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Assessment of climate change impact on yield of major crops in the Banas River Basin, India

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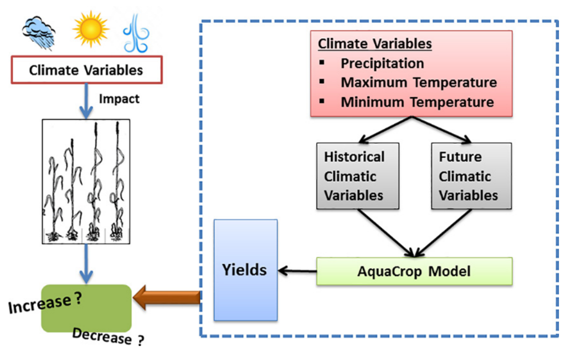
HIGHLIGHTS

- Three crops are used for future yield prediction in the basin.
- Variation in temperature and precipitation pattern will affect the crop yields.
- AquaCrop predicted crop yields in Banas Basin of future period 2021–2050.
- With the increase of CO_2 and temperature the crop yields show an increasing trend.

GRAPHICAL ABSTRACT



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ABSTRACT

Crop growth models like AquaCrop are useful in understanding the impact of climate change on crop production considering the various projections from global circulation models and regional climate models. The present study aims to assess the climate change impact on yield of major crops in the Banas River Basin i.e., wheat, barley and maize. Banas basin is part of the semi-arid region of Rajasthan state in India. AquaCrop model is used to calculate the yield of all the three crops for a historical period of 30 years (1981–2010) and then compared with observed yield data. Root Mean Square Error (RMSE) values are calculated to assess the model accuracy in prediction of yield. Further, the calibrated model is used to predict the possible impacts of climate change and CO_2 concentration on crop yield using CORDEX-SA climate projections of three driving climate models (CNRM-CM5, CCSM4 and MPI-ESM-LR) for two different scenarios (RCP4.5 and RCP8.5) for the future period 2021–2050. RMSE values of simulated yield with respect to observed yield of wheat, barley and maize are 11.99, 16.15 and 19.13, respectively. It is predicted that crop yield of all three crops will increase under the climate change conditions for future period (2021–2050).

1. Introduction

In the world, 80% of the agricultural area is covered by rain-fed agriculture and generates about 60% of the world food (FAO, 2008). Agricultural production is greatly affected by climatic factors like changes in greenhouse gas concentrations, radiation, water scarcity, precipitation and temperature. According to the Food and Agriculture Organization (FAO), world agricultural production growth is expected to decrease with annual rate of 1.5% by the year 2030 and then a further reduction by 0.9% till 2050, compared with 2.3% growth per year since 1961 (FAO, 2003). Climate change is posing significant change in water supply and further threats to food productivity in various parts of the world (Smith, 2013; Hanjra and Qureshi, 2010; Knox et al., 2012;

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Kummu et al., 2012). Climate change may affect the agriculture production and food security due to variation in the spatial and temporal distribution of rainfall and the availability of resources like water, land, capital, biodiversity, and terrestrial resources (Lin, 2011). In India, the total food production has increased at a much faster pace than the population in last few decades. Due to this, there is a huge stress on groundwater resources and degradation of land quality. Largely, the Indian agriculture and food production is highly vulnerable to climate change due to the high sensitive to monsoon variability. Lobell et al. (2012) found that the wheat growth in northern India is highly sensitive to temperature > 34 °C. The Intergovernmental Panel on Climate Change (IPCC, 2007) reported that 0.5 °C rise in winter temperature is likely to reduce wheat yield by 0.45 tons/ha in India (Easterling et al., 2007).

Crop simulation models have been widely used to simulate biomass and yield of different crops (Challinor et al., 2010; Rotter et al., 2011; Bird et al., 2016). AquaCrop is a crop water productivity simulation model developed by the Food and Agriculture Organization (FAO) of the United Nations (FAO, 2009; Hsiao et al., 2009; Steduto et al., 2009). Farahani et al. (2009) used the AquaCrop model for understanding the behavior of crop under full (100%) and deficit (40, 60, and 80% of full) irrigation regimes in the summer season of the Mediterranean environment of northern Syria. Abedinpour et al. (2012) simulated the AquaCrop model for kharif Maize crop in a semi-arid environment of India using two years (2009 and 2010) experimental data for model calibration and validation. The model predicted that the water productivity range from 2.35% to 27.5% for different irrigation and nitrogen levels. Mkhabela and Bullock (2012) calibrated and validated the AquaCrop model for wheat yield and total soil water content on the Canadian Prairies and observed that the simulation of wheat grain yield and soil water content are within acceptable range. Simba et al. (2013) used AquaCrop model for investigating climatic characteristics responsible for yield in the maize, sorghum and millet crop varieties and calibrated the model by using the parameter water balance, biomass production and yield. Saad et al. (2014) calibrated the AquaCrop model in Egypt to assess crop water productivity of maize crop under non saline and saline soil conditions. Singh et al. (2013) used the AquaCrop model to estimate the 10 varieties of wheat yield production under the full irrigation schedule during 2008–2009 and 2009–2010 at the farm of Uttar Banga Krishi Viswavidyalaya Dakshin Dinajpur District. Kumar et al. (2014) simulate the four wheat varieties grain yield and water productivity under the different salinity modules in the Water Technology Centre (WTC), Indian Agricultural Research Institute (IARI), New Delhi and found that the AquaCrop model gives the good prediction of yield as compared to the water productivity and biomass in the wheat grain. Pawar et al. (2017) used the calibrated AquaCrop model to evaluate the different irrigation schedules under mulch and non-mulch condition for cabbage plant and observed the 80% of the harvesting index of cabbage plant. Rajasthan receives about 80% of its total annual precipitation through monsoonal precipitation. The state is facing the challenge of limited water resources availability which is directly linked to the agriculture production and food security issues. The Banas River Basin is a seasonal river and covers almost half of the state area. Considering the location of the study area in the semi-arid climatic condition, it is highly vulnerable to climatic conditions, water availability, and agricultural productivity. This study is an attempt to understand the linkage between climate change, water and agriculture production. The present study aims to assess the climate change impacts on wheat, barley and maize crops in the basin, under past and future scenarios of Coordinated Regional Climate Downscaling Experiment–South Asia (CORDEX-SA), by coupling crop models with ensemble climate models scenarios. The main objective of the study is to predict the effect of climate change scenarios on the different crops using an ensemble mean of three climate models. Section 2 introduces the study area, whereas the materials and methods are presented in Section 3. Section 4 presents the results of climate change impacts on crop yield, followed by a discussion and conclusions in Section 5.

2. Study area description

The Banas River Basin is located in east-central Rajasthan, between latitudes 24°15′ and 27°20′ N and longitudes 73°25′ and 77°00′ E as shown in Fig. 1. The elevation of the study area lies between 176 m and 1305 m. It originates in the Khamnor hills of the Aravali range and flows along its entire length through Rajasthan (Department of Water Resources). It is bounded by the Luni Basin in the west, the Shekhawati, Banganga and Gambhir Basins in the north, the Chambal Basin in the east, and the Mahi and Sabarmati Basins in the south. Basin is covering an area of about 45,833 km^2 with a total length of about 512 km (Department of Water Resources). The Banas River covered the 13 districts namely, Sawai Madhopur, Jaipur, Ajmer, Tonk, Rajsamand, Banswara, Chittaurgarh, Udaipur, Bhilwara, Dausa, Nagaur, Sikar and Bundi.

In the Rajasthan state, there are three types of cereal grown, i.e. primary, secondary and principal. The average yield of principal cereals of Rajasthan is higher as compared to the primary and secondary cereals. The maize, wheat and barley come under the principal cereals, and cultured under the irrigation and confined to the limited area, but the secondary cereals are mostly grown under rain-fed conditions (Sen and Abraham, 1966). Fig. 2 shows the trends in crop yield of the maize, barley and wheat crops of the historical period (1981–2010) and it is observed that all the crops are showing an increasing pattern. In this study, only climate data are used as variable without changing the other parameters like seed variety, sowing date, soil characteristics, management practices, and irrigation practices.

According to the Agricultural Department of Rajasthan, the state has been divided into 10 agro-climatic zones. These zones have been classified on the basis of precipitation, temperature, topography, cropping pattern, soil characteristics and irrigation patterns. But the Banas Basin covers five agro-climatic zones that are shown in Table 1.

3. Materials and methods

In this study, secondary datasets are collected from the agricultural department and the Indian Meteorological Department (IMD). Data required for AquaCrop (crop development, irrigation schedule soil profile and ground water level) are collected from the agriculture department. Meteorological data includes daily maximum and minimum temperature, precipitation from the period 1981 to 2010. The evapotranspiration (ET_0) values are calculated by the ET_0 calculator and further used as an input in the crop model. Detailed flowchart and methodology framework is shown in Fig. 3. Future climate data is retrieved from the Coordinated Regional Climate Downscaling Experiment–South Asia (CORDEX-SA) and bias-correction are performed for the scenarios RCP4.5 and RCP8.5. The AquaCrop model is calibrated and validated for three different crops (wheat, maize and barley) for the period 2006 to 2010. Crop yield of three crops are predicted using bias-corrected climatic scenarios for future period 2021-2050.

3.1. Crop information

Maize crop is C4 plant and most important cereals for both human and animal consumption. The production of maize is about 594 million tons from about 139 million ha (FAOSTAT, 2000). In the present and future range of atmospheric CO_2 concentrations vary from 300 to 1000 μmol/mol (Goudriaan and Unsworth, 1990). According to the Cure (1985) and Cure and Acock (1986), the stomatal conductance and transpiration of the maize crop may decrease to 40% and 28% at high atmospheric CO_2 and light conditions. The maize crop is grown when the mean daily temperatures is above 15 °C. According to the FAO, the mean daily temperatures of the growing period is >20 °C and the maturation period of the early and medium grain varieties take 80–110 days and 110–140 days, respectively. When the mean daily temperature is below 20 °C, the maturation period extends up to 10–20 days.