IMPACTS OF CLIMATE CHANGE ON CROP WATER REQUIREMENT UNDER MULTI - REPRESENTATIVE CONCENTRATION PATHWAYS DURING MID-CENTURY: A CASE STUDY OF D. I. KHAN

Muhammad Shahzad Khattak*[1], Barkatullah[1], Ayesha Aziz[1], Jamil Ahmad[2], Mohammad Sharif[3], Mukand Singh Babel[4], Muhammad Fahad[5]

ABSTRACT

Climate change is a major problem which directly affects agricultural economy of a region as the crop water requirements of major crops is increased. This study was conducted to estimate evapotranspiration (ETo) and crop water requirements (CWR) of wheat and maize crops of the study area during mid (2040-2059) century under emission scenarios based on Representative Concentration Pathways (RCPs). The methodology employed here involves the comparison of temperature and precipitation data projected by different GCM with the observed data. The delta change and ratio method was used to obtain the corrected value of temperature and Precipitation (PPT) for the future. The ETo calculator of Food and Agriculture Organization was used to calculate evapotranspiration. The CWR of wheat and maize crops was computed using CROPWAT 8.0. Results showed that out of sixteen GCMs, only four models i.e., bcc_csm1_1_m, gfdl_cm3, miroc5 and noresm1_m, were considered suitable for simulating the present day climate for the study area. The Ensemble average of these four selected models showed an increase in mean temperature of 2.07 oC and 2.47 oC, and an increase in PPT of 8% and 10% under RCP 4.5 and 8.5, respectively. Similarly, ETo showed an increase of 17% and 21% under both scenarios. Ensemble seasonal CWR of wheat crop under RCP 4.5 is projected to be increased by 10%, while under RCP 8.5 it increased by 8%. The CWR of maize crop is projected to increase by 10% and 15% under RCP4.5 and RCP8.5, respectively.

KEYWORDS: *Temperature, Precipitation, Climate Change, ETo Calculator, CROPWAT 8.0.*

INTRODUCTION

There is a near unanimity in the scientific community that the world climate has been changing since the beginning of the industrial revolution in the mid-19th century as a result of rapidly increasing concentrations of Green House Gases (GHGs) in the atmosphere. The present amount of CO_2 in atmosphere is 391 ppm and has increased by 40% since pre-industrial age[1-14]. At the time of IPCC fourth assessment report concentration of CO_2 was 379 ppm[2-13] and within 8 years this concentration has increased with a rate of 1.5 ppm per year[1-14].

General circulation models (GCMs) are currently the most widely used tools for simulating the global climate system response to increasing greenhouse gas concentrations, and for providing estimates of climate variables on a global scale. In order to provide a range of possible future scenarios for the evolution of atmospheric composition, a set of scenarios known as Representative Concentration Pathways (RCPs) has been adopted by climate researchers[3,4]. The RCPs form a set of greenhouse gas concentration and emission pathways designed to support research on impacts and potential policy responses to climate change[4,5,23]. These RCPs complement and, are meant to replace earlier scenario-based projections of atmospheric composition for some purposes, such as those from the Special Report on Emissions Scenarios[6-23]. As SRES explicitly considered the effects of prescribed levels of emissions into the atmosphere. However, there was (and still is) enormous uncertainty regarding contributing factors such as population growth, economic development and technological advances, hence the move towards RCPs. The RCPs are being used for driving climate model simulations planned as part of the World Climate Research Program's Fifth Coupled Model Intercomparison Project (CMIP5)[7-23] and other comparison exercises. On the basis of multi-gas emission scenarios, the scientific community is using four RCPs (i.e. RCP 8.5, 6, 4.5 and 2.6) for various impact studies. The detailed overview of such scenarios can be seen in van Vuuren et al. (2011)[5]. IPCC (2013)[1] reported that under RCP 8.5 the whole changes in the mean annual temperature exceeds 2°C in the mid of this

1 Department of Agricultural Engineering, University of Engineering & Technology, Peshawar*
2 Department of Chemical Engineering, University of Engineering & Technology, Peshawar
3 Department of Civil Engineering, Faculty of Engineering and Technology, Jamia University, New Delhi, India
4 Water Engineering and Management, Asian Institute of Technology, Thailand
5 Department of Civil Engineering, University of Engineering & Technology, Peshawar

century relative to baseline period of 1990. Over most of the land areas the increase ranges from > 3°C to > 6°C over South and Southeast Asia and over high latitudes respectively in late-21st century. While these changes are reported less than 2°C under RCP 2.6.

In 1900-2005, there was a significant increase in precipitation in Northern and Central Asia and decline in the Southern Asia (IPCC, 2007)[2]. The frequency of heavy precipitation events is increasing but that of light rain events is decreasing in South Asia[1]. During the 20th century increasing annual mean temperature trends have been observed[1] at the country scale in East and South Asia. Spatially, increase in rainfall is stronger over the northern parts of South Asia, Bangladesh and Sri Lanka, with a weak decrease over Pakistan. Alam et al. (2015) developed a physically based hydrological model for determining the potential impact of climate change on water availability of Brahmaputra River Basin in India by using RCPs scenarios. Ali et al. (2015) used RCPs 4.5 and 8.5 to predict twenty first century climatic and hydrological changes over mountainous upper Indus Basin. The increase in temperature is particularly higher in the northern parts of Pakistan compared to the southern parts[8-15]. Naheed et al. (2013) estimated crop water requirement in different regions of Pakistan under the assumption of temperature increase of 1°C, 2°C and 3°C from their current normal values and none of the IPCC scenario has been used. Khattak (2011)[9-20] used IPCC SRES A2 and B2 scenario to estimate future crop water requirement in Peshawar valley for different crops. Ahmed (2016)[1-10] discussed water related impacts of climate change in a review paper related to Pakistan. It is clearly evident from the review of literature that the climate in Pakistan has undergone a marked change. Consequently, the agriculture sector is likely to experience water stress. However, the impact of climate change on crop water requirement has not yet been studied in Pakistan under new IPCC scenario of RCPs. Therefore, the objective of the present paper is to evaluate the impact of climate change on reference evapotranspiration and CWR of wheat and maize crops in one of the southern districts (arid region) of Khyber Pakhtunkhwa namely, Dera Ismail (D.I) Khan.

STUDY AREA

Dera Ismail Khan district is located in the southern part of Khyber Pakhtunkhwa, Pakistan within the latitude and longitude of approximately 31°83' and 70°91' respectively (Fig.1). The average elevation of the study area is 173 m above sea level. The study area lies in the arid zone marked with hot summers and mild winters. The mean annual temperature of the area is 24°C with minimum and maximum average temperature of about 17°C and 32°C, respectively. During winter the mean maximum and minimum temperatures are 20.3°C and 4.2°C, while during summer these values are 42°C and 27°C, respectively[11-21]. Mean annual temperature and precipitation for the period of 1970 to 2012 is given in Figure 2. The average annual rainfall based on the observed data is 290 mm. The range of annual precipitation varies from 50 to about 500 mm, while the range of mean annual temperature varies from 23.3 to 26 °C.

Most of the area of the district is of flat dry alluvial plain type, commonly called as Daman which constitutes more than 80% of the whole area[13-22]. Most of the soil in D.I. Khan is considered as medium textured[14-19]. The area is bounded by the Suleiman mountain range in the west and by CRBC (Chashma Right Bank Canal) in the east. The slope is found to be southeast wards[3-15].

DATA AND METHODLOGY

The observed minimum and maximum temperature, rainfall, relative humidity, sunshine hours and wind speed for Dera Ismail Khan were collected from Pakistan Meteorological Department. These data are available for the period 1970 to 2012. The ET_o for the period 1970 to 2012 have been calculated using ET_o Calculator[6-16] which is based on FAO Penman-Monteith equation[2-17]. For the analysis of changes in CWR, the mean temperature and precipitation data for the study area is required. The projected data for mid century (2040-2059) and baseline (1986-2005) was obtained from the outputs of sixteen GCM models given in the Fifth Phase of the Coupled Model Intercomparison Project (CMIP5) for two IPCC Representative Concentration pathways (RCPs) scenarios i.e., RCP 4.5 and RCP 8.5. These dataset were downloaded from Climate Change Knowledge Portal 2.0 administered by the World Bank[5-18].

A comparison of the baseline data from 16 different GCMS under RCP 4.5 and 8.5 with the observed data of D.I. Khan from 1986 to 2005 was carried out. To

Figure 1: Map of D.I. Khan Source: Modified from Rahman et al. (2012)[28-12]

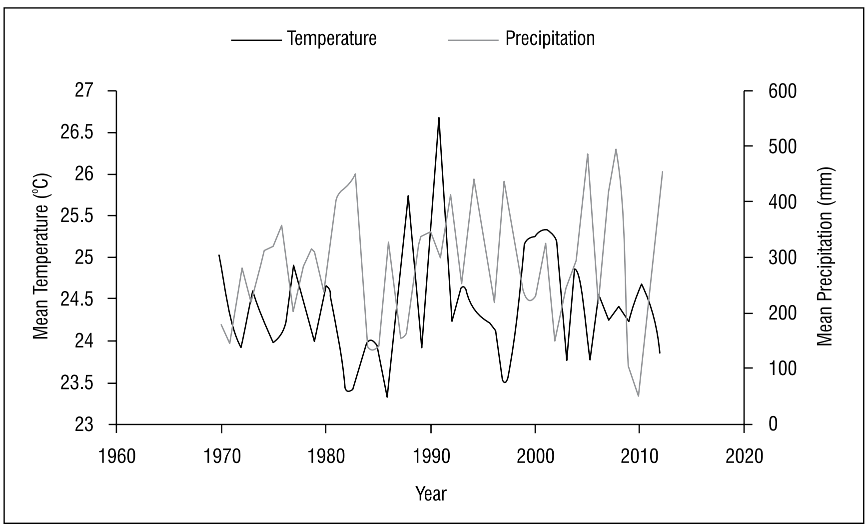

Figure 2: Mean annual temperature and precipitation (1970-2012)

get a reasonably accurate estimate of future temperature and precipitation for the calculation of future ET_o and CWR, it was considered essential to apply bias correction to the temperature and precipitation data. For bias correction of temperature and precipitation data, the delta change and ratio method[18-21,19-37;29-20] were used, respectively. The basic feature of the ratio method is that although the corrections are made to the observed precipitation data, but important characteristics of the data such as the frequencies of wet and dry days are not altered. Additionally, the standard deviations of the data are not changed. The mathematical equations used for future temperature and PPT calculations are given by equations 1, and 2, respectively.

$$T_c = T_{obs} + (T_{GCM} - T_{base}) \tag{1}$$

Where, T_c is corrected mean temperature, T_{obs} is observed mean temperature for the period of 1986 - 2005, T_{GCM} is future mean temperature given by GCMs for RCP 4.5 and 8.5 and T_{base} is baseline mean temperature for GCMs.

$$P_c = P_{obs}\left(\frac{P_{GCM}}{P_{base}}\right) \tag{2}$$

where, P_c is corrected monthly PPT, P_{obs} is mean monthly observed PPT for the period of 1986 - 2005, P_{GCM} is future mean monthly PPT given by GCMs for RCP 4.5 and 8.5 and P_{base} is the baseline mean monthly PPT for GCMs.

To calculate future ET_o, a regression relationship was derived between ET_o and the mean monthly temperature data. Different types of relationships (linear, nonlinear, exponential) between ET_o values and mean monthly temperature for the period of 1970 to 2012 were investigated, and the best fit (R^2 = 0.898) relation was chosen for the study area (Figure 3). The developed model (Equation 3) was then used to calculate future ET_o of each month of D.I. Khan for the mid-century by substituting the respective corrected mean monthly temperature values corresponding to RCP 4.5 and RCP 8.5.

$$ET_o = 16.989 \times e^{0.069T} \quad (3)$$

where ET_o is monthly evapotranspiration (mm) and T is the mean monthly temperature (°C)

Crop evapotranspiration is estimated using the following equation:

$$ET_c = K_c \times ET_o \quad (4)$$

where, ET_c is the crop evapotranspiration in millimeter per month, K_c is the crop co-efficient at specific growth stage and ET_o is reference crop evapotranspiration in millimeter per month. For Effective precipitation calculation, the United States Department of Agriculture Soil Conservation Service (USDA-SCS) method was adopted[16-22]. The equation used to compute the effective monthly rainfall is given by equation (5)

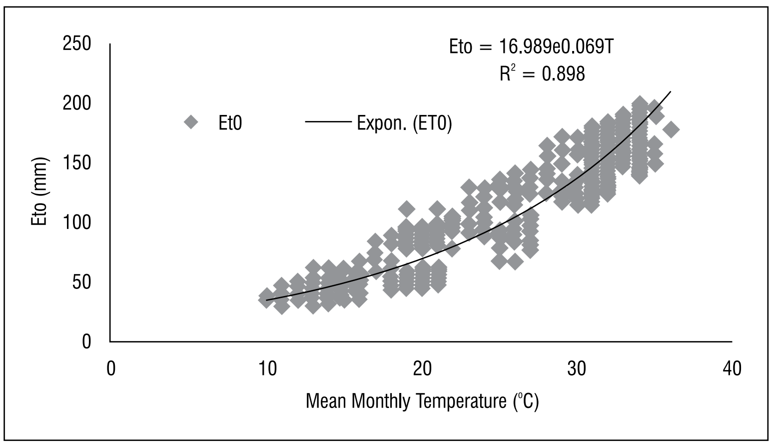

Figure 3: Relation between mean monthly temperature and ETo

$$P_{eff} = \frac{P_{total}\,(125 - 0.2P_{total})}{125} \quad (5)$$

where,

P_{eff}=effective rainfall (mm) and P_{total} = total rainfall (mm)

Crop Water Requirements (CWR) is the function of climatic conditions like temperature, precipitation, relative humidity, wind speed, sun shine hours etc, crop area and the climate type such as humid, sub-humid, arid or semi-arid, soil type, growing seasons and crop production frequencies[6-16; 9-23]. The procedure used to estimate CWR using CROPWAT 8.0 is presented in flow diagram (Figure 4) and is given by equation 6.

$$CWR = ET_c - P_{eff} \quad (6)$$

The data pertaining to the date of planting and harvesting of wheat and maize crops were obtained from the statistical department of Agricultural Training Institute, Peshawar. Planting of wheat (Rabi crop) starts from October and ends in December, whereas the harvesting starts from March and ends in May. Planting of maize (Kharif crop) starts from March and ends in May, whereas harvesting starts from June and ends in July. The wheat growing period of 160 days and maize growing period of 120 days is taken. The crop coefficient (K_c) values for different growth stages (initial, mid and late) of wheat and maize crops were obtained from FAO database. K_c values for wheat are 0.7 during initial stage, 1.15 during mid stage and 0.4 in late stage. For maize, the values of K_c are 0.7 during initial stage, 1.15 during mid stage and 0.25 to 0.4 during late stage[2-17].

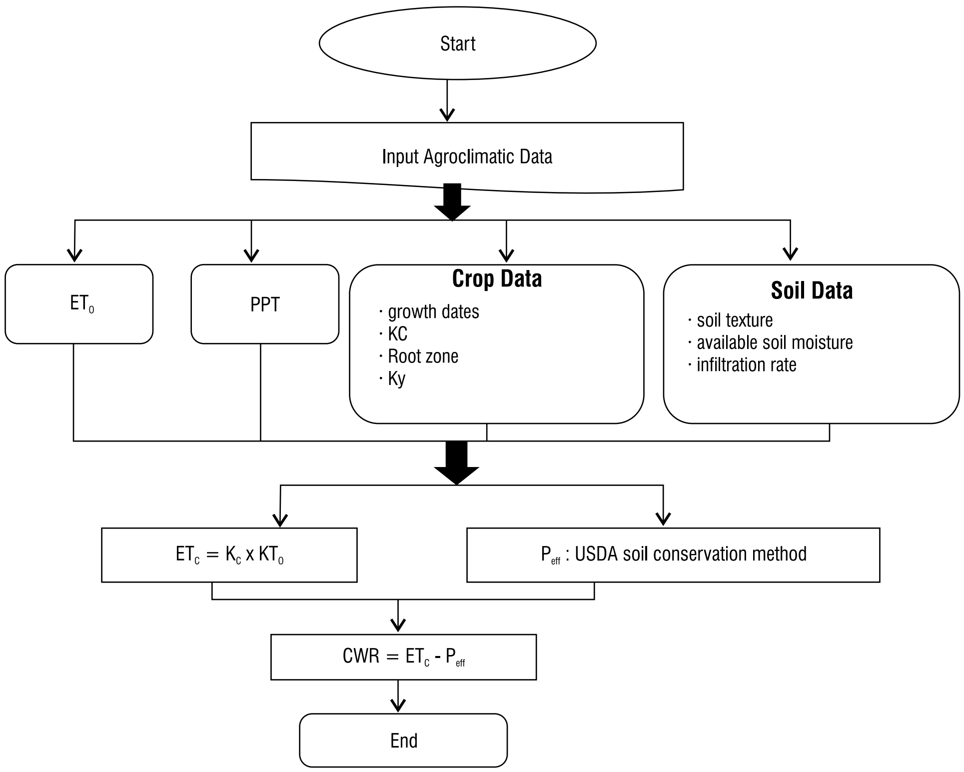

Figure 4: Flow chart of CROPWAT 8.0

RESULTS AND DISCUSSIONS

Selection of suitable GCM for the study area

Baseline data of mean temperature and total annual PPT of sixteen GCMs was compared with observed data of D.I. Khan for the period of 1986 – 2005. Out of these sixteen models only four models i.e., bcc_csm1_1, gfdl_cm3, miroc5 and noresm1_m, were showing approximately same pattern as was observed over the period of 1986-2005 (Table 1). From Table 1, it is clear that almost all models under estimated the mean temperature on annual basis. The bcc_csm1_1_m model is showing an error in mean annual temperature and total annual precipitation of 6.36% and 29.41%. The percentage error in mean annual temperature and total annual precipitation shown by gfdl_cm3 were 21.14% and 5.90%, and miroc5 and noresm1_m were showing less error in case of total annual PPT and were found to be -0.61% and 1.82%, respectively. Maximum percent error in mean annual temperature was 61.13% in bcc_csm1_1 while maximum percent error in mean annual PPT was 1547% in csiro_mk3_6_0 model.

Thus it can be concluded that a single model may not be capable to represent both temperature and precipitation with same accuracy. Therefore it is better to choose some suitable models (after validation) for each of the different parameters. In our case, we choose, bcc_csm1_1_m; gfdl_cm3; miroc5; and noresm1_m model for further analysis and to reduce further the uncertainty, the Ensemble average of these four model is used.

Temperature and Precipitation in mid-century under RCP 4.5

The climate conditions, for RCP 4.5, obtained from the four selected GCM models (after bias correction), during mid-century, were different than the present conditions. The change in mean monthly temperature during mid-century is given in Figure 5.

Table 1. Percent Error of GCMs baseline relative to the observed climate data

S.No.	Model	Temperature			Precipitation		
		Observed	Modeled	PE (%)	Observed	Modeled	PE (%)
1	bcc_csm1_1	24.59	15.26	61.13	305.15	155.81	95.85
2	bcc_csm1_1_m	24.59	23.12	6.36	305.15	235.81	29.41
3	ccsm4	24.59	22.58	8.91	305.15	419.19	-27.20
4	cesm1_cam5	24.59	22.36	10.00	305.15	479.11	-36.31
5	csiro_mk3_6_0	24.59	22.71	8.29	305.15	18.53	1546.79
6	fio_esm	24.59	16.99	44.73	305.15	358.42	-14.86
7	gfdl_cm3	24.59	20.30	21.14	305.15	288.14	5.90
8	gfdl_esm2m	24.59	22.82	7.76	305.15	158.55	92.46
9	giss_e2_h	24.59	24.96	-1.50	305.15	69.27	340.52
10	giss_e2_r	24.59	24.72	-0.51	305.15	73.12	317.33
11	ipsl_cm5a_mr	24.59	21.37	15.05	305.15	38.56	691.36
12	miroc_esm	24.59	17.94	37.07	305.15	621.27	-50.88
13	iroc_esm_chem	24.59	17.52	40.33	305.15	561.81	-45.68
14	miroc5	24.59	20.29	21.19	305.15	307.01	-0.61
15	mri_cgcm3	24.59	23.40	5.08	305.15	74.18	311.36
16	noresm1_m	24.59	18.57	32.44	305.15	299.71	1.82

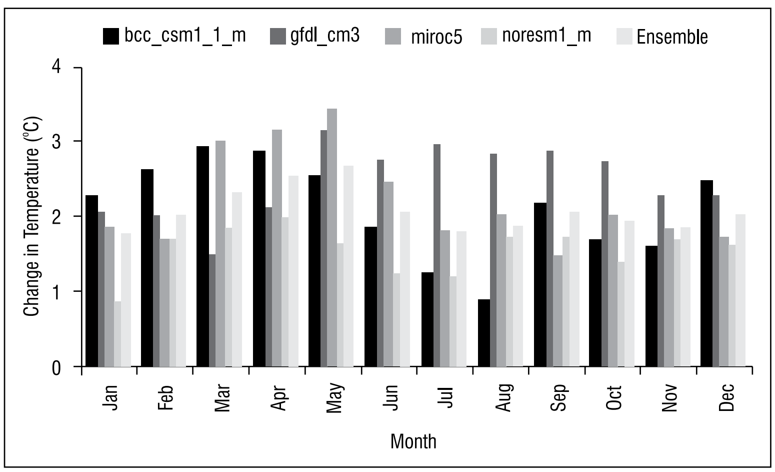

Figure 5: Change in Temperature during mid-century relative to baseline under RCP 4.5

Mean monthly temperature has been increased in each month for all selected models. In mean monthly temperature maximum increase was seemed to be occurring by 3.43 °C in the month of May shown by miroc5 model. As an average, the highest increase in mean monthly temperature was also noted in the month of May i.e., 2.69 °C. The lowest increase in temperature i.e., 0.86 °C was predicted in the month of January shown by noresm1_m model. As an Ensemble average, the minimum increase in mean monthly temperature was seemed to be 1.77 °C in the month of January.

The change in precipitation during mid-century is irregular and the trend is not like temperature. Different model shows different results in each month (Figure 6).

From Figure 6 it is clear that the highest increase i.e., 201.67% in monthly precipitation has been observed in the month of June shown by gfdl_cm3 model followed by bcc_csm1_1_m model i.e., 194.07% in month of October. Maximum decrease was noted in month of February i.e., 67.29% shown by bcc_csm1_1_m model followed by the month of November i.e., 53.73% shown by the

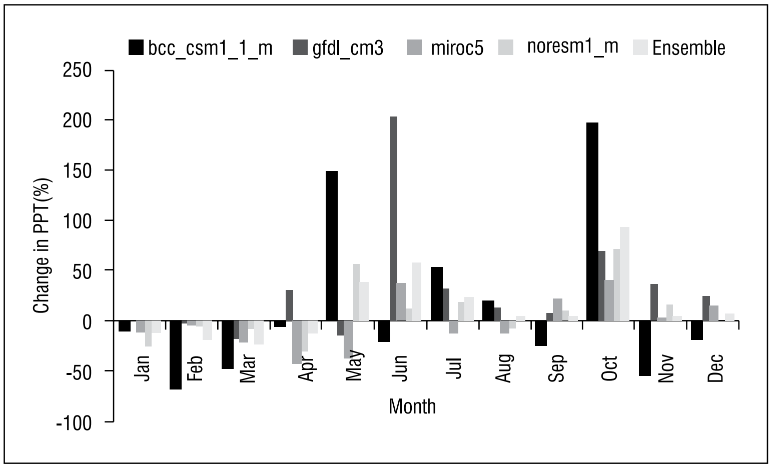

Figure 6: Change in Precipitation during mid-century relative to baseline under RCP 4.5

same model. As an Ensemble average, maximum increase i.e., 94.06% has been revealed in month of October and maximum decreased i.e., 23.21% was occur in March and approximately no change were seen in November.

Temperature and Precipitation in mid-century under RCP 8.5

RCP 8.5 is the warmest scenario of all other scenarios and showing greater change in temperature than RCP 4.5 in mid century. All selected GCMs are showing increase in temperature for all months as shown in Figure7.

It is clear from Figure7, among all GCMs, gfdl_cm3 show maximum increase in temperature for all months except January, April and November. The maximum increase in temperature relative to the baseline temperature was projected by gfdl_cm3 in month of July 4.5 °C i.e., followed by the month of June i.e., 3.69 °C. The minimum increase was projected in month of July i.e.,

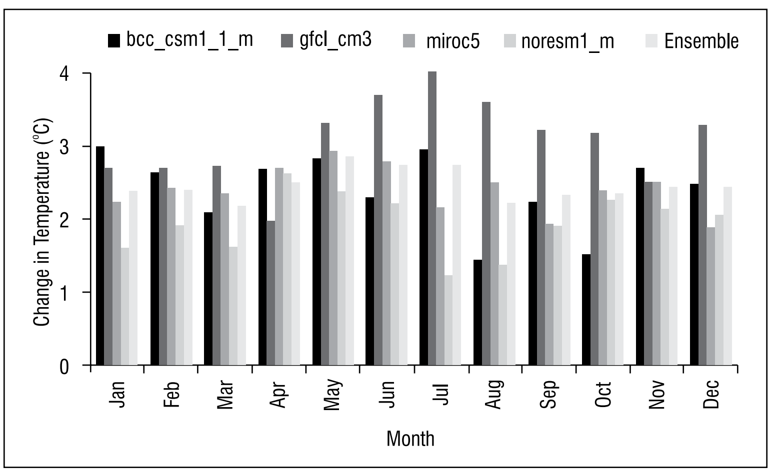

Figure 7: Change in temperature during mid-century relative to baseline under RCP 8.5

1.24 °C under noresm1_m. As an Ensemble average, maximum increase in temperature was predicted in month of May followed by the month of June i.e., 2.87 °C and 2.75 °C, respectively, and minimum increase was observed in month of March followed by the month of September i.e., 2.20 and 2.23 °C, respectively. In all cases increase in temperature can be seen and thus indicating warming trend that will effect crop water requirements and growth. Extreme heat caused by high temperature may result in premature growth, shift in growing stages or permanent damage to various crops and plants.

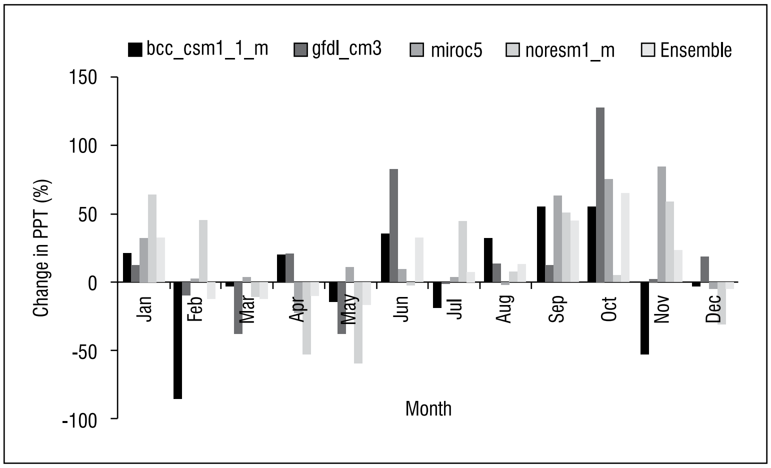

Figure 8: Change in Precipitation during mid-century relative to baseline under RCP 8.5

As in the case of RCP8.5, precipitation showed inconsistent patterns with some models projecting an increase, while others projecting a decrease. The inconsistency in the direction of precipitation changes is clearly evident from Figure 8. As shown in Figure 8, the maximum increase of 126.88% in monthly precipitation, relative to baseline, was projected by gfdl_cm3 for the month of October. The maximum decrease in precipitation, relative to baseline, was projected by the bcc_csm1_1_m model for the February.

As an Ensemble average of GCMs, maximum increase was presumed in month of October i.e., 65.29% followed by the month of September i.e., 45.15% relative to the baseline precipitation and maximum decrease was observed in month of February and March i.e., 11.96 and 11.64%, respectively.

Overall Change in Temperature and Precipitation under RCP 4.5 and 8.5

From Table 2, it can be observed that the maximum annual increase in temperature as projected by gfdl_cm3 under RCP 4.5 and 8.5, were 2.5 ^oC and 3.12 ^oC, respectively. Under RCP4.5, the maximum annual increase in PPT of 27% was projected by gfdl_cm3 model, whereas noresm1_m projected an increase of 15% under RCP8.5. As an Ensemble average for different models, the increase in PPT was 8% and 10% under RCP 4.5 and 8.5, respectively.

Table 2. Projected annual change in Temp and PPT under RCP 4.5 and 8.5 for mid century

Models	RCP 4.5		RCP 8.5	
	Temp (oC)	PPT (%)	Temp (oC)	PPT (%)
bcc_csm1_1_m	2.08	8.75	2.41	6.3
gfdl_cm3	2.46	27.45	3.12	9.43
miroc5	2.21	-6.85	2.4	9.68
noresm1_m	1.55	3.59	1.95	14.8
Ensemble average	2.07	8.23	2.47	10.05

Change in ETo relative to baseline under RCP 4.5 and 8.5

ETo under RCP 4.5 in mid-century

It is clear from the Figure 9 that the maximum decrease was observed in the month of March. In most months, ETo tends to increase and the maximum increase was observed in the month of November followed by December and September. In all months, except January, February, April and May, the maximum change in ETo was projected by gfdl_cm3 model. In January, February, and December, the maximum change was projected by bcc_csm1_1_m. The noresm1_m projected the maximum change in April, whereas the maximum change in May was projected by miroc5. As an Ensemble average, maximum increase was found in November and December, i.e. 47.64 and 43.91% respectively and maximum decrease in ETo was predicted to be 10% in March in mid century under RCP 4.5.

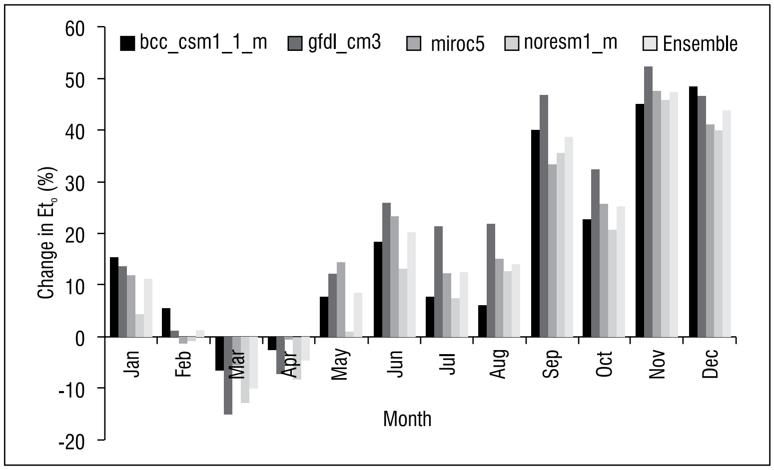

Figure 9: Change in ETo during mid-century relative to baseline under RCP 4.5

ETo under RCP 8.5 in mid-century

It can be seen in Figure 10, the maximum change in ET_o relative to baseline was observed for gfdl_cm3 from April to December, barring November. In the month of November and January, maximum change was projected by bcc_csm1_1_m. The maximum change in ET_o was projected by noresm1_m in the month of March. The decrease in ET_o for the months of March and April was projected to be in the range of 7.46 to 14.28% and 3.38 to 8.11%, respectively. The Ensemble average results from all models indicated the maximum increase in ET_o of 54.03% for the month of November, whereas the maximum decrease was 4.70% for the month of April.

The future ET_o results for mid century are shown in Table 3. The maximum increase (26.6%) in ET_o was

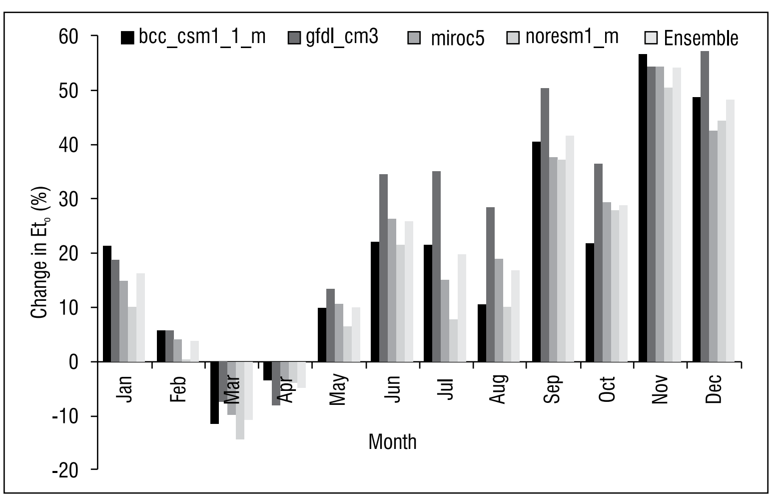

Figure 10: Change in ETo during mid-century relative to baseline under RCP 8.5

Table 3. Projected change in ETo under RCP 4.5 and 8.5

Models	RCP 4.5	RCP 8.5
	ETo (%)	ETo (%)
bcc_csm1_1_m	17.27	20.24
gfdl_cm3	20.97	26.6
miroc5	18.12	20.05
noresm1_m	13.21	16.52
Ensemble	17.39	20.85

observed for gfdl_cm3 under RCP 8.5, whereas the minimum increase (13.21%) was for noresm1_m under RCP 4.5. Overall, under both RCPs an increase in ET_o was projected for mid century. The Ensemble average showed an increase of 17 and 21% for RCP 4.5 and RCP 8.5, respectively.

CWR of Wheat in Mid Century under RCP 4.5 and RCP 8.5

CWR under RCP 4.5 in mid-century

The projections of CWR of Wheat in D.I. Khan under different models showed a slight increase during the beginning and middle of the season, and an increase of up to 125% during middle and late season for all models, except gfdl_cm3. Under gfdl_cm3, the CWR during these stages was projected to decrease (Figure 11).

A very small change was observed during the beginning of the season for all models, especially nerosm1_m as shown in Figure 11. In the month of November all GCMs showed an increase in CWR in the range of 1.68 - 4.28%, except noresm1_m which showed a decrease of the order of 0.37% in CWR. In the month of December, CWR were projected to increase for bcc_csm1_1_m and gfdl_cm3 by 9.45 and 1.15%, respectively. The CWR decreased for miroc5 and noresm1_m by 1.38 and 0.69%, respectively. In the month of January, CWR were observed to increase for all GCMs in the range of 5.96 to 13.91%. Similarly, in the month of February, CWR was projected to increase in the range of 2.53 to 38.61. In the month of March, the CWR was projected to increase in the range of 4.98% to 48.64%. During the mid and end of the season, CWR was projected to increase by the maximum amount, especially for bcc_csm1_1_m. The maximum increase in CWR of 87.50% was projected to occur during the end of the season. Seasonal CWR were projected to increase in the range of 3.84 to 22.81%. As an Ensemble average, the maximum increase of 71.88% in CWR was found for the month of April.

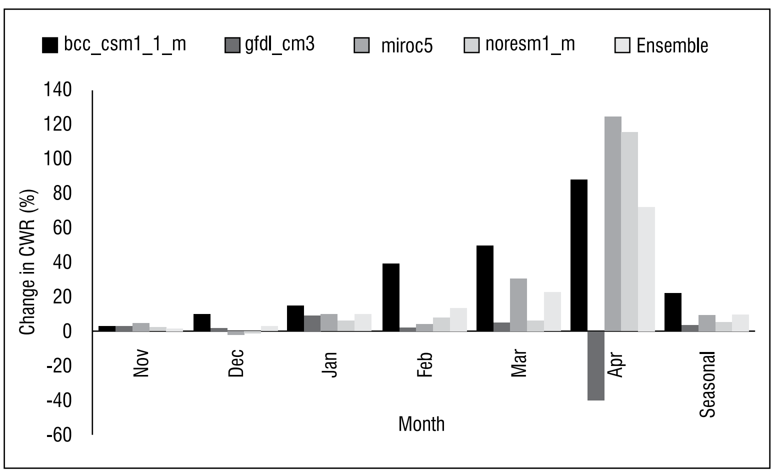

Figure 11: Change in CWR during mid-century relative to baseline for wheat under RCP 4.5

CWR under RCP 8.5 in mid-century

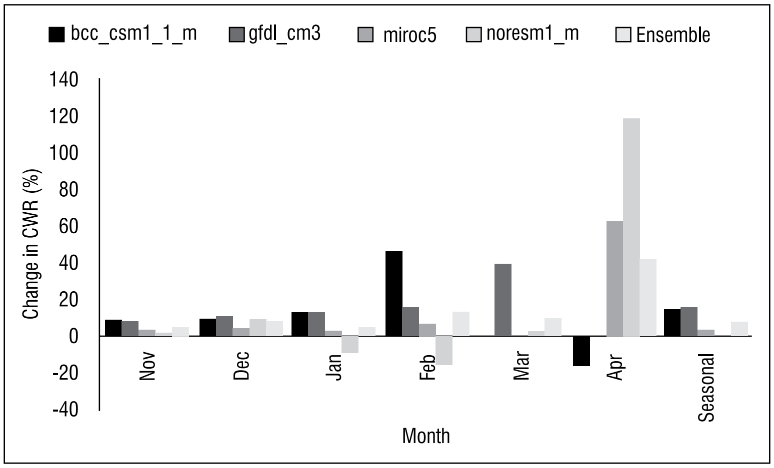

Figure 12: Change in CWR during mid-century relative to baseline for wheat under RCP 8.5

In mid century, not greater change was observed to be occurring in CWR of wheat except for the month of April. The maximum change of the order of 188.75% was projected to be occurring in the month of April for noresm1_m (Figure 12).

As shown in Figure 12, a comparatively small change in CWR of wheat relative to the baseline was observed in the starting months of the season, and almost no change was observed in the month of March under gfdl_cm3. Change in CWR for November month was in the range of 1.68 to 8.38%, and 4.15 to 10.14% in December. There was an increase of 3.09 to 12.58% for bcc_csm1_1_m, gfdl_cm3 and miroc5, and a decrease of 8.83% for noresm1_m in the month of January. A similar pattern was shown by these GCMs in the month of March, where the miroc5 and gfdl_cm3 projected an increase in CWR of the order of 0.69 and 38.91%, and a decrease of around 0.18% under bcc_csm1_1_m. In the month of April it was observed to increase in the range of 0.02 to 118.75. Seasonal CWR were projected to decrease for noresm1_m by 1.05%, but were projected to increase for other GCMs in the range of 3.82 to 15.99%. As an Ensemble average, maximum increase in CWR was found to be in month of April as 41.41%. While Ensemble average of seasonal CWR was predicted to be 8.29%.

CWR of Maize in Mid Century under RCP 4.5 and RCP 8.5

CWR under RCP 4.5 in mid-century

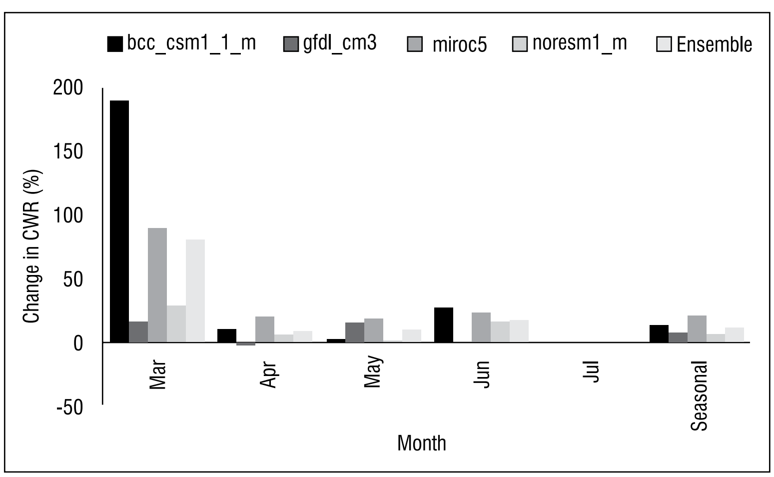

Figure 13: Change in CWR during mid-century relative to baseline for maize under RCP 4.5

The pattern of increase in CWR of maize relative to the baseline was opposite to that of wheat. The CWR for maize exhibited a maximum increase towards the start of the season. By the end of the season, the change in CWR of maize was significantly lower (Figure 13).

The increase was the maximum for the month of March; it ranged from 15.22 to 189.13%. The increase in CWR in the month of April was projected to be of the order of 5.88 to 19.86%, whereas the decrease was projected to be 2.70% under gfdl_cm3. In the month of May, it was projected to decrease by 1.09% for noresm1_m, whereas an increase in the range of 1.24 to 17.99% for other GCMs was projected. In the month of June, 0.55 to 26.31% increase was projected in the CWR of maize relative to baseline. No change was observed in the month of July because there would be sufficient rainfall to satisfy the CWR during this period. Seasonal CWR was projected to increase in the range of 5.59 to 20.65%. As an Ensemble average, maximum increase in CWR was predicted to be 80.43% in the month of March. While Ensemble average of seasonal CWR was predicted to be 11.25%.

CWR under RCP 8.5 in mid-century

Increase of CWR in mid century for RCP 8.5 followed the same pattern as that under RCP 4.5. As before, the maximum increase of CWR relative to baseline was observed to be occurring in the month of March for gfdl_cm3 (Figure 14). It can be seen in Figure 14, the CWR was observed to decrease for bcc_csm1_1_m by 13.04%, and increase by 8.70 to 110.87% relative to baseline in the month of March. A decrease of 0.87% in CWR was projected in the month of April under gfdl_cm3. The projected increase under other GCMs was in the range of 3.09 to 16.49%. For the month of May and June, the CWR was projected to increase in the range of 10.48% to 14.73% and 20.44% to 27.89%, respectively. No change was observed in the month of July because of sufficient rainfall during this period. The seasonal CWR was projected to increase in the range of 11.68 to 16.76%. As an Ensemble average, maximum increase in CWR was found to be in month of March as 38.04%. While Ensemble average of seasonal CWR was predicted to be 15.25% at the mid centaury.

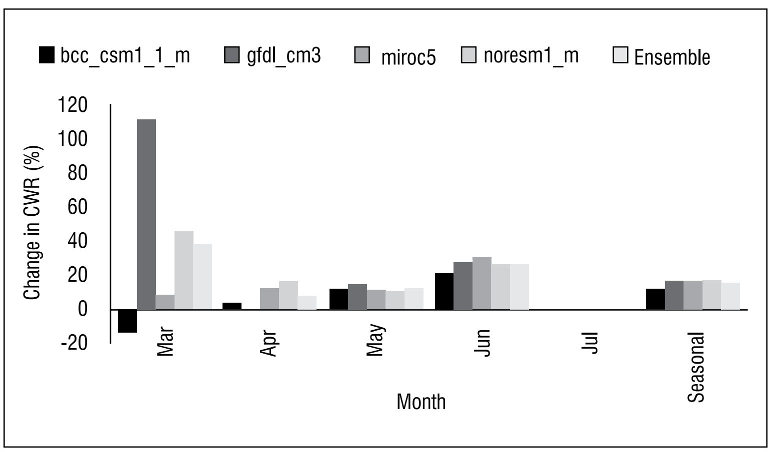

Figure 14: Change in CWR during mid-century relative to baseline for maize under RCP 8.5

Keeping in mind these results for various parameters policy makers need to focus on future water requirements for the area. Crop scientists should introduce new crop varieties to resist higher temperature and may ensure food security. The use of sprinkler and trickle irrigation must be promoted in study area as they save greater amount of water which are usually wasted by ordinary irrigation methods. Conservation and economical use of water for crops must be given due attention in policy making. Rise in temperature will cause increase in energy demands for cooling thus demanding for alternate sources of energy. The use of solar plants in government departments and offices will help overcome energy crises in future. More research is needed to see the possible effects of higher temperature on plant growth. Addressing the issues related with warming trends in temperature should be the prime focus of research organizations. Climate change is an issue of vital importance for sustainable agriculture, food security and human survival. It is the need of the time to fully focus on climate change and formulate mitigation strategies to counter balance adverse effects of increasing regional warming.

CONCLUSIONS

This study was conducted to find temperature, PPT, ET_o and CWR of Wheat and Maize crops of the study area during mid-century (2040-2059) under RCPs 4.5 and 8.5. Past climatic data was taken from Pakistan Meteorological Department for the period of 1970-2012. Future temperature and PPT data for RCPs 4.5 and 8.5 was downloaded from Climate change knowledge portal 2.0 for mid-century of sixteen GCMs. The temperature and PPT variable of 16 GCMs were compared. Delta change and Ratio method was used to obtain the correct value of temperature and PPT for the future. ET_o calculator of FAO was used to calculate ET_o of the study area for the past data and for future ET_o calculation a regression model was developed. CROPWAT 8.0 of FAO was used to calculate CWR of wheat and maize crops during mid-century. The overall specific conclusion drawn from this study revealed that

1. The most suitable GCMs for the study area are bcc_csm1_1_m, gfdl_cm3, miroc5 and noresm1_m.

2. For the mid century, the increase in temperature was projected to be 2.07 and 2.47 °C under RCP4.5 and RCP8.5, respectively. Overall, an increase in PPT was projected to be 8 and 10% under RCP4.5 and RCP8.5, respectively.

3. An increase of ET_o is predicted under both RCPs. An increase of 17 and 21% in ET_o is predicted under RCP4.5 and RCP8.5, respectively for the mid century.

4. Overall, the CWR of wheat is projected to increase by 10% and 8% under RCP4.5 and RCP8.5, respectively. The CWR of maize during mid century is projected to increase by 11% and 15% under RCP4.5 and RCP8.5, respectively.

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