Chapter 12
Quantitative Assessment of Impact of Climate Change on Crop Yield over Sikkim and Central Region of India

Ankit Balvanshi, Vikas Poonia, H. L. Tiwari, Manish Kumar Goyal, Anil Kumar Gupta, and Akhilesh Gupta

Abstract The present work focuses on (1) assessing the yield of rice, wheat crop under RCPs scenario 4.5 and 8.5 using AquaCrop yield simulating model and (2) determining the best sowing date of crops for maximum yield output across Sikkim and Central region of India. The bias corrected GCM outputs were utilised to simulate the yields of wheat and rice. The AquaCrop model was first calibrated (1998–2007), validated (2008–2015) and then future yield of wheat and rice was simulated for years 2021–2099. The Aquacrop simulated results over Sikkim shows an increase in yield of 0.5–20% for rice crop and 2–44% for wheat crop during the future years 2021–2099. For the Central region of India, the result depicts the highest impact of future climate with reduction in crop yields particularly during for future period (2081–2099) under RCP 8.5 climate scenario. Under the changed climate over Central India, shifting of planting date of rice (5 days later for period 2021–2060, 10 days later for period 2061–2099) and for wheat (15 days later for

A. Balvanshi
Department of Civil Engineering, National Institute of Technology, Ponda, Goa, India

V. Poonia
Infrastructure Development, Indian Institute of Technology, Indore, Madhya Pradesh, India

H. L. Tiwari
Department of Civil Engineering, Maulana Azad National Institute of Technology, Bhopal, India

M. K. Goyal
Department of Civil Engineering, Indian Institute of Technology, Indore, Madhya Pradesh, India

A. K. Gupta
ECDRM Division, National Institute of Disaster Management, Ministry of Home Affairs, Government of India, New Delhi, India

A. Gupta (✉)
Department of Science and Technology, Government of India, New Delhi, India
e-mail: abalvanshi@nitgoa.ac.in

period 2021–2099) is proposed as a practical adaptation measure for sustaining the future yields.

Keywords Aquacrop · Climate scenarios · GCMs · RCP 4.5 · RCP 8.5

12.1 Introduction

The performance of crops is majorly dependent upon the phenomenon of climate. Agriculture, more than any other economic sector, is most affected by climate change due to its global distribution and strong ties to and reliance on climatic and environmental elements. As a result, climate change's effects on agricultural productivity have an impact on the socio-economical component at both the macro and local levels. Climate change has arisen as a major worry worldwide in terms of socioeconomic and environmental sustainability as greenhouse gas concentrations have risen (Simonovic 2017; Das et al. 2020; Poonia et al. 2021a, b, c). Furthermore, rising greenhouse gas levels exacerbate extreme weather patterns, aids in occurrence of flood – drought events frequently (Das and Umamahesh 2017). The levels of carbon dioxide gas have been found rising in the atmosphere since the late nineteenth century's industrial revolution, and it is anticipated that by 2056, the concentration will have doubled (Simonovic 2017). According to the intergovernmental report of climate change (IPCC AR5 2013), mean temperature has risen by around 0.6° Celsius at global scale, and based on future estimates under various climate projections, it is expected to rise by 1 till 5 degrees Celsius by 2100 years. Temperature data spanning more than 100 years shows that India has warmed by around 0.5 degrees Celsius (Subash et al. 2013), Whereas forecasts based on various climate change scenarios show a rise of roughly 3–5 degrees Celsius by the completion of 2100 years (Kumar et al. 2006). Looking at this prospective, an agriculture-based economy such as India, will get severely impacted by the negative effects of climate change. For example, the catastrophic drought in 2016 claimed the lives of over 330 million people and caused an estimated $100 billion in economic losses (ASSOCHAM Report 2016).

The climate system can be analyszed by the GCMs that have necessary information of climate structure in a basic form. These GCMs are thus powerful enough to develop specific climatic conditions and aid to analyze the impacts of climate change (Johnson and Sharma 2009; Balvanshi and Tiwari 2018). Crop models aids to diminish the time required in field experiments and also reduction in risks involved (Foster et al. 2017). This alternative method to employ the crop models for prediction of crop yields is quite accurate and cost effective. Crop yield simulation models like APSIM (Wang et al. 2002), DSSAT (Jones et al. 2003), and FAO AquaCrop (Sandhu et al. 2015; Steduto et al. 2009; Sethi et al. 2016) model has been utilized for developing proper management practice in the agricultural division. The AquaCrop model consists of several sets of incorporated in a user-friendly interface. The model

is preferred for simulation of yields of various crops (Foster et al. 2017). Calibration and validation was conducted for maize crop by employing the Aquacrop model for diverse watering conditions. The water productivity (WP) fluctuated in the range of 2.35–27.5% (Abedinpour et al. 2012). APSIM wheat simulating model was employed for the Bhopal study area of India. A decline of 8% wheat yield was observed on every 1 °C enhancement in temperature and it was concluded that environmental factors have significant effects on wheat grain and biomass yield (Mohanty et al. 2015). Another yield model DSSAT CERES using GFDL CM3 GCM was employed to find the effect of climate change on Wheat crop. It was found that RCP 8.5 resulted in severe impact and yield decreased by 61% (Patel et al. 2018). CROPGRO Soybean model was employed at Jabalpur to find the impact of climate change on the yield. RCP 8.5 showed a marginal decline in yield by 2020 while by the year 2050 RCP 2.6 and 8.5 showed decline in crop yield (Walikar et al. 2018). AQUACROP model for Soybean crop was employed on study at Ujjain district in Madhya Pradesh.

Across Sikkim and Central part of India, there is a scarcity of thorough studies that look at key crop productivity on a regional basis. Furthermore, in the context of crop yield model, the uncertainty information provided by climate models and scenarios appears restricted. Despite the fact that a small number of studies have been undertaken in this region to assess the impact of climate change on crops, past research has been confined to a single crop study and has been based on previously defined climate change scenarios (Deb et al. 2015a, b). Keeping in view the economic importance of agriculture in Sikkim and Central Region of India, the present study was conducted for rice and wheat crops under future climate scenarios RCP 4.5 & RCP 8.5. The Aquacrop models was checked for its accuracy and reliability in determination of future yield and the impact of climate change on the crop yields over the study regions was quantified in this research work.

12.2 Study Area and Data Utilized

12.2.1 Study Area Description

This research work has been carried out on the two diverse regions which are situated in Sikkim and Central state of India (Fig. 12.1a).

Sikkim (Fig. 12.1b), is the first selected study area located in the East-Himalayas portion, with a physical occupancy of roughly 7096 km^2 with latitudes of 27° 07′ E – 28° 13′ E and longitudes of 88° 01′ N – 88° 92′ N. The area's elevation goes from minimum 192 m to 7403 m of maximum elevation above M.S.L. The area's elevation spans from 192 to 7403 metres above sea level. Over the surveyed sites, yearly mean precipitation ranges from 2300 to 3400 mm. The monsoon season (May–September) is when the majority of the rain falls, accounting for 85% of the total annual rainfall. Precipitation during the monsoon season lies in between 2000 and 2900 mm per year. The annual maximum temperature lies in range of 30–33 °C
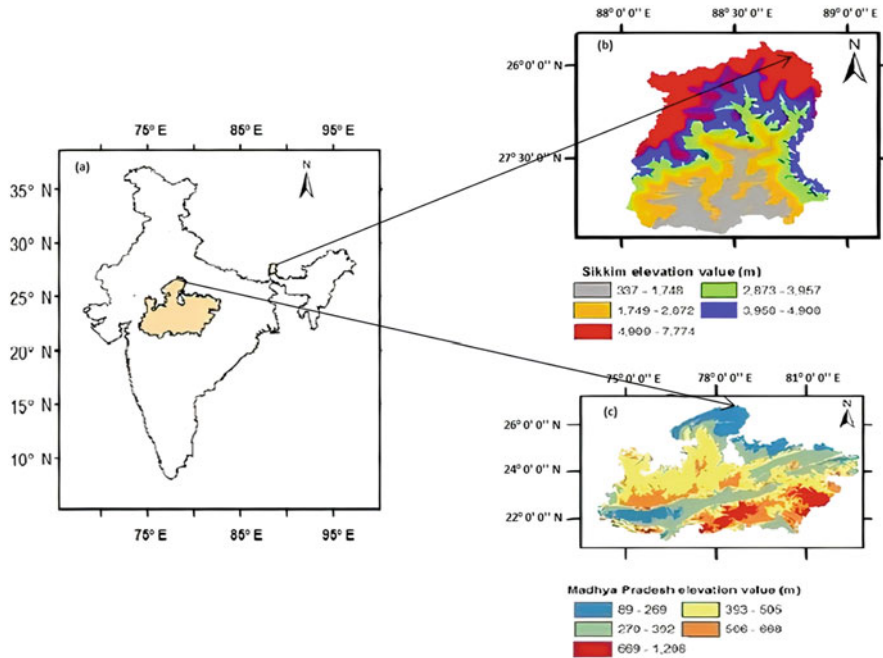
Fig. 12.1 (**a**) Location map of Sikkim and Central state over India; (**b**) DEM of Sikkim region; (**c**) DEM of Central Region Madhya Pradesh state of India

while minimum temperature lies in range of 1–6 °C. Sikkim's steep terrain makes it unsuitable for agricultural techniques. Soil erosion and water loss are aided by the sloping landforms. Despite these drawbacks, agricultural techniques are carried out by using terraces to transform rocky terrain to cultivated land. Maize, rice, and wheat are the main crops farmed in Sikkim.

The second selected study area is the Sehore district Central India which stands in the foothills of Vindhyachal Range (Fig. 12.1c). On the basis of physiography, Sehore district comprises of valleys formed by the three major rivers i.e. Narmada basin, Chambal, and Betwa. Sehore district lies between 22°32′N – 23°40′N latitude and 76°22′E – 78°03′E longitude. The Sehore district comprises of Aashtha, Icchawar, Budhni, and Nasrullaganj tehsils. The region encompasses an area of 6578 km^2 with an average elevation of 502 m. The average precipitation in the region is 1217.7 mm, average min-max temperatures are 10.4 °C & 40.7 °C respectively. Wheat, Rice, Maize, Soybean are the principal crops grown in this central region of India.

12.2.2   Meteorological Data Utilized

The India Meteorological Department high resolution ($0.5° \times 0.5°$) gridded precipitation and temperature data was employed in this research work. IMD dataset has been used in many recent studies (Kumar et al. 2021; Poonia et al. 2021a, b). The wind speed data was downloaded from Terrestrial Hydrology Research Group accessible at a resolution of ($0.5° \times 0.5°$), while the relative humidity statistics were taken from NCEP/NCAR reanalysis dataset. The GCMs viz. "ACCESS1.0, CanESM2, CCSM4, CNRM-CM5, and MPI-ESM-LR" have been employed in this research work. The high-resolution future dataset for the climate scenarios RCP 4.5 & RCP 8.5 were utilized as inputs to Aquacrop model to determine crop yields. The historical period (1998–2015) for the Aquacrop model calibration (1998–2007) and validation (2008–2015) was considered as the base period for setup of the Aquacrop model. The future period (2021–2099) with RCP projections 4.5 & 8.5 were subdivided into years (2021–2040, 2041–2060, 2061–2080 & 2081–2099) for better projected yield analysis. For the crop yield simulation, the typical sowing dates prevalent in the respective study regions were determined based on important literature work (Deb et al. 2015b; Balvanshi and Tiwari 2019).

12.3   Methodology

To complete the objective of this research work, historic climatological data (precipitation, relative humidity, wind speed, and max-min temperatures) from 1998 to 2015 were gathered. The future projected climatic data for years 2021 to 2099 for scenarios RCP 4.5 and 8.5 were also collected to do simulation of yield using Aquacrop model. The 1st study area Sikkim is divided into East Sikkim, West Sikkim, and South Sikkim while for the 2nd study area Sehore region which comes under the central part of India is considered for the yield forecast.

12.3.1   Crop Yield Simulation Using Aquacrop Model

AquaCrop is a menu-driven program with a well-developed user interface. The model is preferred for simulation of yields of various crops. Input consists of weather data, crop characteristics, and soil and management characteristics (Raes et al. 2009; Foster et al. 2017). Soil characteristics are divided into soil profile and groundwater characteristics and management practices into field management and irrigation management practices (Mohammad et al. 2018).

The historic data from year 1998 to year 2015 is used for the Aquacrop model calibration and validation. The future projected data was used as input to the calibrated Aquacrop model and future yields were obtained under RCP scenarios 4.5 & 8.5 for the years (2021–2040, 2041–2060, 2061–2080 & 2081–2099).

12.3.2 Model Performance Evaluation Using RMSE and Coefficient of Determination (r^2)

The accuracy in simulating the yield of the model was evaluated using the Root Mean Square Error, RMSE, and Coefficient of Determination r^2 criteria's (Das et al. 2020).

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (P_i - O_i)^2} \tag{12.1}$$

Where, O and P are observed and predicted values, respectively.

A models fit improves as RMSE approaches zero.

$$r^2 = \left(\frac{\sum_{i=1}^{n} (O_i - \overline{O})(P_i - \overline{P})}{\sqrt{\sum_{i=1}^{n} (O_i - \overline{O})^2} \sqrt{\sum_{i=1}^{n} (P_i - \overline{P})^2}} \right)^2 \tag{12.2}$$

A models fit improves as r^2 approaches unity.

12.3.3 Evaluating Uncertainty of GCMs for Future Yield Simulation

For accurate generation of future projections, it is necessary that GCM used for climate studies should have least level of uncertainties. For this, the possibility theory (Zadeh 1999) is utilized to evaluate the uncertainty of GCMs. The probabilistic analysis helps to induce higher accuracy in finding more suitable GCM with lesser uncertainties for the study region.

12.3.4 Adaptation Strategy to Combat Impact of Climate Change on Crop Yield

Firstly, the AQUACROP model was employed for simulating the yield in the future periods (2021–2040, 2041–2060, 2061–2080 & 2081–2099) with RCPs 4.5 and 8.5 climate scenarios with normal planting date. However, the simulated yield with normal planting date shows significant increase in yield over the Sikkim region while remarkable declination in the yield particularly was found in the Central Region of India. Hence it necessitates the need to adopt a suitable and economic measure so as to reduce the impact of future climate for the Central region of India.

The shifting of planting dates was chosen as adaptation measure and new simulated yield was generated using AQUACROP for all future scenarios. The simulation for wheat crop with a shift of 15 days later in planting date gives maximum wheat yield and simulation for rice crop with shift of 5 days later during period (2021–2060) & 10 days later during the period (2061–2099) resulted in maximum future yield.

12.4   Results and Discussion

12.4.1   Aquacrop Model Efficiency During Calibration and Validation for the Sikkim Region

The crop yield model was calibrated (1998–2007) and validated (2008–2015) over the historic period (1998–2015) for the rice and wheat crops. The Table 12.1 and Fig. 12.2 ahead depicts the accuracy values during the years 1998–2007.

The model showed satisfactory efficiency values during the calibration (refer Fig. 12.2) and validation (refer Fig. 12.3), hence the calibrated parameters values were fixed for the future yield prediction of the region.

12.4.2   Aquacrop Model Efficiency During Calibration and Validation for the Central Region of India

The crop yield model was calibrated (1998–2007) and validated (2008–2015) over the historic period (1998–2015) for the rice and wheat crops for the Sehore region on Central India. The Fig. 12.4 and Table 12.2 ahead depicts the accuracy values during the years 1998–2007.

From the Fig. 12.4 and Table 12.2, it was found that the Aquacrop model perform efficiently during the calibration the validation periods for the Sehore region. The calibrated parameter values were now fixed and utilized in the future crop yield simulation for the RCP scenarios 4.5 and 8.5.

Table 12.1 Model efficiency during calibration and validation over Sikkim region

Period	Stations	Rice r^2	Rice RMSE	Wheat r^2	Wheat RMSE
Calibration	East Sikkim	0.81	5.35	0.76	17.20
	West Sikkim	0.73	4.77	0.76	10.72
	South Sikkim	0.93	7.32	0.71	14.33
Validation	East Sikkim	0.86	3.82	0.72	5.56
	West Sikkim	0.76	1.64	0.68	19.38
	South Sikkim	0.86	1.42	0.67	9.44
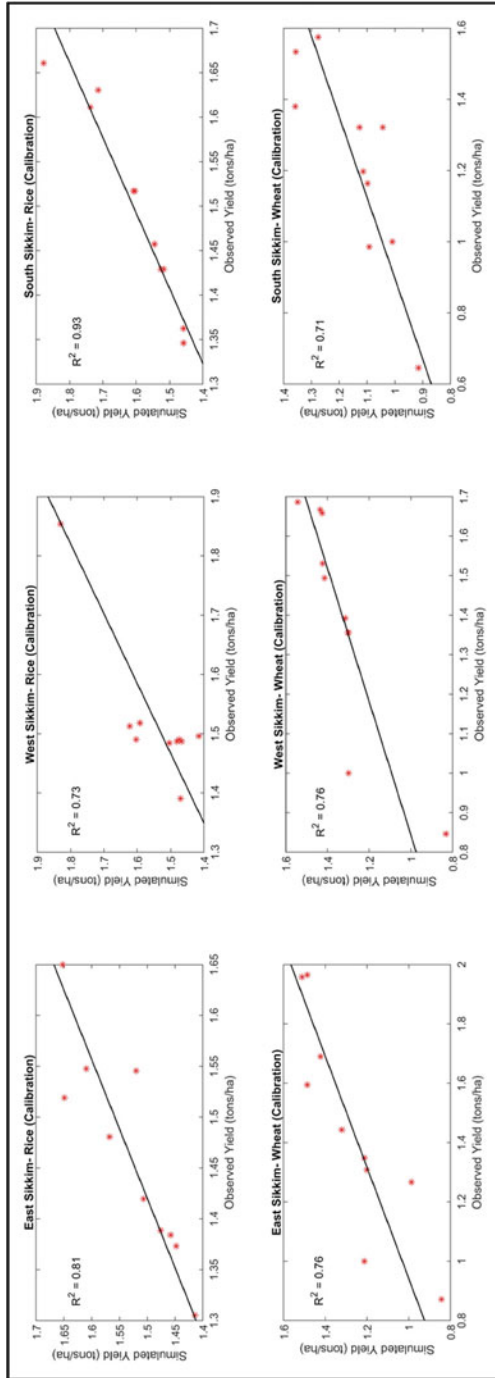
Fig. 12.2 Coefficient of determination charts during calibration for the Aquacrop model over the Sikkim region
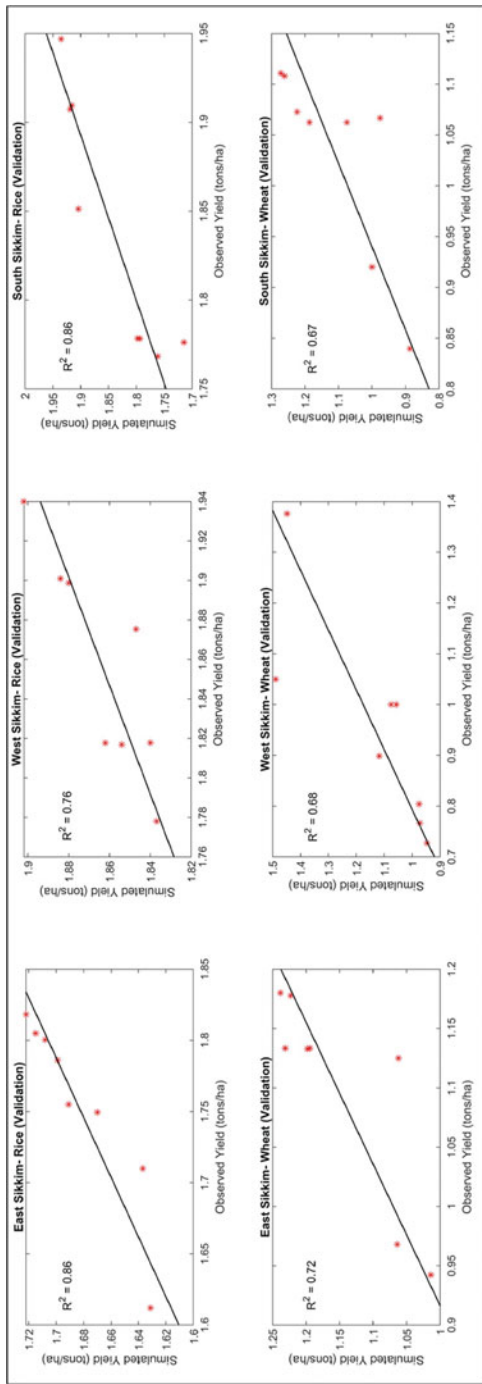
Fig. 12.3 Coefficient of determination charts during validation for the Aquacrop model over the Sikkim region
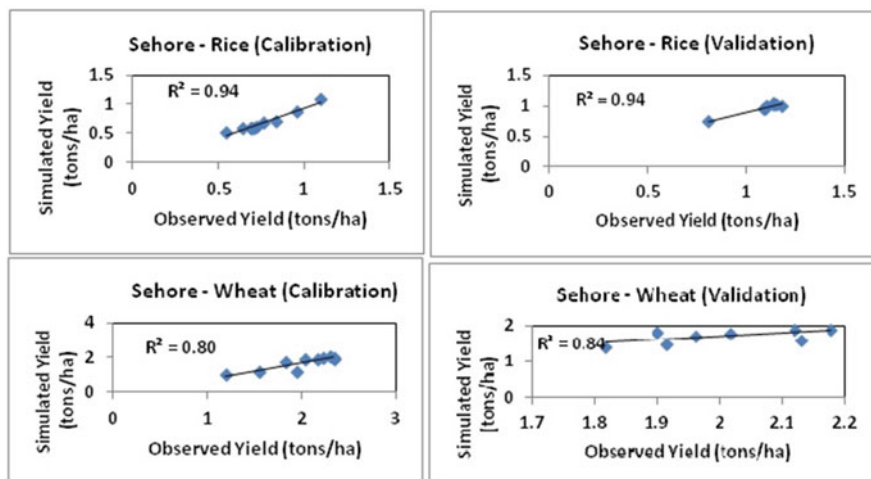
Fig. 12.4 Coefficient of determination charts during calibration and validation for the Aquacrop model over the Central region of India

Table 12.2 Model efficiency during calibration and validation over Central region of India

Period	Stations	Rice		Wheat	
		r^2	RMSE	r^2	RMSE
Calibration	Sehore- Central India	0.94	0.08	0.80	0.34
Validation	Sehore- Central India	0.94	0.11	0.84	0.33

12.4.3   Future Simulated Yield of Crops

The future yield was predicted for the future years 2021–2099 by employing the calibrated Aquacrop model over the selected study areas. The Sections 12.4.3.1 and 12.4.3.2 ahead portrays the future predicted yields by the selected GCMs under RCP scenarios 4.5 and 8.5 for the Sikkim and Central region of India respectively.

12.4.3.1   Sikkim Region

The future yield of rice and wheat crops was simulated using the calibrated Aquacrop model for the Sikkim region. The Fig. 12.5 ahead portrays the comparison in yields of rice and wheat future yields with their observed yield.

During the period 2021–2099, the average projected rice yield (refer Fig. 12.5) in East Sikkim is expected to increase by 11–20%, in West Sikkim by 5–17%, and in South Sikkim by 0.5–14%. During the period 2021–2099, the increase in the mean wheat yield (refer Fig. 12.5) varies between 2% and 5% in East Sikkim, 21–41% in West Sikkim, and 26–44% in South Sikkim. Overall it is found that the current
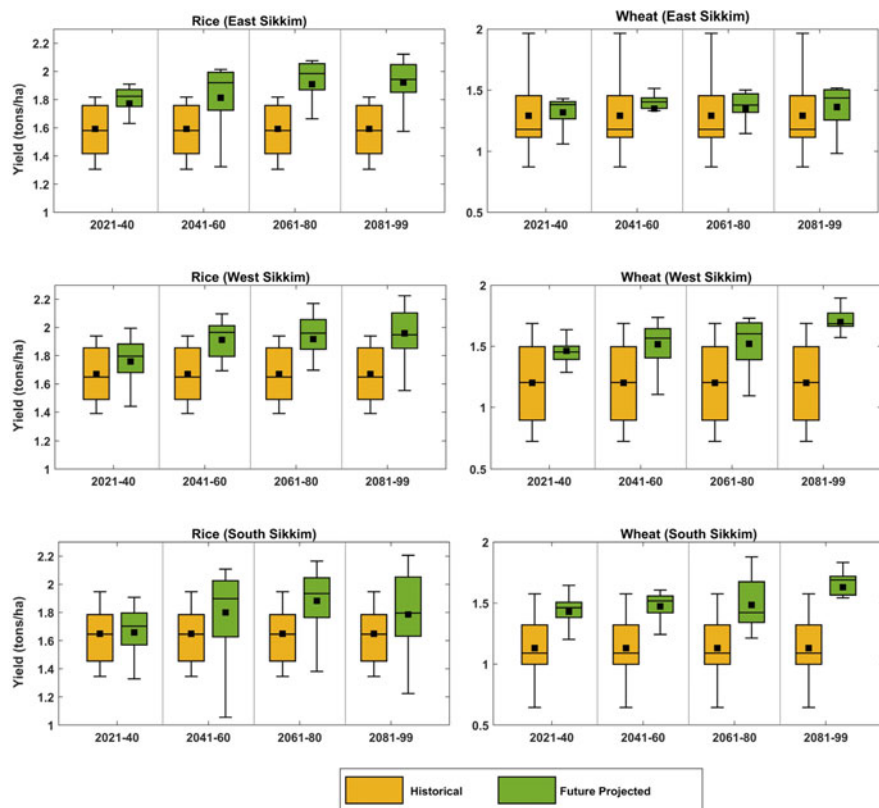
Fig. 12.5 Future projected yield of Rice and Wheat for Sikkim region

practices in growing of the rice and wheat crop is adequate for the future also and no adaptation measure is further required for Sikkim region.

12.4.3.2 Central Region of India

The calibrated Aquacrop model for the Central region was utilized to project the future yield under climate scenarios RCP 4.5 & RCP 8.5 (refer Fig. 12.6). The average observed yield of rice crop in central region Sehore during the period (1998–2015) is estimated to be 0.90 tons/ha. The average observed yield of wheat crop in central region Sehore during the period (1998–2015) is estimated to be 1.99 tons/ha.

The simulated future yield of rice shows a gradual decrease in the future periods and depicts high declination towards the years (2081–2099). The worst scenario is found to be RCP 8.5 under which the simulated yield drops till 0.72 tons/ha (Refer
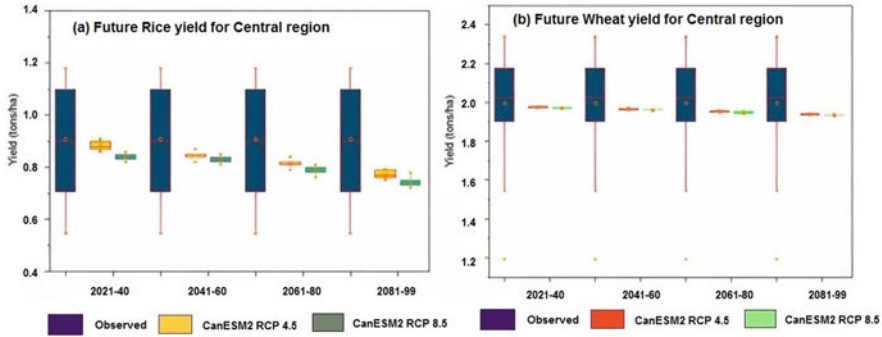
Fig. 12.6 Future projected yield of Rice and Wheat crop for the Central region

Fig. 12.6a). During the period (2081–2099), the simulated wheat yield drops to 1.93 tons/ha under the climate scenario RCP 8.5 (Refer Fig. 12.6b).

It can be concluded that the current crop growing practices prevalent in the Central region are not efficient enough to safeguard yield against the future climate change.

Adaptation Strategy by Shifting Sowing Dates

The yield simulating model AQUACROP was employed again keeping in priority to minimize the impact of climate change on the yields of rice and wheat crops in the Central region of India.

The plantation dates of the crops rice and wheat were altered (15 days ahead, 10 days ahead, 5 days ahead, 5 days later, 10 days later, 15 days later) and an optimum date was obtained that provides maximum yield to withstand negative impact of climate change in the future periods.

From Tables 12.3 and 12.4, it is seen that the future yield of rice and wheat is deteriorating under RCP 8.5 climate scenario. The prime reason for the decrease in yield can be the inclination in maximum-minimum temperatures over the study region.

The optimum dates obtained after multiple Aquacrop model simulations with alteration in planting dates for rice was 5 days later for period 2021–2060 then 10 days later for period 2061–2099 and for wheat crop was 15 days later for period 2021–2099 (refer Tables 12.3 and 12.4). The new plantation date proposed for crops resulted in maximum value of simulated yield in future periods and thus it can reduce the negative impact of climate change on agricultural crop yield.

Table 12.3 Percent changes in yield for rice crop with changed planting dates

Normal planting date: 15th November	Climate scenario	Average yield year (1998–2015)	% change year (2021–2040)	% change year (2041–2060)	% change year (2046–2060)	% change year (2061–2080)	% change year (2081–2099)
Planting 15 days ahead	RCP 4.5	1.993	−0.3	−0.5	−0.8	−0.9	−1.2
	RCP 8.5		−0.3	−0.6	−0.9	−1.0	−1.3
Planting 10 days ahead	RCP 4.5	1.993	−0.2	−0.5	−0.8	−0.9	−1.2
	RCP 8.5		−0.2	−0.6	−0.9	−0.9	−1.2
Planting 5 days ahead	RCP 4.5	1.993	−0.2	−0.5	−0.8	−0.9	−1.1
	RCP 8.5		−0.2	−0.5	−0.9	−0.9	−1.2
Planting 5 days later	RCP 4.5	1.993	−0.2	−0.5	−0.8	−0.9	−1.1
	RCP 8.5		−0.2	−0.5	−0.9	−0.9	−1.2
Planting 10 days later	RCP 4.5	1.993	−0.2	−0.4	−0.7	−0.9	−1.1
	RCP 8.5		−0.2	−0.5	−0.9	−1.1	−1.1
Planting 15 days later	RCP 4.5	1.993	**−0.1**	**−0.4**	**−0.7**	**−0.8**	**−0.9**
	RCP 8.5		**−0.2**	**−0.5**	**−0.8**	**−1.0**	**−1.0**

Table 12.4 Percent changes in yield for wheat crop with changed planting dates

Normal planting date: 24th June	Climate scenario	Average yield year (1998–2015)	% change year (2021–2040)	% change year (2041–2060)	% change year (2046–2060)	% change year (2061–2080)	% change year (2081–2099)
Planting 15 days ahead	RCP 4.5	0.90	0.0	−0.3	−0.6	−0.7	−2.4
	RCP 8.5		−0.4	−1.0	−0.7	−2.3	−5.0
Planting 10 days ahead	RCP 4.5	0.90	0.1	−0.3	−0.5	−0.7	−2.3
	RCP 8.5		−0.3	−0.9	−0.6	−2.2	−5.0
Planting 5 days ahead	RCP 4.5	0.90	0.1	−0.2	−0.5	−0.6	−2.3
	RCP 8.5		−0.1	−0.8	−1.6	−2.2	−5.0
Planting 5 days later	RCP 4.5	0.90	**0.2**	**−0.2**	**−0.5**	**−0.6**	−2.2
	RCP 8.5		**0.0**	**−0.8**	**−1.5**	**−2.1**	−5.0
Planting 10 days later	RCP 4.5	0.90	0.0	−1.3	−1.9	−2.6	**−2.0**
	RCP 8.5		−0.8	−2.0	−3.9	−5.2	**−4.1**
Planting 15 days later	RCP 4.5	0.90	0.0	−1.3	−2.0	−2.6	−2.2
	RCP 8.5		−0.8	−2.1	−3.9	−5.3	−4.2

12.5   Conclusions

In this research work, the Aquacrop yield simulating model was tried and tested on the two diverse regions of India viz. Sikkim and Central India. The model was first calibrated and validated during the historic years so that the efficiency in model results can be seen. Further the model was simulated for the future period

(2021–2099) by using the GCM data as input and the future crop yields of rice and wheat crops under climate scenarios RCP 4.5 and RCP 8.5 were estimated. It was found that the 1st selected study area-Sikkim, have increased yield results for the future years especially during (2081–99). The reason here can be presumed for the increase in yield of rice and wheat that the altitude is higher as well as temperatures are low in addition with increasing the CO_2 is facilitating the crop growth. On the other hand, the 2nd selected area – Central Region of India, have shown decrease in the yield of rice and wheat. The RCP scenario 8.5 portrays the maximum yield reduction and hence a sustainable adaptive measure by altering the planting dates was adopted to address the losses in this agricultural economy. It was concluded that the Aquacrop model performs quite accurately over the selected regions of India and can be furthermore utilized in other parts to reduce the agricultural risks due to climate change.

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