exists for Rohri canal command districts.

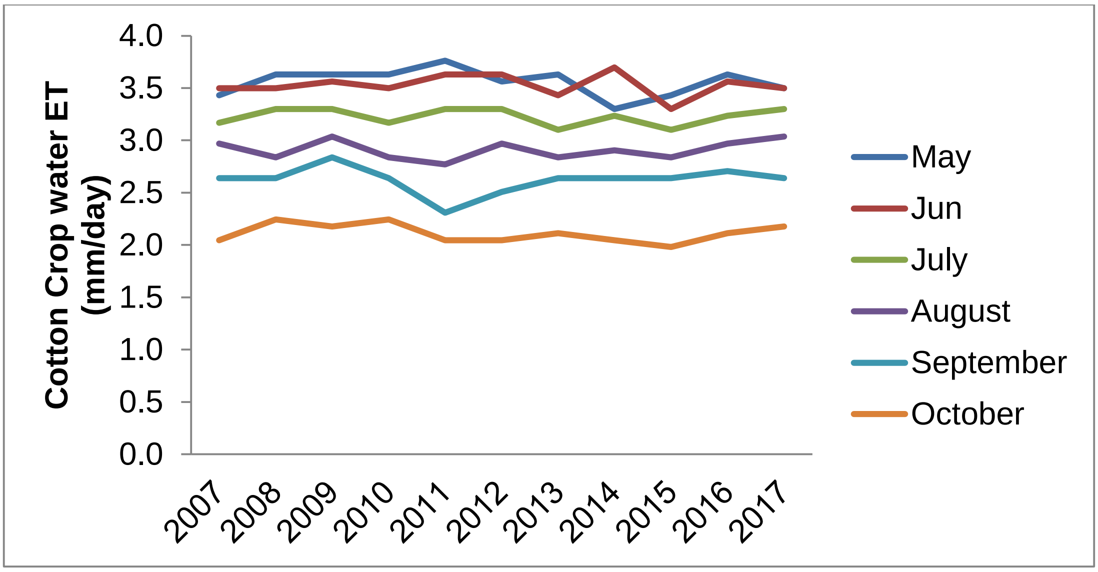


Figure 25: Cotton crop water requirement (ET)-Padidan

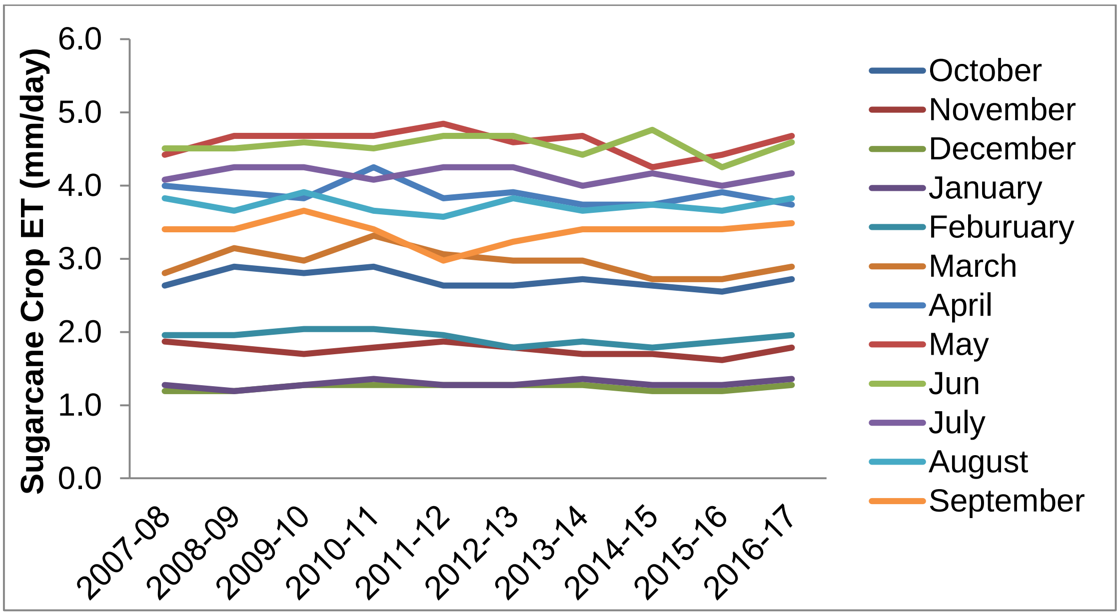


Figure 26: Sugarcane crop water requirement (ET)- Padidan

Tandojam located adjacent to district mitiari, Hyderabad, Jamshoro forms the mix cropping irrigated zone located in the command of perennial Rohri canal. A comparison of average of daily mean temperature during 2007-17 shows a sharp decline in August 2012 temperature by 15ºC. This is the rarest example of cold wave during summer months (Figure 36).

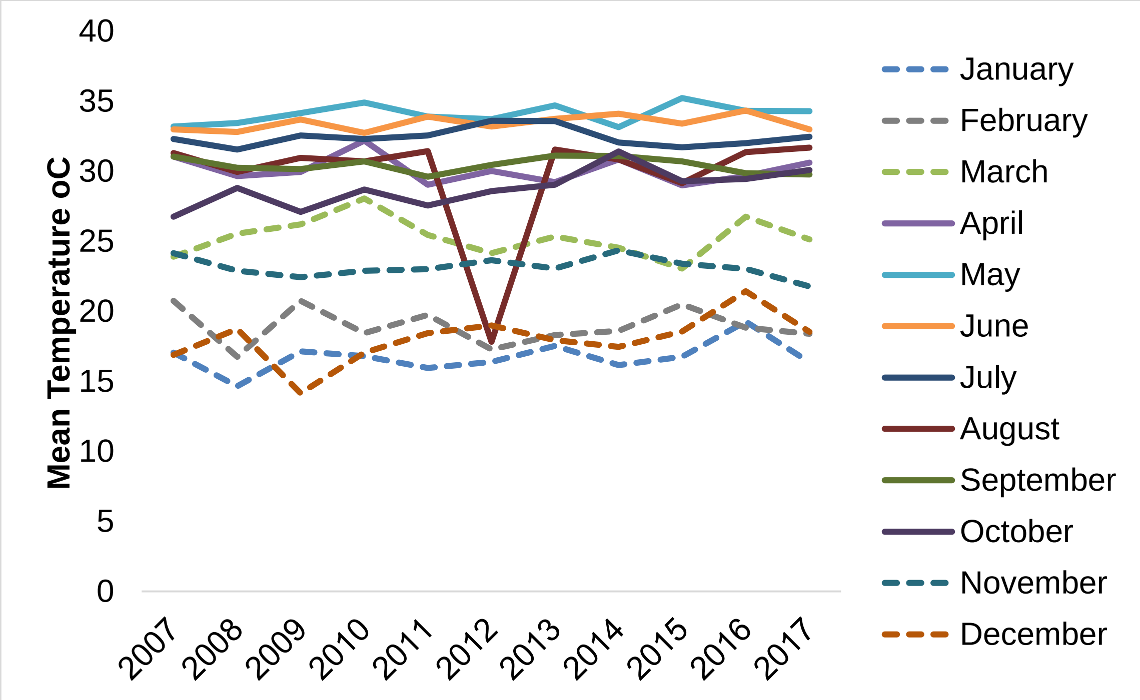


Figure 27: Temperature variations at Tandojam stations (2007-17)

The decadal temperature variation hints towards lowing of winter temperature whereas the summer months follow a linear temperature trend. Rainfall trend, even during monsoon months has shown record low since 2014 onward. Peak rainfall event was received during September 2011 followed by three peak rainfall events during August 2008, 2010, 2011 and 2013. Rainfall during month of July remained consistent between years 2008-11 up to 100 mm whereas June month has only received good rainfall during 2008 and 2010 (Figure 37).

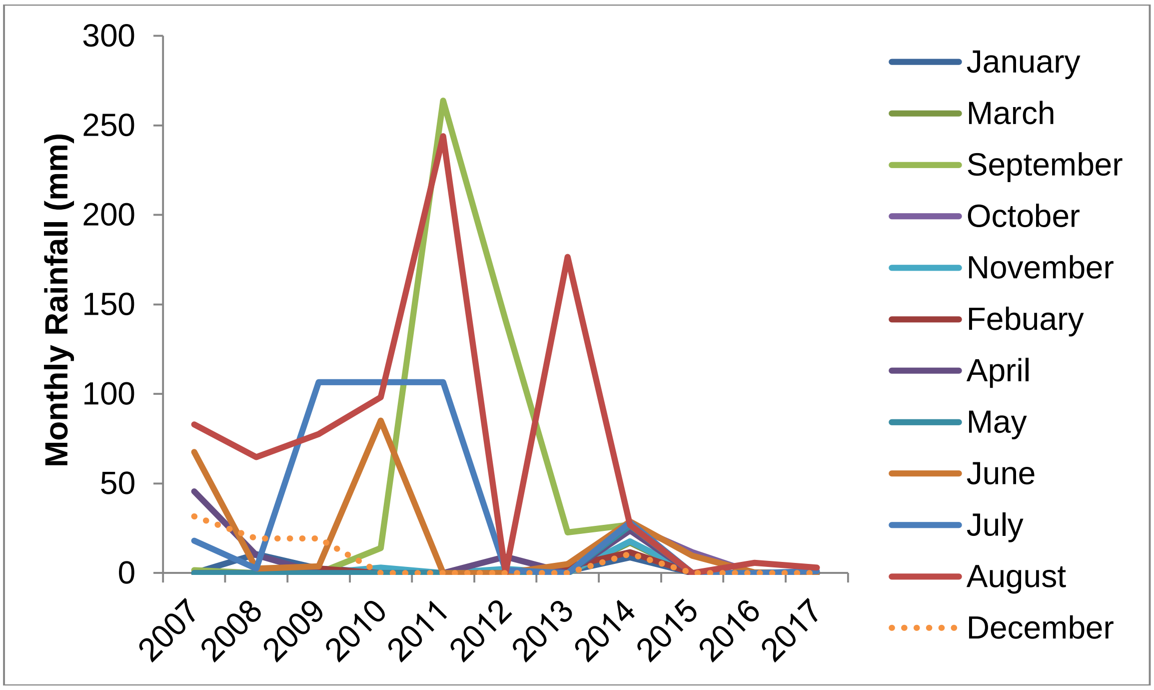


Figure 28: Precipitation variations (2007-17) Tandojam

Climate trend shows increasing day time temperature, reduced precipitation and high evapotranspiration which is resulting into higher crop water demand up to year 2012-13. During March, crop water requirement has remained the highest which is increasing gradually. These climate heat waves during March enable farmers to harvest crop earlier than previous years. In rest of the Rabi month except March, crop water requirement is showing reduced trend by higher than that of year 2007-08 (Figure 38).

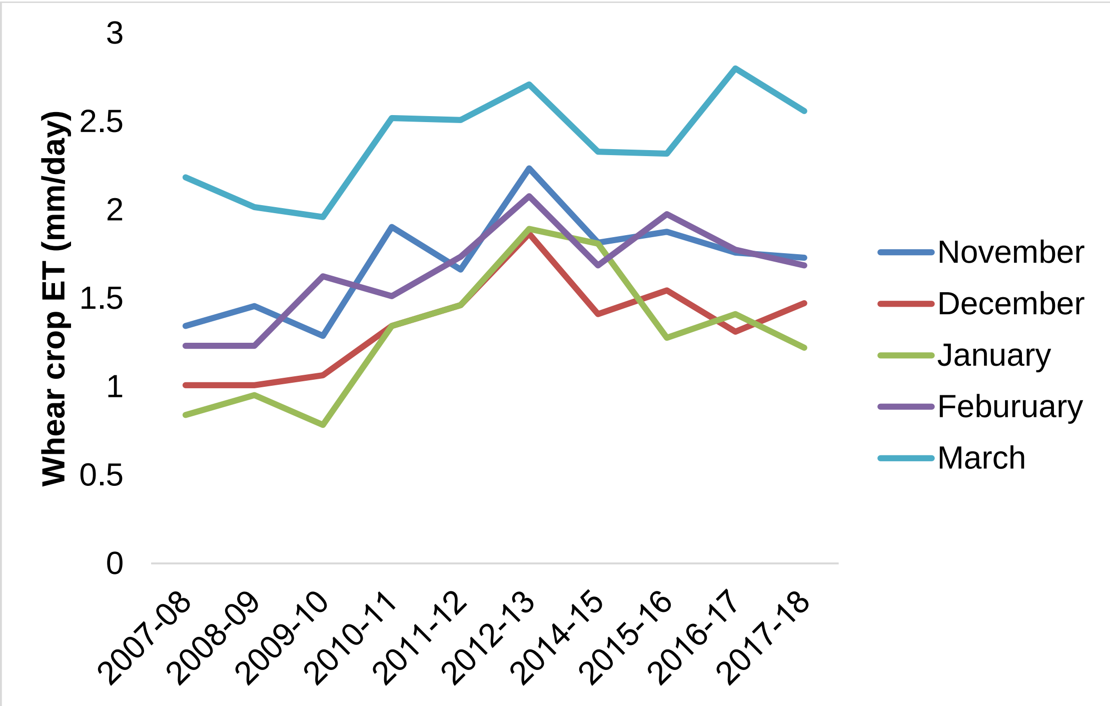


Figure 29: Water requirement (ET) of wheat crop- Tandojam

Cotton crop is the major Kharif crop in this part of Sindh province whereas rest of the crops include vegetable, fruits and pulses. Cotton crop for bringing immediate cash relief to the farmer is a preferable cultivation choice for farmers. Water requirement of cotton crop has increased over 10 year period of study by approximately 40% across all cropping month. Due to consistent dry climate and minimal precipitation since 2014, reliance on canal water has increased.

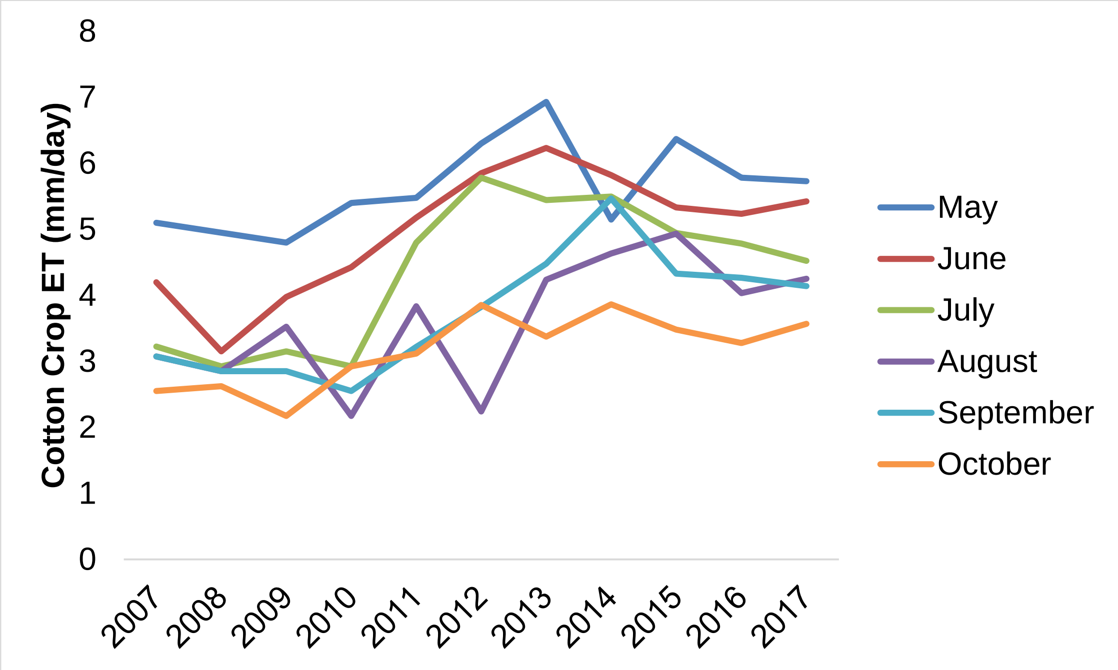


Figure 30: Water requirement (ET) of Cotton crop- Tandojam

Sugarcane is the additional crop in this cropping zone which grows along with routine crops such as wheat and cotton. During the observation period crop water requirement of sugarcane crop vary between 0.98 mm/day to 6.46 mm/day. A monthly analysis of this crop over a period of 10 years shows an increase in crop water requirement both in summer and winter months; highest in August and September and lowest in March. Event in August 2012, crop water requirement remained among highest values of the observation period (Figure 40).

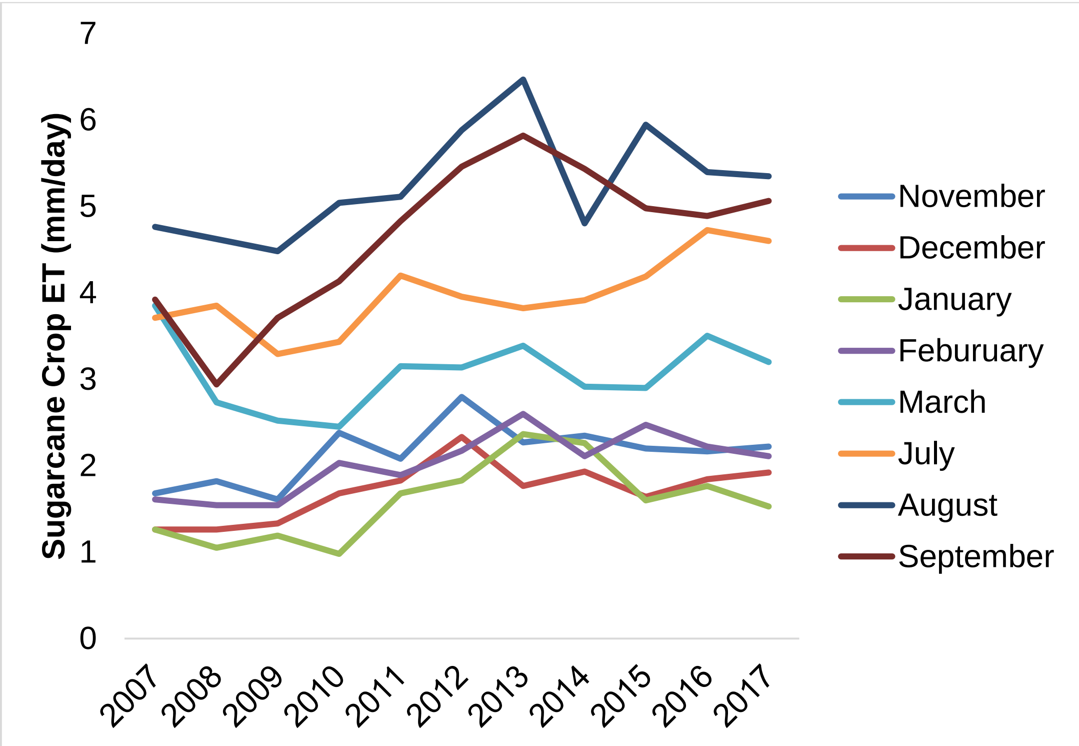


Figure 31: Water requirement (ET) of sugarcane- Tandojam

Punjab Province

The irrigated cropping zones of Punjab Province are covered by 10 agro-met stations of Pakistan Meteorological Department. The Agro-met station of Faisalabad represents respective irrigated zone representing Chiniot, Faisalabad and Toba Tek Singh. The Jhang District also a part of Faisalabad irrigated zone but it has its independent Agro-met station. Unlike Sindh, in Punjab Rabi Season comprise of 5 months starting from November to April. According to study period data, coldest month during Rabi season is January and hottest month is April preceded by March. These two months are critical for the production and higher water productivity of wheat crop. Over a decade of observation, the mean temperature of February and March has risen by 0.8-1.5ºC (Figure 41). During Kharif months, average variations in temperature is linear except for the month of October showing recurring high and lows over the decade of observation. June is the warmest month that must have increased crop water requirement for cotton, sugarcane and rice crop.

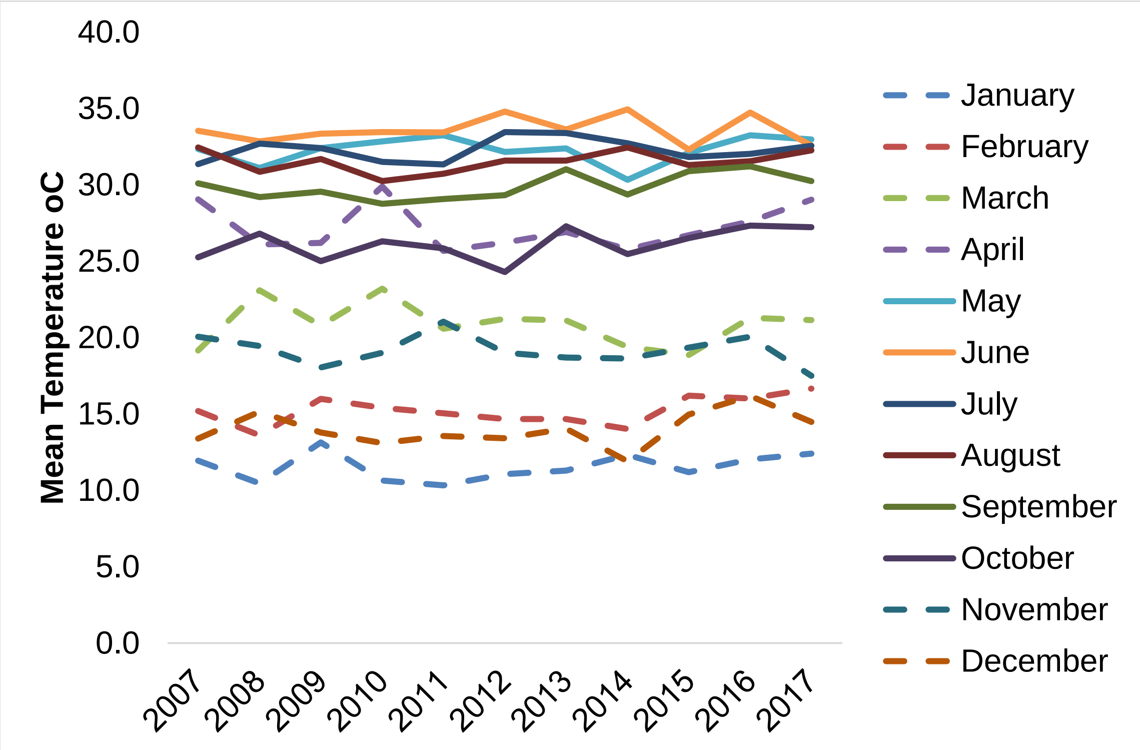


Figure 32: Mean monthly temperature variation-Faisalabad

Summer rainfall is spanning from May to September, high precipitation was recorded during years 2008, 2010, 2013, 2014 and 2016. In year 2017, rainfall has shown a decreasing trend, however, precipitation during Rabi months is increasing. These precipitation trends show a high contribution into crop water requirement and on some instance loss of crop due to flooding (Figure 42).

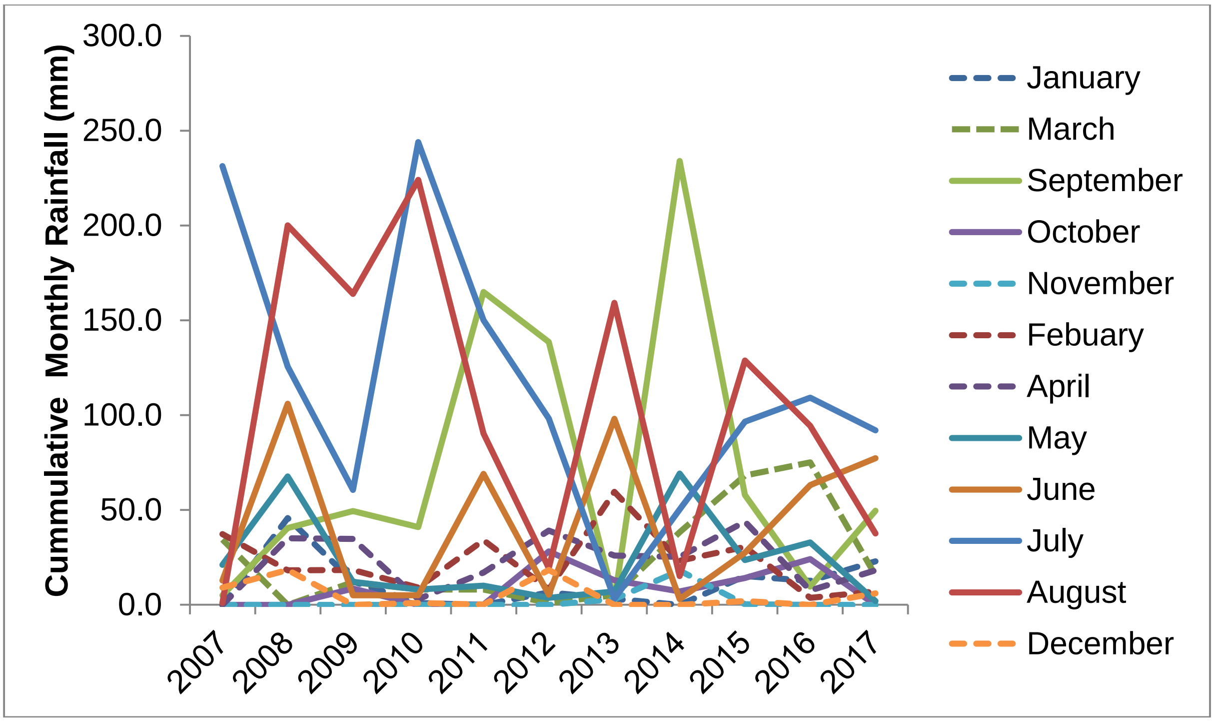


Figure 33: Cumulative Monthly rainfall- Faisalabad

A comparative observation of crop water consumed by wheat crop during 2007-2012 reveals that due to rise in temperature during month of March, 2010, crop water consumption raised by 0.192 mm/day. This rise is within the threshold of irrigation system and wheat crop itself (Figure 43).

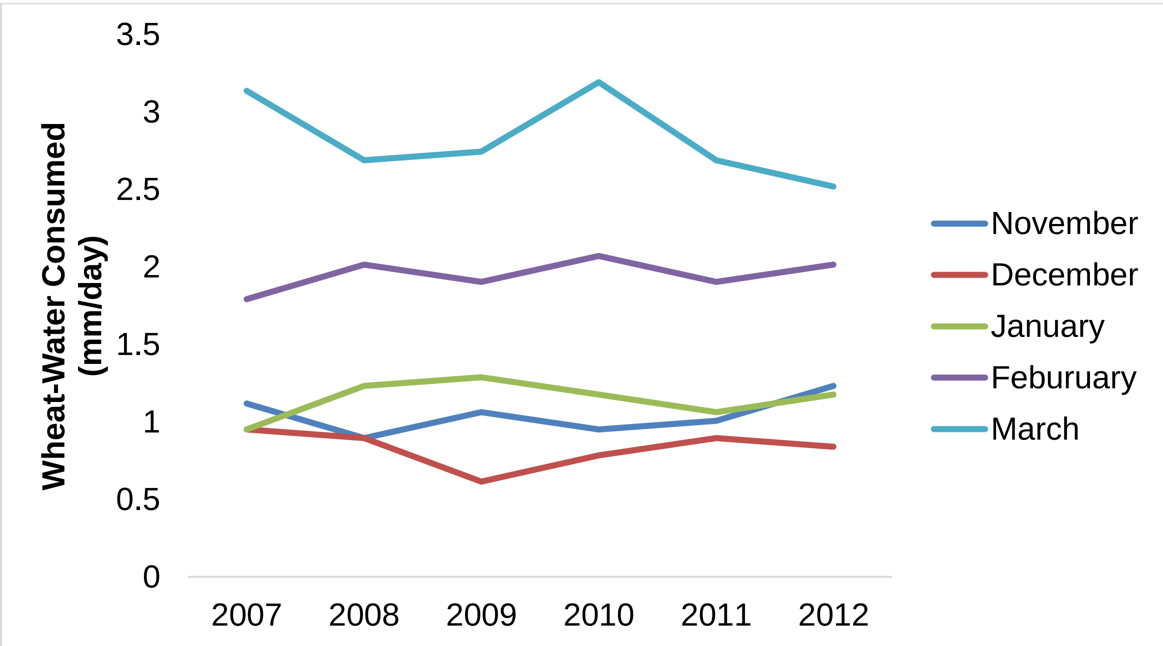


Figure 34: Wheat Crop water consumption- Faisalabad station

Like Wheat crop, water consumption by the sugarcane crop increased by temperature rise, for instance during March 2010, water consumption increased however reduced considerably during July 2010. Similar to minor variations in temperature over the decade, the crop water consumption rate by the sugarcane crop remained linear (Figure 44).

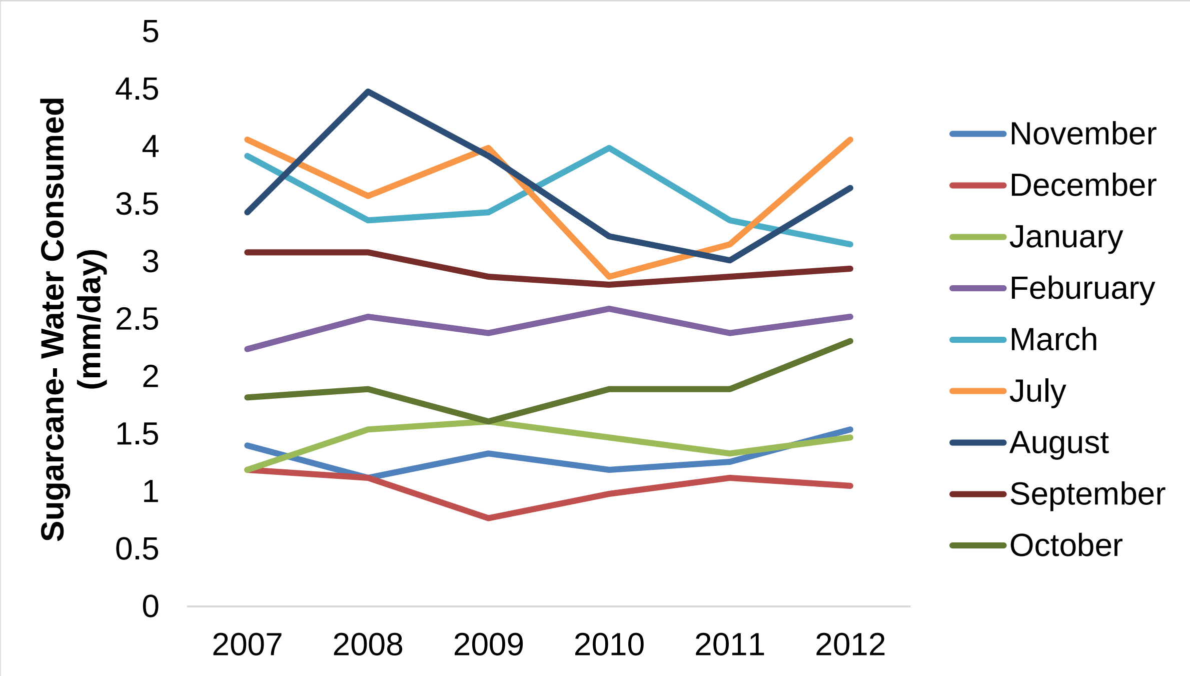


Figure 35: Water consumed by sugarcane crop (2007-12) - Faisalabad station

Water requirement of rice crop remained highest during August 2008 but reduced in 2010 attributed to peak rainfall season in 2010 at Faisalabad station. Except from month of September, water requirements during Kharif season (2007-12) has shown increasing trend (Figure 45).

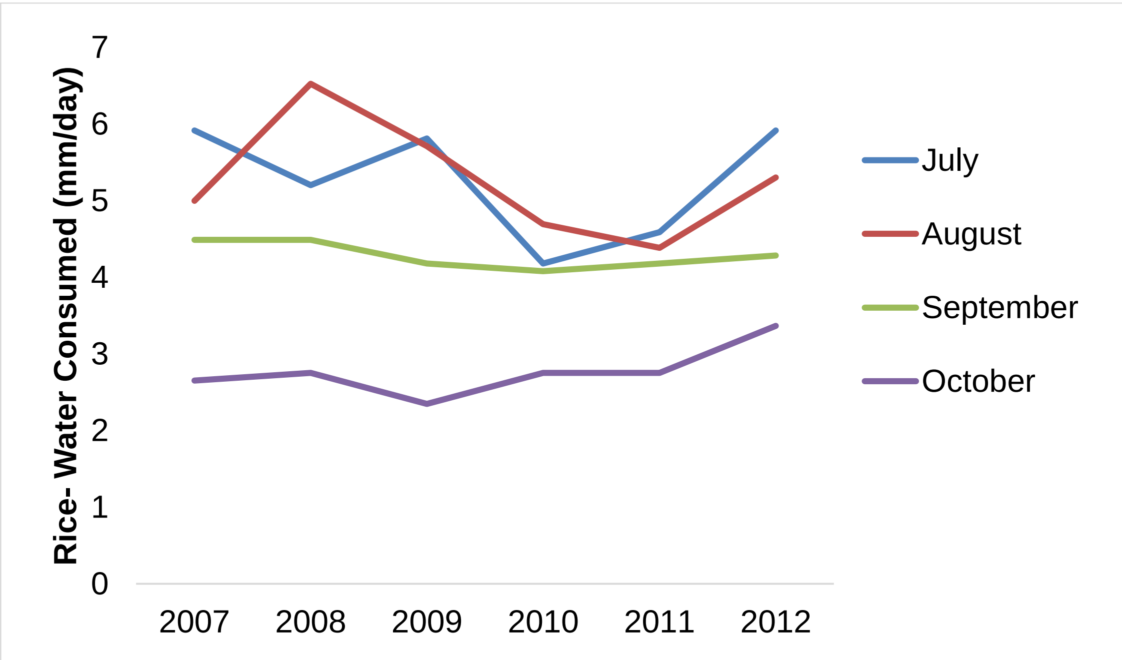


Figure 36: Crop water requirements of Rice crop (2007-12) – Faisalabad

Water requirement of sesame crop is competing with high delta crops such as Sugarcane and rice. In this crop too the water requirement seems to have been increasing due to temperature rise trend in Kharif months. However, more wet days during monsoon period tend to reduce water requirement of crops as observed during June, July and August month of 2010 and 2011 (Figure 46).

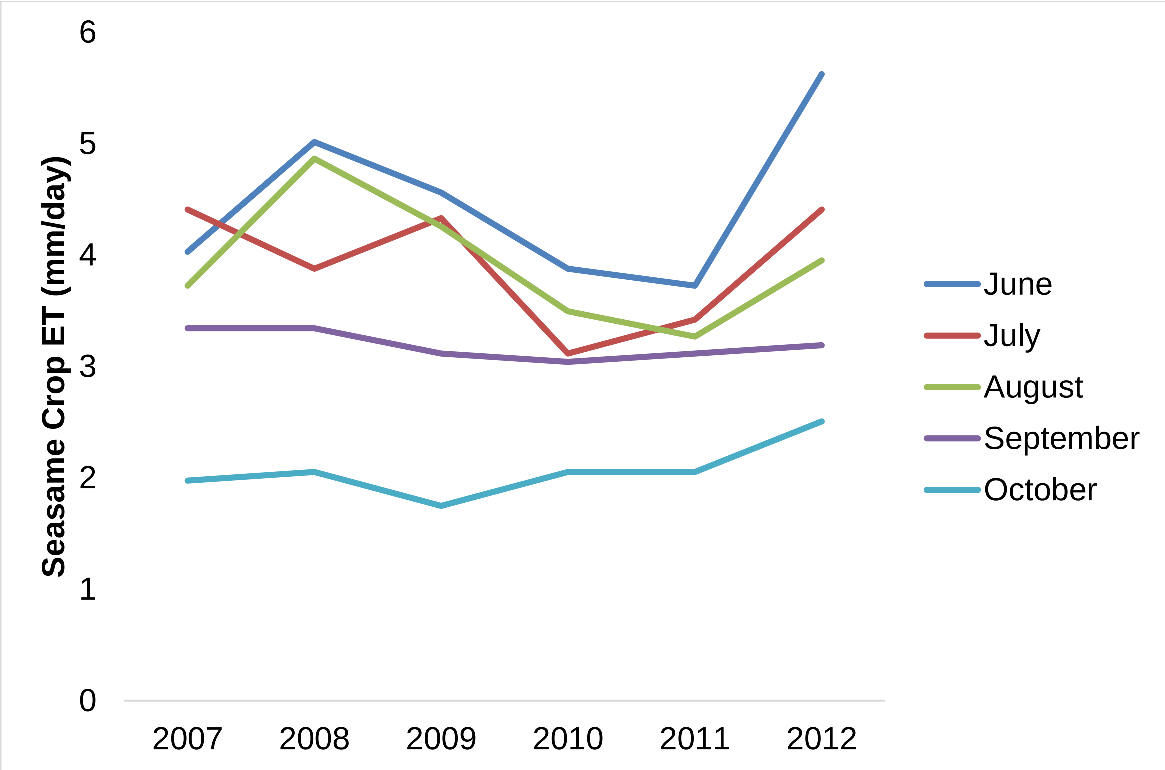


Figure 37: Water requirement of Sesame crop- Faisalabad station

Jhang district is a part of Faisalabad irrigation zone and Faisalabad division for development estimates. Considering the proximity of district Muzzaffargarh, agro-met observations for Jhang are also considered reference for this district.

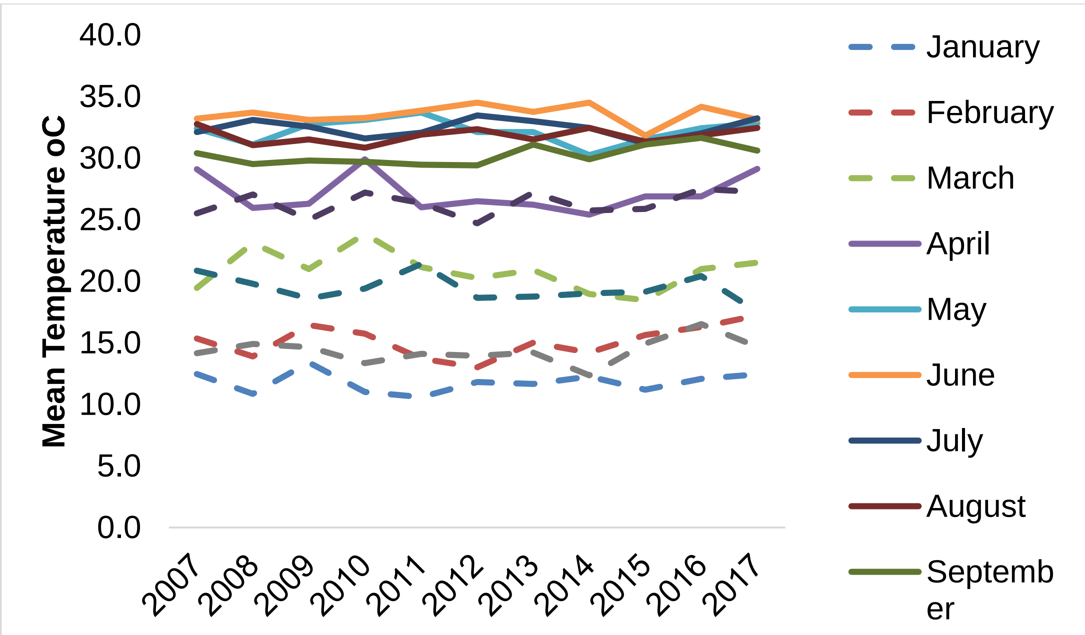


Figure 38: Temperature variations (2007-17) – Jhang

Temperature records for Jhang station depict higher variations in consecutive years but linear trends over decade (Figure 47). The summer and some of the winter months have also shown increase in temperature except for November and December. Peak in mean temperature was observed in year 2010 in April and March which was also observed in Sindh. Precipitation pattern in Jhang clearly reveal June, July, August and September months receiving substantial rainfall ranging from 37-300 mm in a day. Highest rainfall was recorded in July 2016, followed by August of same year. In 2010, a historical year of rainfall, precipitation during these monsoon months was high but not recorded at peak as in Sindh Province for most of the stations. Precipitation tendency is also increasing in late months of Rabi season; April and March which is a challenge for the ripening wheat crop (Figure 48).

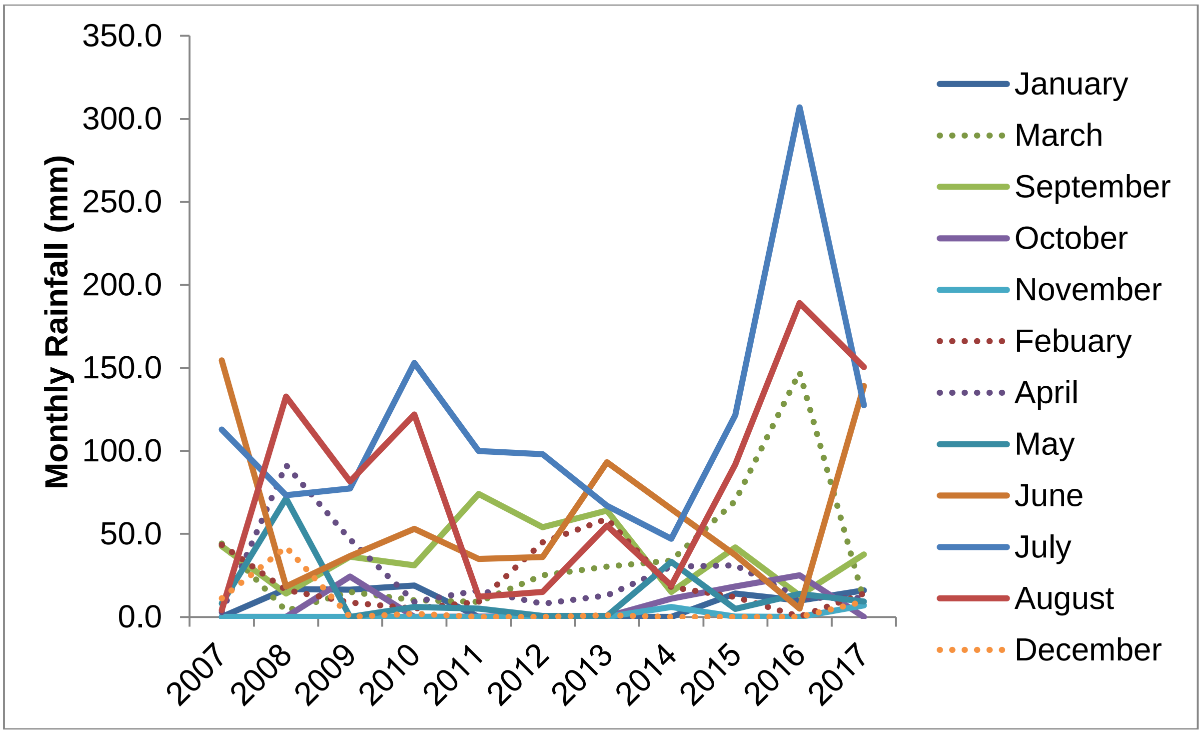
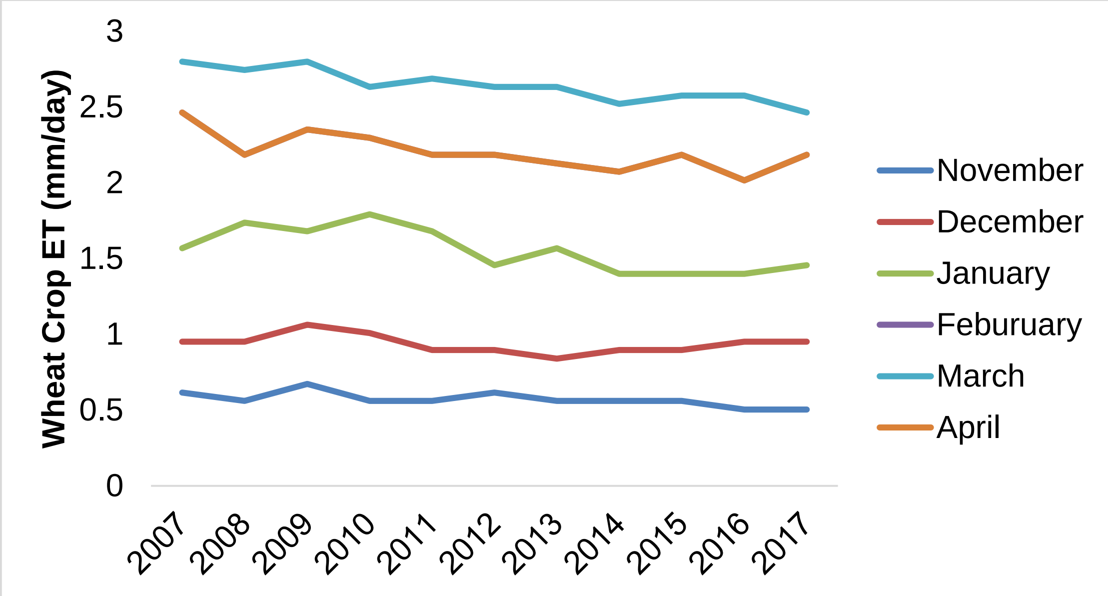


Figure 39: Precipitation variations (2007-17) in Jhang

Jhang station and its referenced districts, Jhang and Muzzafargarh are predominantly wheat and cotton zones with lesser cultivation trends towards rice and sugarcane. Therefore, crop water requirement of two major crops was observed (Figure 49).



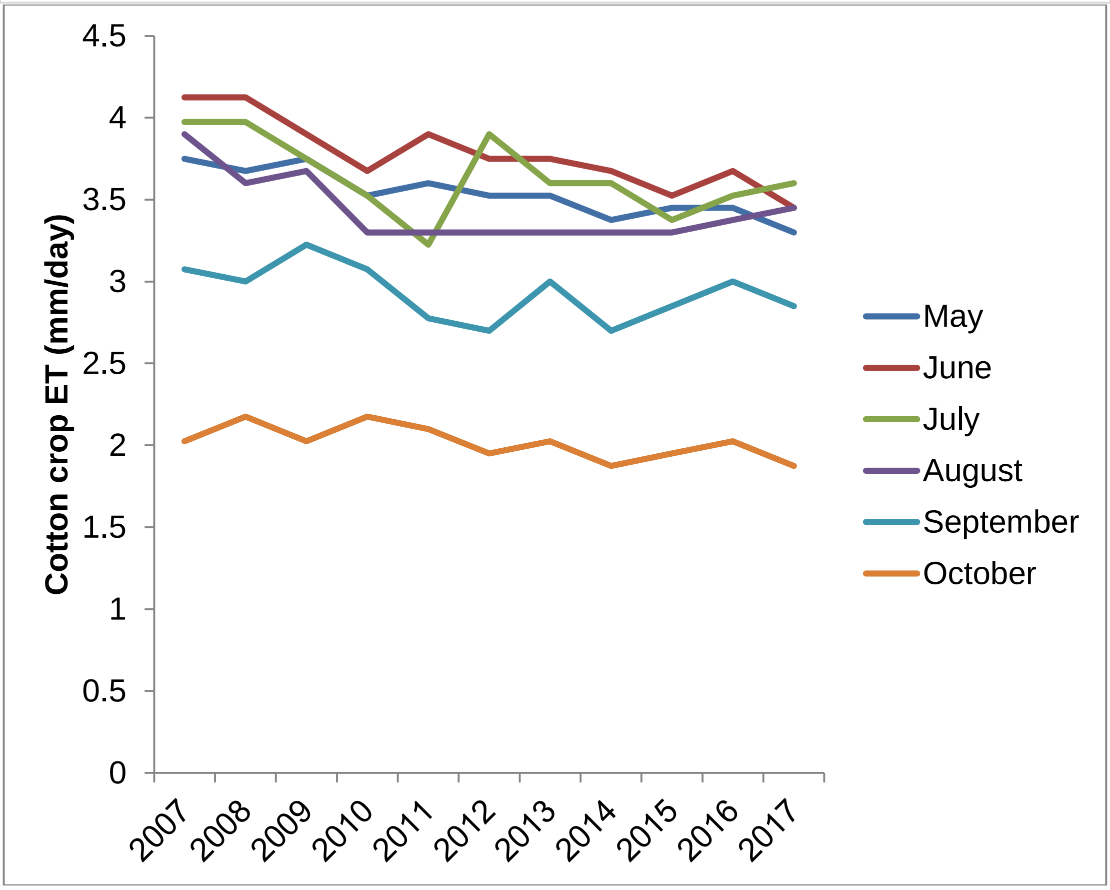


Figure 40: Water Requirements (ET) of Major crops- Jhang

Rabi season is a bit longer in Punjab compared to Sindh province, where harvesting of wheat crops begins by the mid of March month. Water requirement of wheat crop is a bit lower ranging from 0.5-2.7 mm/day showing a linear trend over 10 years with not much increase in water requirement for the crop. However, weather trends such as heavy rainfall associated with storms and high difference in day and night time temperature may cause losses to wheat crop on its harvesting stage. Cotton crop on the contrary is not susceptible to damage however; high rainfall events by the end of August may cause losses to cotton crop. Over the observation years, crop water requirement during Kharif months is showing a decline with consecutive fluctuations during July and September over the studies decade.

Mandi Bahauddin is one of the intensely cropped and irrigated districts of upper Punjab and its agro-met data is also considered as reference for Hafiz Abad district in this study because of geographical proximity and similarity in cropping pattern. Over a decade, the summer months recorded to have temperature 2-3ºC in comparison to the normal weather trend of the studied period. This temperature rise was observed during 2012, 2013 and 2016. This slight change in mean average monthly temperature may have impacted the crop water requirements of summer crops during early days of sowing. Similarly, month of April is also showing temperature rise trend reaching at peak during 2010 (Figure 50).

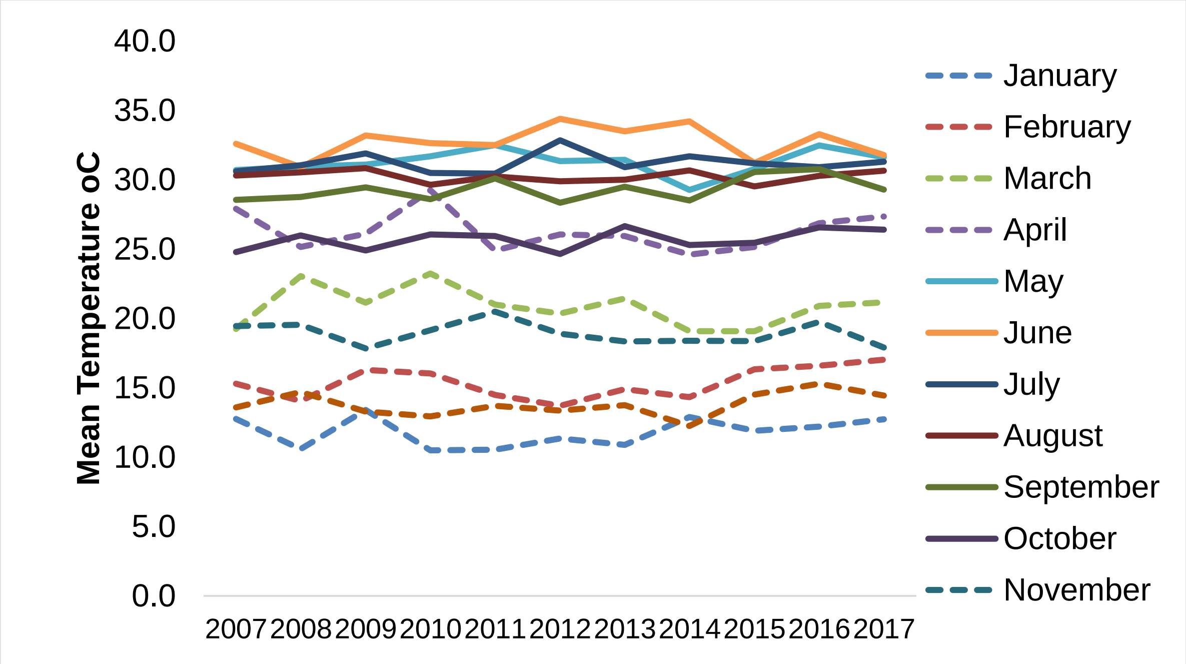


Figure 41: Temperature variations (2007-17)- Mandi Bahauddin

Temperature also fluctuated variably during winter months of years studies, for instance February, March and December are showing temperature rise tendency, whereas November is recorded to have declining temperature. Similar to temperature, precipitation trend has also represented variable tendency over the years (Figure 51).

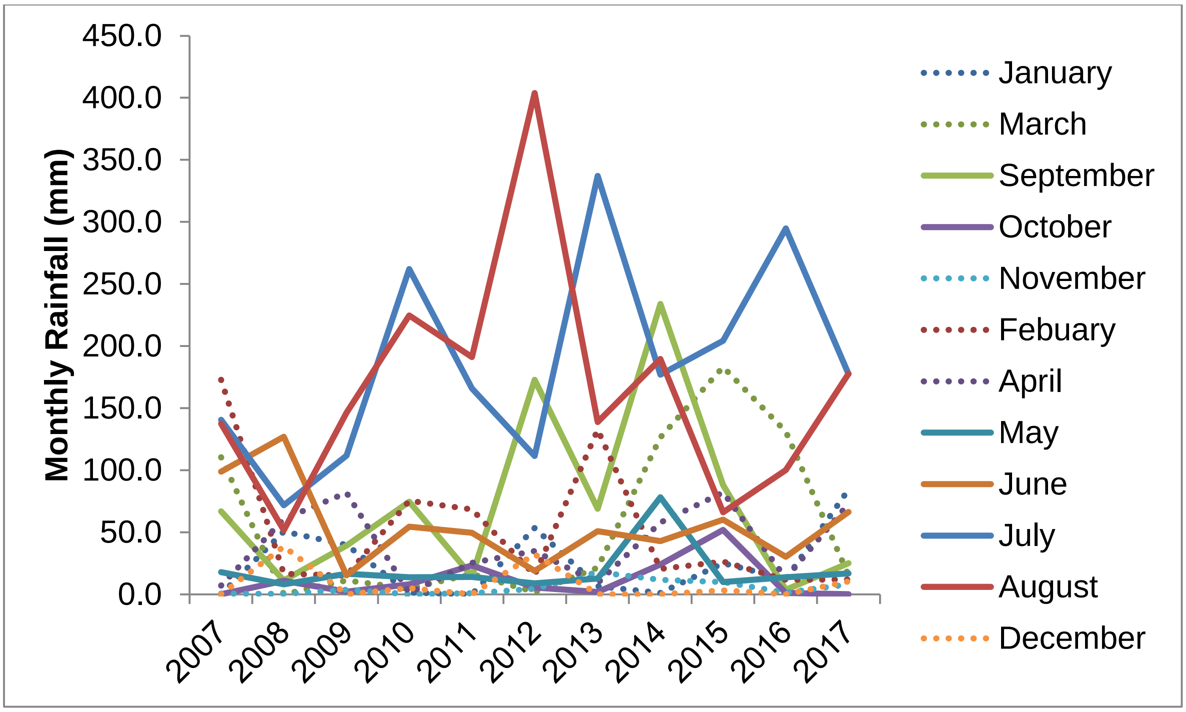


Figure 42: Precipitation variations (2007-17)- Mandi Bahauddin

The data shows higher rainfall contribution in Rabi season during last month's considerably a threat to maturing wheat crop. Rainfall peaks in February is shifting toward March from year 2013-16. Similarly, higher precipitation during April is on the rise. During Kharif months, peak rainfall event was recorded in August 2012, followed by July 2013, 2016 and 2010, September 2012-15. None of these rainfall event superimpose except for August and September. A general glimpse of precipitation pattern reveals a very active monsoon starting from the month of July to September that is beneficial for the high delta Kharif crop of the areas; Rice and Sugarcane. This high availability of rainwater during Kharif season reduces the need for surface water supply which becomes merely a surplus flowing in canals. In Mandi Bahauddin region; Rice and Wheat are major crops whereas sugarcane is less popular choice among the farmer of both districts (Figure 52).

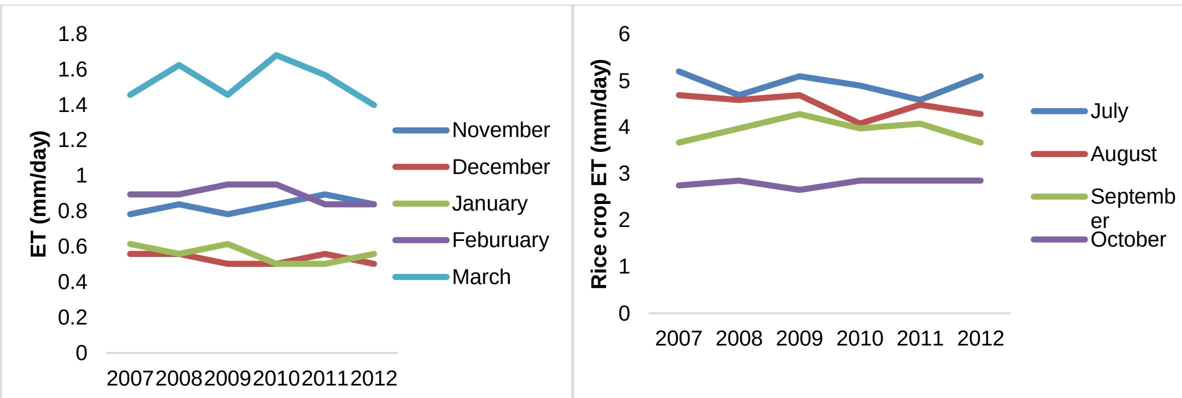


Figure 43: Water requirements (ET) of Major crops- Mandi bahauddin

Rabi month March 2010 indicates highest water requirement of wheat crop during the record temperature year. On the entity, water requirement of wheat crop ranges between 0.68-1.68 mm/day during entire cropping period. High precipitation trends in later months of Rabi have the potential to reduce canal water required by the wheat crop. In Kharif months of July August and September show a high crop water requirement for the rice crop, but these months are also the moistest months of the year (Figure 45). In the specific case of Mandi bahauddin, climate trends are in agreement to the crop water requirement but also an indication of high floods if these rainfall events are not scattered over a month.

The second rice-wheat zone of Upper Punjab region is Sialkot and its surrounding districts; Narowal, Gujranwala and Gujrat. Other common and less popular crops are mustard, sugarcane and vegetables. Over the studied decade, temperature variations in Sialkot districts are highly variables. Unlike other districts, of Punjab and Sindh, average mean temperature of March and November are almost similar. Kharif side, October month is colder than April months making Rabi season prolonged into Kharif season starting from warm May. Temperature peaks were observed during April and March 2010 indicating a country wide dry Rabi period and heat wave. Warmest month of the year is June that has represented consecutive high and lows during 2007-17 (Figure 53). It is quite significant from the recorded data that in Sialkot district and its allied stations summer months are showing reducing temperature with consistent heat waves and winter months are becoming warmer with consistent cold waves. Precipitation trends in Rabi season are representing higher precipitation during March and April months, a peak harvesting season for Wheat crop (Figure 54). Very less likely rainfall events during early months of Rabi season. Peak rainfall event was recorded in August 2013 followed by September 2014.

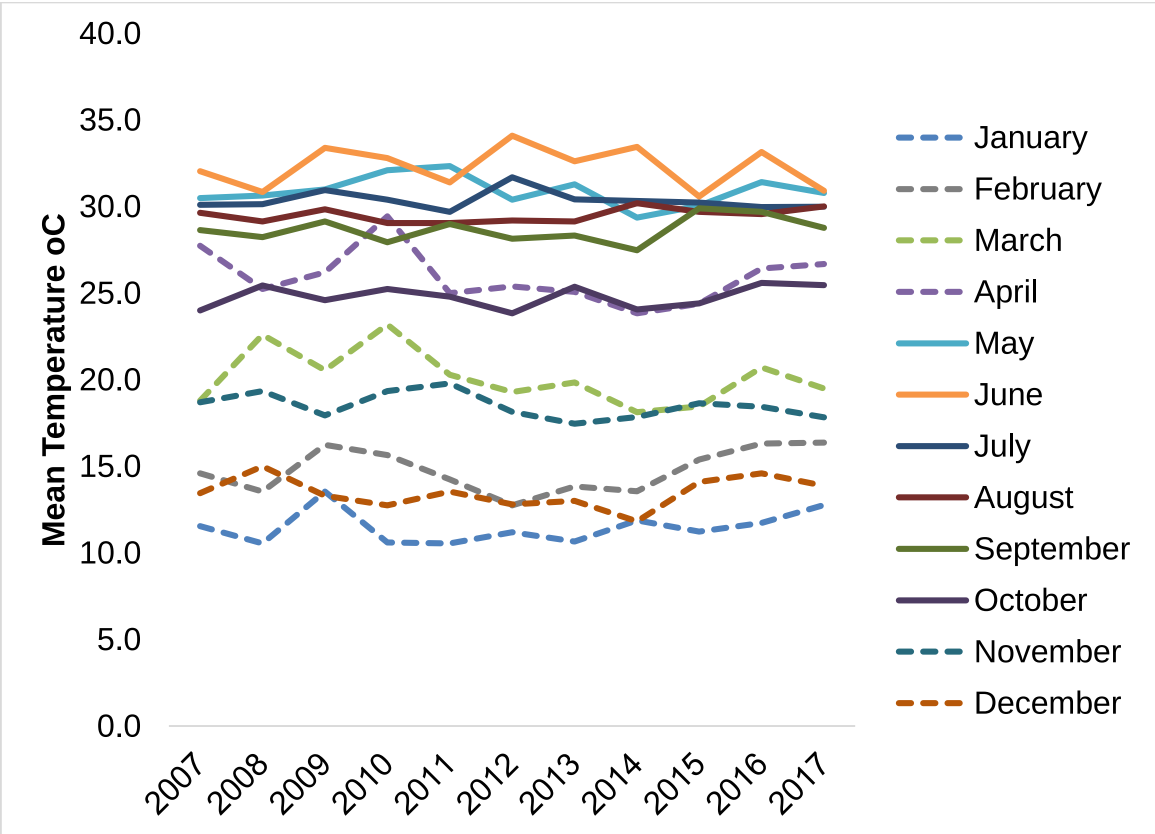


Figure 44: Temperature variations (2007-17)-Sialkot

A significant change for the climate of this region is a single record of 500 mm monthly rainfall in month of September seconded only by 143 mm rainfall event in 2011. High rainfall was recorded more frequently during July except for a relatively drier year in 2011 and 2016. Precipitation trends in August month somehow follow trends of July month but still a monthly rainfall of 670 mm is challenging for the rice crop and relief from surface and groundwater utilization.

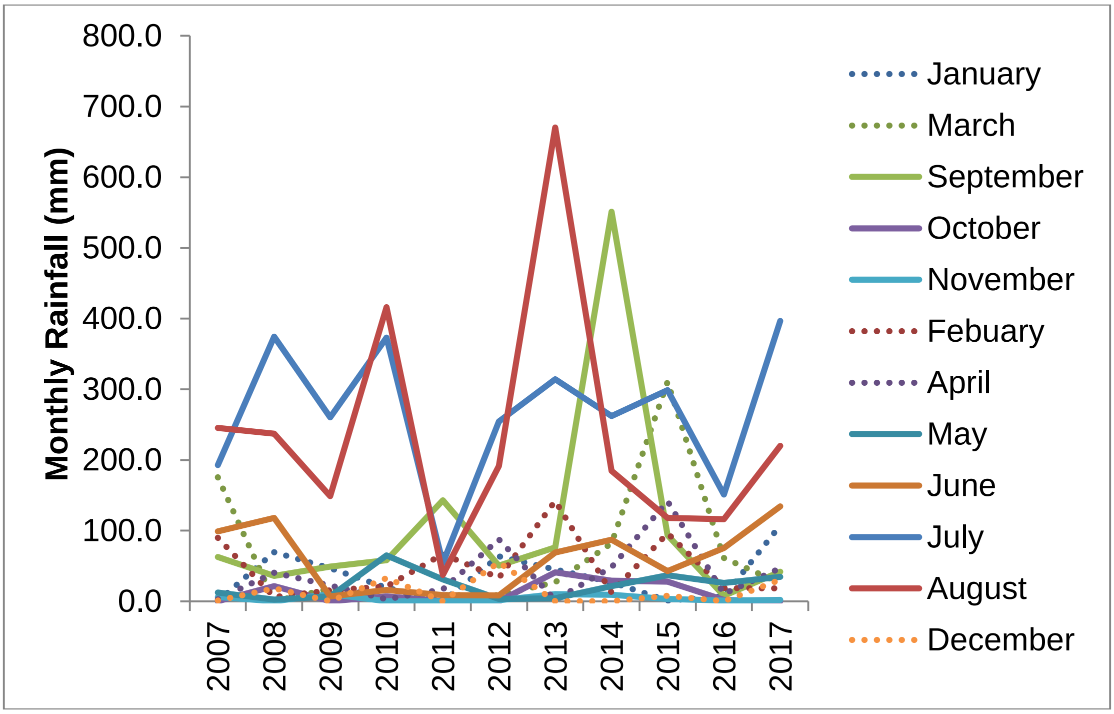
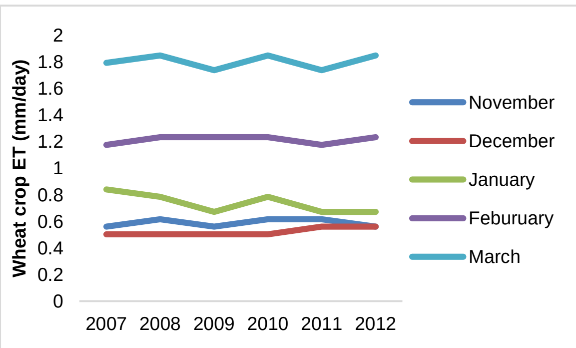


Figure 45: Precipitation variations (2007-17)- Sialkot

Crop water requirement trend is showing a picture similar to rising temperature in Rabi season, overall crop water requirement is increasing over the years during 2007-17. Temperature peak in March and January 2010 had increase daily requirement of wheat crop. On the contrary, rice crop is showing linear water requirement trends during July and August and declining daily water needs in September and October. The precipitation and temperature variability have not dangerously impacted crop water requirement of both crops creating canal water demand issues. On the contrary, untimely precipitation is challenging for wheat crop and excess rainfall during Kharif months is calling for water storage measures to enhance water availability during early Rabi months (Figure 55).



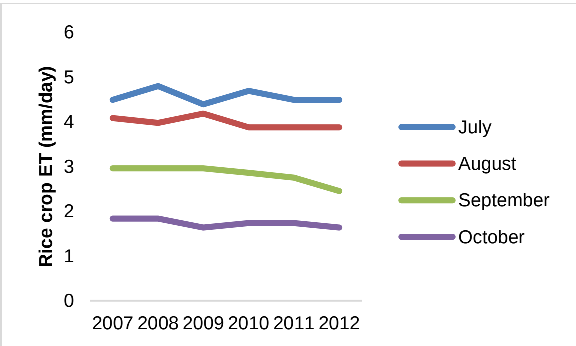


Figure 46: Water requirements (ET) of major crops – Sialkot

Lahore is an important part of upper Punjab of irrigated zone with agro-ecological conditions feasible for Rice-Wheat. The agro-met station of Lahore represents the irrigated districts of Sheikhupura, Nanakana Sahib, Kasoor and Lahore. Winter season in Lahore zone has not witnessed much variation if years 2007 and 2017 are observed as individual cases. In 2008, mean temperature during April, January and February months has shown a slight decline followed by an increase in 2009, these fluctuations continue until year 2017. In Kharif season, a temperature rise was observed during June and July months of year 2012 followed by temperature returning normal the next year (Figure 56).

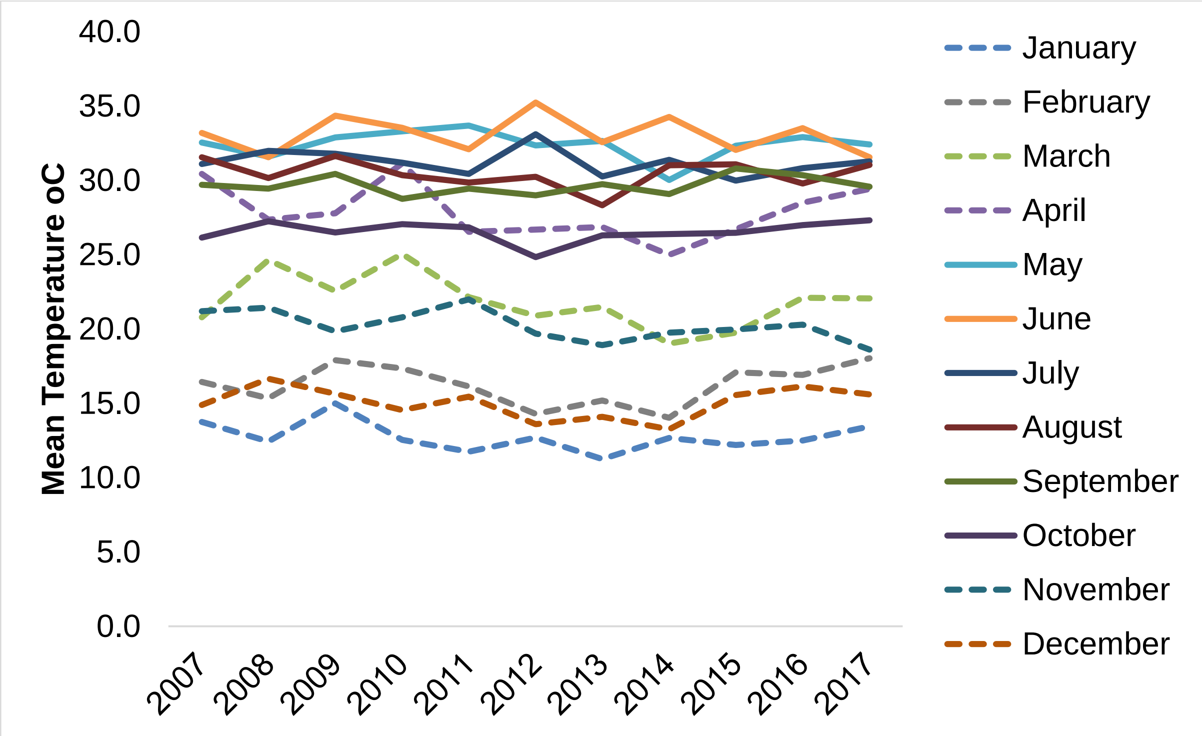


Figure 47: Temperature variations (2007-17)- Lahore

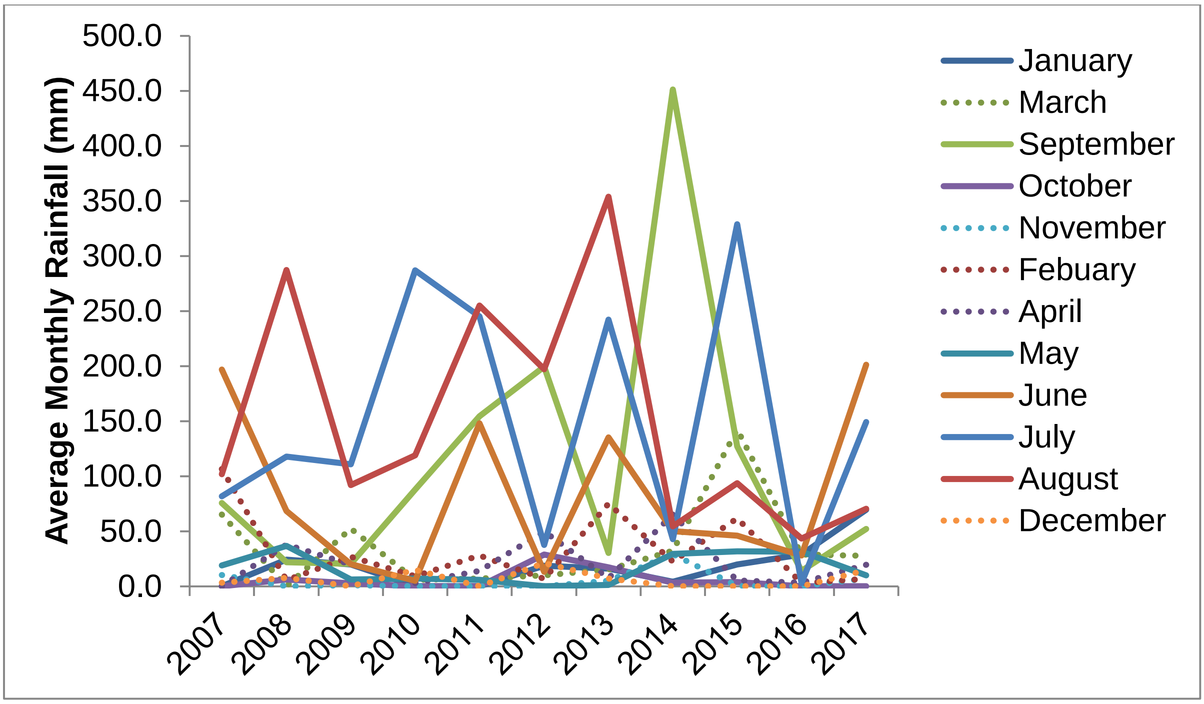


Figure 48: Precipitation variations during (2007-17)- Lahore

The precipitation date shows a high cumulative annual rainfall in Lahore during summer and winter months (Figure 57). In 2014, peak rainfall of the decade was recorded during September which also caused flood in Ravi River. In general, Lahore zone receive high monsoon rainfall during June 15 to September 15 each year. Trend of low intensity rainfall during Rabi season is also common but such events are shifted from December-January in 2007-09 to February-March by year 2013 and onward. This shift in rainfall pattern has enhanced reliance of crops on canal water during early months of Rabi season. Increasing rainfall trend in late Rabi season coupled with increasing temperature is not beneficial for mature wheat crop. Rainfall accompanied by high speed wind may result in crop lodging reducing per unit crop yield for wheat crop (Figure 58).

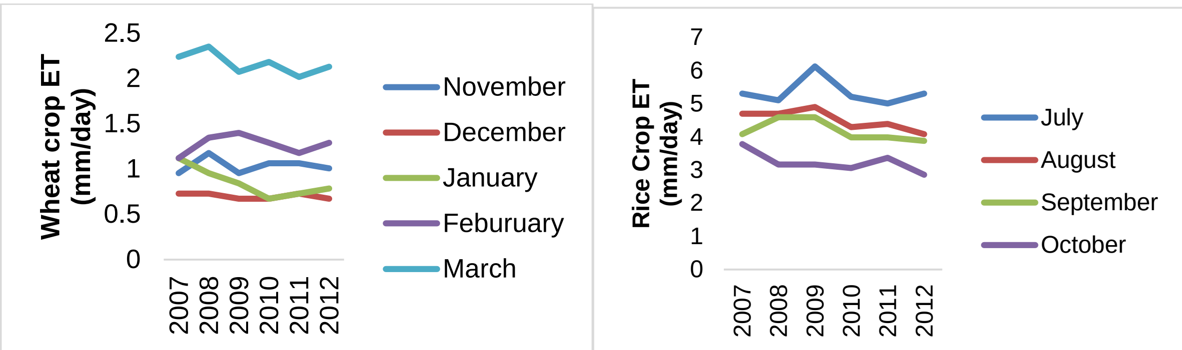


Figure 49: Water Requirements (ET) of Major Crops- Lahore

Water requirement of rice crop reached to the highest value of 6.12 mm/day in July 2009 and after a decline in 2010, it continues to rise up to year 2012. During rest of the Kharif months, crop water requirement has shown a declining trend over an observation period of 05 years (2007-12). Precipitation and temperature during 2012-17 shown alternate high lows which certainly contain an impact on crop water requirement of rice crop. These trends show linear impact of climate changes over the years on Kharif crop. On the contrary, in Rabi season temperature and crop water requirement continues to rise. Increasing rainfall intensity during February and March may add into the water balance for Rabi season.

Sargodha division and its allied districts located at the north of Lahore is a mix cropping zone with having high trend for orchards, wheat, rice, Sugarcane and Maize as dominant crops. Over the year's rice cultivation trend has reduced which is replaced by maize cultivation particularly in Sargodha district in comparison to Mianwali, Bhakkar and Khushab districts of this division. Agro-met station located in Sargodha is taken as reference to determine water requirements of major field crops; Wheat, Sugarcane and Maize.

Temperature trends has remained similar to that of Lahore stations, alternate high and lows during winter months and an increasing trend in mean temperature of the day during February and March months (Figure 59). A temperature peak was recorded during winter and early summer month of Year 2009 and early Kharif months of year 2010. In comparison of individual years; 2007 and 2017 temperature and of August and September months seems to have risen, but September month is showing an alternate high and low trend that is likely to follow in upcoming years. Precipitation trends for Sargodha station reveal a homogenous frequency of rainfall during summer and winter months. During the studies years, only two rainfall events in December were recorded that were higher than 10 mm (Figure 60).

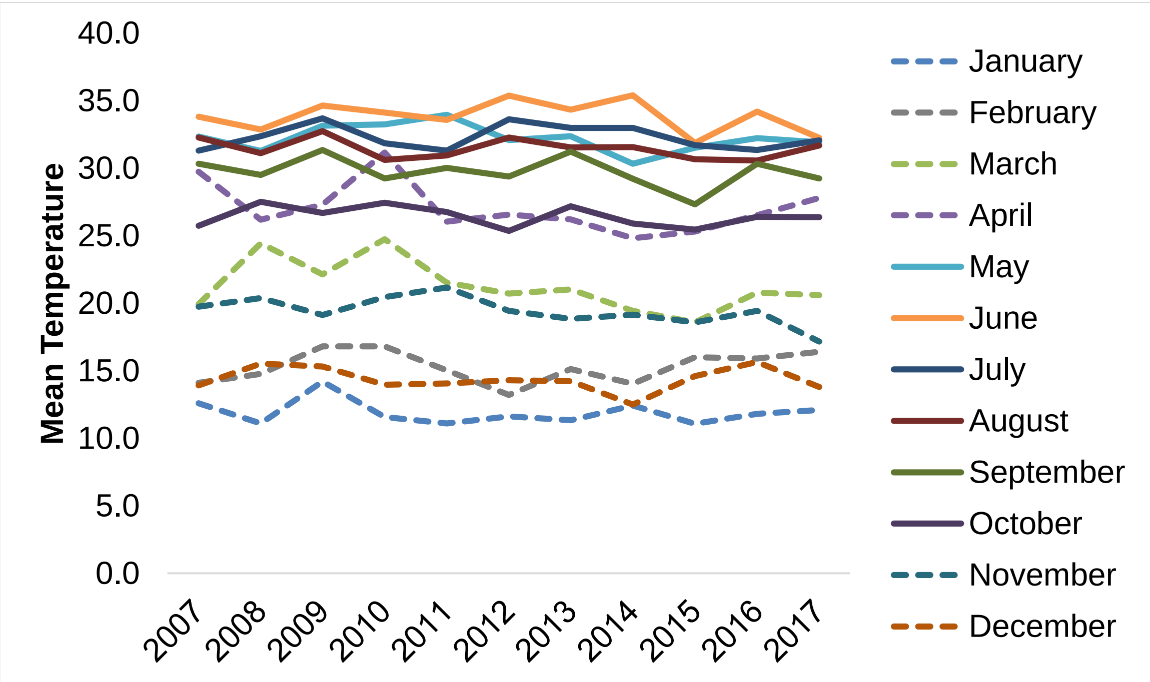


Figure 50: Temperature variations (2007-17) - Sargodha

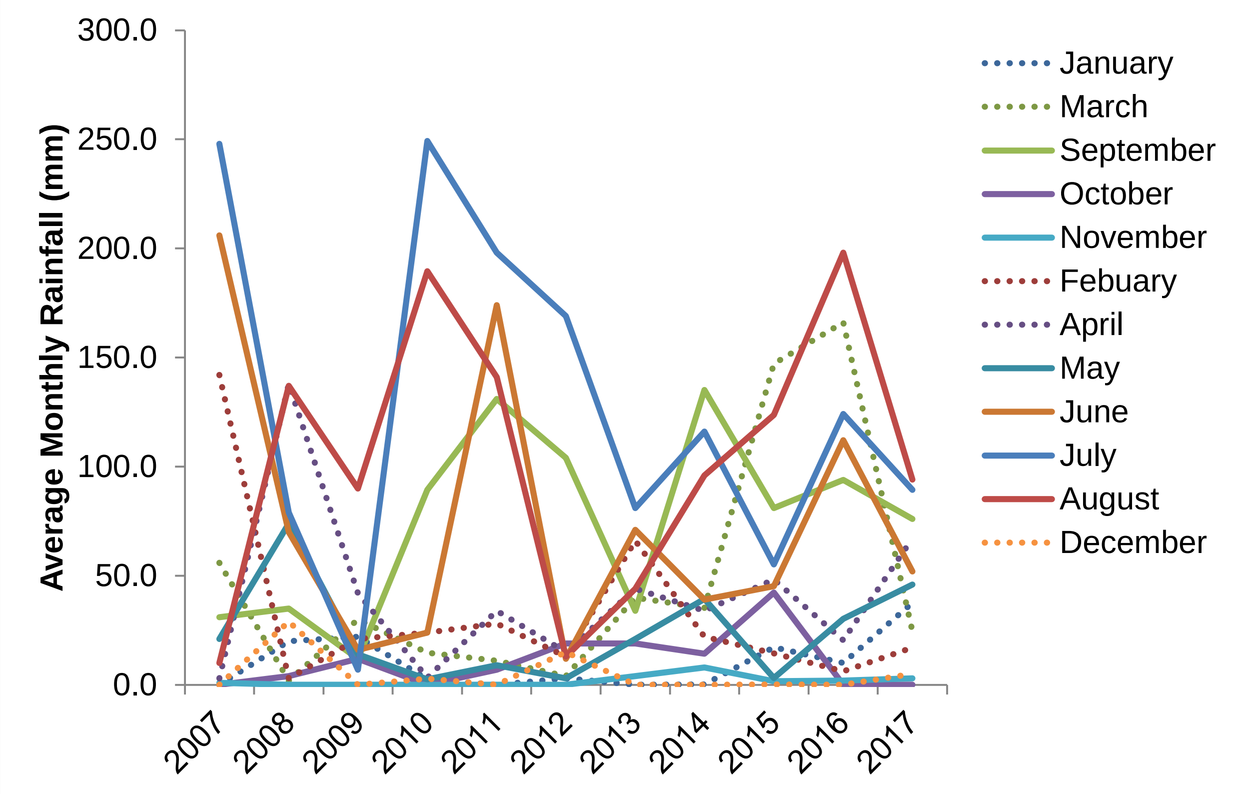


Figure 51: Precipitation variations (2007-17) - Sargodha

Precipitation tendency during last months of Rabi season is increasing. One high rainfall event during April and March was recorded in 2008 and becoming more frequent since year 2014-17. Monsoon season pre-dominantly spans over July to September months, although since 2015 this rain pattern seems to have shifted from July to August (Figure 61).

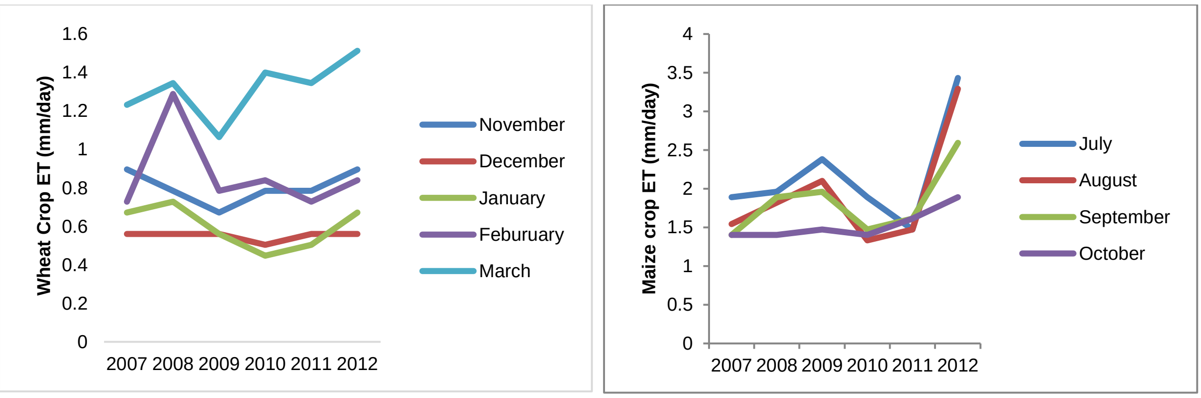


Figure 52: Water requirement (ET) of Major Crops- Sargodha

Maize is a major Kharif crop for Sargodha district whereas for the rest of the division it is less popular. According to evapotranspiration records during 2007-12, the crop water requirement for maize crop is increasing reaching to the peak in year 2012. Considering the temperature trends, increasing and decreasing alternately during summer months, the water requirement of maize crop is also raising. Similar trend has been observed for the wheat crop during Rabi months. Crop water requirement of wheat crop is increasing with rising daily mean temperature. High water requirement of wheat crop during March month has been supplemented by record rainfall during the recent years. This alteration in rainfall frequency is beneficial for Rabi crop so far, further shifts in rainfall peak to April month endanger the overall productivity of wheat crop (Figure 62).

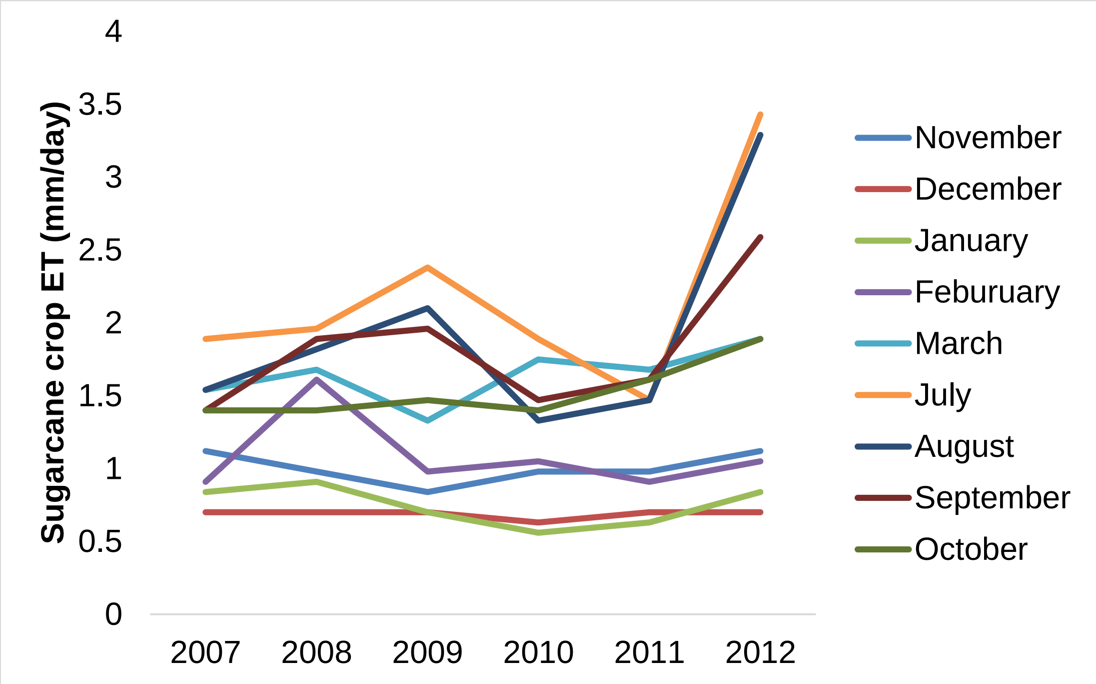


Figure 53: Water requirement (ET) of Sugarcane crop- Sargodha

Sugarcane is an annual crop but given the lesser priorities of local farmers towards field crop and several other factors, sugarcane cultivation is declining in Sargodha but it is still a major perennial crop of the division. Temperature rise in 2012 summer months is principally responsible for high crop water requirement of this crop. It is also noted that, July and August months receive maximum rainfall; therefore, water balance for the cropping year is maintained. It is also noted that water requirement of sugarcane in Sargodha starts from 0.6 mm/day compared to Sindh where Sugarcane water requirement during December is well above 1.5 mm/day.

After Sargodha division, Sahiwal division is the largest maize cultivation area including Pakpattan, Okara and Sahiwal districts. The agro-met station of Sahiwal is considered as reference for studying climate variations and crop water requirements of Major crops. Over the study period, variation in temperature remained linear and homogenous to upper Punjab districts and agro-met station (Figure 63). During Rabi period, April and February months are becoming warmer. There is no significant difference in the temperature of Kharif months except for fewer high and lows during alternate years. These heat waves are further supplemented by the high intensity rainfall during warmer month. Such as, temperatures in August have increased but at the same time precipitation during August month are also increased during studied months. A record rainfall trend during September 2010-2013 prevailed in this decade (Figure 63). In later years, rainfall events during June and August became more recurrent compared to July and September. In the contrast of other central Punjab districts, rainfall tendency during Rabi months remained low except for high rainfall event during February 2012-14 and high precipitation arch starting from March 2013 to 2017.

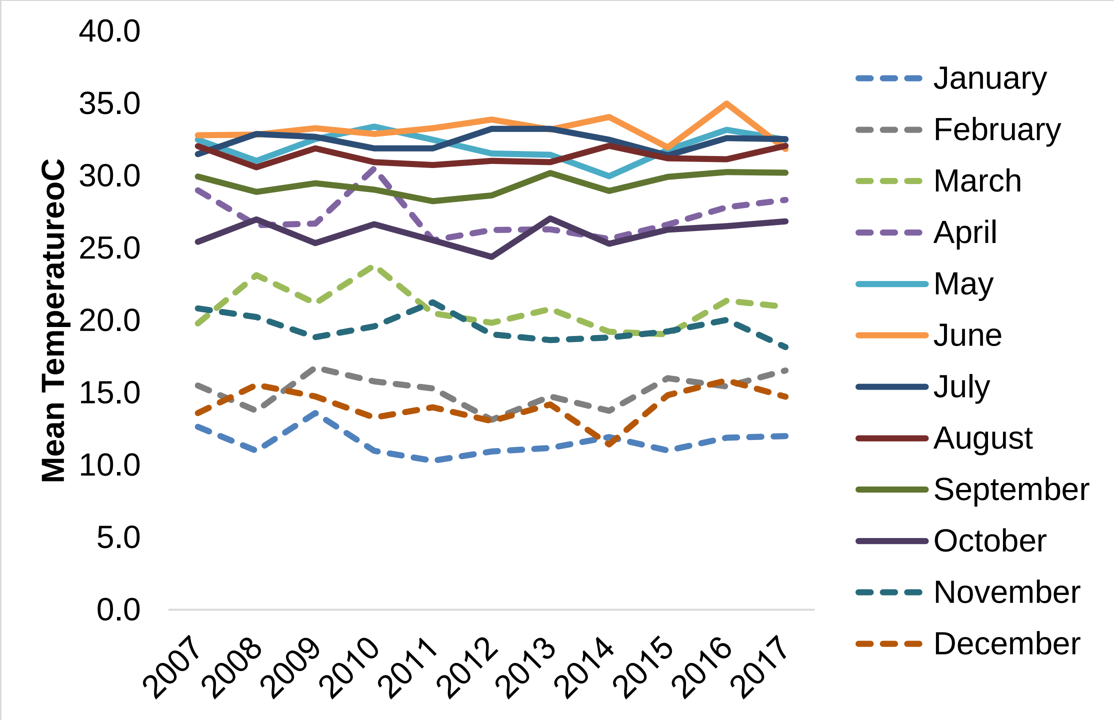


Figure 54: Temperature Variations (2007-17)- Sahiwal

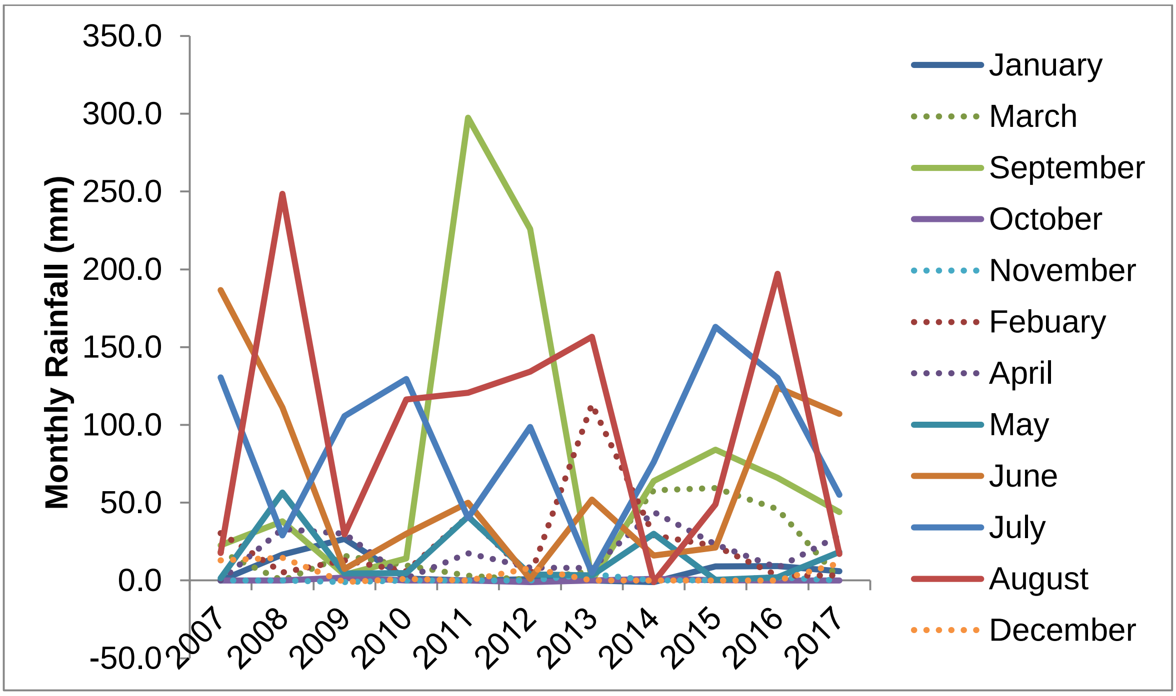
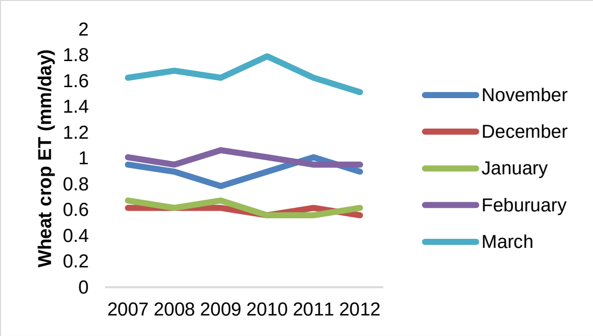


Figure 55: Precipitation variations (2007-17)- Sahiwal

Rising temperature and rainfall pattern have profound impact on crop water requirement and seasonal water balance for the major crops cultivated in the district. During the observation period of 2007-12, crop water requirement for wheat crop is increasing for in January and declining in March and November whereas remains the same in February (Figure 65).



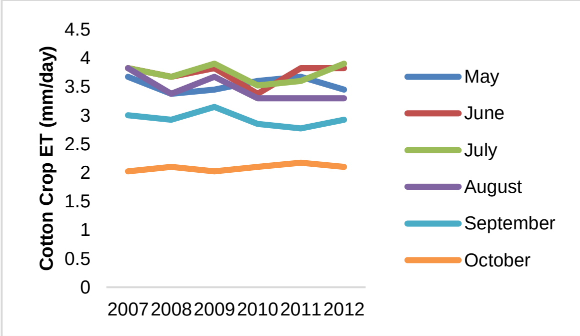


Figure 56: Water requirement (ET) of Major Crops- Sahiwal

In November, crop stage is still minor more evapotranspiration is caused from soil surfaced rather from plant itself therefore this decline in ET is not considerable. As for cotton crop, ET is increasing in July and September months and the temperature scenario up to 2017 also hints towards further increase in ET. Whereas the precipitation trend during these months is reducing. In this case it is very much possible that for Sahiwal division, climate stress may enhance water requirement of cotton crop increasing reliance on canal water and good quality groundwater (Figure 66).

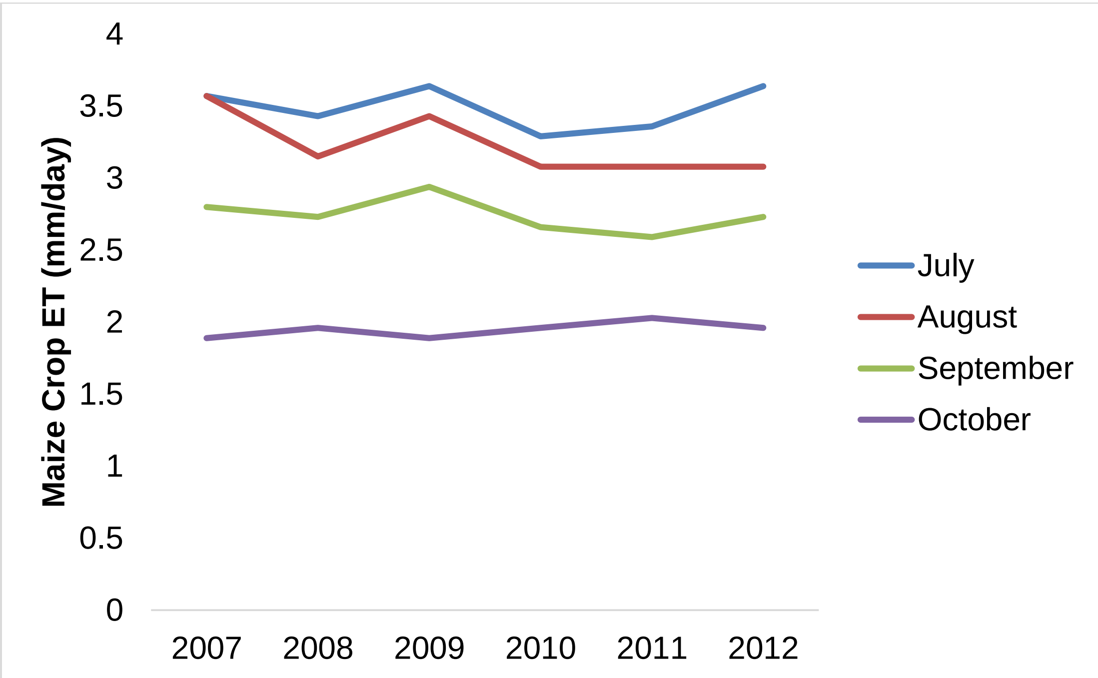


Figure 57: Water requirement (ET) of Maize crop- Sahiwal

Maize crop is becoming a popular because of its immediate cash value and it's increasingly replaced by the sugarcane crop. In Sahiwal district, Maize crop represents a crop water requirement ranging between 1.89 mm/day to 3.64 mm/day competitive to Sugarcane crop but spans over only 04 months. During the studies period (2012-17) Maize crop has shown a linear water requirement trend, increasing only in July due increasing temperature in this part of the year.

Multan division begins the largest hub for wheat-cotton zone and represent high cotton producing districts including; Lodhran, Khanewal, Vehari, Multan and

Muzzafargarh districts. Multan division generally represents arid climate. Due to marginal quality groundwater, reliance on canal water is high.

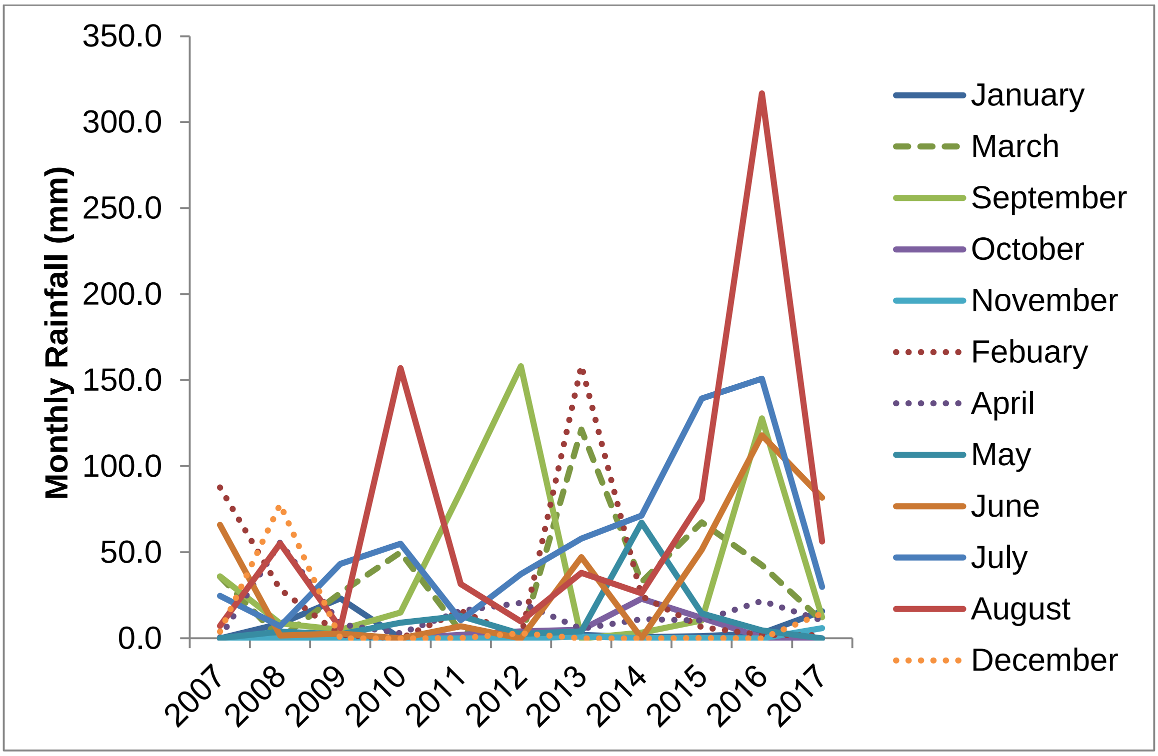


Figure 58: Precipitation Variations (2007-17)- Multan

A record rainfall event up to 300 mm/month was recorded during August 2016 and 15 (Figure 67). During these two years over the decade under observation, monsoon season spans over months starting from June to September. High rainfall was also recorded during March in 2010, 2013 and 2015 with two year return period. During most part of the decade, Rabi season remained dry except for December 2008 which is similar to the wet spell in upper Sindh. Temperature has shown increasing trend during January-April in Rabi months whereas follows a linear variation trend during summer months (Figure 68). Warm month of June is similar to other stations of Punjab province.

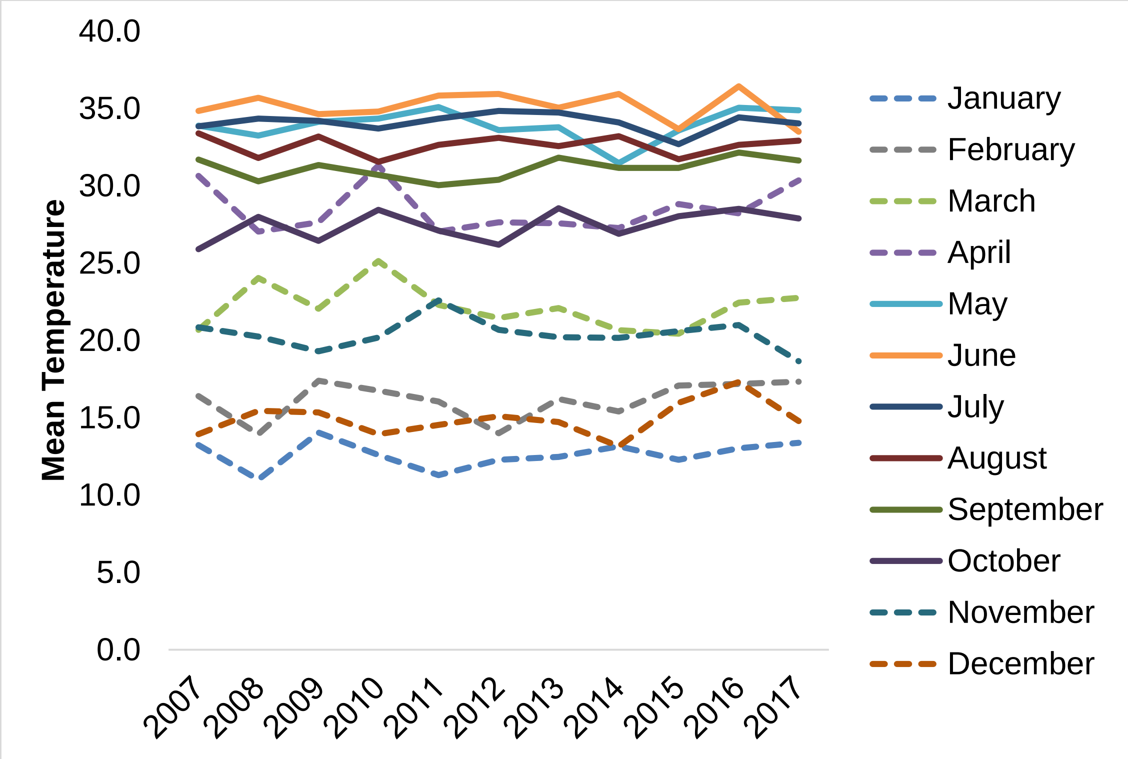


Figure 59: Temperature variations (2007-17) - Multan

The temperature variations very prominent during the first half of the decade which is also reflected in crop water requirement of Rabi and Kharif Crops. Months of January, February and March are showing increasing crop water requirement up to 0.5 mm/day attributed to increasing temperature. For Kharif crop, Cotton, the ET value is showing a rising trend in June and August months. The Value of ET for cotton crop ranges between 2.6- 6.75 mm/day and a slight increase in water requirement may cause water stress in water supplies (Figure 69).

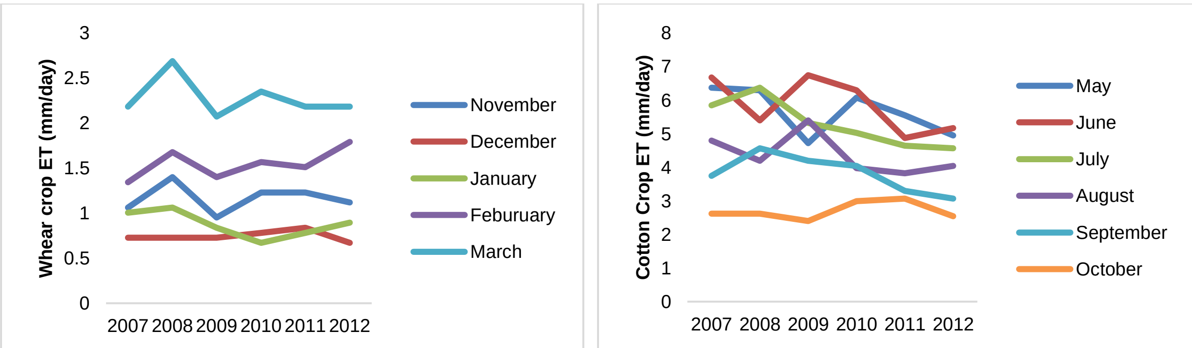


Figure 60: Crop water requirement of Major crops (2007-12)-Multan

Bahawalpur division represents for south irrigated region of Punjab province. Due to water availability, this region is a cotton-wheat zone but owning to the economic choice of farmers, sugarcane cultivation is also becoming popular. Temperature variations in Bahawalpur are synchronous to Multan division, except month of January in Rabi season. A sudden rise in temperature was observed in 2009 during late Rabi months. The temperature changes are similar to the rest of the districts of Punjab with repeated high and lows during June and increasing trend for July and August (Figure 70).

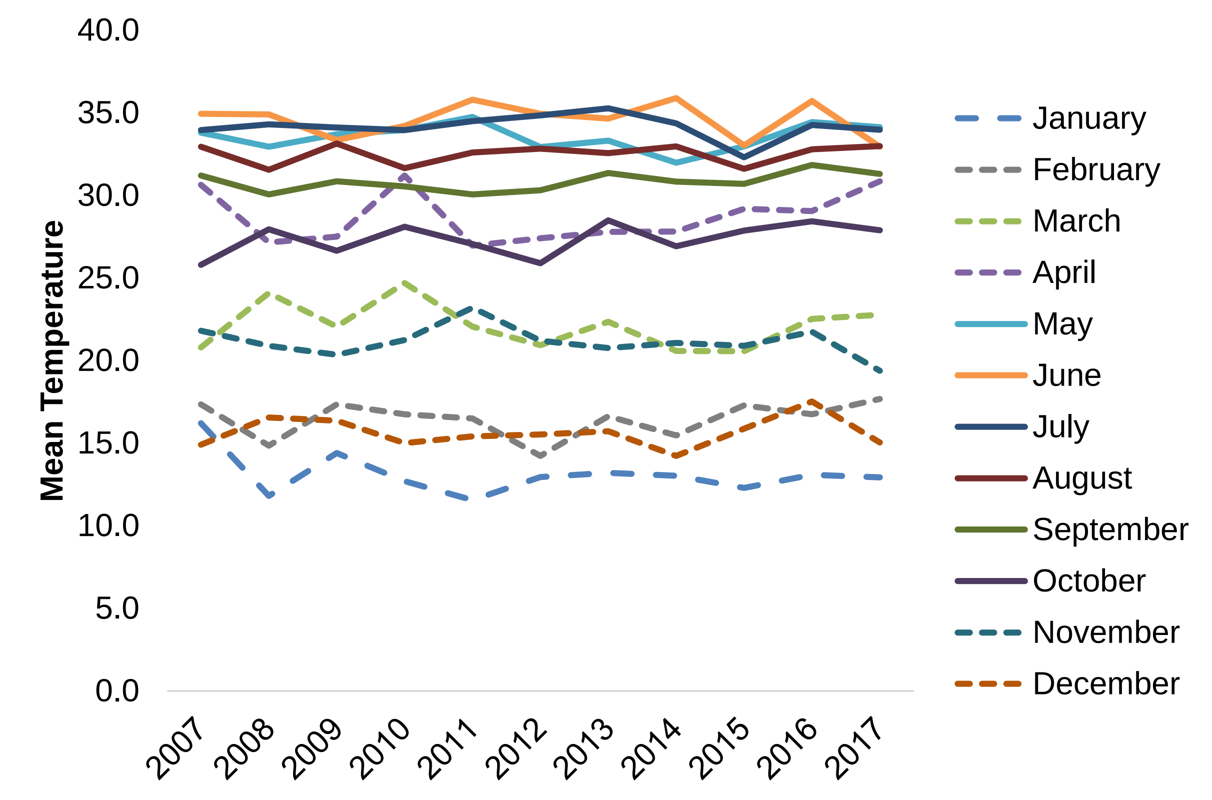


Figure 61: Temperature Variations (2007-17)- Bahawalpur

Precipitation trends in Bahawalpur are unlike Multan division. Peak rainfall was recorded in August 2010 and moistest monsoon occurred only in 2015 spanning over June-September (4 month spell). Precipitation during Rabi season is also higher in comparison to Multan; precipitation spells more than 17 mm/month are recorded during 2007-17. In 2017, precipitation is showing a decreasing trend except for the month (Figure 71).

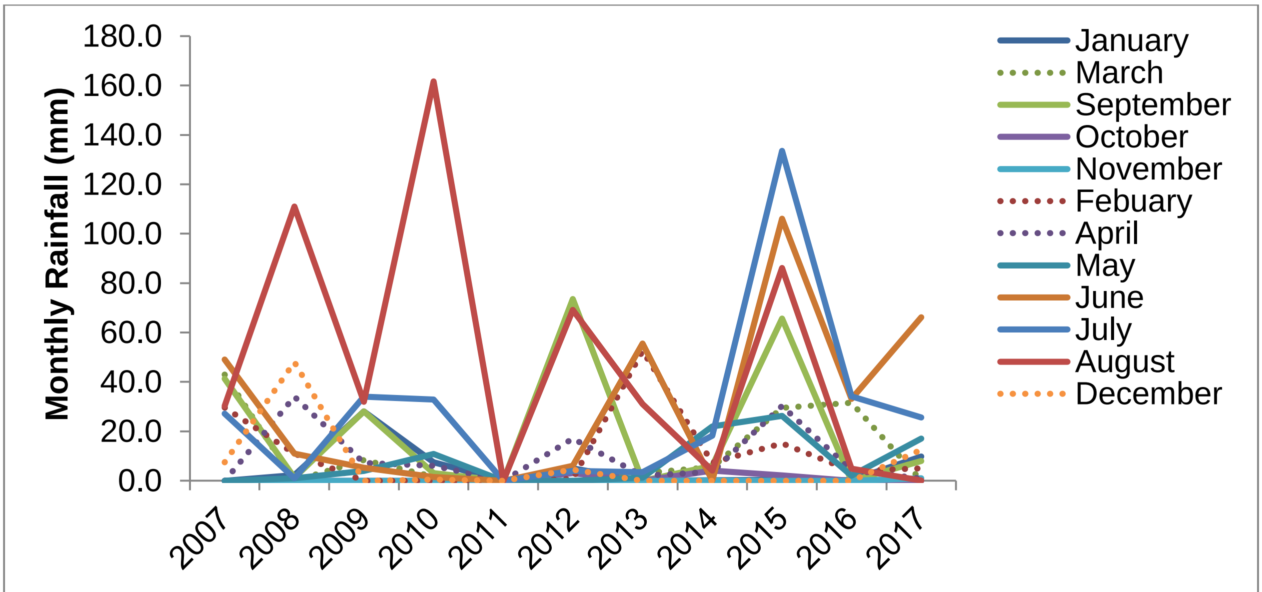


Figure 62: Precipitation variations in Bahawalpur (2007-17)

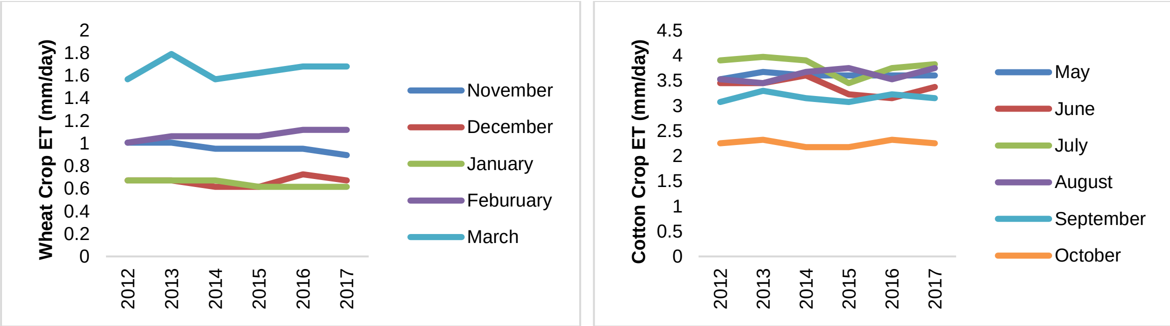


Figure 63: Water requirement (ET) of Major Crops

Water requirement of wheat crop in the part of Punjab ranges between 0.6-1.8 mm/day (Figure 72). Good rainfall tendencies during in Rabi months have also supplemented crop water balance of the cropping period. In cotton crop, water requirement is higher only during the drier parts of Kharif months; May and June. Crop water requirement is sufficiently balanced by the rainfall events in scattered over July and August months. In addition to two full crops over the year, a perennial sugarcane crop is also becoming increasingly popular in Bahawalpur division. Crop water requirement for this crop follows a linear trend only a slight increase in July and August 2017 due to approaching dry spell after a wet monsoon year of 2016 (Figure 73).

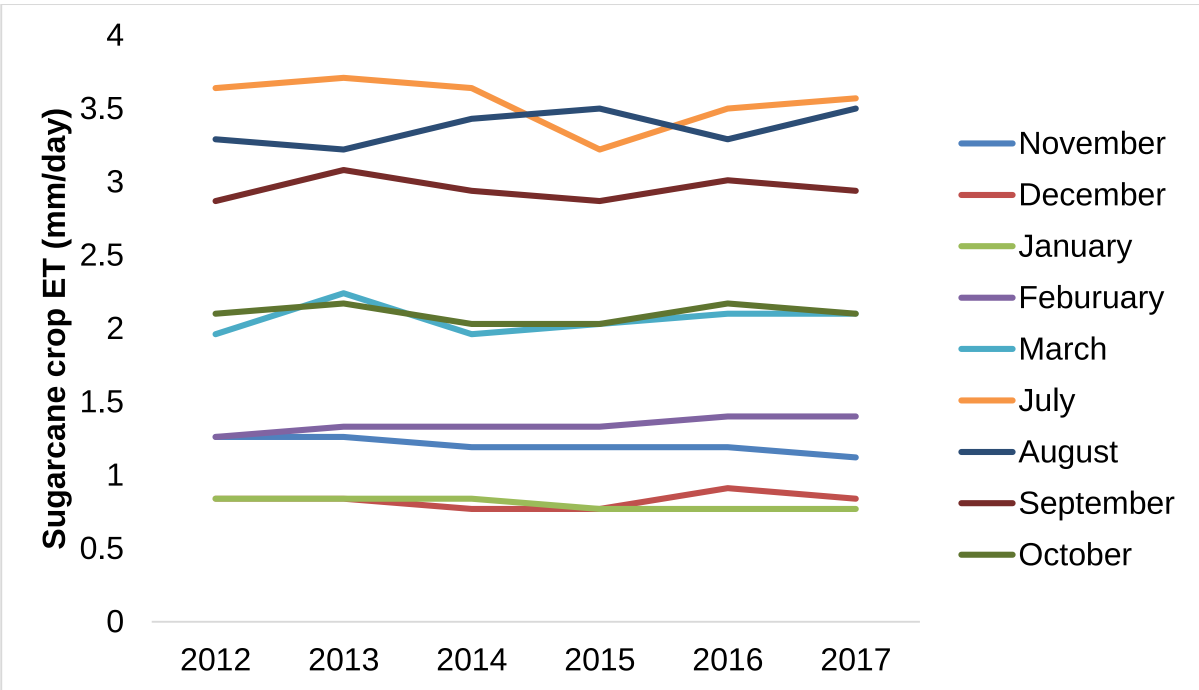


Figure 64: Water requirement of Sugarcane crop (2012-17) Bahawalpur

Derajat areas, irrigated by D.G. Khan Canal, CRBC canal along the western border of Punjab province with Balochistan province forms highly fertile irrigated belt of Dera Ghazi khan division. The division represents district Rajanpur, Dera Ghazi Khan is a cotton wheat and rice zone.

4.3. Crop Variations in Irrigated Zones

4.3.1. Rice-Wheat Zone

Balochistan Province-Irrigated Plain

The irrigated plain of Balochistan province forms rice-wheat zone as Wheat represents 31.8% and Rice represents 36% of the cropped area compared to the total cropped area of 58% of the actual command area of canals. Other major crops are rapeseed mustard, vegetables, onion and fodder crops. A comparison of yield of major and minor crops is shown in Figure 74.

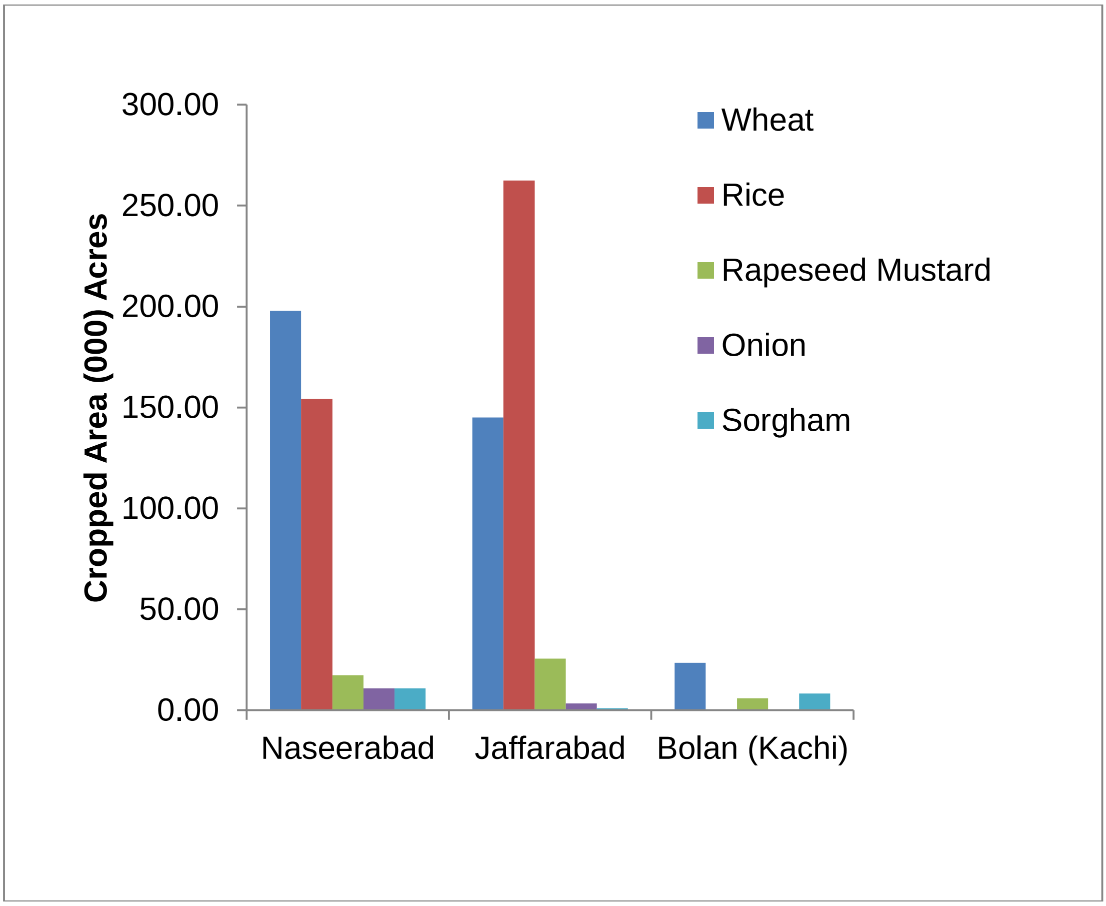


Figure 74: Cropping Pattern in Rice- wheat Zone of Balochistan
(Source: Development Statistics of Balochistan 2002-2017)

Figure 74 represents 15 years average of prevailing cropping patterns in irrigated districts of Balochistan. Cropping pattern is dominantly rice-wheat and farmers' preference varies for cultivation on onion and Sorgham crop. More canal water is available during Kharif season therefore; farmers prefer cultivation of more crops during Kharif season compared to Rabi season. Fodder is also a preferable crop for irrigated districts of Balochistan cultivated on 18.41 thousand acres in Rabi season and 13.67 thousand acres in Kharif season. Fodder crop bring higher value in form of cash and also serve as food source for livestock population of the region.

Sindh Province

Districts falling in the right bank command area of Sukkar and Guddu barrage canal command including; Larkana, Kashmore, Kumber Sahdadkot, Jacobabad, Dadu and Shikarpur districts. Highest crop cultivation districts are Shikarpur and Dadu districts in combination of wheat crop during Rabi season. Other crops such as sugarcane and cotton are grown on few thousand acres but this proportion is minor to make a difference for water shortages on irrigated land. The six-year average of canal irrigated areas reveal that Jacobabad district maintains a cropping intensity of 88% dedicated to two major crops (Figure 75). Farmer does have preference for minor crops such as 60-70 acres for vegetables, pulses and Mustard crops. These choices are not significant to create a difference in agricultural earning and its contribution into GDP making the high value of canal water supplies.

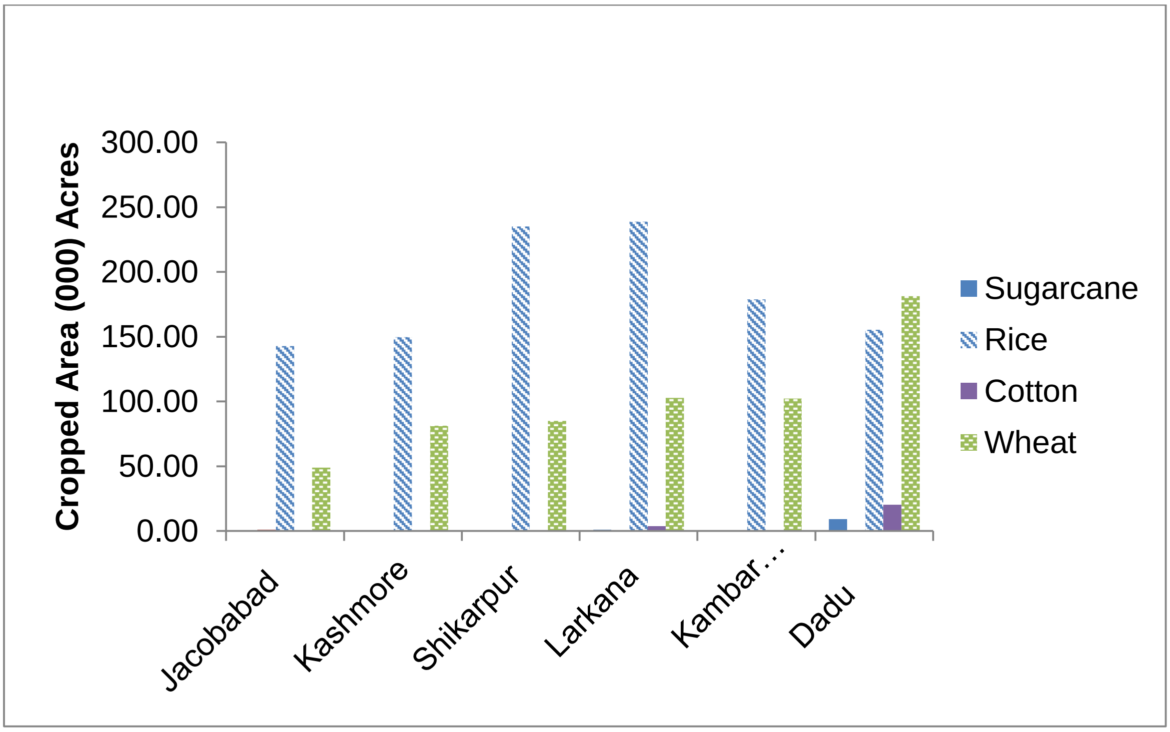


Figure 75: Rice-wheat zone in Sindh Province

Cropping intensity of district Kashmore is 140% dedicated to wheat and rice crops, the contribution from sugarcane crop is very minor. District Shikarpur has the largest areas irrigated by canals and have a cropping intensity of 83% for wheat and rice crop during Rabi and Kharif seasons each. Larkana district has the highest ratio of rice crop compared to other districts in rice-wheat zone. The cropping intensity is 91.5% per each cropping season of the year. Cropping intensity in district Kamber Shadadkot is 110% during each cropping season with higher preference of farmers for rice crop. Dadu district is the only district in rice-wheat zone having higher ratio of wheat crop compared to rice with additional share of sugarcane and cotton crop. In this zone, wheat cultivation is generally less compared to rice crop and this difference may be the result of lesser coverage of canal irrigation during Rabi season than in Kharif season.

Punjab Province

Higher water availability and lesser crop water requirement of crops in various agro-ecological zones provide a relief to farmers to adapt to new crop type. Farmer's choice of crop in the presence of availability of irrigation water is often made due to economic value of various crops and raw material, low cost of certain crops and post-harvest management of crops. Rice-wheat zone of Pakistan comprises districts in Sialkot division and Lahore Division. Due to their proximity, Faisalabad, Mandi Bahauddin, Sargodha and Jhang follow the similar cropping pattern. Average cropped area during 2007-2016 is calculated to estimate the cropping trend in these five divisions during the observation period (Figure 76).

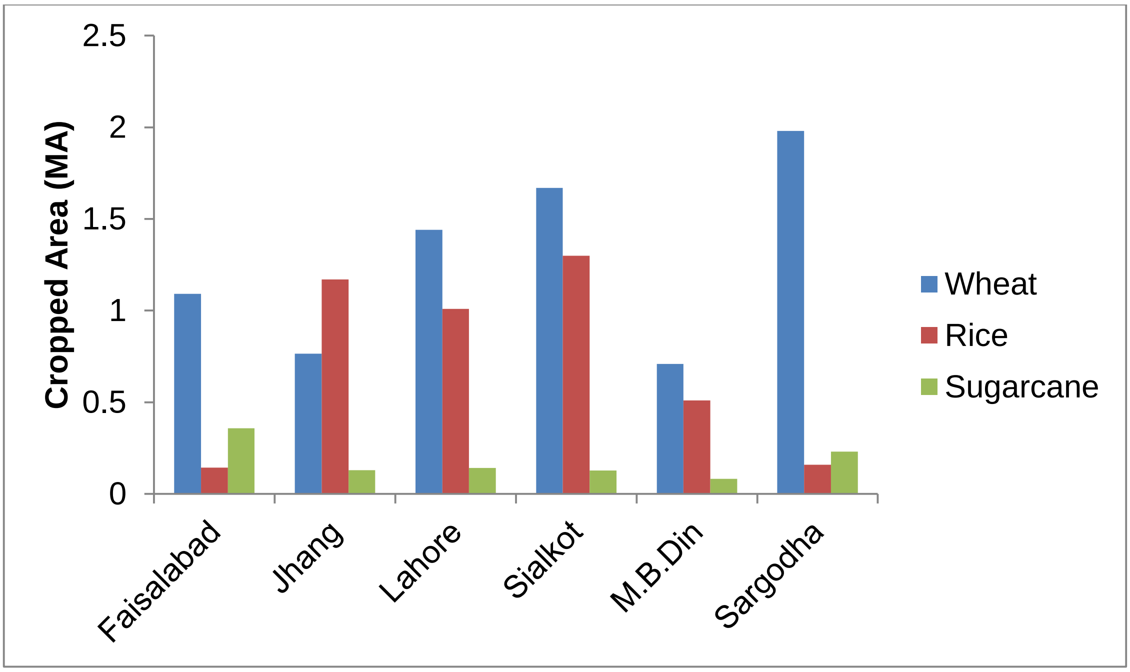


Figure 65: Cropping pattern variations in Rice-Wheat zone (2007-16)

Cropped area is provided in (million acres), wheat remained the most prominent crop among all divisions which was followed by Rice crop. In Faisalabad and Sargodha division cultivation of sugarcane is more popular than rice crop. However, in Jhang district rice crop is given more priority than even wheat crop. In this case, Rice-Wheat zone has expanded to Jhang district.

4.3.2. Cotton-Wheat Zone

Punjab Province

Cotton-wheat zone is the largest zone in Punjab province mostly including more arid parts of the province. Still, cotton-wheat zone is settled with high delta crops such as rice and sugarcane due to high availability of water. To find variations in cropping pattern, average crop area is calculated from crop cultivation statistics (2007-2016). The results show that dominantly cotton zones; Multan and Bahawalpur remained consistent to cotton-wheat cultivation practice, where wheat crop exceed cotton crop as farmer's choice for cultivation. In Multan and Sahiwal, farmers have shifted to more non-traditional crops such as Maize other than their designated cropping zones. Maize crop has water requirement equivalent to sugarcane crop, the only diffidence is length of cropping months, which is 4 months for maize crop and 12 months for Sugarcane crop (Figure 75).

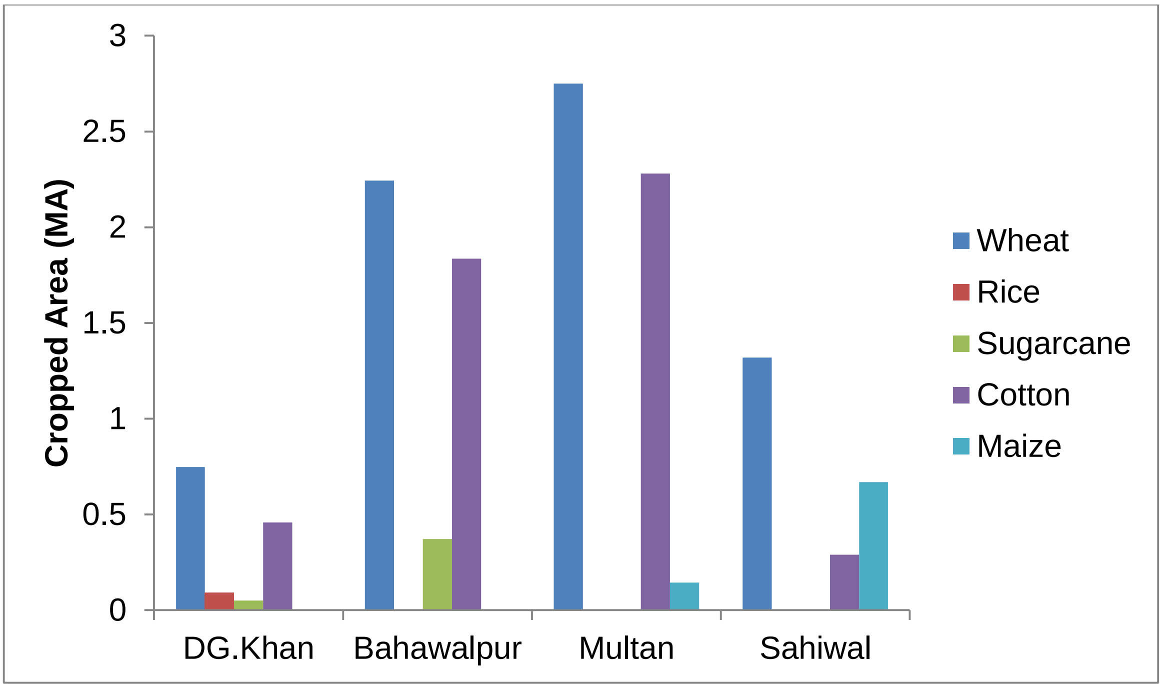


Figure 66: Cropping pattern changes in Cotton-Wheat zone

In Bahawalpur and DG Khan Division high delta crops such as sugarcane and rice are more common. This shift in cropping choices by the farmers creates water shortage for the designated crops in an agro-ecological zone. A self-adaptation creates water availability issue for other farmers and loss of value of fresh water.

Sindh Province

Cotton-wheat zone is the largest irrigated zone of Sindh province and of Pakistan. In Sindh province, canal irrigated district situated on the left bank of Indus River, Guddu and Sukkur barrage forms cotton wheat zone. Cotton-wheat zone is shared by sugarcane, banana and rice crops with variance (Figure 76).

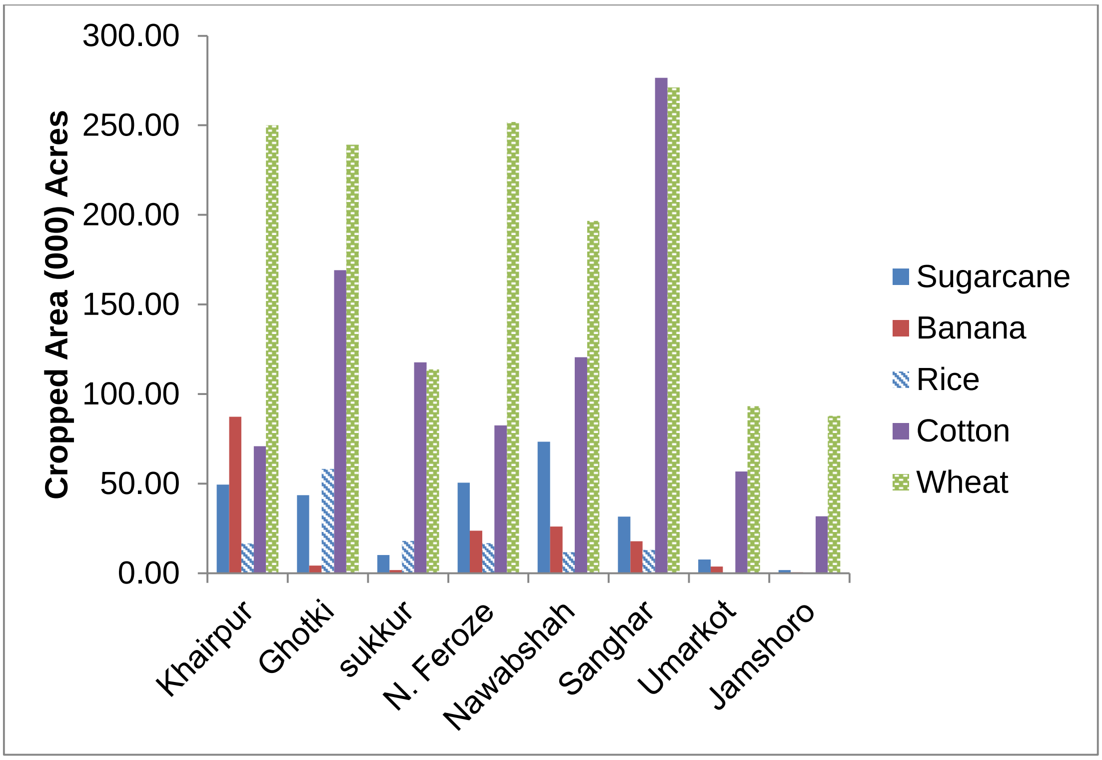


Figure 76: Cotton-wheat zone of Sindh Province

District Sanghar has the competing coverage of cotton and wheat crops during both the seasons. About 70,000 acres of agricultural land is covered by high water consuming rice crop, perennial sugarcane and banana crops. Sanghar districts also have preference for vegetable and pulses crops but their share is not consistent with national needs. Sanghar district is followed by Ghotki and Nawabshah districts with higher preference to wheat crop compared to cotton crop. Other Kharif crops such as Rice is also cultivated claiming the share of Kharif water allocation from canals. In addition to these, Banana and Sugarcane crops are also very popular. Naushehro Feroze and Khairpur districts also have high preference for wheat crop compared to cotton crop, but in Khairpur district, banana is being cultivated on 87,000 acres claiming a fair share in irrigation water. Sukkur, Jamshoro and Umarkot districts have similar land use intensities with respect to crops under consideration. In Sukkur district, similar land use intensity is maintained for Cotton and wheat crop in addition to rice and sugarcane. In Jamshoro and Umarkot district wheat cultivation is higher compared to cotton crop. Umarkot district is located in geographical proximity of district Tharparkar and Thar Desert therefore, some sorts of vegetables are grown in these districts meeting the socio-economic need of local farmers (Figure 77).

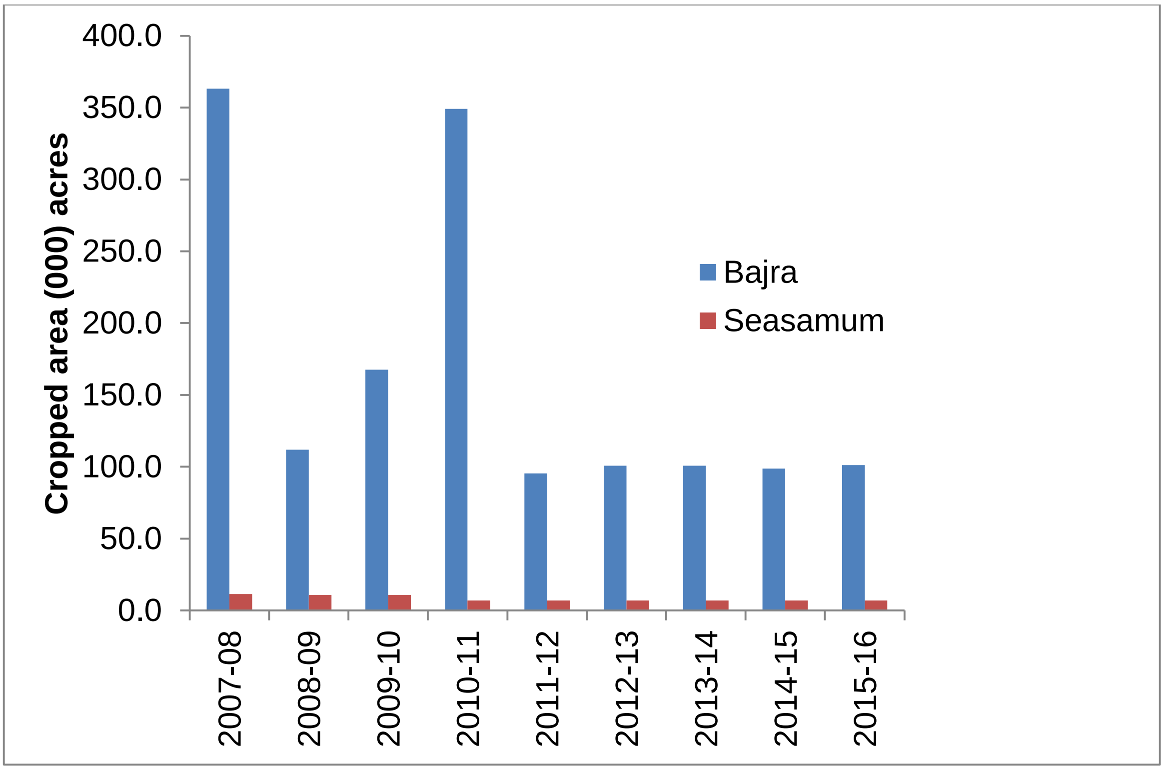


Figure 77: Crops in district Tharparkar

Pearl millet or Bajra may be regarded as the major crop in this district. Its cultivation peak was recorded during 2007-08 and 2010-11, Rabi season followed by the historical floods in Indus Basin. The second big crop in the district is Seasmum, other than this a few thousand acres of Chillies are also recorded. Wheat and cotton crops are also grown but they are not seemed consistent over 10 years observation period.

4.3.3. Sugarcane mix

Sugarcane mix zone only exists in Sindh province it includes lower Sindh districts of Kotri Barrage command area and some districts of central Sindh in the command of Rohri canal diverted from Sukkur barrage. Central Sindh is generally cotton-wheat zone with additional cropping of sugarcane, banana and rice crop. In district Matiari, cotton-wheat cropping zone is common but Banana and Sugarcane crop continue to occupy the irrigated land throughout the year. This scenario indicates that farmers are practicing a cropping intensity of 200% meeting the irrigation deficit through groundwater wherever necessary (Sindh Development Statistics, 2007-16). As shown in Figure 78, rice crop is also cultivated on 26,000 acres in Matiari. Cropping trend in Tando Allahyar follows a similar trend because of its geographical proximity with Matiari district. Cotton and wheat are major crops followed by Sugarcane and Banana crops. Through intercropping practices cropping intensity of 200%, with half of the irrigated land remain occupied by Banana and Sugarcane crops.

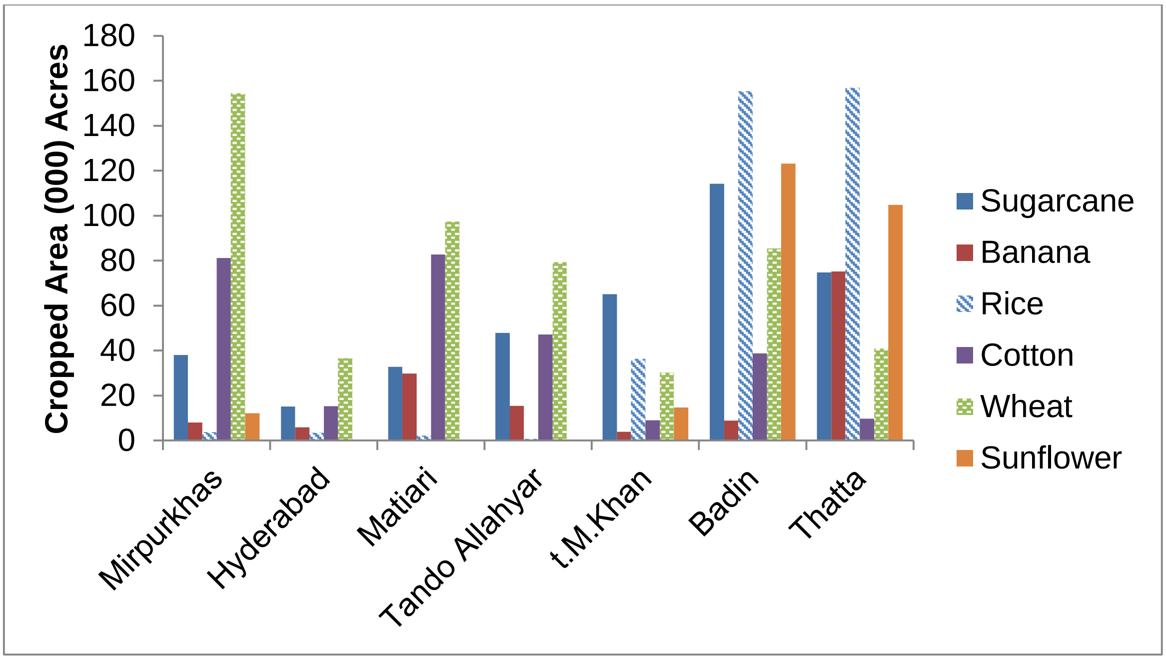


Figure 78: Sugarcane mix zone in Sindh province

District Hyderabad has the least irrigated sown area, 49000 acres compared to other studied district and follows the similar pattern; major crop is wheat followed by cotton and sugarcane. Banana is cultivated on 5900 acres. Next wheat-sugarcane-wheat district is Mirpurkhas that also falls in the command of Rohri canal with a cropping intensity of 150% only. Wheat is the most dominant crop whereas rest of the year is occupied by high delta crops like; cotton, sugarcane, banana, Sunflower and Rice.

The biggest sugarcane mix zone in Sindh lies in the command area of Kotri barrage spanning over Thatta, Badin and Tando Muhammad Khan districts. Wheat crop is less common, it appears that farmer cultivate wheat only suitable to their soil situation and befitting their food requirement. High delta crop such as Sugarcane and rice are their major focus, cotton is being sown on around 34,000 acres in Badin and 14,000 acres in Tando Muhammad Khan and Thatta but not much as compared to the major crops. Sugarcane cultivation is the highest in Tando Muhammad Khan with a cropping intensity of 150%. In Badin district, cropping intensity is 90%; farmers are cultivating 10% less of their irrigated lands. This is probably due to high irrigation requirement of rice crops that is very common in this part of Sindh province. Similarly, cropping intensity in Thatta district is 91%, with banana-sugarcane-rice as major crops. Rice is only a 4 months crop whereas banana and sugarcane occupy the field perennially. Banana orchards are semi-permanent with crop age of 7-10 years variable on the basis of crop variety and feasible agro-ecological conditions. Sunflower crop has highest preference in this part of the province, most probably availability of market to sell this crop and a diversity of procurers. A high preference of high delta crops annually and conventional irrigation practices are limiting farmers to irrigate their entire cultivable land falling in the command of canals diverted from Kotri barrage.

4.4. Crop Pricing/Surplus in Irrigated Agriculture

Sugarcane is cash crop which provides an immediate cash relief to farmer after one year of hardwork and application of more than 1500 mm of water on annual basis. However, the depth of water varies according to the province, same as support prices for sugarcane as commodity. In Punjab province, the support price for 1000 kg (1 tonne) of sugarcane crop has increased by Rs. 3000; same as the number of sugar mills to process cane into various products, principally Sugar. On an average 65 tonnes of sugar is produced by utilizing one tonne of sugarcane (Table 5). The ratio varies as sugar mills also produce other products of cane and store molasses for future consumption. By the increase in support price for sugarcane, the profit of sugar has reduced in comparison to water consume. In comparison of values; price of 1 tonne of sugar is Rs. 751 higher than the cost of 1 tonne of sugarcane and water consumed to grow. Value of water will be further reduced if total cost of production is also accounted for. This comparison determines the low value of irrigation water by the cultivation of sugarcane.

Table 5: Pricing and cost comparison of Sugarcane crop inputs and outputs in Punjab Province

Year	No. of Mills	Cane Produced (million tonnes)	Cane: Sugar (ton/ton)	Support price (Rs/tonne) at factory gate	Water: Sugar (value in Rs)
2007-08	42	40.31	1:73.26	1500	1:2441
2008-09	45	32.39	1:62.33	2000	1:1558
2009-10	46	31.32	1:59.39	2500	1:1187
2010-11	46	36.04	1:71.73	3125	1:1147
2011-12	44	42.90	1:72.63	3750	1:968
2012-13	44	43.00	1:73.77	4250	1:867
2013-14	44	43.70	1:76.73	4250	1:902
2014-15	45	41.08	1:72.22	4500	1:802
2015-16	45	41.97	1:67.62	4500	1:751

Note: Sugar price of Rs. 50 per kg is taken to calculate the profit.

A similar comparison for Sindh province shows Rs. 2625 increase in support price at factory gate for sugarcane and high ratio of profits (Table 6). This situation further lowers the value of canal irrigation water in monetary terms.

Table 6: Pricing and cost comparisons of sugarcane crop input and outputs-Sindh Province

Year	Mills	Cane Produced (million tonnes)	Cane: Sugar (ton/ton	Support price (Rs/tonne) at Factory gate	Water: Sugar (Value in Rs)
2007-08	29	18.79	1:83	1675	1:2478
2008-09	30	13.30	1:73	2025	1:1811
2009-10	31	13.51	1:81	2550	1:1596
2010-11	33	13.46	1:96	3175	1:1519
2011-12	34	10.79	1:117	3875	1:1515
2012-13	34	15.90	1:97	4450	1:1093
2013-14	37	18.36	1:104	4300	1:1216
2014-15	37	16.62	1:109	4550	1:1205
2015-16	38	17.98	1:105	4300	1:1227

The higher ratio of sugar production in Sindh province shows that factories have higher preference for sugar production compared to other sugarcane products. Sugar contents in the sugarcane crop also influence the amount of sugar produced. In these cases, sugar content in sugarcane at factory gate remained 8.7-9.5% (Agri-Statistics of Pakistan, 2015-16).

Wheat crop is the major crop of Pakistan and it is being cultivated in almost all irrigated and rain-fed districts. Wheat is serving as the food crop of the nation and to meet the food need of growing population cultivation of wheat is the basic choice of all farmers. The choice of wheat crop cultivation is not related to the support price because wheat production has remained higher during the years when cost of 1000 kg wheat was as low as Rs. 25,000 (Figure 79). The choice of wheat cultivation is also independent of production to area ratio. For instance, in Sindh province, the production ratio has mostly remained more than 1.0 which did not impact the increase in area coverage of wheat crop in the province. Similarly, In Punjab and Balochistan province this ratio has remained mostly lower than 1.0 but farmers remained consistent on growing wheat crop.

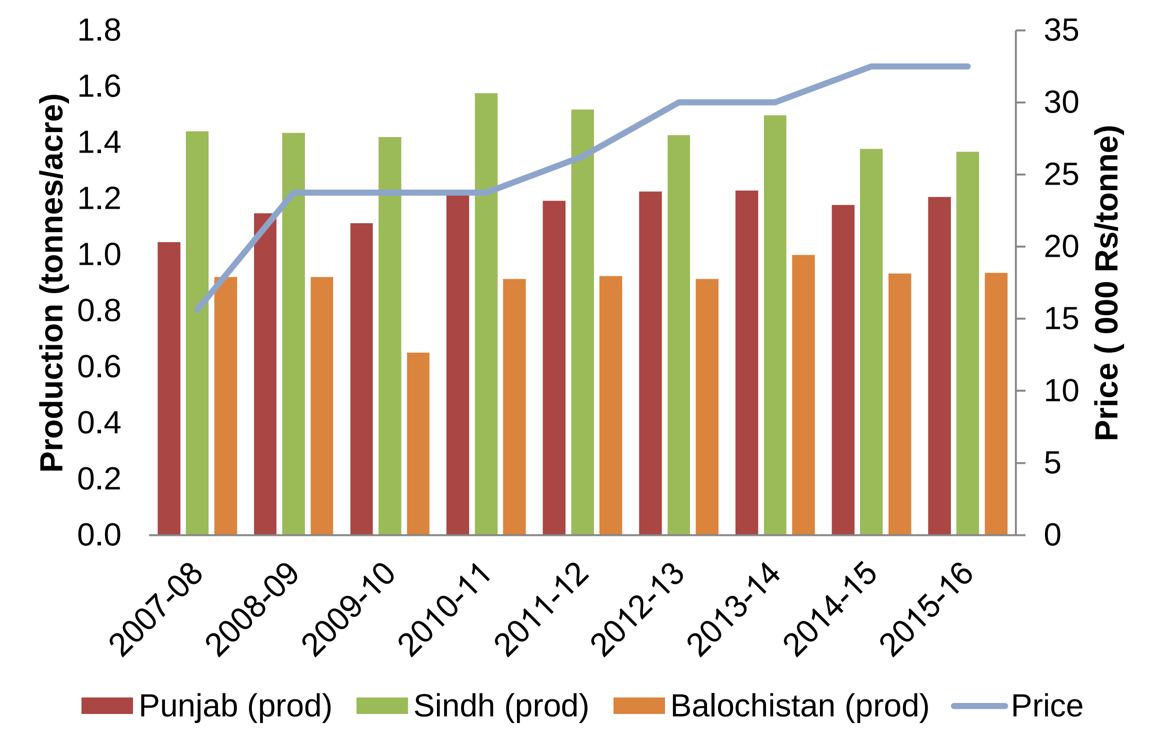


Figure 79: Pricing and choice of wheat cultivation

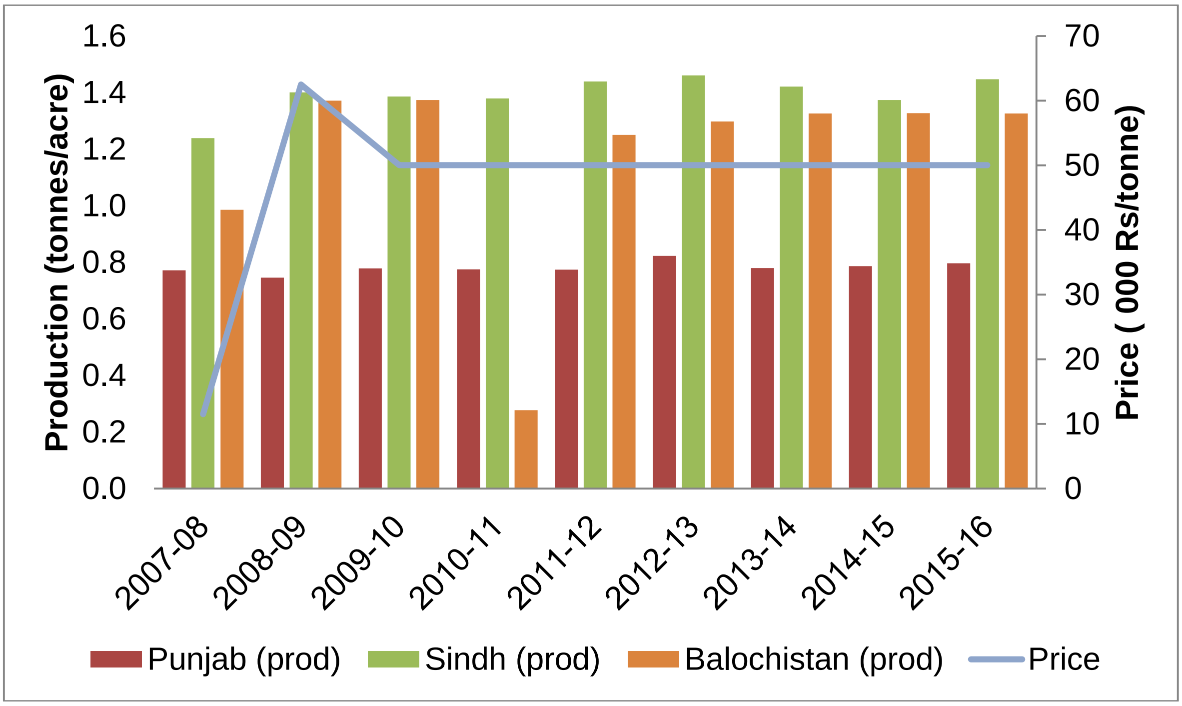


Figure 80: Pricing and choice of rice cultivation

Rice crop has remained a high choice in specific agro-ecological zones of Pakistan where land is feasible for rice crop. In Sindh province, it has been observed that cultivation of rice crop is mostly dependent upon the availability of water. Despite high allocation and consumption of water in most of the canal command, Sindh province maintains a high crop production ratio with respect to acreage. In case of Punjab, an 80% production in comparison to coverage of area is the lowest among three provinces; even Balochistan province except for year 2010-11 has a production percentage of 140% of the cropped area (Figure 80).

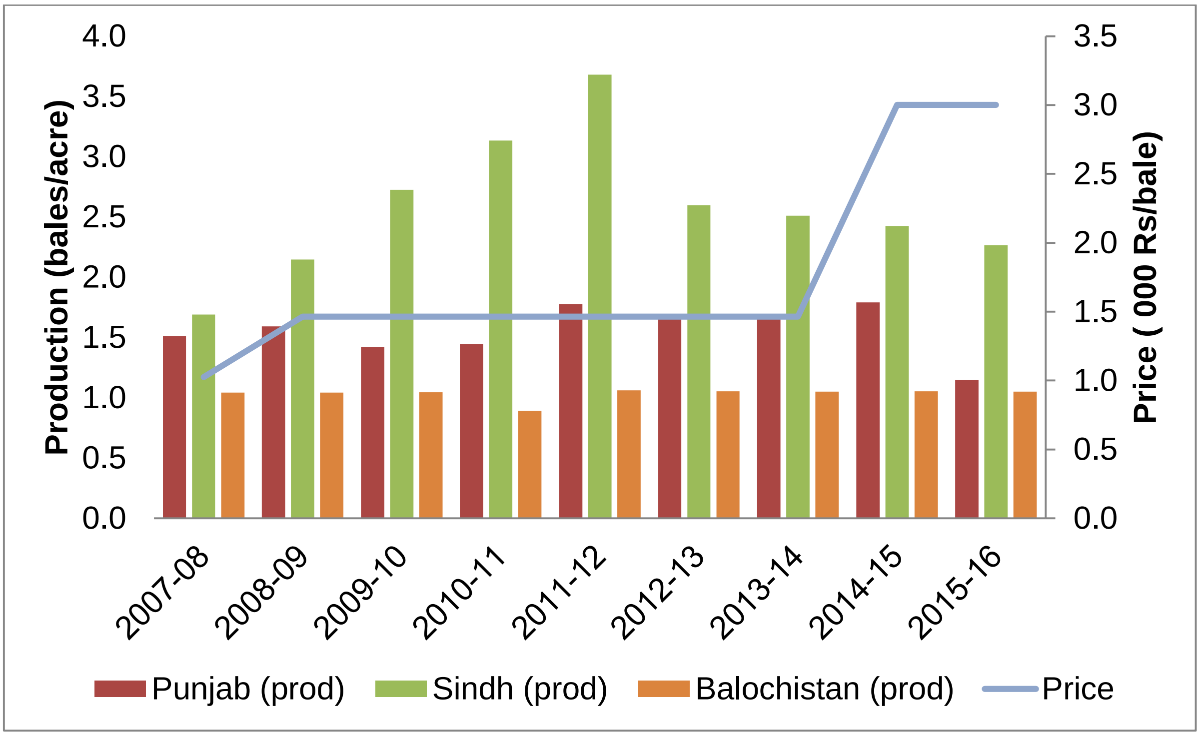


Figure 671: Pricing and Choice of cotton crop

Cotton crop is one among the major cash of the country with high demand of it into local textile and yarn manufacturing industry. Production of cotton is counted in terms of bales (one bale= 375 lb). At the time of procurement, the assessment of bale production is done by lint testing of cotton seed. The comparison in Figure 81 shows that per acre production of bales remained very low in entire country and relatively better in Sindh province. According to Agricultural Statistics of Pakistan (2015-16), this reduction in production is lower per acre yield, impact on cotton crop by untimely rainfall, excessive insect-pest attack resulting into lower yield and lint length of cotton seed. Moreover, less friendly prices, climate change and high vulnerability to insects is the reason for farmer's lower interest in cotton crop cultivation.

5. Recommendations/Way Forward

5.1. Redefined Cropping Pattern

Climate change has a tendency to increase temperature and difference in day and night time temperature impacts wind speed, relative humidity, evapotranspiration by crop and bare soil as well as soil temperature. All these factors impact the growth and production in of crops in some way or the other. Increasing temperature for agro-climate to some extent stimulates biological processes and within the threshold of crops and their climate relevant properties it has healthier impact on crop yield. At the same place, biological processes of plant diseases and insect pests also triggered endangering the crop growth and its production (Tubiello and Velde, 2011). In particular case of Pakistan, Climate change seems to have impact the maturity stage of all major crops. For instance, Wheat crop is the basic food crop for the nation and it is sown during winter months. In earlier years, one or two rainfall events during vegetative growth period of the wheat crop used to have beneficial impact on crop growth. In recent year, rainfall events are negligible during safe months but becoming more recurring and intensive during the ripening stage of wheat crop. This situation impacts crop yield by loss of crop near to harvest. In case of Cotton crop, the heavy rainfall events in districts of cotton-wheat zones starting from last week of August to mid of September are becoming more apparent. This shift in precipitation from mid of July to August has resulted into increased insect attack on cotton crop and reduced yield of crop due to premature shedding of cotton balls under heavy rains. Sugarcane crop is become more expensive for farmers to grow with limited return and difficulty to sell the commodity on factory gates. Moreover, sugarcane is a perennial crop which becomes a hard to manage crop during Rabi season when canal water allowance is half than that of Kharif season. In this regard, following suggestions are placed:

i. There is a need to introduce climate smart varieties which have the tendency to resist insect attacks and yield more production.
ii. Wheat forms the major food crop of people in Pakistan, Autumn variety of maize must be encouraged at least on 10% land under wheat crop.
iii. Canal allocations are made on the basis of agro-ecological zones, crop quota must be fixed every year to limit the experimentation of high delta crops by the farmers.
iv. Pulses are important food commodity but they are being imported in large quantities, therefore, measures must be taken to increase the production of pulses.
v. New crops must be experimented in Rice-wheat zone of Punjab due to lower productivity of crop.

5.2. Redefining Water Allocation

Canal water allocation is already made according to the water requirements of various cropping zones, however, excessive water allowances in some big canals, for instance Rohri and Nara canals in Sindh, DG Khan and Muzzafargarh Canal in Punjab are leading farmers to practice high delta cropping during Kharif season. Moreover, revamping and remodeling of various canals in Sindh and Punjab, development of Kachhi canal in Balochistan, improvement of water courses has improved the water availability and water allowances of canals, whereas water rotation system at farm level is same. Despite higher availability of water, farmers are not expanding the coverage of canal water rather they are practicing over irrigation on crops compared to their actual requirement. In this regard, following are proposed:

i. Crop water requirements of various crop calculated in this report provides a clear idea of actual crop water requirements of major crops.
ii. Crop water allowance in canals must be redefined by conducting the agro-ecological survey of canal command.
iii. Crop water requirement estimations must to be used to design new allowances in canals of Pakistan.
iv. Water allowance must be reduced in those areas where fresh quality water is available, and increased in areas where groundwater is brackish or saline.

v. Survey of cropped area in comparison to irrigated area must be used to increase or decrease water allowances.

6. Conclusions

Pakistan is an agrarian economy and ranked highly in international market for production of major crops; Wheat 7th, Sugarcane 5th, Rice 10th, Cotton seed 4th, Banana 54th, Onion 9th, Maize 22nd and Lentils 22nd among approximately 50 countries (Govt of Punjab, 2019). Pakistan also has one of the extensive and longest irrigation systems capable of diverting 104 MAF at canal head to support agriculture sector. To improve the conveyance efficiency for this system, extensive public sector investments have been made. This additional availability of water has not improved the share of agriculture in national GDP, predicting a very poor and slow return on public sector investments. These gaps in production and efforts are the result of a number of factors; including variation in climate, alterations in designated cropping patterns, poor support prices of cash crop and poor value of water against the value of processed agricultural products such as sugar and cotton products. Climatic variations are not as high as predicted by the climate change prediction and models but they are sufficient in pace to increase crop water requirements and crop production in the absence of required amount of water. Over a period of 10 years (2007-2017); one historical flood has been recorded in River Indus, 2014 in River Ravi and Chenab and last years of the decade remained drier than the previous years. Rainfall pattern during early Rabi season has shifted to late Rabi months. During months of March and April, high difference in day and night time temperature during these months are resulting into recurring events of windstorm accompanied with rainfall and sometime hail turning blessing into bane. Such events recurring every year are causing wheat crop lodging reducing the yield of crop. These weather anomalies, started in some districts are spreading sporadically and returning annually. In 2018, the heat wave of March through Punjab and Sindh province including shortage of canal water enhanced day light factor leading to early maturity of wheat crops resulted in lighter grain size and hence the overall yield of crop. Kharif crops such as cotton has also suffered from 14 to 30 days shift in monsoon peaks in cotton growing areas of Punjab. Starting from mid-August to the mid of September, high intensity rainfall events causing light boll size for cotton, shedding of flowers and infestation of insects hampered cotton crop reducing overall value of irrigation water.
Increase in land coverage by high delta crops, Sugarcane and Rice even in areas of low rainfall may have increased the cash earning by the farmers but reduced the value of Water. Rice and sugarcane are crops of high choice in dry climate districts having marginal to poor quality groundwater such as; D.G.Khan, Muzzafargarh, Bahawalpur division, Mirpurkhas, Ghotki, Tando Allahyar and Matiari districts of Punjab and Sindh provinces. Increasing shift from designated crop zones may have increased overall crop production of a particular crop but it has reduced the irrigated area coverage in respective canal commands, jeopardizing water rights of tail enders creating water scarcity situation. Remodeling of Abbasia canal in southern Punjab, Nara Canal in Sindh, Patfeeder canal in Balochistan and constructing an entirely new Kachhi canal has improved water availability for respective command areas. Redesigning water allowance and improving farmer's water conservation skills are least taken care of, therefore farmers are still practicing over irrigation on area being irrigated in pre-modeling era.

Poor value of irrigation water and increasing water shortages during the cropping seasons are very low support prices of food crops in comparison to actual cost of production of these crops. Wheat is the first and foremost priority by and large all farmers of Pakistan for fulfilling their basic food needs. Rice crop is prioritized for cultivation due to its higher cash value in due to export potential of Pakistani rice. Consistently lower support prices in comparison to increasing cost of agricultural input leave no option in front of farmers to grow wheat on more land with limited efforts; less water conservation method, carefree application of irrigation water and intercropping with high delta crops particularly both in Punjab and Sindh province. Lower support prices of raw Cotton and Sugarcane crops in comparison to the value of industrial products are also strong reasons for disturbing cropping pattern and over irrigation practices by farmers. Sugarcane crop earn very low for farmer less than 200 rupees per 40 Kg whereas a factory owner earns 20 times more but converting sugarcane into sugar. This imbalance in the support prices reduces the monetary value of water used to produce this raw cane. Unable to break the glass ceiling of support pricing farmer opts more sugarcane and over irrigate it throughout the year to enhance its sucrose weightage. The support price of cotton crop is of similar scenario. In the absence of equitable pricing for low and good quality cotton seed, farmers put limited efforts on improving quality of the produce rather focus on its weight to earn more cash. This once again lowers the value of water used for irrigation and nurturing these cash crops.

This system of support pricing and consistent cropping patterns has restricted farmer's attention towards high delta crops despite facing losses at the hand climatic anomalies. There is need to shift to crops with more cash value to ultimately increase the earned value of per unit water consumed. Crops like Maize, lentils and pluses are sold in the market on whole sale basis. Maize crop serves as raw material for human and animal food. Certain oil and food industries rely on this product. Maize crop is also serving as rich green fodder for livestock. There are other crops such as lentils, potato, onion and garlic seed that are sold in market on whole sale pricing basis. Moreover, most of these crops are being imported to meet the national food needs. A shift from traditional cropping patterns to more unconventional crop choices is needed to increase the value of water. Pakistan may have ranked highly among top countries producing rice, wheat, cotton and sugarcane but its contribution into global production of these crops is way less. Therefore, climate change offers an opportunity to attempt this alteration and try new crops and verities not only to enhance the value of water consumed but to lighten the burden on public exchequer by reducing import volume.

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Appendices

1.1 Canal Network in Sindh