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Short Communication

Impacts of climate change on future crop water demand in an agricultural watershed in Mayurbhanj district of Odisha, India

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It is a well-known fact that the phenomena of global warming and anthropogenic climate change are global drivers of changes in rainfall pattern, hydrologic processes, streamflows, groundwater level, water resources availability, and frequency and intensity of hydroclimatic extremes (droughts, floods, heat waves), and are also likely to impact water quality, agricultural productivity, food security, socio-economic development, and community resilience at local-to-regional levels (IPCC, 2021). Though rainfed agriculture is most prevalent in India, irrigation using surface and groundwater resources is also practised in many places to meet the growing demands of production, for instance, in non-rainy (Rabi) season. Especially since the crop evapotranspiration and irrigation demand depend on local climate (temperature, rainfall, evapotranspiration, among other factors), the impacts of climate change on agrarian activities and irrigation water requirement also need to be investigated in a regional context. Hence, it is necessary to understand and evaluate the impacts of climate change on the different resource systems and to adapt to the uncertainties of future climate by means of sustainable practices (Rehana and Mujumdar, 2013; Aswathi *et al.,* 2022; Abrha and Hagos, 2022). Sustainable water management in future in agricultural communities can be possible by adopting integrated resources management, precision agriculture, and decision support systems for irrigation scheduling, based on regional level studies and analyses.

Researchers employ general circulation models (GCMs) to simulate the global climate and generate climate change projections for future periods. GCMs can provide future projections under different scenarios that represent climate change storyline with different magnitudes of level of greenhouse gas emissions and radiative forcing leading to global warming. Then, downscaling methods such as the Statistical Down Scaling Model (SDSM; Wilby *et al.,* 2002) are used in climate change studies to obtain future data at different local-to-regional scales as well as point observations from the coarse scale GCM outputs. While downscaled climate projections in conjunction with hydrological models can be used to assess changes in water balance variables under potential climate change, it is necessary to run crop water models with downscaled future climate projections to evaluate the likely impacts of climate change on future agricultural water use.

In the present study, the climate change impact assessment analysis is conducted over an agricultural watershed (a part of the Subarnarekha River Basin, covering 1223 square kilometers in area) in the Mayurbhanj district in the state of Odisha in India. The study watershed outlet is located at 21.68°N latitude and 87.04°E longitude. Observed gridded daily rainfall and temperature (minimum and maximum) having spatial resolution of 0.25° and 1° respectively, obtained from the India Meteorological Department (IMD) for the 1961–1990 (baseline) period are used for simulating baseline period crop water requirements over the study watershed. Using the bilinear interpolation method, temperature data are re-computed at 0.25° spatial resolution for use in the study. GCM projections of daily rainfall and temperature for the future period (2041-2070) are utilized in this study, assuming a changed future global climate, at risk because of growth in population and unsustainable socioeconomic development represented by a pessimistic climate change scenario known as the Shared Socioeconomic Pathway (SSP5-8.5). Future projections obtained from a Coupled Model Intercomparison Project phase 6 (CMIP6) GCM – the Canadian Earth System Model 5 (CanESM5) developed by the Canadian Centre for Climate Modelling and Analysis (CCCma), at 2.8° spatial resolution are then downscaled using the SDSM tool to get future climate variables at 0.25° grid resolution. These data have been used

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Table 1: Projected changes (Δ) in monthly temperatures (T_{min}, T_{max}) and monthly rainfall (R) between the baseline period (1961-1990) and future period (2041–2070) over the study area

Month	Minimum temperature (T_{min}; °C)		Maximum temperature (T_{max}; °C)		Rainfall (R, mm)	
	baseline value	Δ_{mean}; [Δ_{max}, Δ_{min}]	baseline value	Δ_{mean}; [Δ_{max}, Δ_{min}]	baseline value	Δ_{mean}; [Δ_{max}, Δ_{min}]
Jan	13.19	-0.09 [0.02, -0.16]	26.33	0.21 [0.28,0.16]	27.30	5.54 [20.66, -16.89]
Feb	16.39	-0.02 [0.11, -0.15]	29.41	0.01 [0.04, -0.04]	23.62	1.08 [1.90, -1.09]
Mar	20.46	0.23 [0.31, 0.16]	33.42	0.05 [0.11,0.01]	26.32	-1.44 [0.19, -3.60]
Apr	24.24	-0.16 [-0.14, -0.18]	36.05	0.01 [0.04.-0.02]	45.30	1.49 [5.93, -2.51]
May	25.92	0.24 [0.32, 0.14]	36.53	-0.21 [-0.08, -0.32]	80.63	12.44 [22.03, -1.26]
Jun	25.99	-0.10 [-0.05, -0.15]	34.39	-0.13 [-0.10, -0.17]	218.67	2.01 [21.06, -10.61]
Jul	25.44	-0.08 [-0.06, -0.10]	32.00	-0.05 [0.04, -0.14]	275.22	5.55 [12.77,1.86]
Aug	25.33	0.03 [0.06, 0.00]	31.58	0.16 [0.24, 0.08]	370.60	-20.95 [-1.51, -49.68]
Sep	24.99	0.02 [0.03, 0.01]	31.86	-0.15 [-0.03, -0.31]	301.16	-36.55 [-20.06, -55.50]
Oct	23.09	0.24 [0.28, 0.19]	31.34	-0.05 [-0.03, -0.06]	141.13	5.43 [33.61, -18.41]
Nov	17.47	0.26 [0.39, 0.13]	29.57	0.05 [0.11, -0.02]	23.34	-1.20 [3.92, -5.24]
Dec	13.52	-0.23 [-0.17, -0.31]	26.78	0.00 [0.04. -0.05]	10.72	3.14 [17.65, -1.56]

Note: '-' denotes a decrease in the variable value in future period. The range of projected future change for the variable is provided in square bracket.

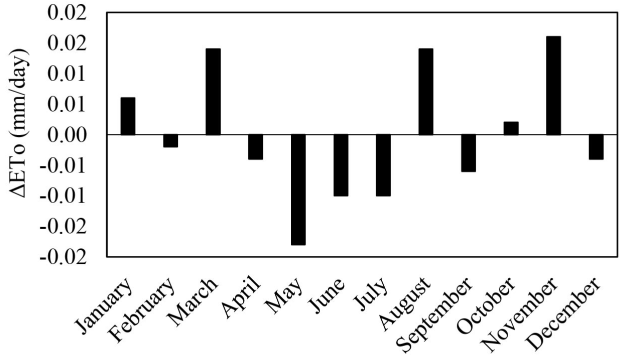


Fig. 1: Projected change in reference evapotranspiration (ΔET_o) between baseline (1961-1990) and future (2041-2070) periods over the study watershed

for simulating the future period crop water requirements over the watershed under the assumption of future climate change.

The Food and Agricultural Organization (FAO)-CROPWAT 8.0 model has been chosen as a tool for estimating crop water requirement values under given meteorological conditions in this study (Gabr, 2022). Hence, the main aim of the paper is to evaluate the likely impacts of potential future climate change on crop water use at watershed scale, by comparing the reference evapotranspiration (ET_o), crop evapotranspiration (ET_c), and crop water requirement (CWR) under SSP5-8.5 scenario-driven climate in future (2041–2070) period in the study watershed with that of the baseline (1961-1990) values. It is noteworthy that there are changes in local climatology in the future period under SSP5-8.5 scenario, and Table 1 lists the projected changes in average monthly rainfall (R) and minimum and maximum temperatures (T_{min}, T_{max}) over the watershed. In the present study, the effect of climate change on local hydroclimatic variables forms the motivation for addressing the impacts of climate change on agricultural water requirements in the study watershed.

Estimation of crop water requirement

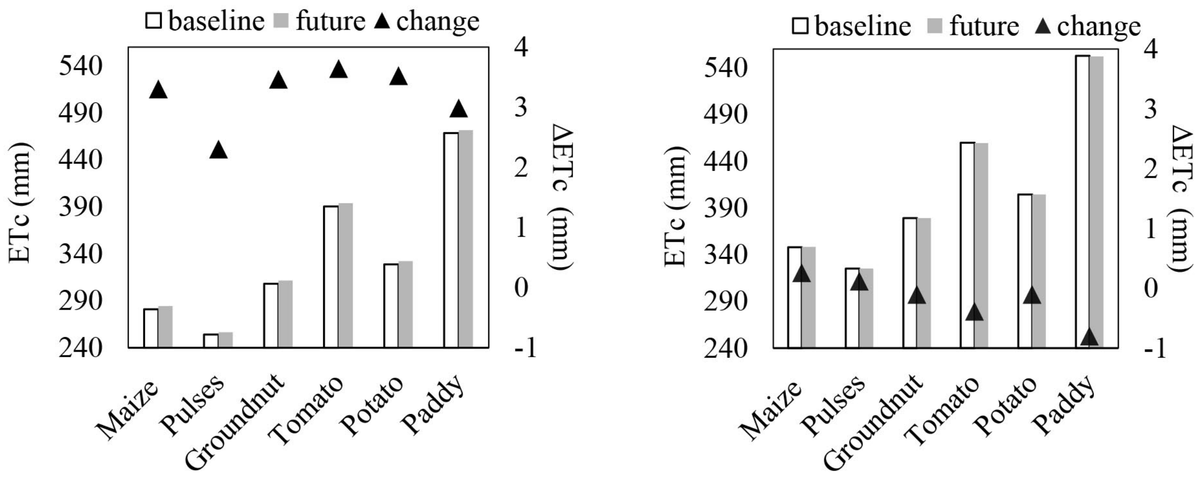
In this study, average monthly rainfall and temperature during *Kharif* and *Rabi* seasons are provided as inputs to the FAO-CROPWAT model to compute evapotranspiration and irrigation demand of following crops: cereals (paddy & maize), pulses, oil crop (groundnut) and vegetables (tomato) and root crop (potato) grown in the study area. The parameters such as wind speed, relative humidity, and radiation for the study region are assumed to remain unchanged in future period in the present study.

In CROPWAT model, the FAO Penman-Monteith approach is adopted for estimating reference evapotranspiration (ET_o; mm/day), and effective rainfall (R_{eff}; mm/day) is computed using the United States Department of Agriculture (USDA)-Soil Conservation Service (SCS) method (Allen *et al*., 2000). Using crop coefficients (K_c), estimation of crop evapotranspiration (ET_c) is performed for the selected crops in the study area and then aggregated for each cropping season (*Kharif, Rabi*) for seasonal CWR computation. We have chosen June-September and October-February months as range of Kharif and Rabi cropping seasons respectively, in this analysis. The CWR is then the difference between the seasonal ET_c and R_{eff}.

Projected changes in evapotranspiration and irrigation requirement

The computed ET_o is maximum in the month of May, while January and December had the least ET_o in the baseline period in the study watershed. The changes in average daily ET_o values between the baseline and future periods under SSP5-8.5 scenario are shown in Fig. 1. Increase in ET_o is observed mostly in March, August, and November in the study area. The increase of ET_o value is maximum in November in the future relative to the baseline period. When there is an increasing trend in ET_o and reduction of rainfall, this could lead to an increase in future irrigation requirement, as noted for the months of August and November.

Estimated changes in average seasonal ET_c values



(a) (b)

Fig. 2: Crop evapotranspiration (ET_c) for (a) Rabi, and (b) Kharif seasons in baseline (1961-1990) and future (2041-2070) periods in the watershed indicated by vertical bar plot, with the corresponding projected changes marked as black triangles along the secondary y-axis.

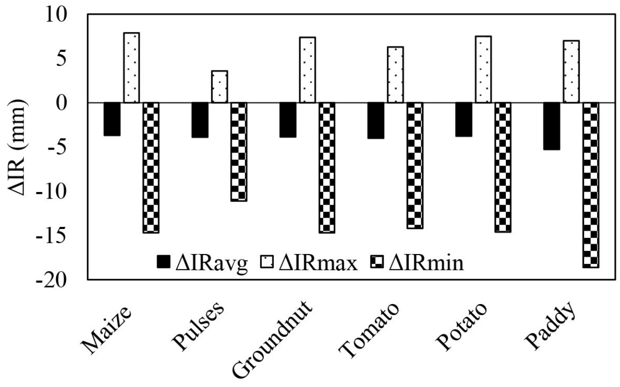


Fig. 3: Projected changes in Rabi season irrigation requirement (ΔIR) in the watershed between baseline (1961-1990) and future (2041-2070) periods

in future periods are shown in Fig. 2. An increase in crop ET_c is projected in Rabi season, by about 3.2 $\pm$ 0.5 mm (Fig. 2a). It is seen that ET_c for Kharif crops do not change much (Fig. 2b), and hence might not contribute to increase in crop water demand in future in this season coupled with a negligible change in seasonal rainfall magnitude. However, from the results of the analysis, the need to assess the impacts of climate change on the Rabi season CWR is noted. Any change in seasonal CWR would mean modifying future water allocation in the watershed to meet the irrigation requirement (IR) of the various crops in the region.

Projected changes in CWR of different crops in future Rabi season are computed as shown in Fig. 3. Crops in the watershed showed on an average a decrease in IR in Rabi season in future (2041-2070) under SSP5-8.5 scenario. The changes in IR vary from crop to crop, and does not suggest any alarming change in IR in future in this watershed for the Rabi season.

Summary of the impacts of climate change

At a local scale, impact of climate change can vary in extent and magnitude, requiring different types of agricultural water management strategies. The present study highlights the application of CROPWAT model in capturing the changes in crop-specific water requirements, in response to the climate change-driven stresses. Under a highly pessimistic climate change scenario (SSP5-8.5), there are notable changes in crop evapotranspiration in future periods captured in this study, especially during the non-rainy season (Rabi). To examine the role of climate change on the crop water use in Rabi season, we compared the climatic factors: rainfall and ET_o, where decrease in seasonal rainfall coupled with increase in ET_o can have direct consequences on crop water demand and IR. The projected changes between baseline (1961–1990) and future (2041–2070) values of ET_o and CWR vary from location to location within the small study watershed, suggesting spatial variability in climatic change patterns and impacts. In the future period (2041–2070), our study projected that irrigation demand for Rabi season on an average shows a decrease, but it could rise upto 4-5% as seen in certain cases. The study can thus be used to assess suitability of different crops at each location based on water resources availability and associated stresses. Further detailed investigations are needed to properly implement irrigation management in the agricultural watersheds to adapt to future climate change.

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Data availability: The hydroclimatic data used in the study are available in the public domain, and some of the data that support the study are available from the corresponding author upon reasonable request.

Authors' contributions: **R Parwin**: Methodology, Investigation, Data curation, Writing-original draft preparation; **A Atnurkar**: Methodology, Investigation, Writing-review and editing; **M Ramadas**: Conceptualization, Visualization, Supervision, Funding Acquisition, Writing-review and editing; **A Agrawal**: Data curation, Formal analysis, Writing-review and editing

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