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Effect of Climate Change on Water Requirements of Crops and Adaptative Water Strategies in Krishna Upper Basin

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ABSTRACT: Climate change effects the irrigation demand of crops and supply by water resources which are highly dependent on pattern of rainfall and temperature. Any imbalance between the demand and supply of soil moisture may lead to adverse effect on crop yield and productivity. It is very essential to focus on water management plans and adaptation strategies to minimize the adverse effect of climate change on crop production. The present study was carried out in Krishna Upper subbasin of Krishna basin with an aim of study the impact of climate change on crop water and irrigation water requirement of crops grown in that region and adaptation strategies to cope with the climate change. It is projected that the net irrigation requirement of crops during *kharif* season is expected to decrease in future because of expected increase in monsoon rainfall. Crop water requirement and net irrigation requirement of crops during *rabi* and summer season is expected to increase for all the sub basins based on climate change scenarios of CNRM climate model. Adaptation strategies includes creation of additional storage for water resources, altering the sowing dates and deficit irrigation strategies. It is found that sub basin wise additional volume of water need to be increased to match with the irrigation requirements in future. Early sowing of crops by 10 days in *rabi* season may save the crops from additional irrigation requirement and match with the baseline periods. Deficit irrigation strategies during non-sensitive stages of crops with 0.9 ETc, 0.8 ETc and 0.7 ETc and full irrigation during sensitive stages for all the sub basins can be adopted to manage irrigation sources in the study area in future.

Key words: Climate change, Krishna Basin, water requirement

Introduction

Crop water demand is sensitive to climate change due to changes in precipitation and temperature. The increase in temperature under various climate change scenarios is likely to increase evapotranspiration demand of crops. Any imbalance between the demand and supply of soil moisture may lead to adverse effect on crop yield and productivity. Several studies were conducted on crop water requirement under the influence of climate change considering different Global Circulation Models (GCMs) and Regional Circulation Models (RCMs) across India as well as across Globe. De Silva *et al.* (2007) assessed the climate change impact on irrigation water requirement of paddy in Sri Lanka using water balance modelling and UK Hadley Centre for Climate Prediction and Research Model (HadCM3). Doria *et al.* (2009) assessed the impact of climate change on crop water availability in southern Quebec. Abeysingha *et al.* (2016) assessed evapotranspiration and irrigation requirements of rice and wheat crops in the context of climate change in the Gomti river basin. Boonwichai *et al.* (2018) conducted a study on the impact of climate change on irrigation water requirement (IWR) and rice crop water productivity (CWP). Kumar *et al.* (2019) developed a hydrological algorithm to map the spatio-temporal pattern of water supply and demand to facilitate the spatial planning of afforestation. Wang *et al.* (2019) analyzed the spatial-temporal variations of irrigation water requirement (IWR) by a modified Penman-Monteith (PM) method. All the researchers concluded that the overall evapotranspiration during crop period and crop water requirement in future would be increased because of alteration in climate variable due to climate change and few of the studies reported that the water needs during *kharif* season would be decreased because of increase in rainfall. Hence, it is very essential to focus on water management plans and adaptation strategies to minimize the adverse effect of climate change on crop production.

The adaptation strategies on water resources management in agriculture in future may provide a solution to achieve the sustainable agricultural production (Santikayasa *et al.,* 2014). Sustainable agricultural outcome in future under changing climate scenarios may be achieved by adopting water management strategies in a basin (Chanapathi *et al.,* 2020). Guo and Shen (2016) suggested adaptation measures such as reducing crop planting area, improving irrigation water utilization efficiency and changing crop planting types according to the water shortage situation in different regions to cope with the impacts of future climate change and human activities on water supply and water demand. Water use efficiency is one of the effective adaptation strategies and showed positive results rather than creating new water storage structure (Biemans *et al.,* 2013). Shifting of sowing date and identifying the showing windows that makes the crop more sustainable (Reddy *et al.,* 2016; Ding *et al.,* 2019). Prasad *et al.* (2012) suggested a set of appropriate contingency measures for optimum crop and soil management to alleviate stress in standing crops due to early, mid and terminal drought situations. *Xiao et al.* (2018) also suggested to change cropping system for reducing planting area of water consuming crop in those over-pumping areas to balance groundwater use and crop yield. Ahmadaali *et al.* (2017) analyzed the effects of water management strategies and climate change on agricultural sustainability found that the scenario of combining the crop pattern change with improving the total irrigation efficiency showed highest values of indices environmental and agricultural sustainability.

It is expected that the impacts of future climate change would be severe in the Krishna basin, because the basin has large semi-arid areas and is mostly rain dependent agriculture. Despite of the uncertainties about the precise magnitude of climate change and its possible impacts, particularly on regional and local scales, measures must be taken to prevent or minimize the impacts of climate change and mitigate and/or adapt to its adverse effects on water resources availability.

Study area

The present study is conducted on Krishna Upper sub-basin with an area of 54, 228 km^2 which comprises of Upper Krishna (K1), Middle Krishna (K2), Ghataprabha (K2) and Malaprabha (K4) sub-basins. The study area is situated between 15°3′ to 18°6′ N latitudes and 73°39′ to 77°23′ E longitudes, extended in the states of Maharashtra and Karnataka. The study area covers parts of Belgaum, Bagalkot, Bijapur, Dharwad, Gadag, Gulbarga, Haveri and Raichur of Karnataka state and Kolhapur, Satara and Sangli districts of Maharashtra state. Vertisols and laterites dominate soils in the basins (Deshpande 1998). Vertisols are the most abundant soils throughout the Deccan Traps. The high-altitude regions of the Western Ghats towards the western part of the study area experiences more rainfall and the eastern part of the study area experiences semi-arid climate. The laterites are mostly found in high rainfall regions of Western Maharashtra State and in the summits of the Deccan Traps.

The location of the study area, sub-basin boundaries and districts covered under the study area are shown in Figure. 1. Rainfall over the study area is erratic with large spatial variability. Upper Krishna basin receives more rainfall (long-term average) of about 981 mm per annum followed by Ghataprabha (778 mm), Malaprabha (660 mm) and Middle Krishna sub-basin (580 mm) respectively.

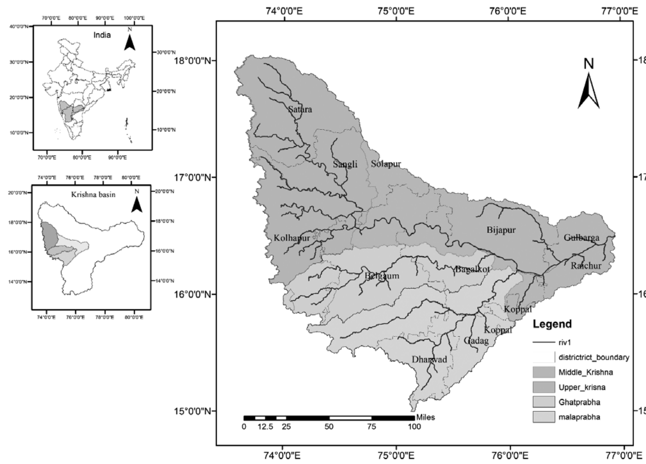

Fig. 1: Location map of the study area

Materials and Methods

FAO irrigation water needs framework and was adopted to calculate the irrigation water requirement for specific crops in the study area. The deficit between crop water requirement and effective rainfall is termed as irrigation water requirement. When the effective rainfall is sufficient to meet the crop water requirement, then the crop does not require irrigation water. If there is no rainfall, then irrigation requirement is equal to crop water requirement.

Data used

Daily rainfall data at grid interval of 0.25° x 0.25° for 30 years (1961-1990) of Indian Meteorological Department (IMD) (Pai *et al.,* 2014) was used. Maximum and minimum temperatures at grid interval of 1° x 1° for 30 years (1961-1990) (Srivastava *et al.,* 2009) was also used for this study. Crops information required for this study were also collected form available online resources and department websites. FAO crop coefficient values of selected crops were used.

The climate projection data (rainfall and temperature) were used to simulate the future irrigation water requirement of crops. The dataset generated by CCCR-IITM (Centre for Climate Change Research-Indian Institute of Tropical Meteorology) using RegCM4 RCM were downloaded from http://cccr.tropmet.res.in/home/esgf_node.jsp CCCR-IITM ESGF data node which is high resolution (50 km) and projection until the year 2099. After bias correction and comparison with historical data, CNRM-CM5 (CNRM) was selected for simulation of irrigation water requirement.

Crop Evapotranspiration (ETc)

Crop evapotranspiration also known as crop water requirement is the loss of water through evaporation from soil as well as loss of water from crop through process of transpiration. These two processes are combinedly know as evapotranspiration as it is hard to separate them.

Crop evapotranspiration can be calculated from the following formula.

$$ET_c = ET_0 \text{ X } K_c \quad (1)$$

where, ET_c = crop evapotranspiration, mm/day; ET_o = Reference evapotranspiration mm/day; K_c = Crop coefficient in fraction

Reference evapotranspiration (ET_0)

Hargreaves equation used to calculate the reference evapotranspiration in the present study. Hargreaves method is the most used temperature-based method and is recommended by FAO as an alternative method for reference evapotranspiration estimation when observed weather data are limited. Hargreaves method is more applicable among the empirical equations in reference evapotranspiration estimation under climate change scenario (Li *et al.,* 2018). The following equation was used to estimate the reference evapotranspiration.

$$ET_0 = 0.0023 \text{ X } R_A \text{X } (T_{mean}+17.8) \text{ X } T_d \; 0.50 \text{ X } (0.408) \qquad (2)$$

where, : Reference evapotranspiration, mm; : Extraterrestrial radiation, MJ m^{-2}; : Mean of maximum and minimum temperatures; : Difference between maximum and minimum temperatures; 0.408 is a conversion factor to convert MJ m^{-2} to mm.

R_A, was estimated based on the location's latitude and the calendar day of the year by following equation (Fisher and Pringle, 2013).

$$R_A = \frac{24\ (60)}{\pi} G_{sc}\ d_r\ [\omega_s\ \sin(\varphi)\ \sin(\delta)+\cos(\varphi)\ \cos(\delta)\sin(\omega_s)] \qquad (3)$$

where, G_{sc}= solar constant (0.0820 MJ m^{-2}min^{-1}); φ = latitude in radians, converted degree latitude to radian =latitude (in degrees) (Π/180).

Based on the Julian day of the year, remaining factors were determined.

$$d_r = 1+0.33 \cos\left(\frac{2\pi}{365} J\right) \quad (4)$$

where d_r= inverse relative distance from earth to sun; J = Julian day (calendar day) of the year

Solar declination (δ) and sunset hour angle (ω_s) in radians were calculated from the following formula.

$$\delta = 0.409 \sin\left(\frac{2\pi}{365} J \text{ -1.39}\right) \qquad (5)$$

$$\omega = \arccos \quad (-\tan(\delta)) \qquad (6)$$

Fixation of date of sowing

Date of sowing for rainfed crops of *kharif* season in the study area were fixed based on the rainfall during the initial period of monsoon season and on the first rainfall event that exceeds 45 mm of rainfall. This analysis was carried out on yearly basis as well as rainfall grid level. These sowing dates were summarized and arrived the common sowing dates for entire study area and across the years. The common dates of sowing for *kharif, rabi* and summer seasons are fixed as 1st July, 1st November and 1st March respectively.

Crop coefficient (K_c)

Estimation of crop evapotranspiration from potential evapotranspiration depends on the crop coefficient. The crop coefficient depends on the crop characteristics including crop canopy, date of sowing/ planting, stage of crop growth and climatic condition including rainfall. The crop coefficients of selected crops of FAO (FAO, 1998) were adopted for the present study. Table 1 presents crop coefficients along with crop duration and stages of selected crops.

Effective rainfall

A portion of rainfall that is stored in plant root zone and which meets the requirement of evapotranspiration is called as effective rainfall and is very essential water resources in rainfed areas. Among the several methods available for estimating the effective rainfall, the present study considered USDA-SCS method of effective rainfall. Using this method, effective rainfall for 10 days and 30 days can be calculated with different equations. In this study, 10 days effective rainfall was calculated during crop periods with the following formula.

$$P_{ER(10days)} = \frac{P_{(10days)}}{125} \times \left(125 - 0.6 \times P_{(10days)}\right) \quad \text{for } P_{(10days)} \leq (250/3)\text{mm} \qquad (7)$$

$$P_{ER(10days)} = \left(\frac{125}{3} - 0.1 \times P_{(10days)}\right) \qquad \text{for } P_{(10days)} > \left(\frac{250}{3}\right)\text{mm} \qquad (8)$$

where, $P_{ER(10day)}$ is 10 days effective rainfall; $P_{(10day)}$ is 10 days cumulative rainfall.

Water requirement for other special needs

In the present study, pre-sowing irrigation was assumed as 75 mm depth of irrigation water for land preparation during *rabi* and summer season (Rao, 2005). The irrigation requirement for special needs for rice crops in the present study were considered as 40, 60, 360 and 100 mm for saturation, evaporation, percolation losses and flooding for cultivation respectively. The total irrigation water required for special needs of rice is assumed to be 660 mm. It is also assumed that there is no salinity problem in the study area. Hence leaching requirement was not considered.

Irrigation water requirement

$$TWR = ETc + \text{Special water need} \qquad (9)$$

$$NIR = TWR - ER \qquad (10)$$

where TWR = Total water requirement; NIR = Net irrigation requirement and ER = Effective rainfall.

Gross irrigation requirement of crops at field level can be calculated by considering application efficiency that account for field application losses. The present study considered application efficiency as 65 per cent for irrigated dry (ID) crops and 85 per cent for rice as recommended by Ministry of Irrigation, Govt. of India (1984). Gross irrigation requirement for each crop in a given season was converted into cubic meter of water by multiplying the crop area. The gross irrigation requirements are calculated using the following equation.

$$\text{Gross Irrigation Requirement, GIR} = \frac{\text{NIR}}{\eta} \qquad (11)$$

where, η = application efficiency

$$\text{GIR (m}^3\text{)} = \frac{\text{GIR(mm)} \times \text{Area (ha)}}{1000 \times 10^4} \qquad (12)$$

Irrigation water requirement for base period and future periods

Crop water requirement (Crop evapotranspiration) and effective rainfall of the study area for base period (1961 to 1990) was calculated using above methodology. Irrigation water requirement for future period was estimated using CNRM climate model with RCP 4.5 and RCP 8.5 scenarios. For further analysis to develop adaptation strategies in the study area, irrigation water requirement for these periods were compared with baseline period. The period from the year 1961-1990 was used as baseline period and was used to compare the corresponding projected net irrigation requirement in future periods (2020-40, 2041-70 and 2071-99) under different climate change scenarios.

Development of water related adaptation strategies

Many researchers have developed adaptation strategies to reduce the impact of climate change in agriculture production. Biemans *et al.* (2013) revealed that the Krishna basin would benefit most by improving the irrigation efficiencies and by increasing storage. Guo and Shen (2016) and Ahmadaali *et al.* (2017) suggested to take adaptation measures like improving irrigation water utilization efficiency and changing crop planting types to cope with the impacts of future climate change on water supply and water demand. Srinivasa Rao *et al.* (2015) suggested alternative crops and crops with wider sowing window (2, 4, 6 and 8 weeks) to be taken up till the cut-off date without major reduction in crop yield. Ding *et al.* (2019) suggested to shift the date of sowing (early) of rice crop and maize respectively to improve the water availability to meet the irrigation water requirement. Based on the earlier studies, it was decided to examine adaptation strategies such as creating additional storage to secure additional irrigation water requirement of crops in future, shifting the sowing dates of crops, deficit irrigation during period of non-sensitive to moisture.

Irrigation water requirement of the baseline period and future periods were compared. The additional irrigation water requirement was multiplied with the extent crops under consideration and converted to volume of water that need to be created additionally to reduce the impact of climate change in future. Deficit irrigation during non-sensitive stages to moisture could reduce the irrigation requirement. Flowering and yield formation stages are more sensitive to moisture. Any shortage of irrigation water during these stages could reduce crop yield considerably. The sensitive stages of different crops were prepared from the FAO Irrigation and Drainage paper 33 (yield response to water). The non-sensitive periods were identified for different crops and reduced crop water requirement (ETc) by 10% (0.9 ETc), 20% (0.8 ETc) and 30% (0.7 ETc).

Results and Discussion

Effect of climate change on rainfall

Projected change average monthly and annual rainfall by climate models with RCP 4.5 and RCP 8.5 under different time periods were evaluated with reference to baseline data. The per cent change in monthly and annual rainfall projected by CNRM with

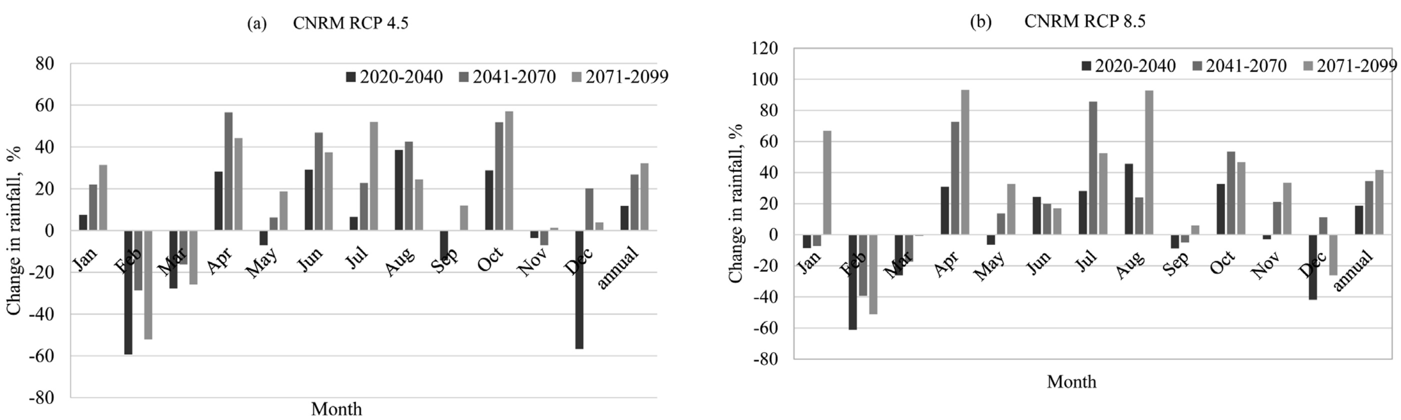

Fig. 2: Per cent change in monthly rainfall projected by CNRM model under (a) RCP 4.5 and (b) RCP 8.5 for different time slicing periods

Table 1: Crop stage, duration and crop coefficients for selected crops

Crops	Duration	Initial stage		Crop Development stage		Mid season stage		Late season stage	
		Duration	Kc	Duration	Kc	Duration	Kc	Duration	Kc
Rice	150	30	0.4	30	0.8	60	1.2	30	0.5
Sorghum	130	20	0.4	35	0.8	45	1.1	30	0.7
Millets	130	20	0.4	35	0.8	45	1.1	30	0.7
Minor millets	130	20	0.4	35	0.8	45	1.1	30	0.7
Maize	125	20	0.4	35	0.8	40	1.2	30	0.7
Wheat	120	15	0.4	25	0.8	50	1.2	30	0.5
Redgram	180	30	0.5	50	0.8	55	1.2	45	0.8
Horse gram	100	20	0.5	30	0.8	30	1.1	20	0.5
Cowpea/ grams	100	20	0.5	30	0.8	35	1.2	15	1.1
Groundnut	130	25	0.5	35	0.8	45	1.1	25	0.7
Sunflower	130	25	0.4	35	0.8	45	1.2	25	0.6
Soybean	150	20	0.4	30	0.8	70	1.1	30	0.6
Cotton	180	30	0.5	50	0.8	55	1.2	45	0.8
Sugarcane	320	30	0.4	50	1.1	180	1.3	60	1.0
Tobacco	180	35	0.4	45	0.8	70	1.1	30	0.8
Brinjal	130	30	0.5	40	0.8	40	1.2	20	0.8
Tomato	130	30	0.5	40	0.8	40	1.2	20	0.8
Onion	150	15	0.5	25	0.8	70	1.1	40	0.9

RCM 4.5 and RCM 8.5 scenarios for different time periods are presented in Figure 2 a&b. It is observed that the change in mean annual rainfall under RCP 4.5 during 2020-40, 2041-70 and 2071-99 are 11.7, 26.7 and 32.2% respectively and under RCP 8.5 scenarios, it is observed as 18.6, 34.5 and 41.5% respectively. The monthly rainfall under RCP 4.5 and RCP 8.5 scenarios for all future periods (2020-40, 2041-70, 2071-99) during the monsoon months of June, July and August and in other season, April and October expected to increase (ranges from 6 to 57%). The per cent change in average monthly rainfall under RCP 4.5 of monsoon months June, July, August and September during the time period 2020-40 is found to be 29, 6.4, 38.6 and -14.3% respectively and under RCP 8.5 scenario it was found to be 24.3, 28.1, 45.3 and -8.8% respectively.

Effect of climate change on temperature

The monthly mean temperature of baseline period and projected monthly mean temperatures by three climate models for different time periods with both RCP scenarios are presented in Fig. 3. It is observed that CNRM projected highest increase in monthly mean temperature during winter months (December, January, February). The projected mean temperature during December, January and February ranged from 24.85 to 27.51℃, 24.96 to 27.22℃ and 26.31 to 28.31℃ respectively against the baseline period 24.23, 23.98 and 25.11℃ respectively. Less increase in monthly mean temperature is observed during the month of May. The projected monthly mean temperature ranged from 30.22 to 31.46℃ against 29.6℃. The monthly mean temperatures under RCP 8.5 for all the months during 2071-99 found to be highest among the two RCPs and three future periods.

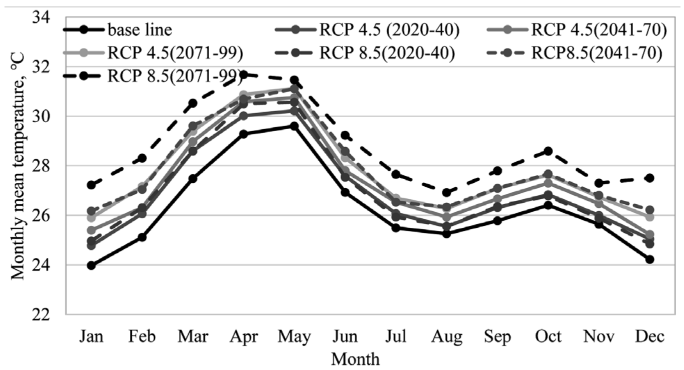

Fig. 3: Effect of climate change on monthly mean temperatures projected by CNRM model

Net irrigation requirement of crops

Sub basin wise projected net irrigation requirement for future periods were compared with baseline period and per cent change in projected net irrigation requirement is prepared and presented in Table 2, Table 3, Table 4 and Table 5 for Middle Krishna, Malaprabha, Ghataprabha and Upper Krishna sub basins. The percentage increase in effective rainfall projected by CNRM model for Middle Krishna sub basin during monsoon, post monsoon and summer seasons are found to be 15.3 to 21.0%, 23.6 to 40.0%, 7.1% to 30.9% respectively under RCP 4.5 scenario and 12.2 to 23.7%, 21.5 to 46.1% and -16.3 to 16.8% respectively under RCP 8.5 scenario. During monsoon period, the projected effective rainfall in other sub basins is observed to

Table 2: Percentage change in projected net irrigation requirement (NIR) of crops by CNRM model in Middle Krishna sub basin

Crops	Season	NIR during baseline period, mm	Change in NIR by CNRM (%)					
			RCP 4.5			RCP 8.5		
			2020-40	2041-70	2071-99	2020-40	2041-70	2071-99
Bajra	*Kharif*	184.7	-22.2	-31.0	-41.1	-27.3	-32.9	-45.8
Brinjal	*Kharif*	203.9	-25.0	-33.1	-43.5	-29.8	-35.0	-46.0
Cotton	*Kharif*	331.1	-7.1	-11.9	-18.0	-10.2	-14.1	-20.0
Grams	*Kharif*	166.9	-27.7	-33.9	-44.3	-29.9	-37.1	-48.7
Groundnut	*Kharif*	181.2	-22.6	-31.5	-41.9	-28.0	-33.5	-45.8
Horse gram	*Kharif*	132.9	-34.1	-38.3	-47.7	-36.6	-42.0	-54.5
Jowar	*Kharif*	184.7	-22.2	-31.0	-41.1	-27.3	-32.9	-45.8
Maize	*Kharif*	187.7	-23.9	-31.5	-41.7	-28.1	-33.3	-46.3
Onion	*Kharif*	293.3	-20.4	-25.2	-33.4	-20.3	-24.1	-33.7
Paddy	*Kharif*	901.2	-6.3	-7.8	-10.5	-6.4	-7.1	-9.9
Redgram	*Kharif*	331.1	-7.1	-11.9	-18.0	-7.8	-10.4	-17.5
Soybean	*Kharif*	241.9	-13.6	-19.6	-29.6	-13.8	-17.2	-28.9
Sunflower	*Kharif*	179.1	-22.2	-31.3	-42.0	-23.9	-27.7	-39.8
Brinjal	*Rabi*	518.6	4.3	5.3	9.0	3.8	5.7	10.5
Maize	*Rabi*	494.0	4.2	4.9	8.4	-0.8	3.8	7.9
Onion	*Rabi*	654.5	4.4	5.8	9.0	-0.8	4.5	8.3
Paddy	*Rabi*	1157.1	2.2	2.9	4.7	-0.6	2.3	4.4
Sunflower	*Rabi*	490.1	4.1	5.1	8.8	-1.0	3.9	8.3
Wheat	*Rabi*	448.6	12.2	12.6	15.9	11.5	12.9	19.6
Brinjal	Summer	521.9	-2.7	-2.9	-3.4	-1.3	-2.3	-2.8
Groundnut	Summer	515.0	-2.7	-2.9	-3.3	-0.9	-2.2	-2.7
Maize	Summer	539.6	-2.0	-1.9	-2.2	-2.6	-1.0	-1.2
Paddy	Summer	1129.2	-1.6	-1.8	-2.1	-1.6	-1.4	-1.5

Table 3: Percentage change in projected net irrigation requirement of crops by CNRM model in Malaprabha sub basin

Crops	Season	NIR during baseline period, mm	Change in NIR by CNRM (%)					
			RCP 4.5			RCP 8.5		
			2020-40	2041-70	2071-99	2020-40	2041-70	2071-99
Bajra	*Kharif*	164.1	-18.5	-30.6	-43.5	-24.4	-31.5	-44.9
Brinjal	*Kharif*	184.6	-22.1	-33.0	-45.3	-27.2	-34.2	-45.0
Cotton	*Kharif*	310.2	-3.5	-9.6	-17.2	-6.9	-12.5	-17.5
Grams	*Kharif*	148.3	-24.0	-33.7	-47.4	-27.6	-36.8	-47.6
Groundnut	*Kharif*	160.7	-18.6	-30.6	-43.7	-24.7	-31.9	-44.2
Horse gram	*Kharif*	114.8	-30.9	-37.3	-49.9	-34.2	-41.7	-53.5
Jowar	*Kharif*	164.1	-18.5	-30.6	-43.5	-24.4	-31.5	-44.9
Maize	*Kharif*	166.9	-20.8	-31.6	-44.5	-25.5	-32.8	-45.5
Onion	*Kharif*	272.7	-19.0	-25.7	-36.5	-20.4	-23.7	-34.8
Paddy	*Kharif*	883.1	-5.6	-7.4	-10.5	-6.0	-6.4	-9.6
Redgram	*Kharif*	310.2	-3.5	-9.6	-17.2	-4.7	-8.0	-15.7
Soybean	*Kharif*	218.2	-9.8	-18.0	-31.0	-11.5	-14.1	-28.3
Sunflower	*Kharif*	160.1	-18.3	-30.3	-43.9	-22.2	-24.6	-38.6
Brinjal	*Rabi*	534.3	-0.5	1.5	4.6	-1.6	1.6	6.2
Maize	*Rabi*	505.9	0.6	2.3	5.2	-4.3	1.3	4.8
Onion	*Rabi*	675.5	-1.0	1.0	3.6	-6.3	0.0	3.1
Paddy	*Rabi*	1150.3	1.8	2.9	4.6	-1.0	2.5	4.3
Sunflower	*Rabi*	503.1	2.0	5.1	-5.0	1.0	4.7	4.4
Wheat	*Rabi*	434.8	0.7	4.0	-2.8	-1.1	5.4	6.8
Brinjal	Summer	443.9	-0.2	-1.4	-3.7	0.6	-0.9	-2.4
Groundnut	Summer	438.3	-0.2	-1.2	-3.3	1.2	-0.4	-2.1
Maize	Summer	461.7	0.4	-0.2	-2.1	-2.3	1.1	0.2
Paddy	Summer	1047.5	-0.3	-1.0	-2.1	-1.3	-0.6	-0.8

Table 4: Percentage change in projected net irrigation requirement of crops by CNRM model in Ghataprabha sub basin

Crops	Season	NIR during baseline period, mm	Change in NIR by CNRM (%)					
			RCP 4.5			RCP 8.5		
			2020-40	2041-70	2071-99	2020-40	2041-70	2071-99
Bajra	*Kharif*	161.4	-24.6	-38.9	-43.5	-32.8	-38.4	-46.1
Brinjal	*Kharif*	185.2	-27.6	-41.4	-46.4	-35.3	-39.9	-47.8
Cotton	*Kharif*	308.6	-6.3	-14.5	-17.7	-11.2	-14.9	-17.6
Grams	*Kharif*	144.4	-31.4	-42.2	-47.1	-37.2	-43.6	-49.8
Groundnut	*Kharif*	158.9	-24.4	-38.9	-43.9	-32.7	-38.2	-46.2
Horse gram	*Kharif*	110.6	-37.3	-45.2	-49.5	-43.5	-48.8	-55.3
Jowar	*Kharif*	161.4	-24.6	-38.9	-43.5	-32.8	-38.4	-46.1
Maize	*Kharif*	163.4	-27.1	-40.1	-44.9	-34.2	-39.6	-47.1
Onion	*Kharif*	270.8	-24.3	-32.9	-37.2	-25.7	-30.3	-35.7
Paddy	*Kharif*	883.9	-6.7	-9.3	-10.9	-7.5	-8.2	-10.0
Redgram	*Kharif*	308.6	-6.3	-14.5	-17.7	-8.5	-11.6	-15.9
Soybean	*Kharif*	215.9	-15.0	-26.0	-31.7	-17.5	-21.6	-28.9
Sunflower	*Kharif*	158.4	-24.0	-38.8	-44.2	-28.7	-32.4	-40.0
Brinjal	*Rabi*	510.0	4.0	5.7	8.5	3.1	6.5	10.3
Maize	*Rabi*	488.6	3.9	5.3	8.0	-0.7	5.0	6.9
Onion	*Rabi*	636.7	4.7	6.6	9.1	-0.2	6.1	7.8
Paddy	*Rabi*	1143.2	2.2	3.2	4.7	-0.3	3.1	4.0
Sunflower	*Rabi*	483.7	3.7	5.5	8.3	-1.0	5.1	7.2
Wheat	*Rabi*	446.5	-4.9	-4.8	-1.2	-8.1	-5.9	0.0
Brinjal	Summer	448.1	-3.5	-4.7	-2.7	-2.8	-4.3	-2.8
Groundnut	Summer	442.6	-2.6	-3.7	-1.6	-1.6	-3.2	-1.8
Maize	Summer	466.8	-1.3	-2.4	-0.4	-3.1	-1.4	-0.1
Paddy	Summer	1050.9	-1.9	-2.5	-1.7	-2.2	-2.2	-1.4

Table 5: Percentage change in projected net irrigation requirement of crops by CNRM model in Upper Krishna sub basin

Crops	Season	NIR during baseline period, mm	Change in NIR by CNRM (%)					
			RCP 4.5			RCP 8.5		
			2020-40	2041-70	2071-99	2020-40	2041-70	2071-99
Bajra	*Kharif*	130.8	-1.7	-28.3	-39.3	-15.8	-26.1	-43.8
Brinjal	*Kharif*	171.6	-16.9	-38.4	-48.6	-28.0	-36.4	-48.7
Cotton	*Kharif*	284.5	3.2	-11.1	-15.9	-3.6	-10.8	-14.8
Grams	*Kharif*	106.6	-2.8	-27.7	-40.3	-15.2	-25.8	-50.0
Groundnut	*Kharif*	129.7	-2.0	-28.9	-39.9	-16.3	-26.5	-42.7
Horse gram	*Kharif*	76.6	-7.5	-30.8	-41.2	-21.6	-32.5	-55.3
Jowar	*Kharif*	130.8	-1.7	-28.3	-39.3	-15.8	-26.1	-43.8
Maize	*Kharif*	129.3	-1.9	-28.1	-39.4	-15.9	-26.3	-44.7
Onion	*Kharif*	246.8	-15.2	-30.2	-37.4	-20.1	-25.1	-38.0
Paddy	*Kharif*	869.2	-4.1	-8.3	-10.5	-6.0	-6.4	-10.1
Redgram	*Kharif*	284.5	3.2	-11.1	-15.9	-2.1	-5.0	-15.3
Soybean	*Kharif*	186.7	2.5	-17.6	-27.8	-5.4	-9.7	-27.9
Sunflower	*Kharif*	128.5	-0.1	-27.8	-39.4	-13.0	-16.1	-36.2
Brinjal	*Rabi*	502.3	2.8	3.9	8.4	2.1	5.0	10.7
Maize	*Rabi*	480.5	2.9	3.6	7.9	-2.2	3.7	7.5
Onion	*Rabi*	630.9	3.2	4.6	8.4	-2.3	4.4	8.0
Paddy	*Rabi*	1137.7	1.5	2.2	4.4	-1.4	2.2	4.1
Sunflower	*Rabi*	475.9	2.7	3.8	8.2	-2.7	3.8	7.8
Wheat	*Rabi*	437.6	-2.9	-3.2	0.9	-4.1	-2.1	4.2
Brinjal	Summer	467.2	-3.9	-6.4	-5.4	-2.9	-4.9	-5.4
Groundnut	Summer	464.1	-3.4	-5.5	-4.6	-2.0	-4.2	-4.9
Maize	Summer	491.3	-2.8	-4.2	-3.5	-3.6	-2.7	-3.9
Paddy	Summer	1067.0	-1.9	-3.1	-2.7	-1.7	-2.2	-2.6

be 9.4 to 16.8%, 28.2 to 42.1% and 4.9 to 20.4% for Malaprabha, Ghataprabha and Upper Krishna sub basins respectively under CNRM with RCP 4.5 and RCP 8.5 scenarios.

The projected net irrigation requirement of crops with CNRM model during *kharif* season is found to be decreased because of increase in effective rainfall during crop grown period. The percentage of decrease in net irrigation requirement of rice, maize, cotton, Soybean during *kharif* season under CNRM model is found to be 3.6 to 10.5, 23.9 to 46.3, 7.1 to 20.0 and 13.6 to 28.9% respectively. The projected net irrigation requirement of rice crop during 2020-40, 2041-70, 2071-99 is expected to decrease 6.3, 7.8 and 10.5% under RCP 4.5 and 6.4, 7.1 and 9.9% under RCP 8.5 scenario. Abeysingha *et al.* (2016), in similar lines, projected the irrigation requirement of rice crop during *kharif* season for future periods expected to decrease by 1 to 5% and also stated that this decrease was due to increase in rainfall during rice growing season in Gomti river basin in India. Lee and Huang (2014) found that the increased effective rainfall neutralized the augmented crop water requirement of rice in Northern Taiwan and projected irrigation water requirements in future periods likely to decrease 0.9 and 2.3% during crop seasons.

The projected net irrigation requirement with CNRM model during *rabi* season is expected to increase by 2.2 to 4.7, 4.2 to 7.9, 4.1 to 8.3, 3.8 to 10.5 and 11.5 to 12.9% for rice, maize, sunflower, brinjal and wheat crops respectively. It is projected that the net irrigation requirement of wheat crop during the period 2020-40, 2041-70 and 2071-99 expected to increase by 12.2, 12.6 and 15.9% respectively under RCP4.5 and 11.5, 12.9 and 19.6% respectively under RCP8.5 of CNRM model. Projected increase in temperatures during *rabi* season increased the evapotranspiration need of the crops may result in increase in projected net irrigation requirement of crops for future periods. Abeysingha *et al.* (2016) also projected similar results for wheat crop in *rabi* season. They found that the projected irrigation needs likely to increase by 17.0 to 28.0, 28.3 to 36.5 and 38.4 to 45.3% during 2020s, 2050s and 2080s, respectively. Rejani *et al.* (2016) studied on projected irrigation requirements of crops grown in Vijayapura district of Karnataka and found that irrigation requirement crops grown in *rabi* season expected to increase considerably and likely to decrease in *kharif* season under projected climate change scenarios with low, medium and high emission scenarios. Rahena and Majumdhar (2013) also projected that the irrigation water requirements for paddy,

Table 6: Additional volume of irrigation water demand in *rabi* season for Middle Krishna sub basin projected by CNRM model

Crops	Baseline period RCP 4.5				Projected additional volume required, MCM					
					RCP 8.5					
	NIR, mm	GIR, mm	Area, ha	Volume MCM	2020-40	2041-70	2071-99	2020-40	2041-70	2071-99
Chickpea	360.10	554.00	314204.39	1740.69	56.81	60.54	100.11	43.71	54.61	121.26
Gram	356.70	548.77	564.77	3.10	0.10	0.11	0.18	0.08	0.10	0.22
Groundnut	448.56	690.09	19251.42	132.85	16.15	16.78	21.14	15.30	17.20	26.04
Sorghum	496.69	764.13	57535.16	439.65	18.15	22.12	37.44	15.93	23.35	45.40
Maize	494.00	760.00	14950.38	113.62	4.77	5.62	9.60	0.00	4.35	9.03
Rice	1157.09	1361.28	75600.16	1029.13	22.95	29.66	48.84	0.00	23.85	45.03
Sunflower	490.09	753.98	32619.60	245.94	10.15	12.53	21.58	0.00	9.60	20.50
Wheat	448.56	690.09	48711.86	336.16	40.87	42.47	53.50	38.72	43.51	65.90
Million Cubic Meter (MCM)				4041.15	169.96	189.82	292.39	113.73	176.57	333.38
Thousand Million Cubic Feet (TMC)				175.70	6.01	6.71	10.33	4.02	6.24	11.78

Table 7: Additional volume of irrigation water demand in *rabi* season for Malaprabha sub basin projected by CNRM model

Crops	Baseline period RCP 4.5				Projected additional volume required, MCM					
					RCP 8.5					
	NIR, mm	GIR, mm	Area, ha	Volume, MCM	2020-40	2041-70	2071-99	2020-40	2041-70	2071-99
Chickpea	342.06	526.25	177663.99	934.96	71.22	79.63	96.49	54.25	72.16	111.79
Gram	340.00	523.08	1575.92	8.29	0.63	0.71	0.86	0.48	0.64	0.99
Groundnut	434.82	668.95	23266.55	155.64	1.15	6.26	0.00	0.00	8.36	10.65
Sorghum	507.84	781.29	137207.19	1071.99	4.63	25.52	56.07	0.00	25.15	78.10
Maize	505.88	778.28	7285.62	56.70	0.34	1.32	2.95	0.00	0.73	2.71
Rice	1150.34	1353.35	4.51	0.06	0.00	0.00	0.00	0.00	0.00	0.00
Sunflower	503.11	774.02	29131.70	225.49	4.62	11.50	0.00	0.00	10.52	9.97
Wheat	434.82	668.95	26433.37	176.83	1.31	7.11	0.00	0.00	9.50	12.10
Million Cubic Meter (MCM)				2629.96	83.90	132.04	156.36	54.74	127.07	226.32
Thousand Million Cubic Feet (TMC)				114.35	2.96	4.67	5.53	1.93	4.49	8.00

Table 8: Additional volume of irrigation water demand in *rabi* season for Ghataprabha sub basin projected by CNRM model

Crops	Baseline period RCP 4.5				Projected additional volume required, MCM					
						RCP 8.5				
	NIR, mm	GIR, mm	Area, ha	Volume, MCM	2020-40	2041-70	2071-99	2020-40	2041-70	2071-99
Chickpea	356.57	548.57	323810.72	1776.34	49.84	58.38	90.05	29.13	62.81	121.46
Gram	356.57	548.57	260.93	1.43	0.04	0.05	0.07	0.02	0.05	0.10
Groundnut	446.47	686.88	140311.75	963.77	0.00	0.00	0.00	0.00	0.00	0.00
Sorghum	490.15	754.08	384120.82	2896.59	109.87	157.60	233.13	86.08	181.89	291.25
Maize	488.65	751.76	36573.51	274.95	10.63	14.63	21.86	0.00	13.71	19.04
Rice	1143.15	1344.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sunflower	483.68	744.13	17836.61	132.73	4.97	7.32	10.95	0.00	6.74	9.54
Wheat	446.47	686.88	65997.16	453.32	0.00	0.00	0.00	0.00	0.00	0.00
Million Cubic Meter (MCM)				6499.13	175.36	237.97	356.06	115.24	265.20	441.39
Thousand Million Cubic Feet (TMC)				282.57	6.20	8.41	12.58	4.07	9.37	15.60

sugarcane and semi dry crops are expected to increase in command area of Bhadra reservoir of Karnataka.

Adaptation strategies

Creating storage volume for additional water demand

It is projected that the crops grown in *rabi* season requires additional water resources because of increase irrigation requirement when compared with baseline period. The irrigation water demand for crops in future during *kharif* is found to be decreasing because of increase in rainfall. The crops such as chickpea, grams, groundnut, sorghum, maize, rice, sunflower and wheat during *rabi* season are considered for estimating the additional storage volume in future periods. The additional irrigation water demand for crops during *rabi* season is presented in Table 6, Table 7 and Table 8 for the sub basins of Middle Krishna, Malaprabha and Ghataprabha sub basins.

The irrigation water demand or gross irrigation water requirement of Middle Krishna sub basin for *rabi* season was estimated as 4041.15 million meter cube (MCM) or 175.70 TMC (Thousand Million Cubic Feet). It is projected by climate projections of CNRM model under RCP 4.5 scenario that the water demand is expected to increase during the period 2020-40, 2041-70 and 2071-99 by 6.01, 6.71 and 10.33 TMC respectively. Under RCP 8.5 scenario, it is expected to increase the demand during the time slice 2020-40, 2041-70 and 2071-99 by 4.02, 6.27 and 11.78 TMC. The additional water demand for Middle Krishna, Malaprabha and Ghataprabha sub basins in percentage of increase is found to be ranged from 1.5 to 5.5, 1.7 to 7 and 2.3 to 6.7% respectively across the future periods and RCPs. These results indicated that the irrigation demand increases more under high emission scenario (RCP 8.5) then low emission scenario (RCP 4.5) and observed that it is more significant at the end of the century than the early century.

Altering sowing dates

Crop water requirement and net irrigation requirement of selected crops in *kharif*, *rabi* and summer seasons are estimated for baseline period and compared with projected crop water requirements and net irrigation requirements for future periods. It is observed that, projected net irrigation requirement of crops during *kharif* and summer season are less than the baseline period. The increase in crop water requirement for future periods in *kharif* season are compensated with increase in effective rainfall during crop season. During *rabi* season, the crop water requirement is found to be increased and no much considerable change is observed in projected effective rainfall. The net irrigation requirement of crops during *rabi* season is expected to increase and adaptation strategies are required for *rabi* season. The crops such as sorghum, maize, rice, sunflower and wheat are selected to test the effect of sowing dates on net irrigation requirement of crops. The sowing date of crops during *rabi* season is selected as 1st of November for baseline period and calculated net irrigation requirement of crops. The projected net irrigation requirement of crops in future are estimated for different dates such as 21-Oct,1-Nov, 11-Nov and 21-Nov during *rabi* season.

The effect of date of sowing on projected net irrigation requirement of crops during *rabi* season is compared with baseline periods at sub basin levels. Comparison of projected net irrigation requirement of crops against to baseline periods for Middle Krishna, Malaprabha, Ghataprabha and Upper

Table 9: Comparison of net irrigation requirement (in mm) in *rabi* season under different sowing dates and climate scenarios in Middle Krishna sub basin

Crops	Date of sowing	Baseline period	Projected NIR by CNRM, mm					
			RCP 4.5			RCP 8.5		
			2020-40	2041-70	2071-99	2020-40	2041-70	2071-99
	21-Oct	496.7	460.8	465.1	476.5	457.4	463.7	488.9
Sorghum	1-Nov		493.2	497.5	514.2	487.5	500.8	531.5
	11-Nov		516.3	525.3	545.2	515.8	528.8	561.3
	21-Nov		540.9	551.9	572.7	542.3	556.0	583.6
	21-Oct		456.6	460.2	470.5	452.4	459.1	482.1
	1-Nov	494.0	489.8	493.4	509.7	484.7	495.8	525.7
Maize	11-Nov		513.0	521.4	540.9	511.5	524.7	557.0
	21-Nov		537.8	548.6	569.0	538.6	552.6	582.9
	21-Oct		1121.4	1128.2	1146.6	1117.1	1131.0	1163.3
	1-Nov	1157.5	1155.3	1164.2	1185.5	1154.6	1168.0	1195.8
Rice	11-Nov		1176.1	1185.7	1208.7	1175.9	1189.8	1219.2
	21-Nov		1193.8	1200.7	1230.7	1198.1	1208.6	1239.8
	21-Oct		455.4	459.4	471.6	452.1	459.2	484.7
	1-Nov	490.1	486.6	491.8	509.2	482.0	495.7	524.4
Sunflower	11-Nov		509.8	520.2	539.5	509.7	523.2	555.8
	21-Nov		535.0	545.2	567.7	535.8	550.2	578.3
	21-Oct		413.7	412.8	419.7	408.0	410.8	430.6
	1-Nov	448.6	442.1	445.9	456.8	438.6	444.5	470.6
Wheat	11-Nov		465.0	469.5	486.5	462.4	473.2	502.8
	21-Nov		487.9	495.7	516.1	487.2	500.8	531.1

Table 10: Comparison of net irrigation requirement (in mm) in *rabi* season under different sowing dates and climate scenarios in Malaprabha sub basin

Crops	Date of sowing	Baseline period	Projected NIR by CNRM model, mm					
			RCP 4.5			RCP 8.5		
			2020-40	2041-70	2071-99	2020-40	2041-70	2071-99
	21-Oct		439.3	446.6	453.3	435.7	443.0	463.5
Sorghum	1-Nov	507.8	469.0	476.3	490.0	463.8	479.4	506.5
	11-Nov		492.7	501.5	519.3	490.7	504.8	535.8
	21-Nov		511.5	522.5	541.8	513.9	525.5	553.2
	21-Oct		434.4	441.5	446.3	430.1	437.3	455.9
Maize	1-Nov	505.9	466.7	473.3	486.6	461.8	474.9	501.2
	11-Nov		490.0	498.4	515.9	486.4	502.2	531.5
	21-Nov		509.6	521.5	539.3	511.1	523.9	555.7
	21-Oct		1094.1	1103.1	1118.1	1088.1	1103.8	1133.4
Rice	1-Nov	1150.3	1124.5	1133.6	1153.6	1123.5	1136.9	1164.8
	11-Nov		1136.5	1145.5	1166.1	1133.3	1149.8	1179.2
	21-Nov		1145.0	1151.3	1178.1	1145.9	1160.4	1191.8
	21-Oct		435.7	442.2	451.2	432.7	440.2	461.6
Sunflower	1-Nov	503.1	464.5	471.8	486.8	460.3	475.5	501.2
	11-Nov		487.1	497.4	514.6	485.0	499.5	530.4
	21-Nov		505.4	515.7	536.7	507.0	520.1	548.3
	21-Oct		392.8	394.1	396.2	386.5	390.7	405.4
Wheat	1-Nov	434.8	424.2	430.6	437.5	420.9	427.7	449.5
	11-Nov		447.8	452.9	468.2	444.2	456.2	482.2
	21-Nov		469.3	478.1	495.5	467.5	481.2	510.3

Table 11: Comparison of net irrigation requirement (in mm) during *rabi* season under different sowing dates and climate scenarios in Ghataprabha sub basin

Crops	Date of sowing	Baseline period	Projected NIR by CNRM model, mm					
			RCP 4.5			RCP 8.5		
			2020-40	2041-70	2071-99	2020-40	2041-70	2071-99
Sorghum	21-Oct	490.2	456.0	462.6	472.1	442.6	451.5	473.9
	1-Nov		485.4	492.0	507.3	471.6	487.3	515.4
	11-Nov		506.8	516.5	535.5	498.8	513.5	544.7
	21-Nov		527.0	538.0	559.1	522.8	537.1	564.0
	21-Oct		451.8	457.9	466.0	437.3	446.1	466.9
Maize	1-Nov	488.6	483.3	489.2	504.2	469.3	482.9	510.3
	11-Nov		504.4	513.9	532.5	494.9	510.2	540.5
	21-Nov		525.0	536.4	556.7	519.6	534.6	565.1
	21-Oct		1111.6	1120.4	1137.5	1097.8	1113.6	1144.0
Rice	1-Nov	1143.2	1142.0	1151.6	1173.0	1133.6	1148.1	1176.4
	11-Nov		1157.2	1167.0	1189.1	1149.4	1164.9	1194.4
	21-Nov		1168.2	1175.3	1204.5	1166.0	1179.3	1210.9
	21-Oct		451.2	457.3	468.4	438.9	447.7	470.8
Sunflower	1-Nov	483.7	479.4	486.4	502.6	467.2	482.8	509.7
	11-Nov		500.8	511.7	530.2	492.9	508.1	539.1
	21-Nov		520.7	531.0	553.7	516.1	531.3	558.8
	21-Oct		410.2	411.4	416.8	393.5	398.9	416.6
Wheat	1-Nov	446.5	439.1	445.1	454.7	426.5	434.8	457.9
	11-Nov		460.7	466.6	482.8	450.2	463.0	489.5
	21-Nov		480.6	489.8	509.1	473.5	488.2	517.5

Table 12: Comparison of net irrigation requirement (in mm) in *rabi* season under different sowing dates and climate scenarios in Upper Krishna sub basin

Crops	Date of sowing	Baseline period	Projected NIR by CNRM model, mm					
			RCP 4.5			RCP 8.5		
			2020-40	2041-70	2071-99	2020-40	2041-70	2071-99
	21-Oct		443.1	441.9	458.9	439.3	446.7	474.5
Sorghum	1-Nov	482.5	472.5	473.7	494.7	467.6	482.1	514.1
	11-Nov		495.9	501.1	522.9	492.6	508.9	542.4
	21-Nov		517.6	526.7	549.0	517.6	534.5	563.8
	21-Oct		439.0	436.8	452.6	434.3	441.3	468.4
Maize	1-Nov	480.5	469.6	469.8	491.0	465.6	477.9	509.4
	11-Nov		493.2	497.5	519.7	489.5	505.3	538.5
	21-Nov		515.1	523.7	545.9	514.3	531.5	564.1
	21-Oct		1098.8	1101.5	1123.6	1094.0	1108.8	1143.8
Rice	1-Nov	1137.7	1129.9	1135.5	1159.7	1128.0	1143.9	1176.2
	11-Nov		1148.5	1155.9	1180.1	1146.0	1162.3	1195.8
	21-Nov		1161.7	1170.0	1199.0	1164.1	1178.0	1213.0
	21-Oct		437.9	437.1	454.9	435.0	442.7	470.7
Sunflower	1-Nov	475.9	466.5	468.6	489.8	461.9	477.3	507.6
	11-Nov		489.8	496.4	517.7	486.7	503.7	536.7
	21-Nov		511.3	520.2	544.1	511.3	528.5	557.9
	21-Oct		397.5	390.7	403.4	391.6	394.3	419.4
Wheat	1-Nov	437.6	426.0	424.8	441.8	422.6	430.3	458.5
	11-Nov		448.6	449.0	470.6	445.3	458.4	488.0
	21-Nov		469.4	475.2	497.4	467.8	484.2	515.0

Krishna sub basins are presented in the Table 9, Table 10, Table 11 and Table 12 respectively. The net irrigation requirement of crops during *rabi* season in Middle Krishna sub basin during baseline periods is found to be 496.7, 494.0, 1157.5, 490.1 and 448.6 mm for sorghum, maize, rice, sunflower and wheat crops respectively. The projected net irrigation requirement for maize using climate projections of CNRM is found to be 456.6 to 482.1, 489.8 to 525.7, 513.0 to 557.0 and 537.8 to 582.9 mm for the sowing date 21st October, 1st November, 11th November and 21st November against the net irrigation requirement of baseline periods with 494.0 mm. The projected net irrigation requirement for wheat is found to be ranged from 143.7 to 430.6, 442.1 to 470.6, 509.8 to 555.8 and 535.0 to 578.3 mm for the sowing dates of 1st October, 1st November, 11th November and 21st November respectively against 490.1 mm during baseline periods. It is observed that the net irrigation requirement of crops sowing date of 21st October is found to match with the baseline period. The projected irrigation water requirement of crops sowing on 11th and 21st November is expected to increase in net irrigation requirement when compared to baseline periods. It is suggested to take up the sowing of crops in *rabi* season between 21st October to 1st November. In any case, if the sowing date is beyond 1st of November, additional water resources to meet the additional water requirement needs to be secured or crops may be changed accordingly. It is also observed that the net irrigation requirement of crops during the future periods 2020-40 is less than the other two time slices 2041-70 and 2071-99. The net irrigation requirement of crops sown on 1st November during the future period 2020-40 requires less net irrigation requirement when compared to baseline period.

Delay (beyond 1st November) in sowing in *rabi* season results less effective rainfall and extending to high temperature periods that increases the irrigation demand in the study area. Early planting in *rabi* season, part of crop water demand may be compensated by effective rainfall in future. Woznicki *et al.* (2015) suggested that shifting of sowing date utilizemore available water and to avoid peak crop development stage occurring in summer months which are projected to experience increase in future temperature. Ding *et al.* (2019) also considered the shifting of sowing date as adaptation strategy dealing with adverse effect of climate change on rice production in China. Kaushika *et al.* (2019) studied the effect of date of sowing on irrigation requirement of crops in futures periods and found that delay sowing increased in irrigation requirement because of increase in the crop ET and low rainfall.

Deficit irrigation strategies during non-critical periods of crops

Deficit irrigation strategy is one of the adaptation strategies in water stress conditions. These deficit irrigation strategies are prepared based on the critical and non-critical periods of selected crops such as cotton (*kharif*), sorghum and wheat (*rabi*) and maize (*rabi* and summer). It is assumed that irrigation is given to compensate crop evapotranspiration (ETc) fully (100%) during critical periods of crops and deficit irrigation with 10%, 20% and 30% deficit i.e 0.9 ETc, 0.8 ETc and 0.7 ETc during

Table 13: Projected crop water requirement (in mm) using CNRM model under RCP 4.5 scenario with different deficit irrigation strategies

Sub basin/ Period	Crop water requirement (in mm) by CNRM model														
	Cotton *(kharif)*			Sorghum *(rabi)*			Maize *(rabi)*			Wheat *(rabi)*			Maize *(rabi)*		
	0.9 ETc	0.8 ETc	0.7 ETc	0.9 ETc	0.8 ETc	0.7 ETc	0.9 ETc	0.8 ETc	0.7 ETc	0.9 ETc	0.8 ETc	0.7 ETc	0.9 ETc	0.8 ETc	0.7 ETc
Middle Krishna															
Baseline period		601.1			445.2			420.4			415.0			587.8	
2020-40	523.2	501.1	479.0	417.6	380.5	343.5	435.5	416.9	398.4	399.0	385.8	372.6	524.4	501.9	479.4
2041-70	507.7	486.0	464.4	428.0	389.9	351.9	445.9	427.3	408.7	409.3	395.9	382.6	528.1	505.3	482.5
2071-99	495.6	474.3	453.0	446.1	406.6	367.1	465.3	446.3	427.4	424.8	411.3	397.8	532.1	509.0	485.9
Malaprabha															
Baseline period		574.7			440.4			440.3			397.9			517.8	
2020-40	518.8	496.9	475.0	418.4	381.4	344.3	437.0	418.4	399.8	397.1	383.9	370.8	506.6	484.6	462.7
2041-70	508.3	486.6	464.9	430.3	392.1	353.9	448.9	430.2	411.5	407.2	394.0	380.7	509.2	487.1	465.0
2071-99	495.3	474.0	452.8	446.5	407.0	367.5	466.2	447.2	428.3	421.2	407.8	394.4	512.4	490.0	467.6
Ghataprabha															
baseline period		580.4			437.4			414.0			397.0			534.0	
2020-40	541.1	518.3	495.4	426.3	387.8	349.8	442.8	424.0	405.1	394.4	381.3	368.1	579.5	554.8	530.0
2041-70	527.9	505.4	482.9	438.6	398.4	359.4	454.5	435.6	416.6	402.5	389.4	376.3	583.7	558.7	533.8
2071-99	515.6	493.5	471.4	456.9	415.7	375.1	474.4	455.1	435.8	418.4	405.1	391.7	587.7	562.4	537.0
Upper Krishna															
Baseline period		567.9			428.4			427.9			385.9			527.5	
2020-40	541.1	518.3	495.4	416.9	380.8	343.6	434.5	416.1	397.6	387.3	374.4	361.5	571.3	546.9	522.5
2041-70	527.9	505.4	482.9	431.3	391.4	353.0	446.4	427.8	409.2	394.8	381.9	369.0	577.3	552.6	527.9
2071-99	515.6	493.5	471.4	448.5	408.4	368.5	465.9	446.9	428.0	411.2	398.1	385.0	581.7	556.7	531.7

non-critical crop periods. These deficit irrigation strategies are applied for projected crop water requirement in future periods and compared with crop water requirement during baseline period at sub basin level. The projected crop water requirement by CNRM model under different deficit irrigation conditions are presented in Table 13 and Table 14 for RCP 4.5 and RCP 8.5 scenarios respectively.

The projected crop water requirement for sorghum is expected to be more against the baseline period for all the sub basins under both the scenarios. It is found that 0.9 ETc strategy for the period 2020-2040 can be adopted for all the four sub basins and both RCP 4.5 and RCP 8.5 scenarios. During the period 2041-70, 0.9 ETc strategy can be adopted for Middle Krishna and Malaprabha sub basins and 0.8 ETc strategy can be adopted for Ghataprabha and Upper Krishna sub basins. The crop water requirement for maize during *rabi* season is expected to increase when compared to baseline period in all four sub basins under both RCPs. It is found that deficit irrigation condition for maize with 0.8 ETc is suitable for Middle Krishna, Malaprabha and Upper Krishna basins and 0.7 ETc deficit condition is suitable for Ghataprabha for future period 2020-2040. During the period 2041-70, 0.8 ETc deficit condition is suitable for Malaprabha and Upper Krishna sub basins and 0.7 ETc deficit strategy may be adapted for Middle Krishna sub basins. It is expected to further increase in crop water requirement for maize during the future period 2071-99 and the deficit irrigation strategies with 0.7 ETc may not be able to match the required deficit irrigation strategy for Middle Krishna, Ghataprabha and Upper Krishna and recommended to avoid maize crop during *rabi* season and go for alternate crops. Deficit irrigation strategies for maize crop during summer season are tested for all the sub basins and found that 0.9 ETc deficit irrigation strategies may be suitable for Middle Kirshna and Malaprabha sub basins. It is observed that the maize crop during summer season in Ghataprabha and Upper Krishna sub basin is found to be not suitable as the projected crop water requirement is expected to increase much high which may not be suited the above said deficit irrigation strategies except 0.7 ETc during 2020-2040.

Similar kind of adaptation strategies were proven by many researchers earlier. Kothari *et al.* (2020) also suggested 20% deficit irrigation strategy for sorghum crop and found that it could be optimal for future climate change conditions as it is more efficient than full irrigation with compromising less than 11 per cent yields. Shrestha and Shrestha (2019) also studied different adaptation strategies to crops under climate change scenarios and found that proper deficit irrigation strategies for winter (*rabi*) wheat stabilize the irrigation water requirement and yields.

Conclusions

Climate model projected that the rainfall during the monsoon season is found to be increasing in future periods and no considerable change in *rabi* season. The mean annual temperature

Table 14: Projected crop water requirement (in mm) using CNRM model under RCP 8.5 scenario with different deficit irrigation strategies

Sub basin/period	Crop water requirement (in mm) by CNRM model														
	Cotton (*kharif*)			Sorghum (*rabi*)			Maize (*rabi*)			Wheat (*rabi*)			Maize (*rabi*)		
	0.9 ETc	0.8 ETc	0.7 ETc	0.9 ETc	0.8 ETc	0.7 ETc	0.9 ETc	0.8 ETc	0.7 ETc	0.9 ETc	0.8 ETc	0.7 ETc	0.9 ETc	0.8 ETc	0.7 ETc
Middle Krishna															
Baseline period		601.1			445.2			420.4			415.0			587.8	
2020-40	515.0	493.2	471.4	416.5	379.5	342.5	434.6	416.3	398.0	399.0	385.8	372.6	526.7	504.2	481.8
2041-70	508.8	487.2	465.6	433.0	394.6	356.2	451.0	432.3	413.6	409.3	395.9	382.6	533.0	510.0	487.0
2071-99	502.4	481.0	459.5	454.0	413.8	373.6	472.7	453.4	434.2	423.5	410.0	396.4	532.9	509.5	486.0
Malaprabha															
Baseline period		574.7			440.4			440.3			397.9			517.8	
2020-40	514.5	492.7	470.9	417.1	380.1	343.1	435.8	417.5	399.2	395.4	382.4	369.3	507.1	485.2	463.3
2041-70	508.6	487.0	465.4	434.1	395.7	357.3	452.6	433.8	415.1	409.9	396.6	383.3	515.6	493.2	470.9
2071-99	503.6	482.0	460.4	454.4	414.2	374.0	473.8	454.4	435.1	428.1	414.5	401.0	514.9	492.1	469.3
Ghataprabha															
Baseline period		580.4			437.4			414.0			397.0			534.0	
2020-40	533.7	511.1	488.5	425.4	387.6	349.6	442.7	424.1	405.5	380.7	367.2	353.7	582.3	557.7	533.0
2041-70	528.0	505.7	483.3	443.3	403.1	363.7	459.6	440.6	421.6	391.1	377.5	363.9	590.2	564.9	539.7
2071-99	522.9	500.7	478.5	451.7	411.9	371.7	470.1	451.0	431.9	412.9	399.4	385.9	569.4	544.6	519.8
Upper Krishna															
Baseline period		567.9			428.4			427.9			385.9			527.5	
2020-40	533.7	511.1	488.5	417.4	380.2	343.0	434.2	415.9	397.6	358.5	344.9	331.3	574.4	550.1	525.8
2041-70	528.0	505.7	483.3	434.9	395.3	356.7	450.6	432.0	413.3	370.1	356.3	342.6	582.5	557.6	532.6
2071-99	522.9	500.7	478.5	455.3	414.8	374.3	472.5	453.2	433.9	385.3	371.5	357.7	584.3	558.8	533.3

is expected to increase in the study area. The monthly minimum and maximum temperatures are expected to increase in future periods. The crop water requirement and net irrigation requirements of crops in all the seasons were found to be higher in Middle Krishna sub basin when compared to other three sub basins. It is projected that the net irrigation requirement of crops during *kharif* season is expected to decrease in future because of expected increase in monsoon rainfall. Crop water requirement and net irrigation requirement of crops during *rabi* and summer season is expected to increase for all the sub basins and climate change scenarios of CNRM model. Sub basin wise water related adaptation strategies to cope with climate change in future are prepared. Sub basin wise additional volume of water need to be increased in order to match with the irrigation requirements of *rabi* season in future. Early sowing of crops by 10 days in *rabi* season may save the crops from additional irrigation requirement and match with the baseline periods. Deficit irrigation strategies during non-sensitive stages of crops with 0.9 ETc, 0.8 ETc and 0.7 ETc and full irrigation during sensitive stages for all the sub basins can be adopted to manage irrigation sources in context of climate change.

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