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Climatic Influence on the Water Requirement of Wheat–Rice Cropping System in UCC Command Area of Pakistan

파키스탄 UCC 관개지역 밀·쌀 재배 필요수량에 대한 기후변화 영향

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Abstract

This study investigated climate change influences over crop water requirement (CWR) and irrigation water requirement (IWR) of the wheat–rice cropping system of Upper Chenab Canal (UCC) command in Punjab Province, Pakistan. PRECIS simulated delta–change climate projections under the A1B scenario were used to project future climate during two-time slices: 2030s (2021–2050) and 2060s (2051–2080) against baseline climatology (1980–2010). CROPWAT model was used to simulate future CWRs and IWRs of the crops. Projections suggested that future climate of the study area would be much hotter than the baseline period with minor rainfall increments. The probable temperature rise increased CWRs and IWRs for both the crops. Wheat CWR was more sensitive to climate–induced temperature variations than rice. However, projected winter/wheat seasonal rainfall increments were satisfactorily higher to compensate for the elevated wheat CWRs; but predicted increments in summer/rice seasonal rainfalls were not enough to complement change rate of the rice CWRs. Thus, predicted wheat IWRs displayed a marginal and rice IWRs displayed a substantial rise. This suggested that future wheat production might withstand the climatic influences by end of the 2030s, but would not sustain the 2060s climatic conditions; whereas, the rice might not be able to bear the future climate–change impacts even by end of the 2030s. In conclusion, the temperature during the winter season and rainfall during the summer season were important climate variables controlling water requirements and crop production in the study area.

Keywords: Climate change, CWR, IWR, CROPWAT, Pakistan

I. INTRODUCTION

The agriculture–based economy of Pakistan, equipped with one of the world's largest irrigation systems, relies heavily on the irrigated agriculture; mainly confined in the Indus Basin Irrigation System (IBIS), to produce up to 90% of total agricultural production. The basic design strategy for the IBIS was to irrigate the maximum possible area with the minimum operational and management inputs; however, the water requirements of the crops were not considered (Qureshi, 2011).

Despite being an agricultural country, approximately 20–34% of the Pakistani population still face food shortage problems and malnutrition (Ghanem, 2008). Insufficient water availability, ineffective use of available water resources and climate change are some of the driving factors behind the low agricultural production and food shortages in the country (Bhatti et al., 2009, Archer et al., 2010, Laghari et al., 2008).

Wheat and rice are the two major staples in Pakistan accounting for up to 50% of daily calorific intake. Food security issues and accessibility are directly related to the production of these two crops. The wheat–rice cropping system covers approximately 14% of the irrigated area in the IBIS with wheat/rice being the dominant winter/summer crop. Official reports from the Pakistan Bureau of Statistics indicated that cultivation area and yield per hectare of both crops were not stable between 2007 and 2012 owing to a constant decline of up to 13% in available surface water supplies since 2003 (Asif, 2013, Ahmad et al., 2007).

Climate change impacts, such as temperature rise and rainfall variability, could significantly influence crop production by limiting water availability and shortening the crop growth period (Farooqi et al., 2005). Recent studies have confirmed that average temperature in Pakistan is rising, especially during the winter season. (Ahmad et al., 2014, Kazmi et al., 2015).

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Furthermore, studies related to the impacts of climate change on the wheat-rice cropping system of Pakistan have indicated a significant yield reduction, which is thought to be mainly due to temperature rises and limited water supplies (Rasul et al., 2012, Rasul et al., 2011, Ahmad et al., 2015).

The largest agricultural province in Pakistan is Punjab where the wheat−rice cropping system is mainly concentrated in the Upper Chenab Canal (UCC) command area; famous for Basmati rice production. The UCC is a non−perianal canal that supplies irrigation water only during the summer season. However, the water supply is not based on crop water requirement (CWR). In winters, groundwater is the main source of irrigation to fulfil the CWR in this area.

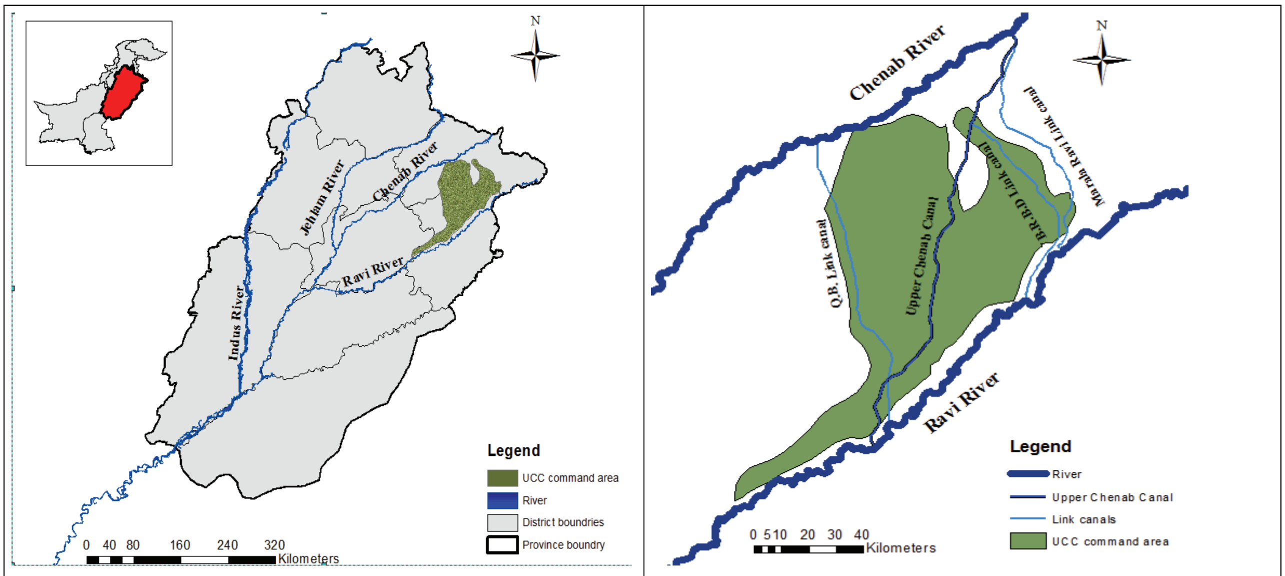
A deficit of more than 40% exists between irrigation demands and supply due to canal water shortages in the UCC command area (Shakir et al., 2010). As the area is already facing irrigation water shortages, it is important to understand probable adverse impacts of climate change on water requirements of the crops so that the available surface water supplies can be efficiently managed. Thus, this study was aimed to probe probable consequences of climate change over the wheat−rice cropping system of the UCC command area. Temperature and rainfall were considered as influential factors to design climatic scenarios, and CROPWAT model was applied to simulate effects of these two climatic factors on crop and irrigation water requirements of the two main crops grown in Pakistan.

II. MATERIALS AND METHODS

1. Study area

The study was conducted in the Upper Chenab Canal (UCC) command area, which is one of the most important irrigation schemes in Punjab Province, Pakistan (Fig. 1). The gross command area of the UCC is 0.64 million hectares, out of which 0.59 million hectares (approximately 90%) is cultivable command area.

Two distinct cropping seasons prevalent in the study area include the winter and the summer season lasting from November to April and May to October, respectively. Wheat covers approximately 50% and rice covers more than 60% of the total cultivable area in the UCC command area during the winter and summer seasons, respectively (Shakir et al., 2010). The area experiences high seasonal temperature and rainfall fluctuations. The average winter and summer temperatures vary in the ranges from 8 to 19 °C and from 20 to 42 °C with the annual average cumulative rainfall of 994 mm, approximately 60% of which occurs in July and August as monsoon rainfalls. Moderately fine to medium texture textures soils prevail in most parts of the UCC command area (Jehangir et al., 2002, Ahmad et al., 2004).



(a) UCC command area in Punjab Province

(b) Major channels in the UCC command area

Fig. 1 The study area: the UCC command area

2. CROPWAT application

The CROPWAT model version 8.0 (Smith, 1992, Derek et al., 1998) was developed by the Land and Water Development Division of the Food and Agriculture Organization (FAO). It was used to estimate the CWRs and irrigation water requirements (IWR) of the wheat−rice system. The depth of water needed to meet crop evapotranspiration losses was defined as the CWR, estimated from the product of reference evapotranspiration (ET_o) and cropcoefficient (K_c). The difference between the CWR and effective rainfall (ER) determines the amount of water that has to be supplied through irrigation as IWR (Allen et al., 1998). The model has been widely used to estimate the CWR, IWR and irrigation scheduling of various crops under different environmental and management conditions (Stancalie et al., 2010, Kuo et al., 2006).

The ET_o was calculated using the FAO-Penman-Monteith (FAO−PM) equation. The K_c values proposed by Ullah et al., 2001 for the wheat−rice system of the UCC canal command were used to calculate the CWR and the monthly effective rainfall was assessed using the United States Department of Agriculture (USDA) Natural Resources Conservancy Service (NRCS) method. A medium type soil texture was selected in the soil module of the model.

For simulation purposes, a growing season length of 170 and 150 days was considered for the wheat/winter season and rice/summer season, respectively. The sowing and harvesting dates for wheat were as set as November 20 – May 10 whereas, for rice these were set as June 10 – October 30 with July 10 being the transplantation date; as per recommendations from the local agricultural department and commonly followed agricultural practices (Hanif Qazi et al., 1997, Pakistan National Commision, 2000) . The simulated results for CWR and IWR were produced on a decadal basis and covered a complete growing period.

3. Climate change scenarios

A number of model-based climate change studies, particularly focussing on the South Asian countries such as India, Bangladesh and Pakistan, had employed and verified *Providing Regional Climate for Impact Studies* (PRECIS) regional climate model's (RCM) ability to simulate the past and project future climate under different scenarios in view of biases/uncertainties inherent to the RCM simulations (Syed et al., 2014, Nazrul Islam et al., 2008, Islam et al., 2011, Ali et al., 2013).

Kumar et al., 2006 gauged the PRECIS's strength by mimicking the past climate over Indian region before its subsequent application for future climate projection and concluded that the model had a good capacity of capturing the mean surface climate. Similarly, after achieving the satisfactory performance of the PRECIS RCM, Islam et al., 2009 used it to study the future warm and cold spell duration frequency over Pakistan. Syed et al., 2014 compared two RCMs: Regional Climate Model version 4 (RegCM4) and PRECIS and found that the PRECIS simulated climatology was closer to the observation with a warm bias of only 2 °C, over central parts of Pakistan.

Pakistan Meteorological Department (PMD) dynamically downscaled gridded monthly average temperature and monthly cumulative rainfall using the PRECIS nested in the ECHAM5 global circulation model (GCM). The GCM's coarser spatial resolution of 1.5° × 1.5° was downscaled to a finer spatial resolution of 0.22° × 0.22° (about 25 km × 25 km) (Ali et al., 2013). The downscaled climate change products were available only for ECHAM5 GCM under one climate change scenario (A1B). Thus, the PRECIS simulations outputs for the historic/control run (1951 to 2000) and the future/scenario run (2001 to 2099) under the A1B scenario for Pakistan's geographical domain were extracted from the PMD's official site (http://www.pmd.gov.pk/rnd/rndweb/rnd_new/climchange.php).

A 30−year dataset from 1980 to 2010, comprising of monthly maximum temperature (T_{max}), minimum temperature (T_{min}), wind speed (u_2), relative humidity (RH), number of sunshine hours (n) and rainfall (P) was also collected from the PMD to devise the baseline climatology for the study area. It was assumed that biases in coarse GCM outputs were significantly removed dynamically through the RCM application; the simplest, but mostly preferred, delta−change method could be used to project the study area's climate for two future time slices: 2030s (2021−2050) and 2060s (2051−2080) against the baseline climatology (1980−2010). The core idea of the delta−change approach is to employ the GCM/RCM simulated climate change−signals/anomalies during the projected period as a source of perturbation in observed data.

Rather than adjusting the GCM/RCM simulation, the delta–change method uses observations and climate change–signals/anomalies. By definition, the delta change method could provide perfect climate change simulations due to its correspondence to the observed climate and hence cannot be tested for the baseline period (Teutschbein and Seibert, 2012).

To generate the future climate during the 2030s and 2060s, the PRECIS simulated climate change–signals/anomalies for temperature and rainfall, calculated on monthly basis between the control and scenario runs, were superimposed over the observed baseline climatology for the grid associated with the study area. Differences between mean values of the PRECIS control run and the corresponding mean values during the future time slices (the 2030s & 2060s) were defined as the climate change–signals/anomalies. Time window of the PRECIS control run (1980-2010) considered in the study corresponded to the available observed weather data during the baseline period. Additive and multiplicative corrections were made to adjust the future temperature and rainfall, respectively. (Miao et al., 2016, Teutschbein and Seibert, 2012, Tabor and Williams, 2010).

The CROPWAT model was used to estimate the CWRs and IWRs of the two crops under the climate conditions of the baseline as well as the 2030s and 2060s for an in-depth impact assessment which could lay the foundation to design mitigation strategies.

4. Verification of the model

Generally, the model results are verified by comparing them with field data. A number of field studies had been conducted in the study area and provide the permissible range of variation in which the wheat and rice CWR may vary. Generally, the wheat and rice CWRs vary in the range of 251 mm – 368 mm and 537 mm – 627 mm, respectively (Ahmad et al., 2004, Jehangir et al., 2007, Pakistan National Commision, 2000, Shakir et al., 2010, Hanif Qazi et al., 1997, Ahmad et al., 2007). Moreover, the International Water Management Institute (IWMI) also conducted a detailed study in 2001 to estimate the ET_o and CWR values of various crops for each canal command in the IBIS, including the UCC (Ullah et al., 2001).

The CROPWAT simulated 30-year averaged monthly ET_o and wheat–rice CWRs were compared with the mentioned studies and satisfactory results were found. The model sometimes overestimates the CWRs, but mostly simulated the CWRs well within the prescribed range (Fig. 2b). Similarly, a comparison between the IWMI's and the model simulated ET_o

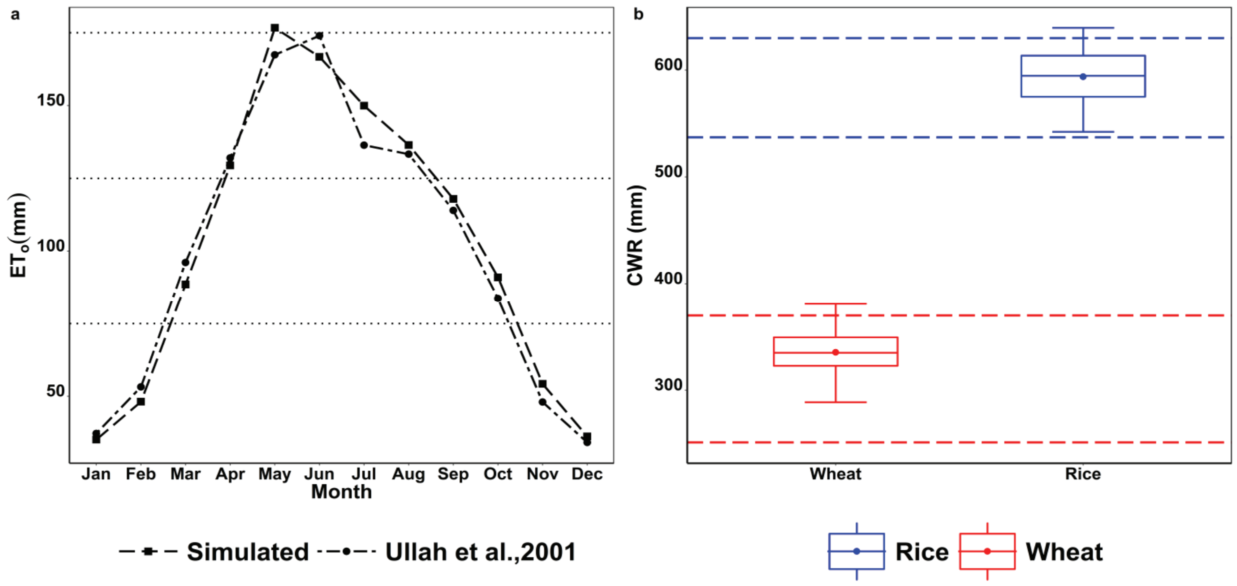


Fig. 2 Verification of CROPWAT for (a) monthly ET_o and (b) CWR. The boxes indicate the upper and lower quartiles, the central horizontal lines and dots represent the median and mean values whereas, the upper and lower whiskers show the range i.e. maximum and minimum values, respectively. The red and blue horizontal lines show the permissible range of variation of wheat and rice CWRs, respectively

values showed a difference of 6.53% and were also in close agreement (Fig. 2a). Thus, CROPWAT performance was considered satisfactory enough for its application to simulate the climate change impacts in the UCC canal command.

III. RESULTS AND DISCUSSION

1. Projected climate

The median, degree and range of variation across monthly, seasonal and annual T_{max}, T_{min} and P for the baseline as well as the future time slices are also shown in Fig. 3 (a−f).

Projections suggested that the future climate of the study area would be much hotter than the baseline period with minor rainfall increments. For the 2060s period, a pronounced temperature rise was shown as compared to the baseline or 2030s during most of the months throughout the year. On average, a monthly temperature rise of 0.5 − 2.0 °C and 2.5 − 4.0 °C, with smallest increments in December and October and highest increments in February and April, were shown during the 2030s and 2060s in comparison with the baseline, respectively. Also, the temperature rise in terms of both the T_{max} and T_{min} was prominent during the winter months starting from November to April (Fig. 3a,c). This implied that the area is particularly susceptible to warming during winters in future. The plausibility of experiencing warmer winters is further reinforced in light of the historic temperature trends across Pakistan. Studies had shown higher warming rates of winters than summers, over the past 30 years, across most of the weather stations in Pakistan (Iqbal et al., 2016, Ahmad et al., 2014, Rasul et al., 2011). Recently, Ahmad and Choi, 2018 also confirmed that the climate of the same study area had been gradually warming up since 1980 due to a temperature rise phenomenon particularly associated with the winter months.

Combining the monthly results did not show any particular discrepancy among the seasonal temperature rise trends during a certain future time slice. For example, during the 2030s both the summer and winter seasonal average temperatures were

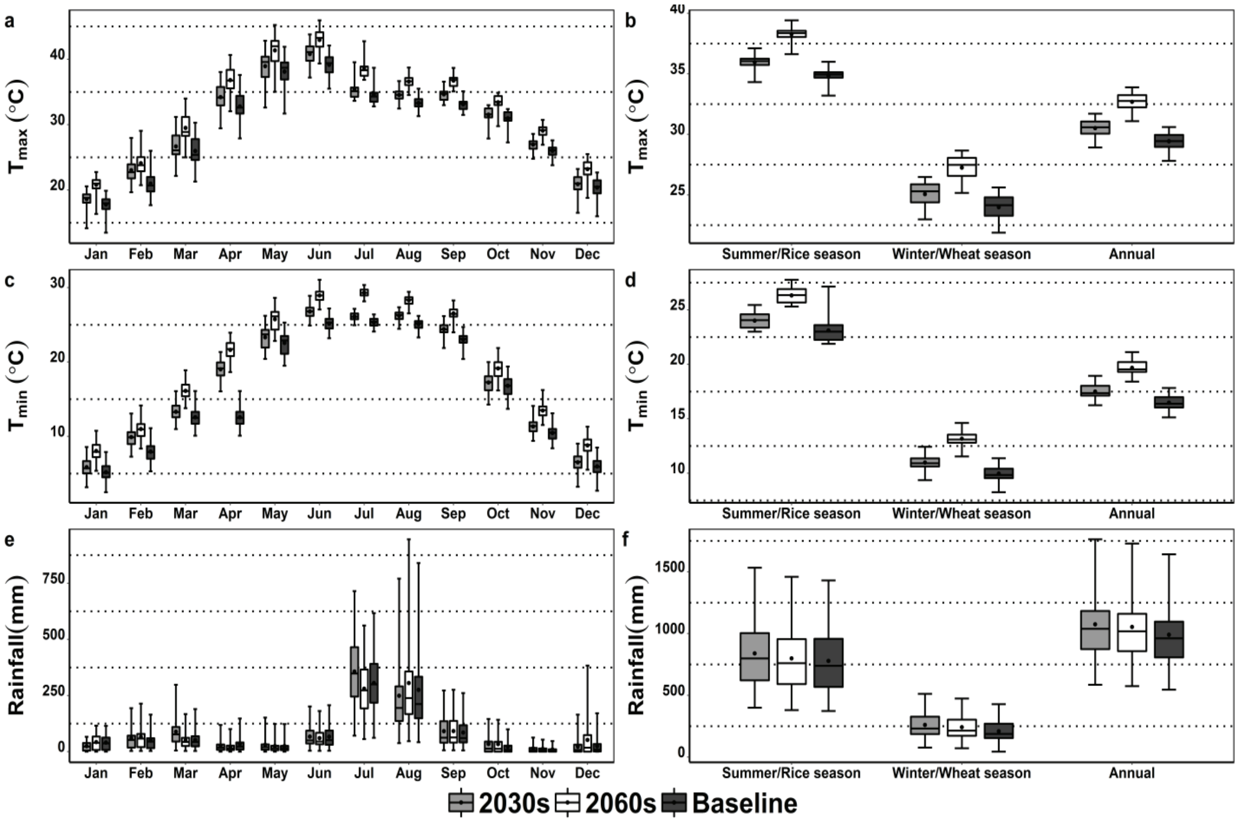


Fig. 3 (a−f) Monthly, seasonal and annual variability in baseline vs projected T_{max}, T_{min} and P. In the boxplots, the boxes indicate the upper and lower quartiles, the central horizontal lines and dots represent the median and mean values whereas, the upper and lower whiskers show the range i.e. maximum and minimum values, respectively risen by 1.1 °C, whereas for both the seasons of 2060s, the temperatures were predicted to rise up to 3.4 °C. A number of studies aiming at predicting the future climate using different GCMs and scenarios had also detected similar trends which are in close agreement with our results (Islam et al., 2009, Syed et al., 2014). For example, Iqbal et al., 2011 downscaled the ECHAM5 projections using the Long Ashton Research Station Weather Generator (LARS) under the A1B scenario and predicted a temperature rise of 1.1 – 3.0 °C by 2065 for a site located near to our study area. Amin et al., 2018 used an ensemble of 40 GCMs to predict the annual average temperature rise of 1.0 °C by 2025 and 2.1 °C by 2050 under the RCP 8.5 scenario for southern Punjab.

However, as indicated by the interquartile range of the boxplots shown in Fig. 3 (b,c), the T_{max}/T_{min} exhibited higher/lower variability during the winter season of both the future time slices and vice versa. This implied that the T_{max} during the winter season and T_{min} during the summer season could be the main variables controlling the warming of the study area in future. As the T_{min} is often associated with night time, hotter days/nights could be expected during the winter/summer seasons. Rasul et al., 2012 also identified that overall night－time temperature is rising at a higher pace than the day－time temperature across Pakistan.

The only noticeable rainfall increment was during the July and August when the major proportion of the annual rainfall occurred as monsoon rains. During the rest of the year, the projected rainfall was either the same or sometimes less than that of the baseline. Obviously, the July and August also showed the highest rainfall variability (Fig. 3e) but there were not any significant seasonal and annual rainfall variation during the 2030s and 2060s in comparison with the baseline (Fig. 3f). Overall, increments of 7.8%, 23.4% and 8.5% for the 2030s and increments of 2.6%, 14.3% and 6.5% for 2060s; in comparison with the baseline were projected for the summer, winter and annual rainfalls, respectively.

The projected future rainfall results indicated that area would receive more seasonal and annual rainfalls in the 2030s period than those of 2060s or baseline. The study area could experience a sharp rise in the magnitude and/or intensity of the monsoon rainfalls, especially during the 2060s. This can lead to excess－water related problems such as waterlogging or flood conditions in the summers followed by a dry or moderately dry winter season.

Under the projected climate attributed with higher temperature and marginal rainfall increments, the UCC’s wheat－rice system could face multifaceted consequences regarding the crop production and available water resources management. For example, the wheat production in the UCC command area is ground－water dependent due to its non－perinial irrigation system. Higher temperature would drive the crop evapotranspiration at higher rates which, if not compensated by enough ER, would result in excess groundwater demands for the irrigation purposes exerting extra pressure on the rapidly diminishing groundwater resources.

2. Climatic influences over Reference evapotranspiration (ETo)

ET_o is often used to conveniently express the atmospheric evaporative demands; based solely over a specific area’s climatic conditions. ET_o is only a function of climate variables such as temperature and/or solar radiation etc., and hence it could be considered as a reliable reflector of the climate change impacts over crop evapotranspiration rates or CWR. Recently, Ahmad and Choi, 2018 had shown that the ET_o of the study area was highly sensitive to the temperature fluctuations. Adnan et al., 2017 had also shown the higher influence of temperature over ET_o in different climatic zones of Pakistan. Thus, a probable temperature rise, as envisaged by the PRECIS projection, could subsequently result in the accelerated atmospheric evaporative demands in the UCC command area. The mean, median values along with the monthly, seasonal and annual variability of the ET_o, estimated through the FAO-PM equation, during the baseline and the future time slices are shown in Fig. 4(a－b).

During the baseline, the monthly ET_o varied in the range of 35 mm to 175 mm with the lowest and highest values being observed in January and June; converging to an average winter, summer and annual cumulative ET_o of 387 mm, 850 mm and 1237 mm, respectively. The interquartile range comparison of the baseline vs projected monthly ET_o showed that in the future it would remain consistently higher throughout the year. Furthermore, a stable increment in the future monthly ET_o was shown from July to December and an unstable or somewhat fluctuating increment was seen from February to June (Fig. 4a).

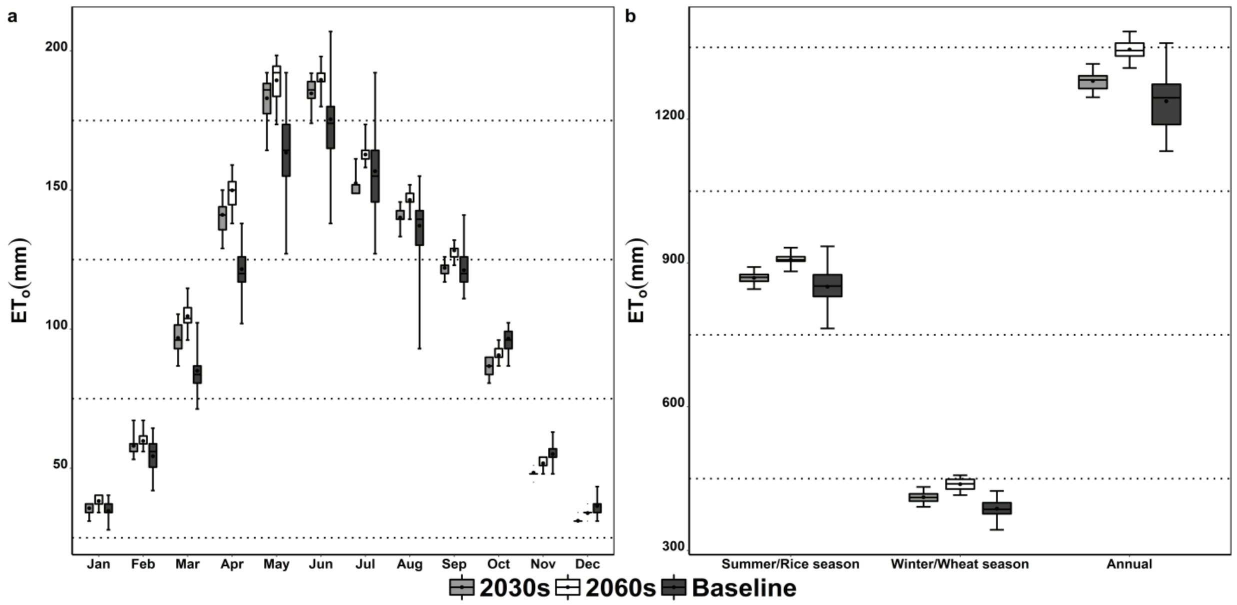


Fig. 4 Boxplots for (a) monthly (b) seasonal and annual ET_o during the 2030s and 2060s with respect to the baseline. The boxes indicate the upper and lower quartiles, the central horizontal lines and dots represent the median and mean values whereas, the upper and lower whiskers show the range i.e. maximum and minimum values, respectively

As expected, the projected temperature rise during the 2030s and 2060s caused the annual ET_o to increase up to 3.5% and 8.7%, respectively. For the baseline, the annual, winter and summer seasonal ET_o varied in the ranges of 1133 mm – 1359 mm, 343 mm – 424 mm and 763 mm - 935 mm, respectively. When compared with the baseline, the average winter ET_o increment (6.2% and 13% during the 2030s and 2060s, respectively) was almost twice than that of the average summer's ET_o (2.2% and 6.7% during the 2030s and 2060s, respectively).

The interquartile range of the projected winter ET_o (for both 2030s and 2060s period) showed a higher fluctuating tendency than that of summer ET_o. This means that the future summers could experience consistent ET_o rises, whereas the future winters could experience erratic ET_o increments (Fig. 4b). Thus, the wheat crop is expected to be more vulnerable to the projected climate change trends.

3. Monthly and seasonal analysis of CWR and IWR under the projected climate

The seasonal means, medians and variability of the CROPWAT simulated CWR, ER and IWR for the wheat–rice system of the UCC canal command under the baseline and PRECIS projected climate are shown in Fig. 5 (a–b). The analysis was also extended to monthly scale and the results are presented in the Fig. 6 (a–f). The monthly time–averaged CWR, ER and IWR during the baseline and the future time slices are also shown in Fig.7 (a–f).

For the baseline simulation runs, the wheat mean CWR of 335 mm varied in the range of 289 mm - 381 mm, while the rice average CWR of 594 mm varied in the range 542 mm – 640 mm. The baseline average ER and IWR were 182 mm and 199 mm for wheat and were 408 mm and 215 mm for rice. These mean values and ranges had been confirmed by the findings of a number of previously conducted field and empirical studies in the same study area (Shakir et al., 2010, Ahmad et al., 2004, Hanif Qazi et al., 1997). Jehangir et al., 2007 concluded from field experiments, conducted at sample farms in the same study area, that the potential CWR for rice varied in the range of 537 mm - 627 mm with an average of 573 mm whereas for wheat it varied in the range of 251 mm – 368 mm with an average of 310 mm.

Both crops showed increasing trends for CWRs under the PRECIS climate change scenarios. The wheat CWR was more sensitive to climate–induced variations than rice, which remained quite resilient against the temperature rise phenomenon. The rises in wheat baseline CWR in comparison with the 2030s and 2060s projected CWRs (6.1% and 11.6%)

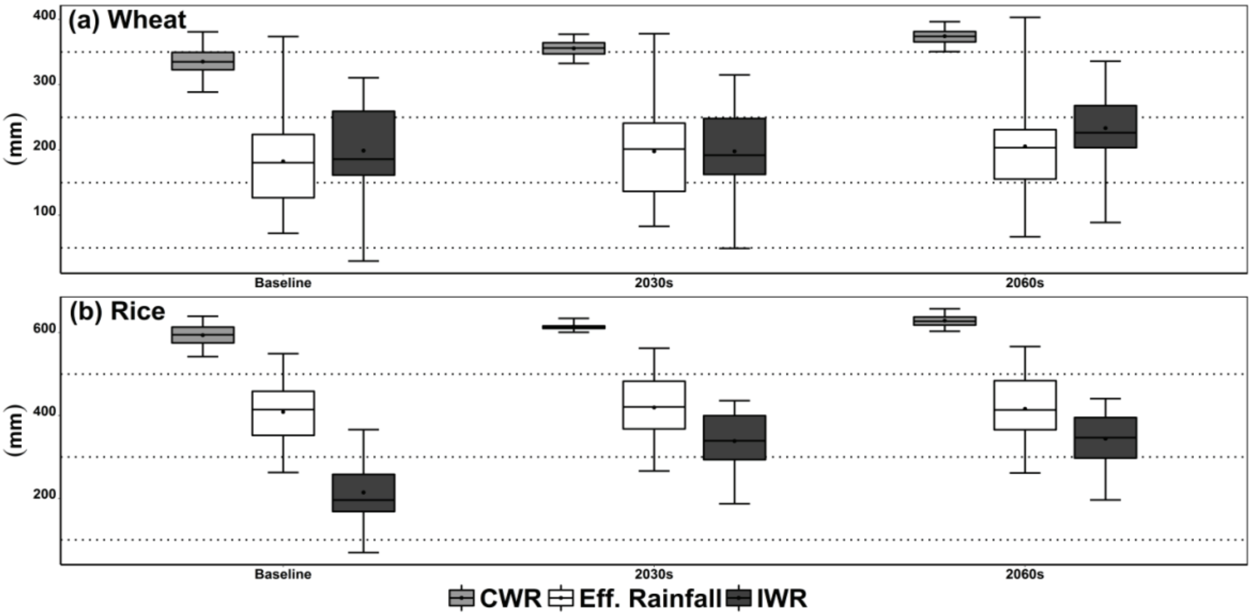


Fig. 5 Seasonal variation in the CWR and IWR for (a) wheat, (b) rice in the UCC command area under climate change projections

were much higher than that of the respective CWRs projected for rice (3.5% and 5.9%) (Fig. 5). These results were further verified by the Pakistan Nation Commission report on climate change impact assessment over agriculture sector. In this report, a probable increase of 2% – 4% and 2% – 5% in the respective rice and wheat CWRs was projected against an expected temperature rise of 1.8 °C by the end of 2050. Moreover, a higher wheat vulnerability to climate change was also emphasized (Pakistan National Commision, 2000).

However, the projected winter seasonal ER increments were satisfactorily higher than the baseline to compensate for the elevated wheat CWRs; but the predicted increments in the summer seasonal ER were not high enough to complement the change rate of the rice CWRs. Thus, the predicted wheat IWR displayed a marginal and rice IWRs displayed a substantial rise especially during the 2060s (Fig. 5).

These results indicate that in terms of CWR, the future wheat crop would be quite vulnerable to temperature–induced climate variations but the positive seasonal rainfall increments might ward off these detrimental impacts. On the other hand, the rice showed lesser variations in the future CWRs but the projected seasonal rainfalls were not enough to reimburse these changes, thus subsequently resulting in the much higher IWRs. This implied that future wheat production might withstand the climatic influences by the end of the 2030s but would not sustain the 2060s climatic conditions without the proper precautionary measures. Similar would be the case for the rice which might not be able to bear the future climate–change impacts even by the end of the 2030s.

As shown in the Fig. 6 (a–f) and Fig. 7 (a–f), the wheat monthly CRWs and IWRs would most likely remain unchanged by the end of the 2060s in the early phonological stages from November to January. Later, during the development and maturity stages from February to April, the wheat IWR would shoot up dramatically mainly due to the higher than the average CWRs and lower than the average ER. A water shortage, accompanied by the heat stress, at these growth stages could result in substantial yield reduction or even crop failure in the worst cases. Thus, additional water resources would be required from February to April to sustainable wheat production in the area. Similarly, the rice CWR and IWR remained unchanged only during the initial growth stages. In the coming months, as the crop matures, both the CWR and IWR were projected to increase dramatically particularly during the 2060s.

Although the rice CWR was found less sufferable from the temperature rise, occurrences of inconsistent rainfalls caused a sharp rise in the monthly IWRs during the rice season. This implies that although the rice might withstand the heat stress but erratic and unpredictable summer rainfalls would be a great obstacle to managing water supplies for the sustainable rice

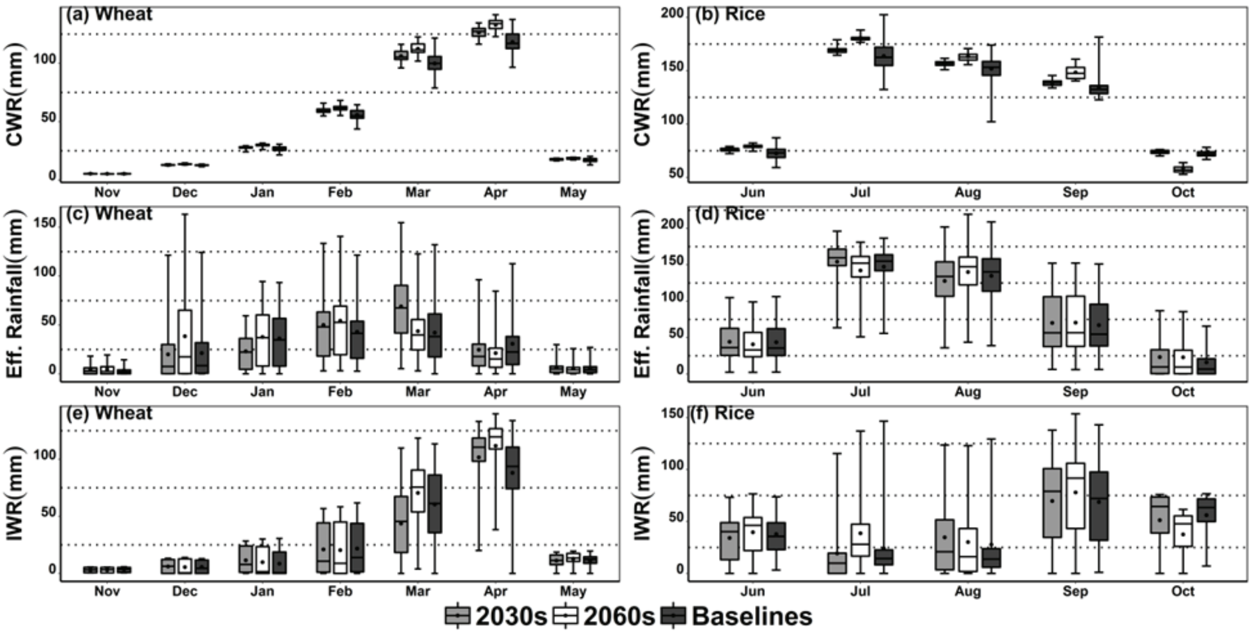


Fig. 6 (a–f) Monthly variation in the CWR and IWR for the wheat−rice system of the UCC command area under climate change projections

productions.

These results indicated that the area would receive sufficient rainfall to fulfil the CWRs during the months when the crops were in their early growth stages. It became necessary to supply irrigation water during the mid-season crop growth stages, but the amount of irrigation water required was highly influenced by climate variation. One possible way of fulfilling the peak monthly IWRs of the crops, during the mid-season growth stages, is to utilize the surplus amount of rainfall water available during the early months of the growing seasons.

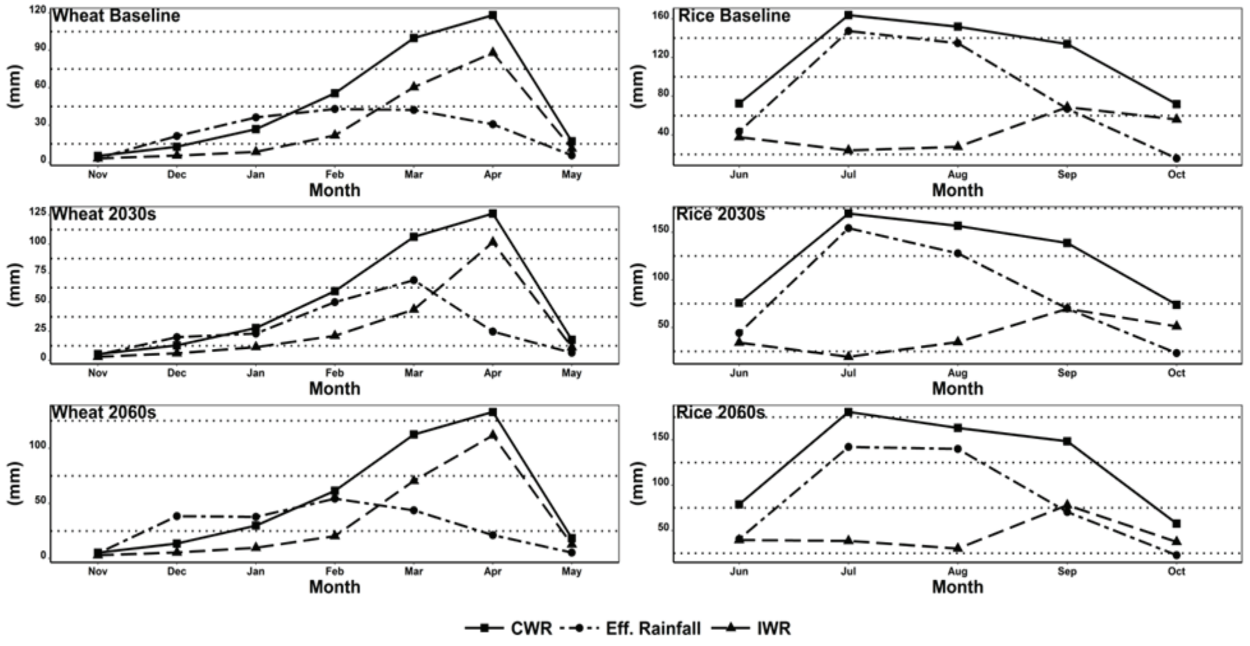


Fig. 7 (a–f) Monthly time−averaged CWR and IWR for the wheat−rice system of the UCC command area under climate change projections

IV. CONCLUSIONS

This study analysed the PRECIS simulated future climate change impacts for the wheat−rice cropping system of the UCC command area, Pakistan; under the delta−change scenarios for two future time slices: 2030s (2021−2050) and 2060s (2051−2080) against the baseline climatology (1980-2010).

The projections suggested that the future climate of the study area during the 2060s would be much hotter, with minor rainfall increments, as compared to the baseline or 2030s. On average, a monthly temperature rise of 0.5 − 4.0 °C was shown, with winter months particularly susceptible to these changes due to a higher temperature variability. The only noticeable increments in the rainfall variabilities and amounts were during the July and August when the major proportion of the annual rainfall occurred as monsoon rains. Overall, increments of 7.8%, 23.4% and 8.5% for the 2030s and increments of 2.6%, 14.3% and 6.5% for 2060s in comparison with the baseline were projected for the summer, winter and annual rainfalls, respectively. The results showed that the area could experience a sharp rise in the occurrence of erratic monsoon rainfalls, especially during the 2060s.

A probable temperature rise resulted in accelerated atmospheric evaporative demands as indicated by the future ET_o variations in the area. A stable monthly ET_o increment was shown from July to December and an unstable or somewhat fluctuating increment was seen from February to June. When compared with the baseline, the winter ET_o increments were almost twice than that of the average summer's ET_o; ultimately causing an annual ET_o rise of up to 3.5% and 8.7% during the 2030s and 2060s, respectively. It was also concluded that the future summers could experience consistent ET_o rises, whereas the future winters could experience erratic ET_o increments; thus making the wheat crop more vulnerable to climate change impacts.

The CWRs and IWRs for both crops increased under the PRECIS climate change scenarios. Overall, the wheat and rice baseline CWRs increased up to 6.1% − 11.6% and 3.5% − 5.9% during the 2030s and 2060s, respectively. In terms of CWR, the future wheat crop would be quite vulnerable to temperature−induced climate variations but the positive seasonal ER increments might ward off these detrimental impacts. On the other hand, the rice showed lesser variations in the future CWRs but the projected seasonal ER was not enough to reimburse these changes, subsequently resulting in the much higher IWRs. This suggested that future wheat production might withstand the climatic influences by the end of the 2030s but would not sustain the 2060s climatic conditions without the proper precautionary measures. Similar would be the case for the rice; which might not be able to bear the future climate−change impacts even by the end of the 2030s.

Monthly analysis showed that the CWR and IWR of both crops would remain unchanged only during the initial growth stages. In the coming months, as the crops mature, both the CWR and IWR were projected to increase dramatically particularly during the 2060s. The results suggested that fewer rainfalls accompanied by the heat stress, during the development growth stages of wheat could result in substantial yield reduction or even failure in the worst cases. Thus, additional water resources would be required from February to April for sustainable wheat production in the area. Although the rice CWR was found less sufferable from the temperature rise, occurrences of inconsistent rainfalls caused a sharp rise in the monthly IWRs during the rice season. This implies that although the rice might withstand the heat stress but erratic and unpredictable summer rainfalls would be a great obstacle to managing water supplies for the sustainable rice productions.

It can be concluded from this study that the temperature during the winter season and rainfall during the summer season are important climate variables that control wheat and rice water requirements and production in the study area.

This study provides useful information that can be used by stakeholders to improve the management of the UCC irrigation system under current climate conditions and to meet any challenges that may arise because of climate change in the future. This study also provides key information that can be used by irrigation managers to improve the allocation of limited water resources according to the requirements of the crops.

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