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Impact of Cropping Pattern and Climatic Parameters in Lower Chenab Canal System—Case Study from Punjab Pakistan

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Abstract: In Pakistan, groundwater resources are depleting at an alarming rate due to intensive pumping, shifting of cropping patterns, and climate change vulnerability. The present study is aimed at investigating groundwater stress in the command area of Lower Chenab Canal (LCC) and associated branch canals. Groundwater stress is determined by considering the cropping patterns, surface water availability, groundwater levels, climatic variation, and crop water requirement (CWR) in the LCC command area. The climatic data is obtained from the Pakistan Meteorological Department (PMD) from 1990 to 2020. The records of temporal variation in cropping patterns are obtained from the Crop Reporting Service (CRS), Directorate of Agriculture, Lahore for the 1995–2020 period and classified according to Rabi season (November to April) and Kharif season (May to October). The LCC surface water flows data and groundwater levels are collected from the Punjab Irrigation Department (PID) Lahore from 2003 to 2018 and from 1995 to 2016, respectively. The CWR is estimated using the Cropwat 8.0 model and groundwater levels are estimated using the Inverse Distance Weighted (IDW) tool of ArcGIS software. It has been determined that Faisalabad, Sheikhupura, and Toba Tek Singh are highly groundwater stress cities having an average drawdown rate of 0.58 m/year. The surface water availability is also decreased from 7.75 to 4.81 billion cubic meters (Bm^3) for the Kharif season whilst 4.17 to 2.63 Bm^3 for the Rabi season. This study concluded that due to severe conditions in highly stressed areas, policy planners, decision-makers, and stakeholders should sincerely take some steps for maintaining groundwater levels either by capacity building workshops for the farmers or limiting the number of tubewells.

Keywords: cropping pattern; water stress; LCC area; surface water availability; CROPWAT

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1. Introduction

Water is essential for human well-being and socio-economic development. In Pakistan, surface water plays a significant role in performing agricultural activities. About 95% of the available freshwater is utilized by the agriculture sector whilst only 5% is used for domestic and industrial activities [1]. The conveyance of surface water is accomplished by the largest irrigation network, namely the Indus Basin Irrigation System (IBIS) [2]. However, the surface water supplies in IBIS are shrinking due to industrialization, urbanization, and exponential growth of population [3–5].

Groundwater is recognized as an alternative source of accessible freshwater, contributing 69% of total accessible freshwater share, and accounting for one-third of global freshwater usage [6–8]. In Pakistan, reliance on groundwater is dramatically increasing.

Approximately 62 billion cubic meters (Bm^3) of groundwater is pumped out each year [9]. Figure 1 illustrates the average annual water balance of IBIS [9]. Watto et al. [10] reported exponential growth of groundwater contribution due to the massive installation of tubewells [11]. The growth rate of private tubewells was 60% only in Punjab province from 1991 to 2000 [12]. More than 70% of urban and 97% of rural populations depend upon groundwater, whilst industries fulfill their major water requirements from groundwater [13,14]. High dependency on groundwater results in a major dropdown of groundwater levels, consequently leading to the water crisis. According to Falkenmark indicator [15], Pakistan met water scarcity criteria in 2005, and there will be an absolute water scarcity in 2025 [16]. Pakistan's Water Resources Vulnerability Index (WRVI) is 77% which indicates that the country would face a serious water crisis shortly [17]. The surface water supplies are limited therefore extensive groundwater pumping is made hence placing Pakistan among the top ten countries that are dramatically affected by water pumping [18].

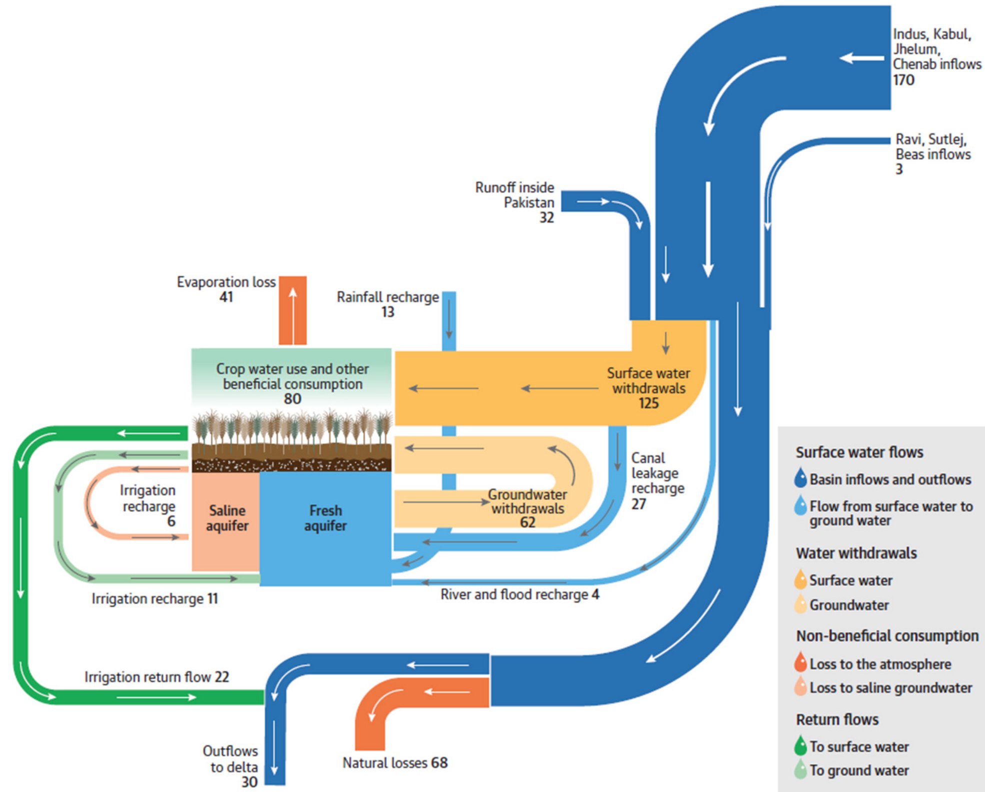


Figure 1. Average annual water balance of the Pakistan Indus Basin [9].

In Pakistan, the agriculture sector is more sensitive as compared to other sectors due to its 19.2% contribution to gross domestic product (GDP) and 38.5% employment in the labor force [19]. Human activities and climate change meaningly affect the flow regimes of surface water and groundwater [20]. For instance, mostly in the eastern region of Pakistan, the temperature is rising, which causes an increase in agricultural water requirements [21] due to increment in evaporation rate, and transpiration rate. In addition, the shifting of rainfall patterns in northern regions of Pakistan creates a significant water shortfall during Kharif and Rabi seasons. Poor irrigation practices further lead to the water crises hence demanding strict implementation of water management strategies for socio-economic development [22,23]. In comparison to other Asian nations with low mean annual rainfall, almost 70% of the rainfall stations tended to increase rainfall during monsoon seasons [13,17]. However, during the last decade, shifting rainfall patterns and rising temperatures also influenced accessible water, resulting in a substantial decline in the countries' freshwater availability [24]. Consequently, a large amount of groundwater is being extracted from the ground to meet the crop water requirements (CWR). Farmers are extracting groundwater to satisfy the agricultural water needs without considering the actual CWR from the perspective of getting maximum yield [1,25]. In this regard, a large number of tubewells (2700 to millions) have been installed in the country during the last 64 years [26] having no systemic trend in tubewell densities. Farmers are pumping the groundwater without any concern about groundwater depletion and its quality. In some areas of Pakistan, the quality of groundwater is degrading day by day due to the disposal of untreated industrial and domestic wastewater in nearby streams [5,9,27].

The Lower Chenab Canal (LCC) is one of the major sections of the IBIS constructed between 1892 to 1898 having a command area of 12,266 km^2 which includes Gujranwala, Hafizabad, Sheikhupura, Nanakana Sahib, Faisalabad, Jhang, and Toba Tek Singh [28]. Climate change, rapid urbanization, inefficient water use, and limited surface water supplies create an alarming situation in the command area of LCC for crop production. Therefore, extensive groundwater extraction is being made to meet the agricultural needs resulting in a massive drop in groundwater levels. The estimation of groundwater degradation is crucial. In this regard, several studies have been reported in the literature. For instance, Ahmed et al. [1] investigated the crop water supply-demand gap of two main distributes (Killianwala and Mungi) in the command area of LCC using CropWat 8.0 model. Land use, soil type, and topography were considered the influential aspects that impact the water deficiency. The recorded average water shortfall is 4.1 million cubic meters per year (Mm^3/year) for Killianwala and 4.9 Mm^3/year for the Mungi distributary. Yongguang et al. [29] quantified the groundwater pumping in Killianwala and Mungi distributaries from 2014 to 2015. It was reported that for both distributaries the groundwater pumping is compulsory due to a shortfall in canal water supplies, but lower demand as compared to canal water however, more for Mungi and less for Killianwala. Usman et al. [30] performed numerical modeling and remote sensing for estimating the inflow and outflow of groundwater in the LCC command area. It was reported that the groundwater inflow is 0.871 folds higher as compared to the pumping rate. However, a significant groundwater drawdown is expected between 2026 and 2035 due to limited canal water supplies. Awam et al. [31] utilized the Soil and Water Assessment Tool (SWAT) for determining the CWR in the command area of the LCC corresponding to varying the climatic parameters. The results shows that the CWR could be increased by 7% and 11% during 2020, under different climatic scenario.

Similarly, the area under groundwater quality associated with LCC has been degraded from 50.35% to 28.95% up to 2030 [12]. The groundwater recharge to withdrawal ratio is 0.8/1.0 resulting in the rapid drawdown of the water table in most parts of Pakistan [32]. Safe groundwater potential is about 53.04 Bm^3 while abstraction is 55.51 Bm^3 with an over-abstraction of 2.47 Bm^3 [33]. This issue with Pakistan's water table suggests that the country's groundwater supply would be insufficient to meet future water demands. This requires continuous monitoring of groundwater and resource management [34].

For sustainable water resource planning, there should be a clear estimation of pressure on the natural water reserves. In this regard, the present study aims to estimate the water supply-demand gap in the areas under the LCC irrigation system. In addition, the groundwater fluctuation both for pre-monsoon and post-monsoon seasons was analyzed and explored using the inverse distance weighted (IDW) method. Identification of water-stressed areas and the effect of climatic parameters on the groundwater and cropping pattern are being explored. Based on the previous literature, there is no research available that identifies the effect of cropping patterns and climatic parameters for estimating groundwater stress, particularly in Punjab, Pakistan. For doing this, meteorological data, groundwater levels, streamflow records, and cropping patterns in the LCC region were collected from the Pakistan Meteorological Department (PMD), Punjab Irrigation Department (PID), and Crop Reporting Service (CRS). After performing feature engineering, the data is employed to estimate the crop water requirements using CropWat [35]. Considering the streamflow and crop water requirement, temporal water deficiency is estimated. The present study could be supportive to employ water management practices, particularly in highly stressed cities nearby the LCC and associated branch canals.

2. Materials and Methods

The methodology and steps employed to determine the groundwater stress in the command area of LCC as shown in Figure 2. The steps comprising of: (i) collection of data from the relevant departments; (ii) data analysis; and (iii) results obtained in terms of highly stressed areas.

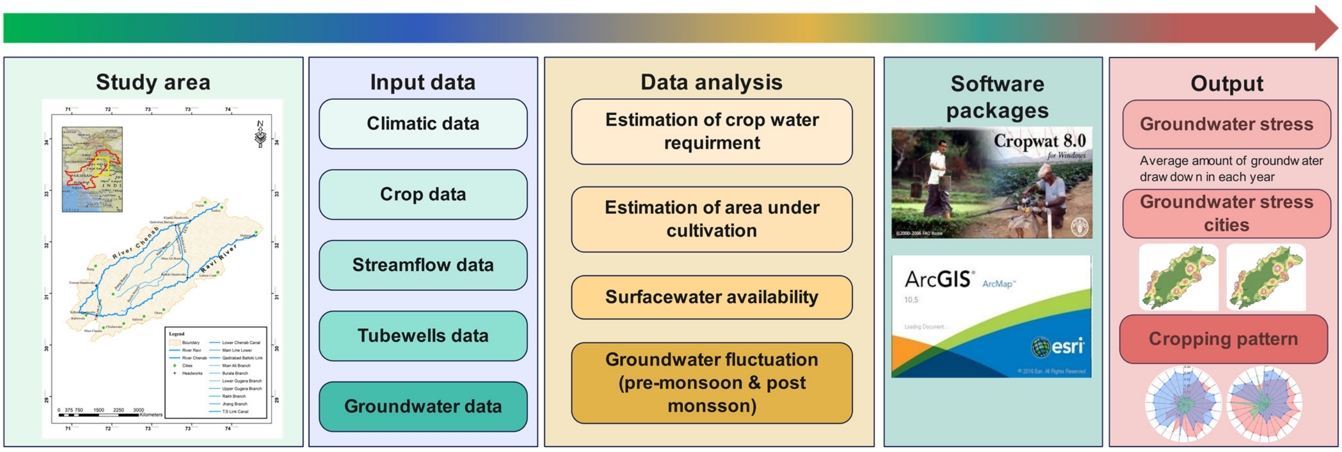


Figure 2. A detailed flow chart of the methodology adopted in the study.

2.1. Study Area

For this research, the LCC area was selected, and the canal network along with the branch canals are shown in Figure 3. The branch canals include the Upper Gugera, Lower Gugera, Burala, Mian Ali, Rakh, Jhang Upper, Jhang Lower, and Bhowana canal. Flow in this study area is Perennial. Divisions, sections, reduced distance, distances, designed head discharge, authorized tail discharge, authorized tail gauge, gross command area, and culturable command area of all of the canals are tabulated in Table 1.

Table 1. Features of main canal, branch canals in Lower Chenab Canal [36].

Description	LCC	Upper Gugera	Lower Gugera	Burala	Mian Ali	Rakh	Jhang Upper	Jhang Lower	Bhowana
Division	Khanki	Upper Gugera	Lower Gugera	Burala	Upper Gugera	Hafizabad	FSD Canal	Jhang	Jhang
Section	Chenawan	Ajniawala	Jaranwala	Farida	Salar	Main Line Lower	Bhobra	Sheikh Chur	Jaura
Distance (km^2)	64.36	90.10	123.89	156.07	32.18	88.50	98.15	59.53	27.35
Designed head discharge (m^3/s)	230.58	210.79	74.84	58.22	20.50	38.34	88.77	42.98	14.33
Authorized tail discharge (m^3/s)	0.00	125.87	16.21	9.00	10.76	11.27	51.93	10.96	10.87
Authorized tail gauge (m)	0.00	3.29	0.00	0.85	0.66	0.69	1.94	0.30	0.30
Gross command area (km^2)	14,973.38	4865.60	62.50	2344.6	30.46	1553.79	1616.43	38.01	12.20
Culturable command area (km^2)	13,759.32	4102.19	51.54	2064.0	25.90	1258.08	1272.17	35.15	8.89

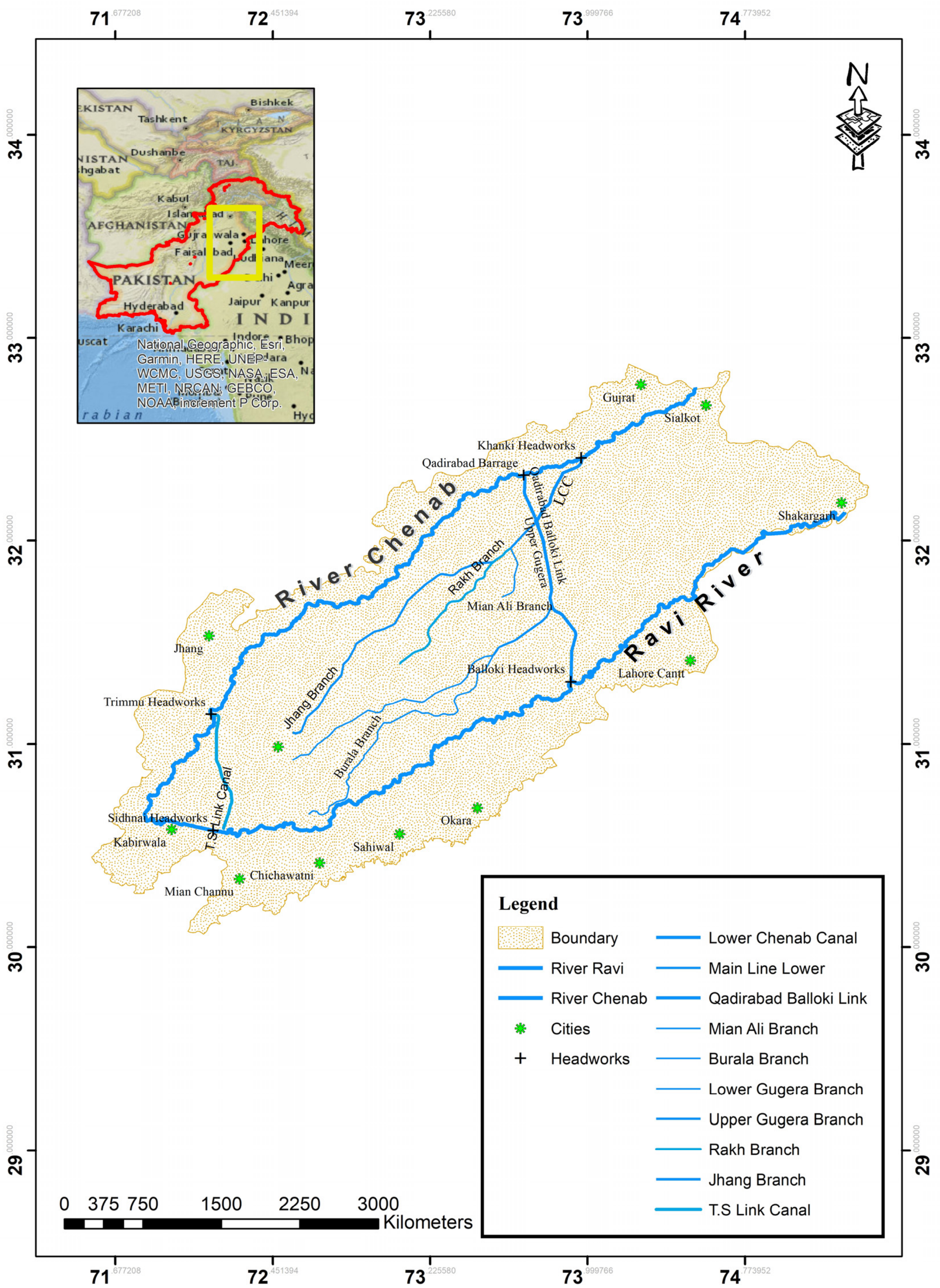


Figure 3. Location map with all rivers, canals, cities, and headworks.

Data collected from various governmental and private departments includes the number of tubewells, canal water supplies, crops grown, climatic parameters, and groundwater levels in various districts of the LCC area, which is tabulated in Table 2.

Table 2. Data collected from various organization.

Parameters	Duration	Department
Climatic Data	1990–2020 *	Pakistan Meteorological Department (PMD)
Groundwater Levels	2003–2018	Punjab Irrigation Department (PID)
Streamflow	1995–2016	Punjab Irrigation Department (PID)
Crops grown	1995–2020	Crop Reporting Service (CRS), Directorate of Agriculture, Lahore
No. of Tubewells	2008–2020	

* Limited for some stations due to not availability of climate stations.

2.2. Crop Water Requirement

Penman-Monteith method [37] is used in CropWat for the estimation of the crop water requirement (CWR). The empirical relationships used in this method is given in Equations (1)–(3).

$$CWR = ET_p \times P_e \tag{1}$$

$$ET_p = ET_o \times k_c \tag{2}$$

$$ET_o = \frac{\left(0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T\ +\ 273}\right)u_2(V_s - V_a)\right)}{\Delta + \gamma(1 + 0.34u_2)} \tag{3}$$

where, in Equation (1), ET_p and P_e stand for potential evapotranspiration, and effective precipitation which excludes the losses in precipitation, respectively. Similarly, the ET_o and k_c used in Equation (2) refer to observed evapotranspiration and crop factor which are different for all of the crops, respectively. However, for determining the ET_o, Equation (3) is used, covering different meteorological and psychometric variables. For instance, in psychrometric variables, actual vapor pressure (V_a), saturated vapor pressure (V_s), psychometric constant (γ), and slope of saturation (Δ) of the studied areas were used. In the case of meteorological variables, net radiations (R_n), wind speed (u_2), soil heat flux (G), and temperature (T) data were deployed in CropWat 8.0, taken from the different meteorological departments as mentioned in Table 2.

For this research, the cropping pattern is analyzed to estimate the area under different crops both for the Rabi and Kharif seasons for the duration of 1995–2020. CWR is estimated for all of the crops and the whole area. Streamflow data is used for the estimation of the surface water availability within the study area for both seasons. The deficit is estimated by subtracting the surface water availability from CWR. Based on the deficit and groundwater levels, the highly stressed areas in the area were taken and analyzed to check the reasons for rapid drawdown.

3. Results and Discussions

3.1. Kharif Crops

Bajra, cotton, sorghum, maize, moong, rice, sugarcane, and fodder are commonly cultivated crops identified during the Kharif season. However, rice, sugarcane, and fodder are extensively grown crops covering more than 70% of total cultivated land in this region. In the last 25 years (1995–2020), the cumulative area for rice cultivation recorded 61,471.8 km^2 followed by fodder and sugarcane having 44,798 km^2 and 43,706.09 km^2, respectively as illustrated in Figure 4. Moong pulse is the least cultivated crop in this region (578.7 km^2), among the mentioned Kharif crops. In comparison to 1995–1996, the overall area under cultivation has dropped around 8.2% during the 2019–2020 period. The maximum and minimum area utilized for crop production was observed in 2004–2005 and 2018–2019 having a gross production area of 8595.5 km^2 and 7171.0 km^2, respectively. In Figure 4 color gradient illustrates the shifting of the cropping pattern in consecutive years. For instance, it has been realized that the cropping pattern of the bajra is static, between 141.6–303.5 km^2 from 1995 to 2020. Similarly, in the case of sorghum and moong, no significant drop or increment in the cropping pattern is observed. However, for cotton, there is a declining trend in the cultivation pattern from 1995 to 2020. In 1995–1996 the area utilized for cotton cultivation is 1205.93 km^2 whilst in 2015–2016 it has been reduced to 364.82 km^2. However, in the case of rice, and fodder the cultivated area is increasing, which indicates the shifting of the cropping pattern toward high delta crops. Consequently, the pressure on the groundwater reserve is progressively increasing.

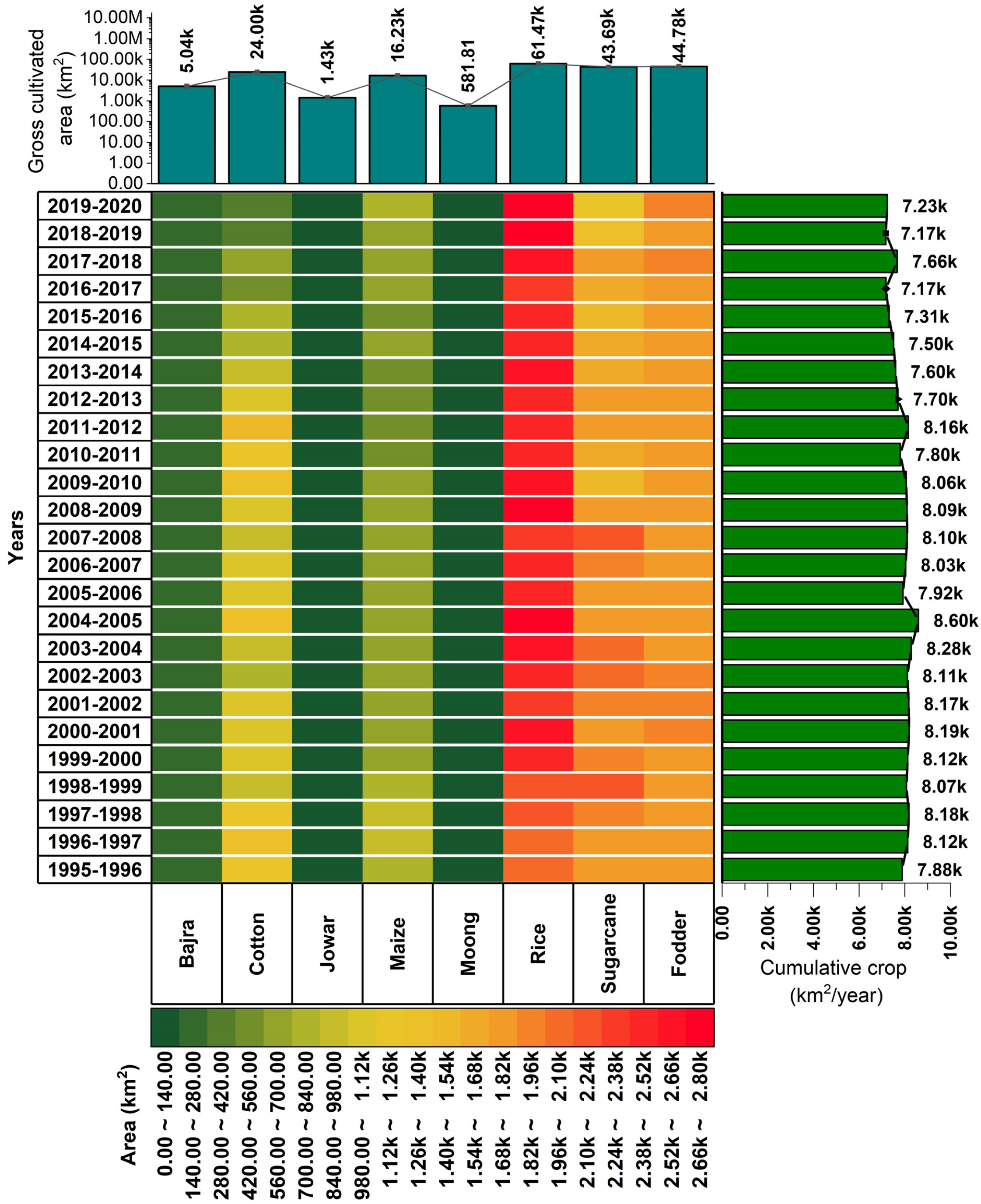


Figure 4. Shift in cropping pattern and cultivated area from 1995 to 2020 in kharif season.

3.2. Rabi Crops

During Rabi season, a total of 11 crops which includes barley, fodder, gram guava, kinnu, linseed, masoor, onion, potato, tomato, and wheat are considered normal crops are grown in this region. However, wheat cultivation is more than the other crops, holding 70% of the land in the region associated with the LCC area. In the last 25 years, the cumulative area utilized for cultivation of the wheat was recorded at 178,547.5 km^2 followed by fodder (Rabi) having a cultivated area of 38,000 km^2. Figure 5 shows the temporal variation in the area utilized for cultivating the Rabi crops. The area employed for the cultivation of barely, guava, linseed, masoor, onion, potato, and tomato ranges between 0.57–382.8 km^2 from the period of 1995 to 2020. Similarly, in the case of gram and kinnu, the area employed for cultivation each year ranges between 382.0 to 764.0 km^2 per year. However, in the case of Fodder (Rabi), the marginal variation is observed in the area utilized for cultivation ranging between 1100 to 1900 km^2 per year. The area for wheat cultivation ranges within higher levels (6070.3–7284.3 km^2 per year). Concludingly, no shifting of cropping pattern is recorded under the studied region during the Rabi season. The cultivated area during the Rabi season in each year is greater than 8093.7 km^2. The reduction in the cumulative area of Rabi crops was estimated at ~5.6%. Wheat is an extensively grown crop in this region.

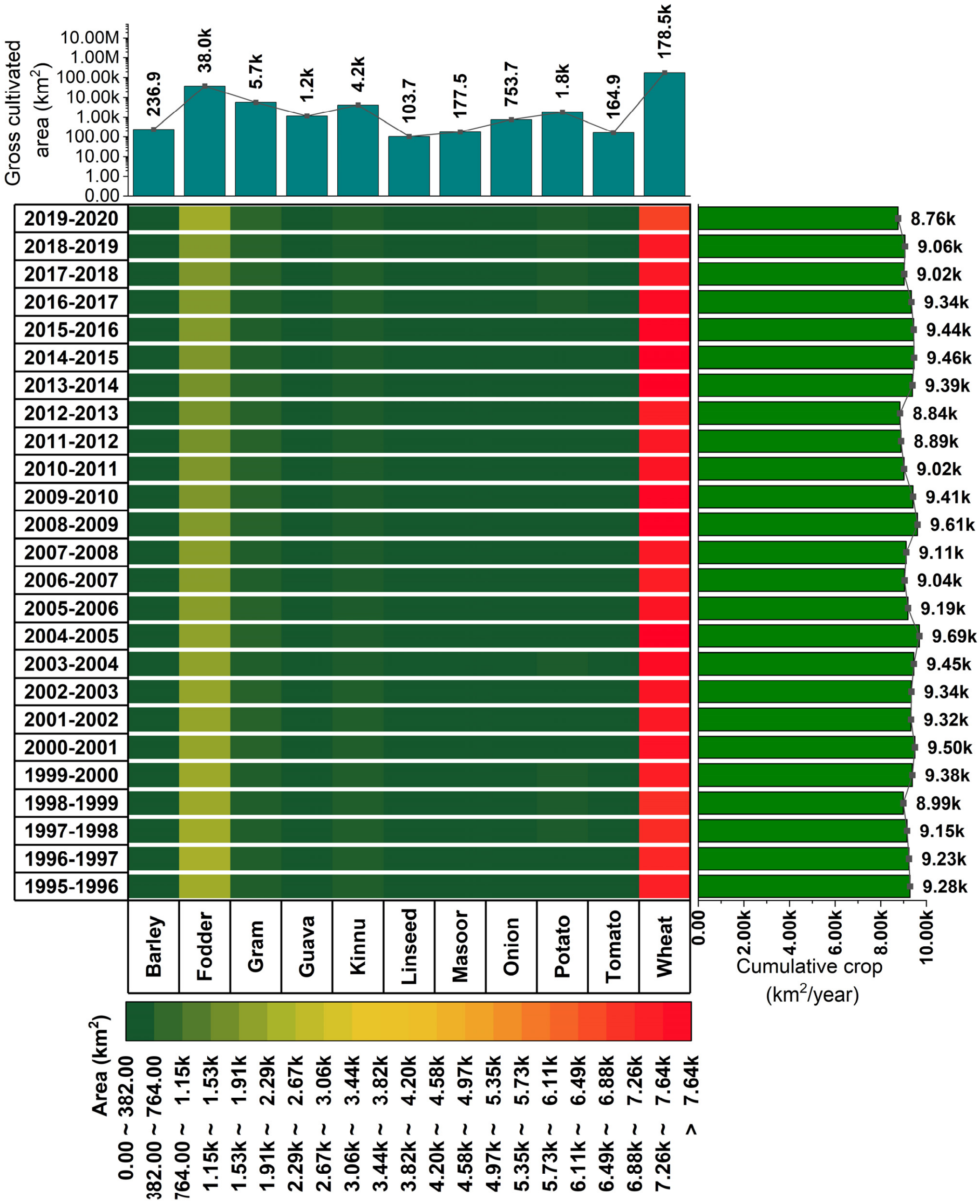


Figure 5. Shift in cropping pattern and cultivated area from 1995 to 2020 in the Rabi season.

3.3. Crop Water Requirement

By using the Cropwat 8.0 model, the crop water requirement (CWR) of the selected crops both for Kharif and Rabi is estimated and presented in Figure 6. A progressive drop is represented in the clockwise direction corresponding to the selected crops. For instance, sugarcane has the highest CWR (1577 mm) followed by rice (1182 mm), guava (1120 mm), kinnu (1067 mm), and so on. In comparison, Shakir et al. [38] reported that for Kharif and Rabi season the CWR range between 300 mm to 1450 mm and 250 mm to 400 mm, respectively. The estimated crop water requirement is in the acceptable range if compared with the study reported by Shakir et al. [38]. Since the area under cultivation is decreasing, CWR should also decrease, for both Rabi and Kharif seasons, at the same rate but due to the use of high delta crops with higher values for crop water requirements, it is decreasing at a lower rate as shown in Figure 7. In addition, Figure 7 defines the area distribution of Rabi, Kharif, and cumulative CWR.

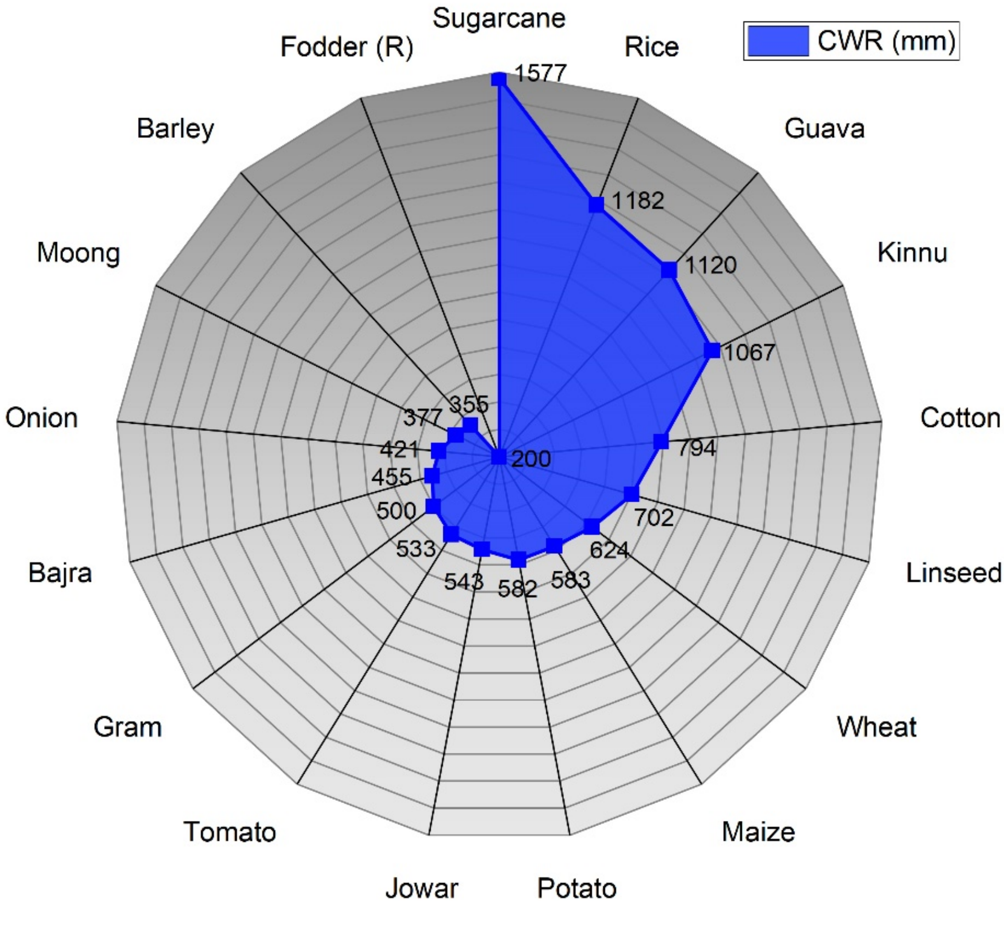


Figure 6. Crop water requirement for all crops grown in LCC area.

3.4. Surface Water Availability

Surface water availability is estimated based upon the streamflow data collected from the PID, for both Rabi and Kharif seasons as given in Figure 8a. Surface water availability in LCC decreased from 11.92 to 5.06 Bm^3 from 1995 to 2002, after that an up and down trend is observed. The minimum surface water availability in LCC was recorded in 2009–2010 having a value of 3.82 Bm^3. On the other hand, the water demand is estimated based on the crop water requirement and cultivated area in the region. Thereby, the water shortfall in the region is shown in Figure 8b. It has been identified that the maximum water shortfall was recorded in 2004–2005 followed by 2009–2010 with the shortfall of 8.89 Bm^3 and 8.77 Bm^3. In 2015–2016 the total water shortfall is 4.56 Bm^3 corresponding to a water supply of 7.51 Bm^3 against the demand of 12.08 Bm^3. In addition, the total average deficit was recorded at

8.02 Bm^3 which creates an alarming situation for the country and emphasizes the pumping of the groundwater for meeting the water shortfall. Waqas et al. [39] employed satellite remote sensing and the geographic information system (GIS) for estimating the dropdown of surface water availability in LCC. The study reported that at the Killianwala distributary the average water supply deficit is 6 Mm^3 whereas in Mungi and Khurrianwala distributary water supply deficits recorded 5 and 5.5 Mm^3, respectively, during the 2009–2010 period.

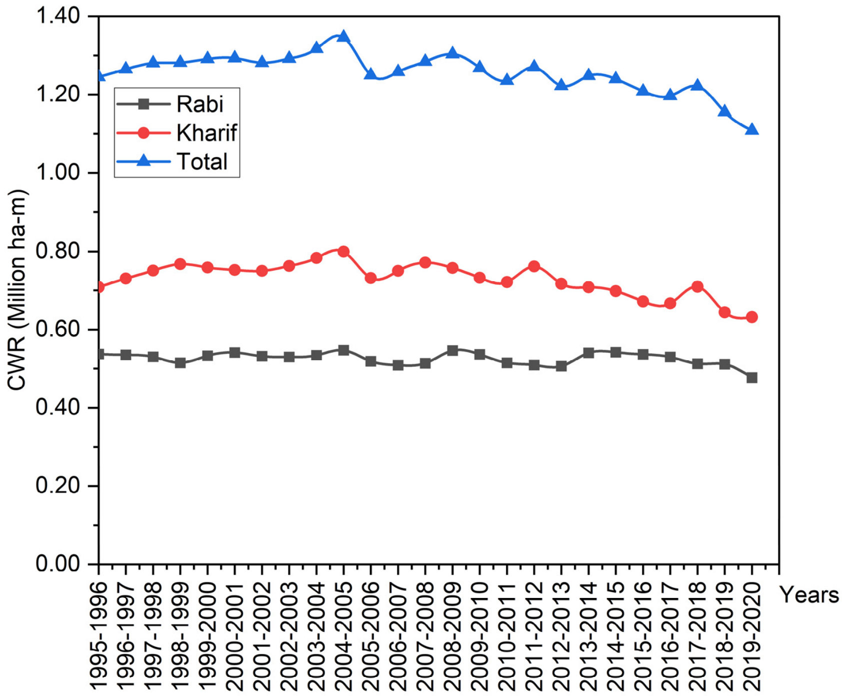


Figure 7. Temporal variation in crop water requirement during Rabi and Kharif season in LCC area.

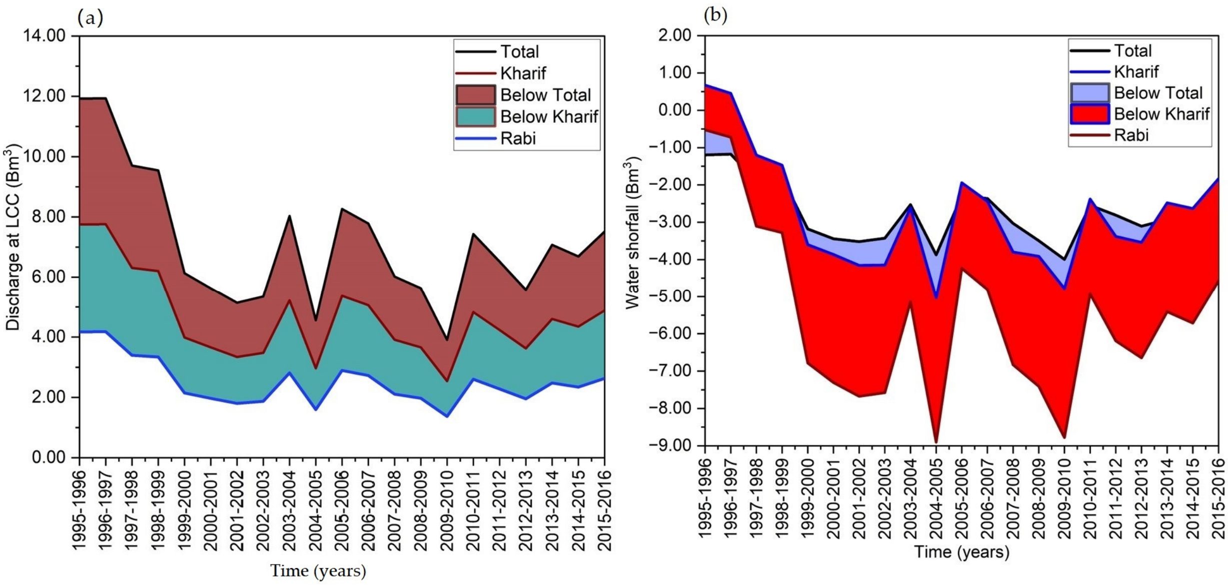
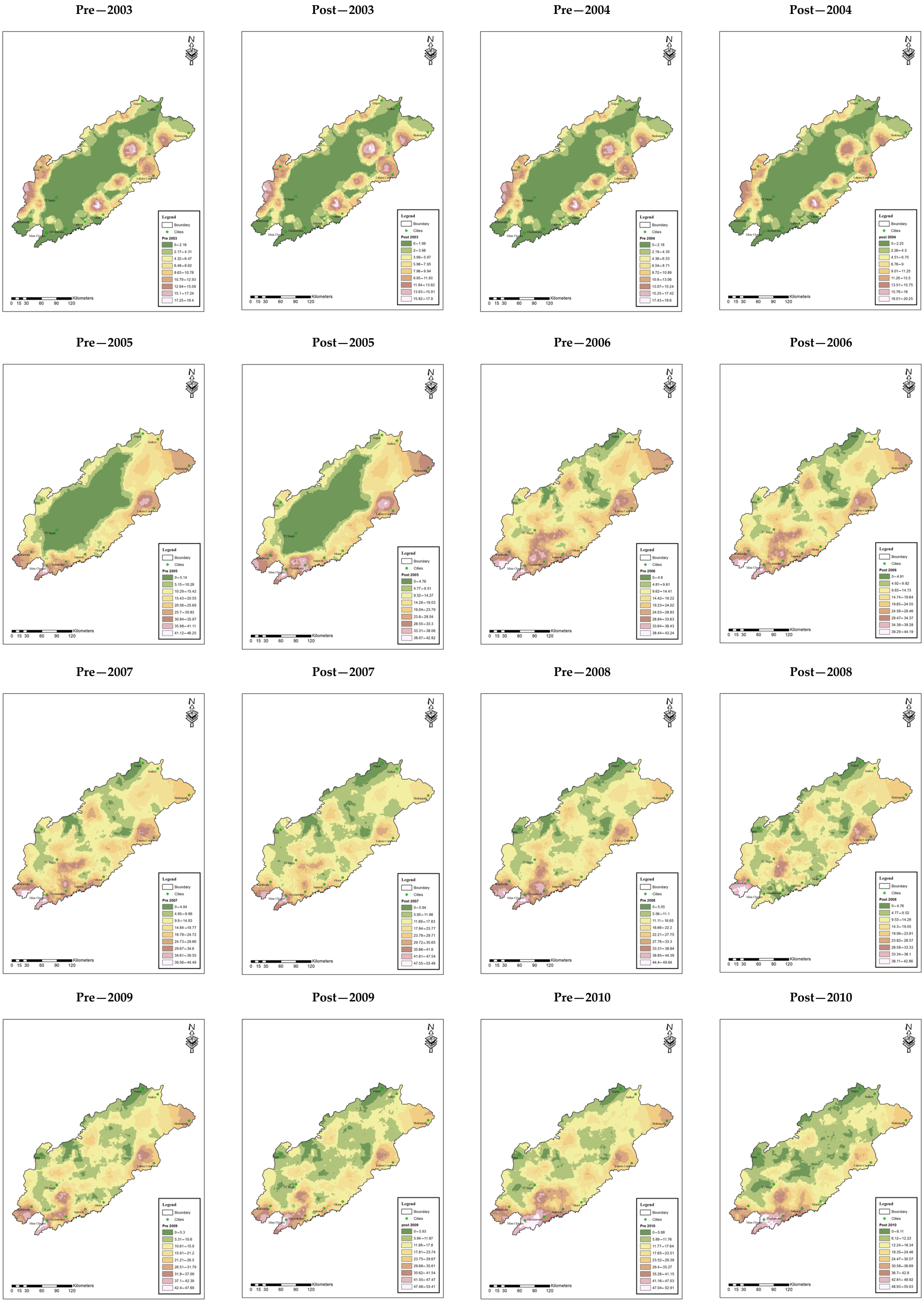


Figure 8. (**a**) Temporal variation in surface water availability, and (**b**) cumulative deficit estimated in Rabi and Kharif season.

3.5. Groundwater Fluctuations

In order to investigate the ground water fluctuations in the studied area, data of the ground water levels at specific localities were collected from the PID. After that, Inverse Distance Weighted (IDW) tool is used in ArcGIS for interpolating the groundwater levels in the whole area from 2003 to 2018 for pre-monsoon and post-monsoon seasons as shown in Figure 9.



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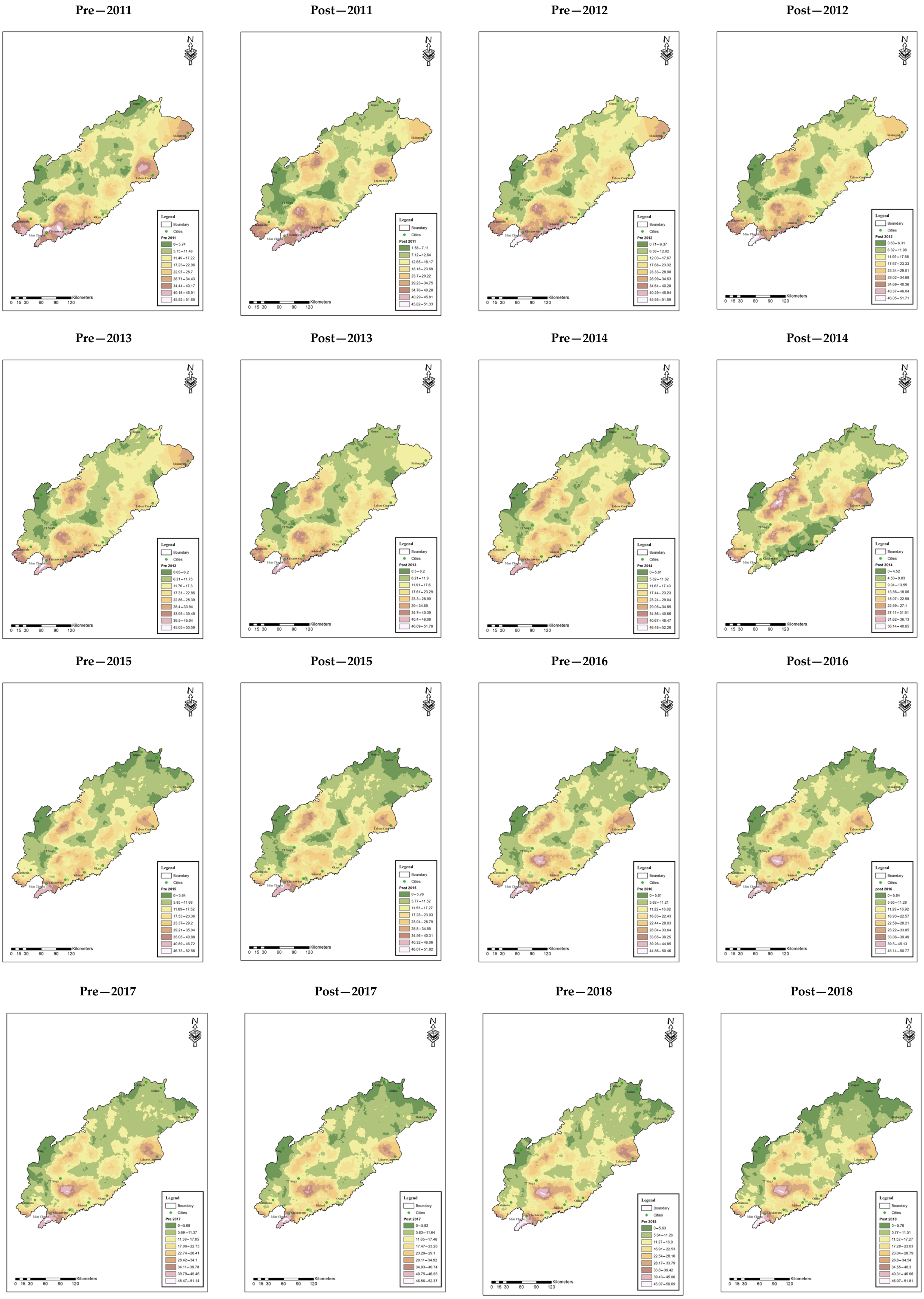


Figure 9. Interpolation of groundwater levels for pre- and post-monsoon from 2003 to 2018.

From these trends, the maximum groundwater depths from 2003 to 2018 vary from 5.91 m to 15.45 m resulting in a 9.54 m (0.61 m/year) drawdown in groundwater depth. For checking the results, a comparison is made between the net deficit and average groundwater levels for the year 2015–2016. The average groundwater depth in 2015 was 6.33 m while it is 6.18 m in 2016 which corresponds to a 0.15 m drawdown. While the net deficit in 2016 was 0.05665 m (56.65 mm), the remaining 0.09 m is used by domestic, industries, etc. In comparison to this study, Qureshi et al. [33] reported that groundwater levels in most of the irrigated parts of the study area have a drawdown up to 6 m which directly increases the pumping cost due to deep well boring.

3.6. Highly Stressed Areas

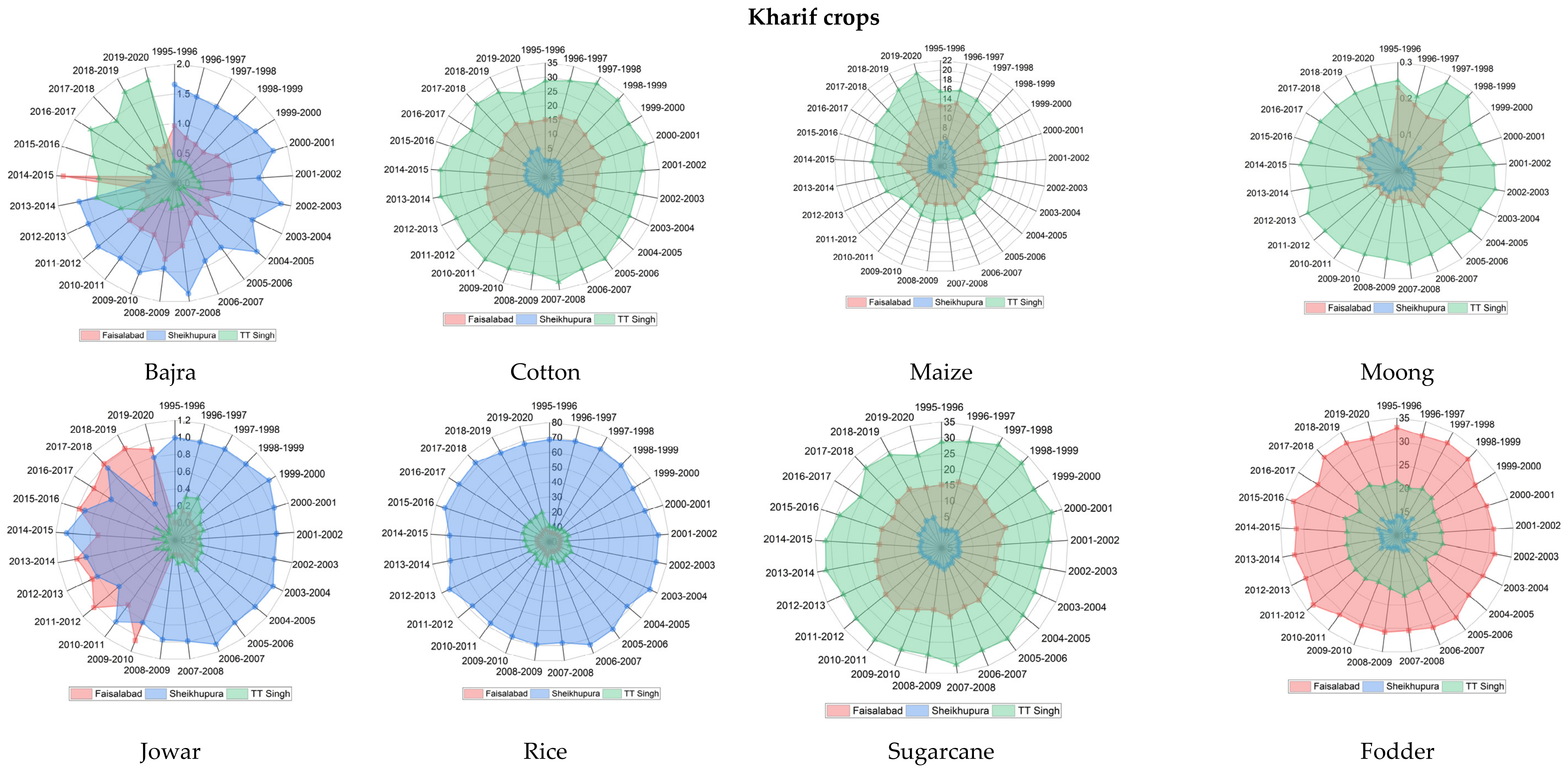
To check the possible cause of stress on groundwater, highly stressed areas in the LCC are identified from groundwater depths. The highly stressed areas are Faisalabad, Sheikhupura, and Toba Tek Singh where the groundwater is depleting abruptly. Average groundwater depletion is 9.54 m (0.58 m/year). Reasons for rapid drawdown are due to different causes such as cropping effect, climatic effect, and effect due to tubewell density.

3.7. Cropping Effect

Since, for high delta crops, crop water requirement is high, the effect of crops is analyzed based on the historical data for the highly stressed areas as shown in Figure 10. In Faisalabad, rice, sugarcane, fodder, and maize cover 6%, 31%, 30%, and 13%, respectively, in the Kharif season while wheat is covering more than 70% area in the Rabi season. Similarly, for Sheikhupura and Toba Tek Singh, the results are summarized in Table 3. Rizwan et al. [40] proposed that if the command area of the LCC crop was cultivated with a cropping pattern containing wheat, rice, and cotton, with high-efficiency irrigation practices then surface water can be saved in a range between 2.768 Bm^3 and 3.699 Bm^3.

Table 3. Summary of the highest growing crop in highly stressed areas in Rabi and Kharif season.

Seasons	Crops	Faisalabad	Sheikhupura	Toba Tek Singh
Kharif Season	Rice	12%	70%	11%
	Sugarcane	31%	9%	23%
	Fodder	30%	15%	21%
	Maize	13%	3%	16%
Rabi Season	Wheat	>70%	>70%	>70%



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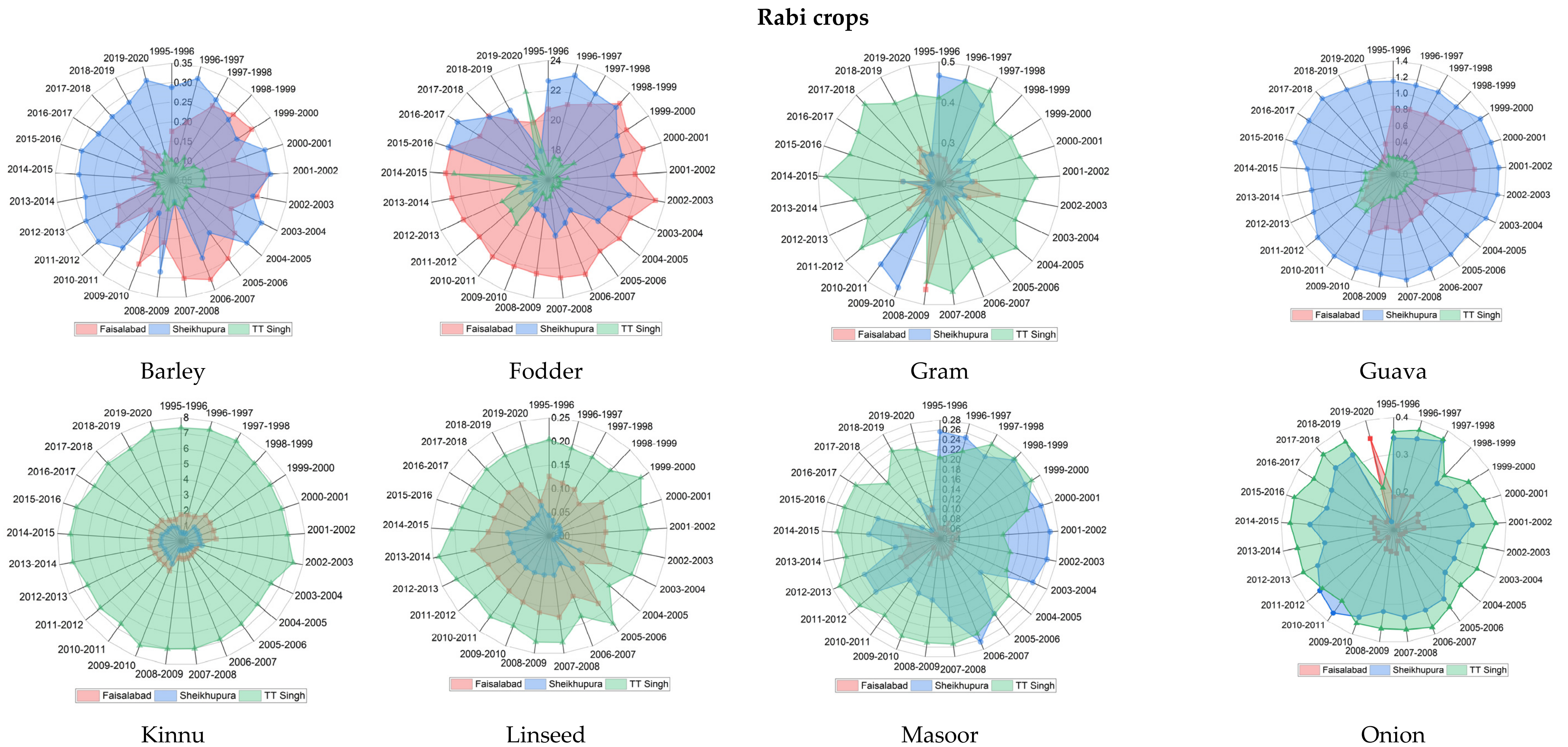

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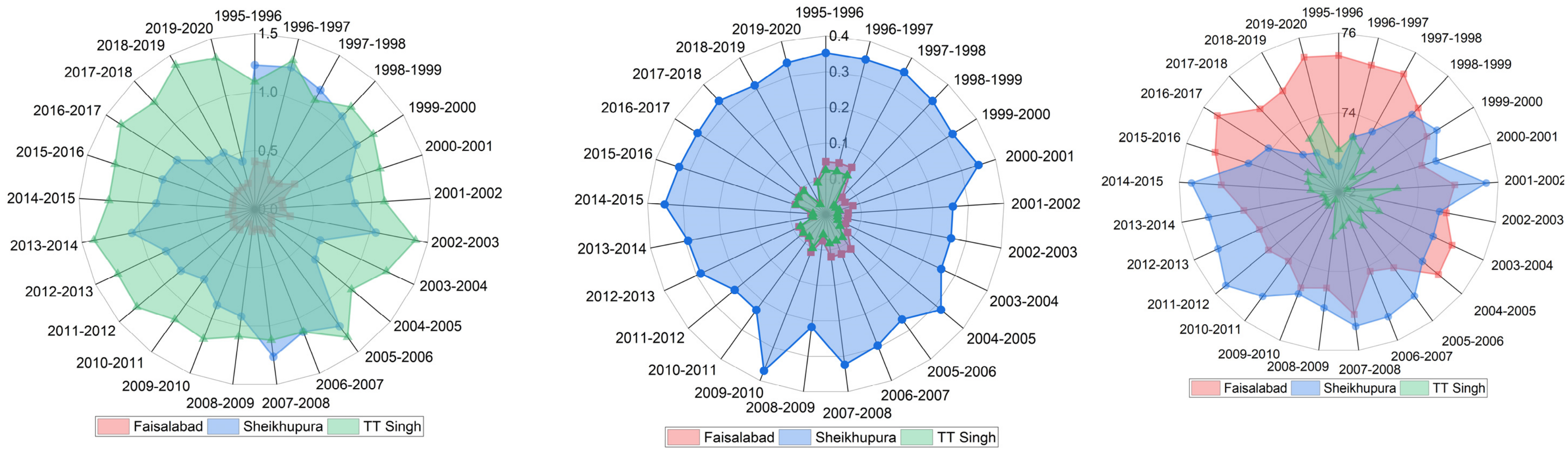

Potato Tomato Wheat

Figure 10. Change in cropping pattern percentages of both Kharif and Rabi crops in Faisalabad, Sheikhupura, and Toba Teik Singh for both Rabi and Kharif crops.

3.8. Climatic Effect and Effect of Tubewell Density

In highly stressed areas such as Faisalabad, Sheikhupura, and Toba Tek Singh, climatic factors are analyzed from the perspective of exploring their impacts on crop water requirements. Rainfall (mm), minimum temperature (°C), and maximum temperatures (°C) are selected as the meteorological parameters that significantly influence the crop water requirement. A comparison matrix of the three meteorological parameters among the highly stressed cities is presented in Figure 11. The maximum temperature recorded in Sheikhupura, Faisalabad, and Toba Tek Singh were 31 °C, 38 °C, and 34 °C, whereas the minimum temperature recorded was 18 °C, 16 °C, and 16.5 °C. The ranges of the temporal variability in the maximum and minimum temperature are summarized in Table 4. Sheikhupura's rainfall pattern is progressively increasing with higher intensity compared to Faisalabad and Toba Tek Singh which reflects the availability of water to fulfill the crop water requirement. In Faisalabad, rainfall has an increasing trend with minimum temperature and maximum temperature of 16 °C and 38 °C, respectively. The results are summarized in Table 4. Awan et al. [31] reported that temperature and rainfall significantly impacted the use of irrigation water. The water consumption in the LCC region could increase from 7% to 11% by the end of 2020.

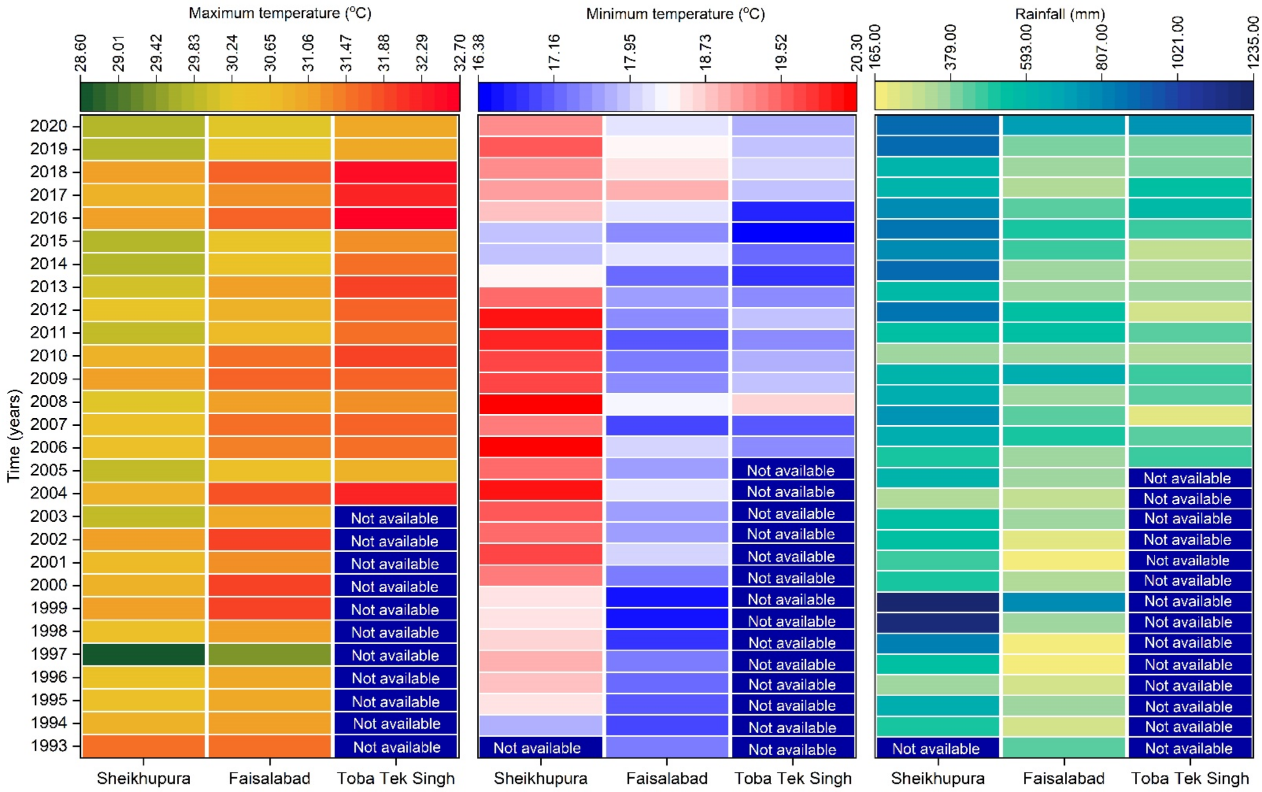

Figure 11. Historical trend of rainfall (**right**), minimum temperature (**center**), and maximum temperature (**left**) in highly stressed areas.

Table 4. Summary of climatic parameters in highly stressed areas.

Areas	Rainfall (mm)	Min Temperature (°C)	Max Temperature (°C)
Faisalabad	500–700	16–19	32–38
Sheikhupura	800–1200	18–20	29–31
Toba Tek Singh	400–700	16.5–18.5	30–34

Tubewells are used for various purposes such as agriculture and domestic and industrial use. Due to the rapid increase in tubewell, the extraction rate has also increased which affected the groundwater levels. Figure 12 shows the tubewell density from 2008 to 2021. In the last decade, the number of tubewells has increased from 225,660 to 338,300 having an average growth rate of 8664.6 tubewell/year.

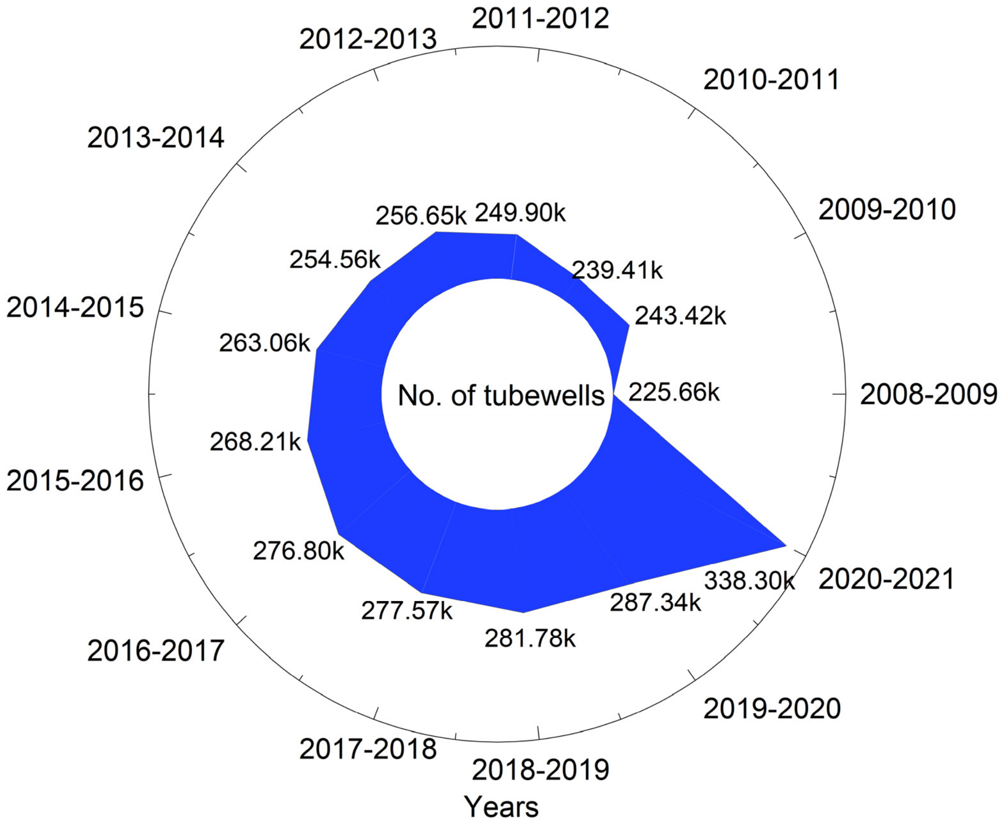

Figure 12. Change in tubewell density from 2008–2009 to 2020–2021.

4. Conclusions

Groundwater is a precious resource that has been rapidly depleting in some places of Pakistan owing to overexploitation. The present study focused on estimating the drop in groundwater levels near to Lower Chenab Canal (LCC) and its branch canals considering the temporal variation in cropping pattern, available surface water supply, and groundwater level. The results showed that rice, fodder, and sugarcane are the most frequent crops grown in the Kharif season occupying 70% of the cultivated land in the study area. Crops growing pattern is shifting towards high delta crops (i.e., rice, and sugarcane), thus increasing the crop water requirement in the region. Wheat is mostly grown in the Rabi season holding 70% of the cultivated area and ranges from 6070.3 to >7689 km^2 per year. On the other hand, from 1995 to 2016, surface water supplies in LCC have declined from 7.75 billion cubic meters (Bm^3) to 4.88 Bm^3 in the Kharif season and 4.17 Bm^3 to 2.63 Bm^3 in the Rabi season. An average groundwater drawdown of 0.61 m/year, is recorded in the LCC region. Faisalabad, Sheikhupura, and Toba Tek Singh are highly groundwater stressed cities due to the shifting of cropping patterns and temporal declination in groundwater levels. In Sheikhupura, cultivation of rice increased from 68% to 84% whilst in Toba Tek Singh rice, maize, and sugarcane cultivation increased from 10% to 25%, 15% to 20%, and 11% to 16%, respectively. The average annual groundwater drawdown in highly stressed cities is recorded at 0.58 m/year which creates an alarming situation. This study recommended taking some serious steps to maintain the groundwater levels by following the recharging techniques, capacity building workshops for farmers, or changing the cropping patterns.

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