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Projecting future changes in water requirement of grain sorghum in India

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ABSTRACT

The spatial distribution and trend in rainfall and crop water requirement for sorghum during different time periods viz. baseline (1981-2010) and two future climate epochs (2021-2050 and 2051-2080) over all major sorghum (*kharif* and *rabi*) growing regions of India was studied using climate change projections data from NorESM-1M model of the CMIP-5 in RCP4.5 scenario. A significant decreasing trend in *kharif* season rainfall is noticed during 2021-2050 over Madhya Pradesh. Majority of the *kharif* and *rabi* sorghum growing regions may receive more rainfall during 2051-2080. Increasing trend is projected for crop water requirement over majority of sorghum regions in both seasons with significant increase over the core growing area of *rabi* sorghum. Regions were identified where moisture stress is likely to be severe during *kharif* and *rabi* seasons.

Keywords: Sorghum, water requirement, irrigation requirement, climate change, India

Sorghum is the 5th major cereal crop in India planted during both monsoon (*kharif*) and winter (*rabi*) seasons, primarily as rainfed crop (92% of the area). About 85% of its production is concentrated in the semi arid regions of Maharashtra, Karnataka, Telangana and Andhra Pradesh (DACNET, 2016). In India, sorghum area and production are showing a decreasing trend, ie., the area harvested has declined from 173.73 to 58.2 million hectares and the production has reduced from 81.04 to 53.9 million tonnes during1970-2014 (FAOSTAT 2014). However adoption of improved cultivars and better management practices (soil/water/nutrient) improved the productivity levels in India (Prey and Nagarajan 2009) and continues to be main staple food for poor and marginal farmers of India (Murthy *et al.,* 2007)

The study of rainfall variability in different seasons indicated decreasing trend in the southwest monsoon rainfall over the India and increasing trend in the premonsoon and post-monsoon rainfall (Dash *et al.,* 2007). Pattanaik (2007) observed a decreasing trend in southwest rainfallover central India during 1941–2002. Kothawale *et al.,* (2010) found that there is an increasing trend in annual and seasonal maximum temperature with significant increase in premonsoon and winter seasons during the period 1971-2007, while minimum temperature exhibits significant increase in all seasons during this period. However according to Representative Concentration Pathways (RCP) 4.5 it is projected an increase in temperature over India ranges from 2.9°C to 3.3°C and rainfall may increase 9.4% by the end of the 21st Century (Chaturvedi *et al.*, 2012). Their analysis also projected a consistent increasing trend in the number of extreme rainfall events over India during the second half of 21st century. Increasing temperature generally leads to a high rate of evapotranspiration, hasty accumulation of growing degree days; thus growth of the crop is earlier, consequential in the decline of phenophase length, finally yield (Attri and Rathore, 2003).

Various researchers have estimated the crop water requirement for different crops in India. Khandelwal and Dhiman (2015) and Mehta and Pandey (2016) computed the net irrigation water requirement for different crops in Gujarat. The net irrigation requirements for enhanced production may be higher for wheat and *rabi* sorghum over some locations in India during future climatic scenarios (Bapuji Rao *et al.*, 2012).

In this study attempt has been made to estimate the spatial distribution and trend of rainfall and crop water requirement for sorghum during baseline period (1981-2010) and in future climatic episodes (2021-2050 and 2051-2080) over major growing regions in India during *kharif* and *rabi* crop seasons. The influence of the crop

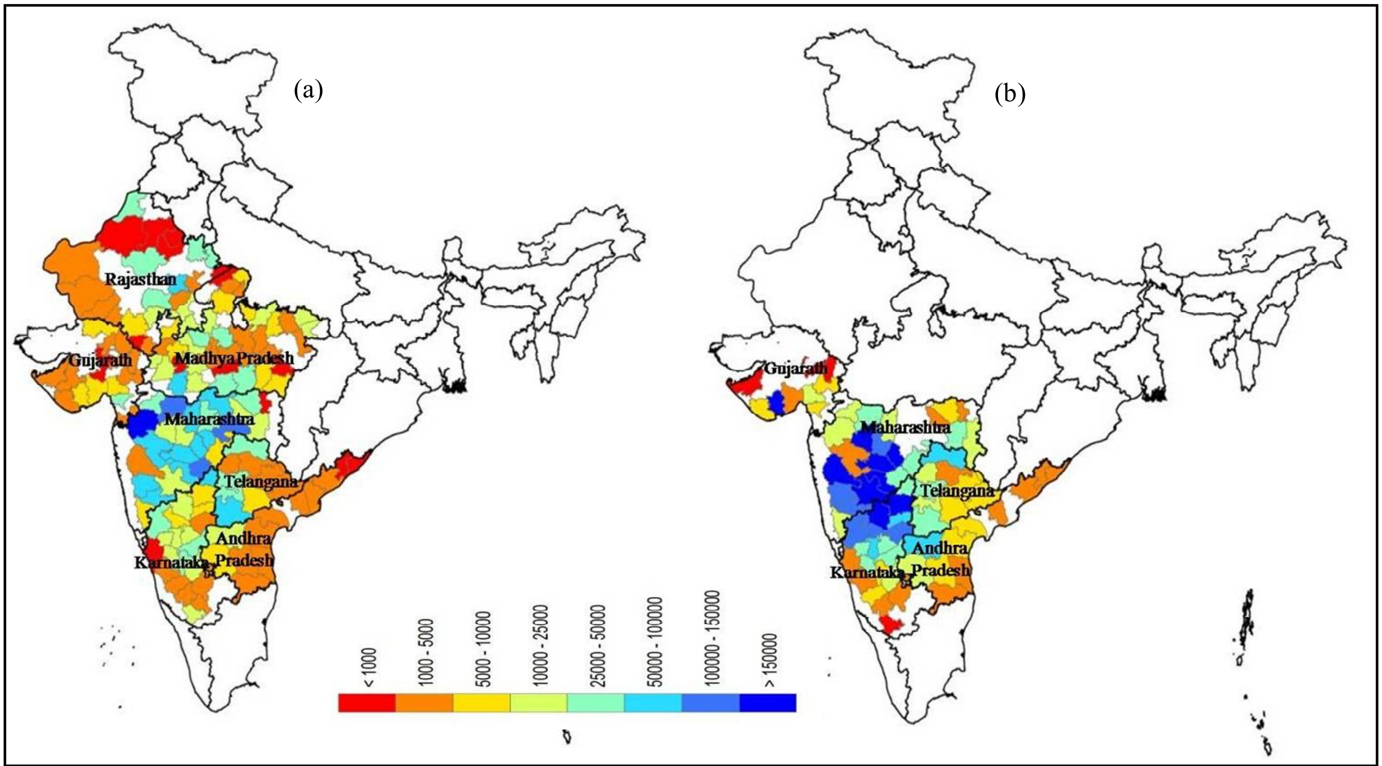

Fig. 1: Distribution of sorghum acreage (ha) during (a) *kharif* and (b) *rabi* seasons

water requirement on the sorghum productivity has also been analyzed.

MATERIALS AND METHODS

Climatic data

For climatic analysis, we considered three scenarios, baseline period of this study (1981–2010) and two future periods (2021-2050 and 2051-2080). Commission of Climatology, World Meteorological Organization (WMO) proposed a rolling set of 30 years normal updated by every 10 years such that 1981-2010 becomes the current base period (Wright, 2012). Since continuous district wise yield data is not available for majority of the districts since 1961 onwards we considered 1981-2010 as the base period of this study instead of widely accepted period 1961-1990. Data on daily maximum and minimum temperatures at 1°x1° and daily rainfall at 0.25°x0.25° resolution for the period 1981-2010 were sourced from National Data Center (NDC), India Meteorological Department (IMD), Pune. Future climatic scenario dataset for 2021-2050 & 2051-2080 were sourced from Coupled Model Inter comparison Project Phase 5 (CMIP-5) (Taylor *et al.,* 2012). CMIP5 climate change projections are driven by new climate scenarios that employed a time series of emissions and concentrations by the representative concentration pathways (RCPs) which consist of four scenarios: RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 (Moss *et al*., 2010). Evaluation study of forty CMIP5 models reveals that five CMIP5 models (CCSM4, GFDL-ESM2M, MIROC5, NorESM1-M and NorESM1-ME) were best suited for Indian conditions (Garg *et al.,* 2015). Among these five, three models (GFDL-ESM2M, MIROC5 and NorESM1-M) have been used in the present study due to availability of data on open source to validate with IMD data.

The spatial daily average maximum (T_x), minimum (T_n) temperatures and rainfall (P_r) of each sorghum growing district for the baseline period (1981-2010) and future climatic epochs (2021-2050 and 2051-2080) were estimated by Thiessen polygon method in GIS (ESRI-ArcGIS 10.0) environment. This method divides the catchment into a series of polygons surrounding each grid and area of the polygons becomes the weight of the grid. The influence of each grid to their respective districts will be quantified and can be an optimum solution for spatial averaging of weather data (Ramaseshan and Anant, 1977). The comparison of the area weighted district wise monthly rainfall, maximum and minimum temperature of the selected CMIP-5 models (GFDL-ESM2M, MIROC5 and NorESM1-M) with IMD historical data for the period 2006-2013 has been carried out using statistical tools like root mean square error (RMSE), D-index

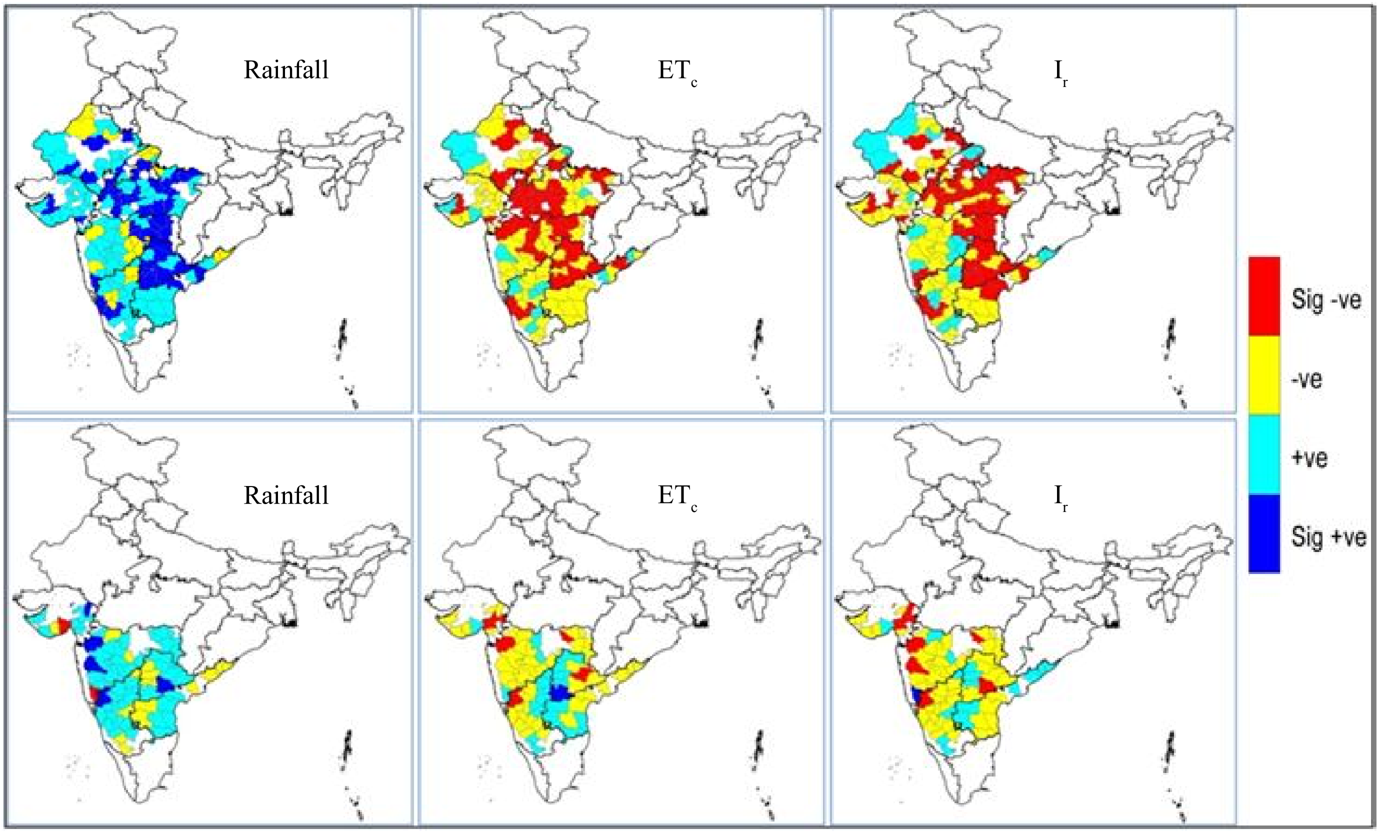

Fig. 2: Spatial variability in correlation coefficients between sorghum yields with rainfall, ET_c and I_r during *kharif* (upper pane); *rabi* (lower pane) crop growing seasons (1981-2010).

Table 1: Inter-comparison of CMIP5 models with IMD data

Statistic	Parameter	GFDL-ESM2M	MIROC5	NorESM1-M
RMSE	Rainfall	155.6	158.4	133.4
	Tmax	2.6	2.4	2.7
	Tmin	2.2	1.8	1.8
D-Index	Rainfall	0.75	0.75	0.80
	Tmax	0.92	0.94	0.92
	Tmin	0.96	0.97	0.97
Correlation (r)	Rainfall	0.58	0.60	0.66
	Tmax	0.85	0.89	0.91
	Tmin	0.93	0.95	0.95

and Pearson correlation coefficient. The results showed that NorESM1-M has the best affinity with IMD data with low RMSE, high D-index and better correlation coefficient values (Table 1). Hence, we selected NorESM1-M projections for the future climatic scenarios in this study.

Sorghum data

Data on district-wise sorghum yields of 137 districts for across our study area for the periods 1980-2010 for *kharif* (137 districts) and *rabi* (66 districts) seasons were sourced from Center for Monitoring Indian Economy (http://commodities.cmie.com).These districts occupy 92 per cent of *rainy* and 94 per cent of *post-rainy* sorghum growing regions in India (Fig. 1).We employed fourth-degree polynomial method for de-trending district level sorghum yields to obtain a stationary time series data.

The sowing time (beginning of the crop season) of each year was determined by rainfall episode to ameliorate emergence and plant growth. The date of sowing of *kharif*

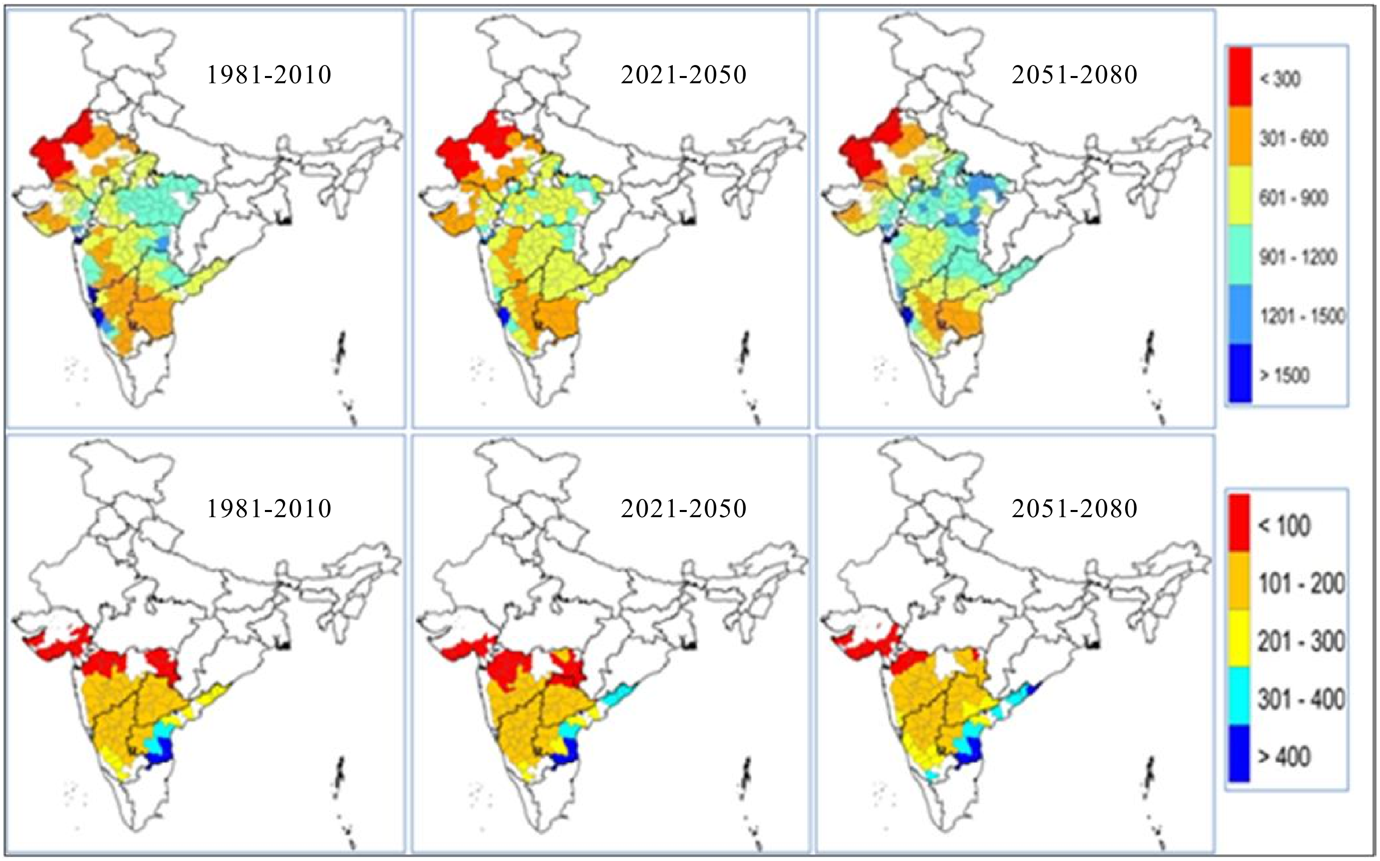

Fig. 3: Spatial distribution of rainfall (mm) during *kharif* (upper pane); *rabi* (lower pane) crop growing seasons during baseline (1981-2010) and future climatic scenarios (2021-2050 and 2051-2080).

season has been set immediate after the commencement of southwest monsoon rainfall over each district (Rana *et al.*, 1999). The *rabi* sowing window was set as 25 September to 15 October and a minimum of 9 mm rain within 5 days was required to trigger sowing (Kholowa *et al.,* 2013).

Computation of crop water requirement

The crop water requirement (ET$_c$) was determined using reference crop evapotranspiration (ET$_0$) and crop coefficient (K$_c$). Penman-Montieth method though considered to be best method to estimate ET$_0$, availability of input data constrains its wide application for Indian conditions. In present study the ET$_0$ was estimated by Hargreaves and Samani(1985) method which requires only T$_x$ and T$_n$ as input values,as given below.

$$ET_0 = 0.0023 R_A T_D^{0.5} (T_m+17.8)$$

Where,R$_A$ is extra-terrestrial radiation (mm day^{-1}), T$_D$ is difference between T$_x$ and T$_n$ (°C),

T$_m$ is mean temperature (°C). ET$_c$ is calculated as $ET_c = k_c * ET_0$

Where K$_c$ is crop coefficient. FAO suggested K$_c$ values for each phenological stages of sorghum (*http://www.fao.org/nr/water/ cropinfo_sorghum.html*) were used in the present analysis. Further, the irrigation requirement (Ir) ie., the difference between the water demand and availability,was computed as

$$I_r = ET_c - P_e$$

Where,P$_e$ is effective rainfall, considered as 70 per cent of the average seasonal rainfall (Dastane, 1974).

Seasonal crop and irrigation water requirements for 137 districts in *kharif* and 66 districts in *rabi* seasons were estimated and trend in them was detected using the Mann Kendall trend tool kit. To quantify the influence of seasonal rainfall, ET$_c$ and I$_r$ on detrended sorghum yields, Pearson's correlation coefficients for both the seasons (*kharif* and *rabi*) were estimated.

RESULTS AND DISCUSSION

Validation of selected CMIP-5 models

The comparison of area-weighted district-wise monthly rainfall, maximum and minimum temperature data from the three selected CMIP-5 models (GFDL-ESM2M,

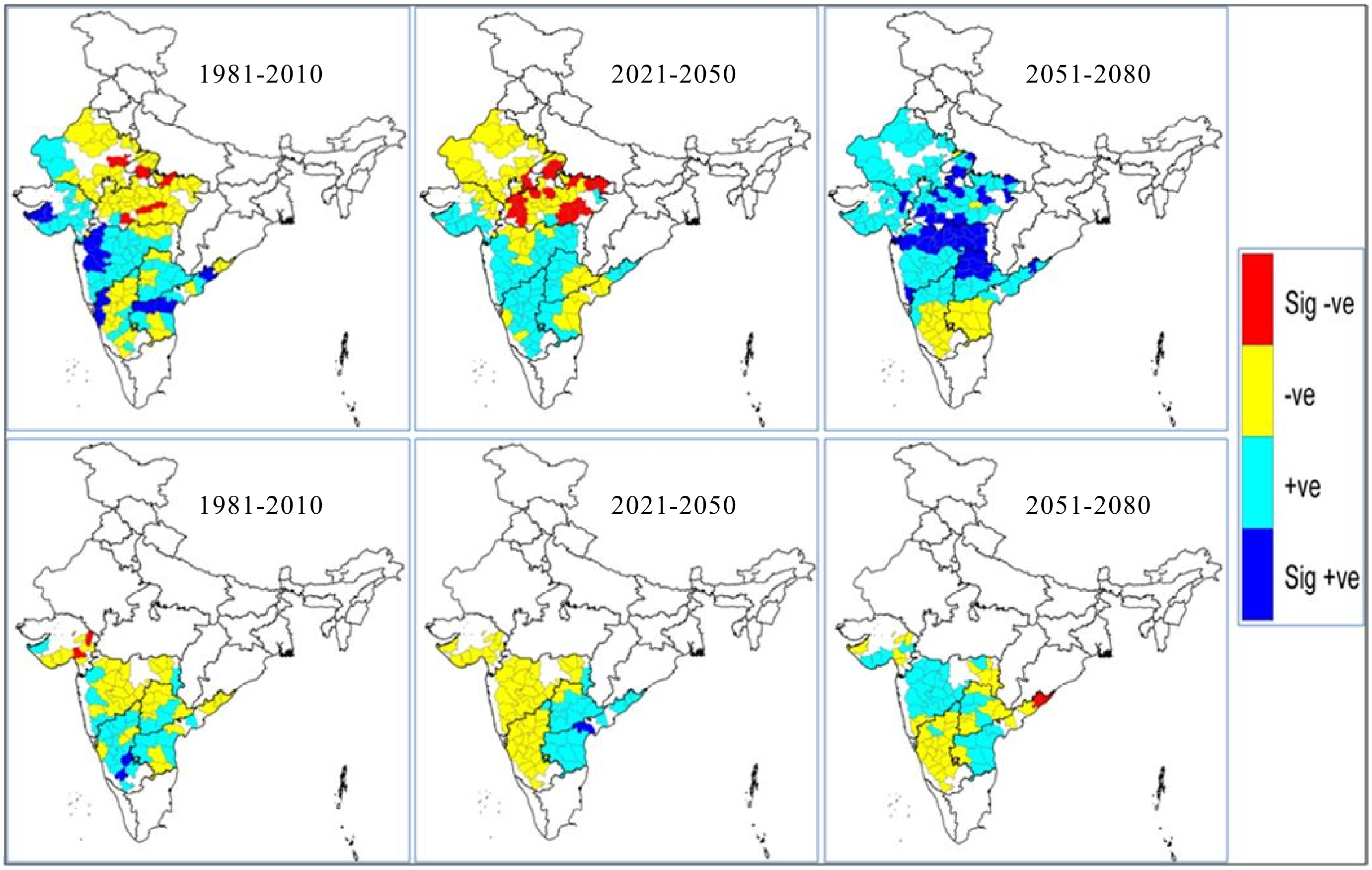

Fig. 4: Spatial distribution of trend in rainfall (mm) during *kharif* (upper pane); *rabi* (lower pane) crop growing seasons during baseline (1981-2010) and future climatic scenarios (2021-2050 and 2051-2080).

MIROC5 and NorESM1-M) for the period 2006-2013 showed that NorESM1-M has the best match with IMD data. NorESM1-M exhibited low RMSE and high D-index and correlation coefficient values (Table 1). Hence, we chose NorESM1-M projections for the future climatic scenarios in the sorghum growing districts.

Sorghum yields in relation to rainfall, ET_c and I_r

The correlation coefficient between sorghum yield and rainfall, ET_c and I_r during both growing seasons (Fig. 2) shows that majority of the total area showed positive correlation with rainfall during both *kharif* and *rabi* seasons and more than 40% of it is significant during *kharif* season. This indicates the substantial importance of rainfall on sorghum yields. Large areas showing negative association with ET_c and I_r during both crop seasons and more than 50 per cent of the area showed significant negative association during *kharif* season indicate that sorghum has undergone moisture stress.

Rainfall distribution and trend

Spatial distribution of seasonal rainfall during *kharif* and *rabi* seasons are presented in Fig. (3). Districts on the north western parts of India received less than 300 mm and some pockets on southwestern region received greater than 1500 rainfall during *kharif* crop growing seasons. The crop is likely to receive less rainfall over Madhya Pradesh during 2021-2050 but higher during 2051-2080. Post-rainy seasonal rainfall ranged between 40 to 510 mm. The *rabi* season rainfall exhibits not much change is anticipated in the future climates as compared to baseline period except in a few pockets in southern Karnataka and Andhra Pradesh where rainfall is projected to increase during 2051-2080.

A decreasing trend in *kharif* season rainfall is noticed over major parts of Rajasthan and Madhya Pradesh states during baseline (1981-2010) and expected in 2021-2050 also (Fig. 4). The mean decline in rainfall over Rajasthan was 2.3 mmyear^{-1} during baseline and likely to be about 3.1 mmyear^{-1}during 2021-2050, whereas over Madhya Pradesh the decline was 3.3 mmyear^{-1} during baseline and projected to decrease by 4.7 mmyear^{-1} during 2021-2050. Conversely an increasing trend (with significant increase over some pockets) persists over major parts of Maharashtra, Telangana, Andhra Pradesh, Gujarat and some regions of Karnataka during these periods. However, most of the *kharif* season

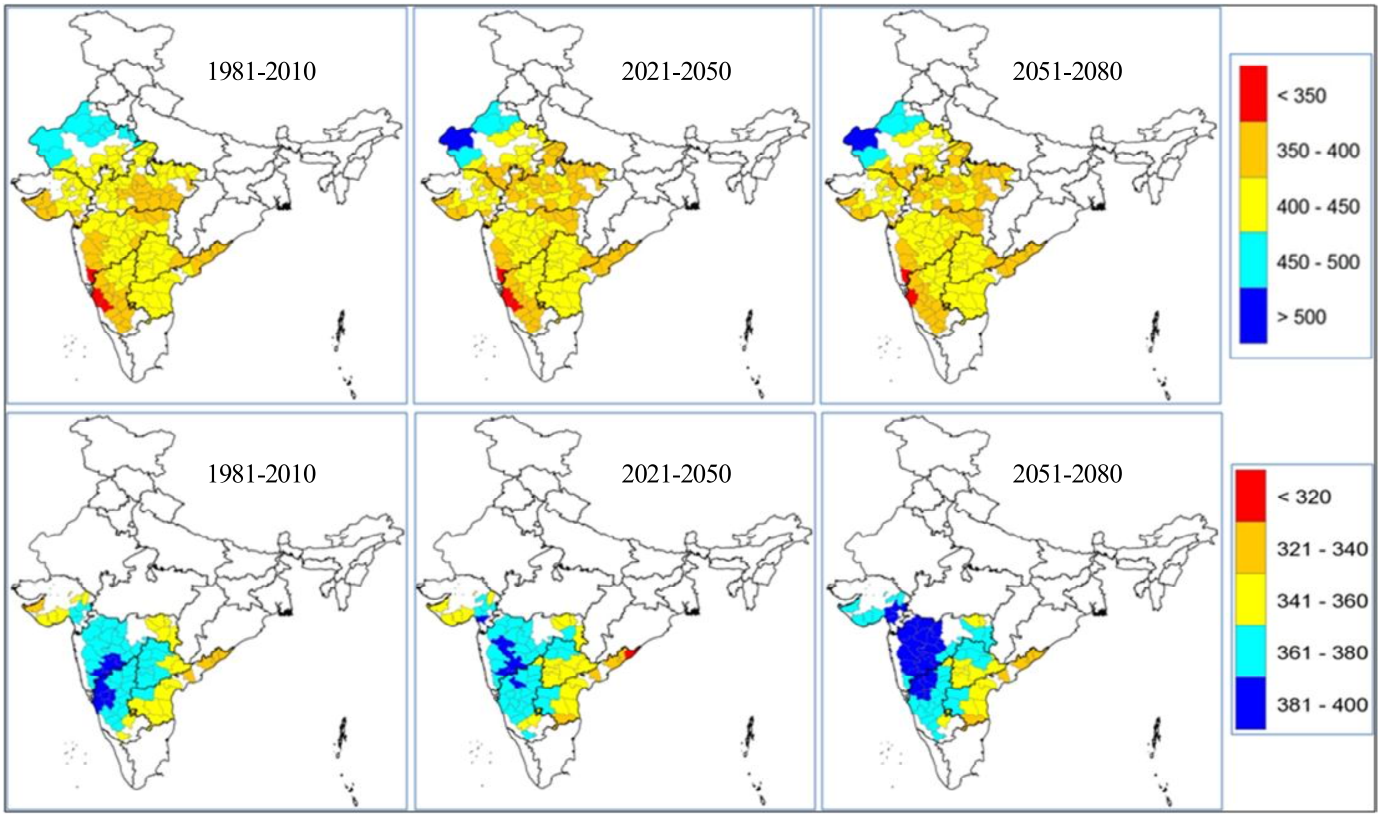

Fig. 5: Spatial distribution of ET_c (mm) during *kharif* (upper pane); *rabi* (lower pane) crop growing seasons during baseline (1981-2010) and future climatic scenarios (2021-2050 and 2051-2080).

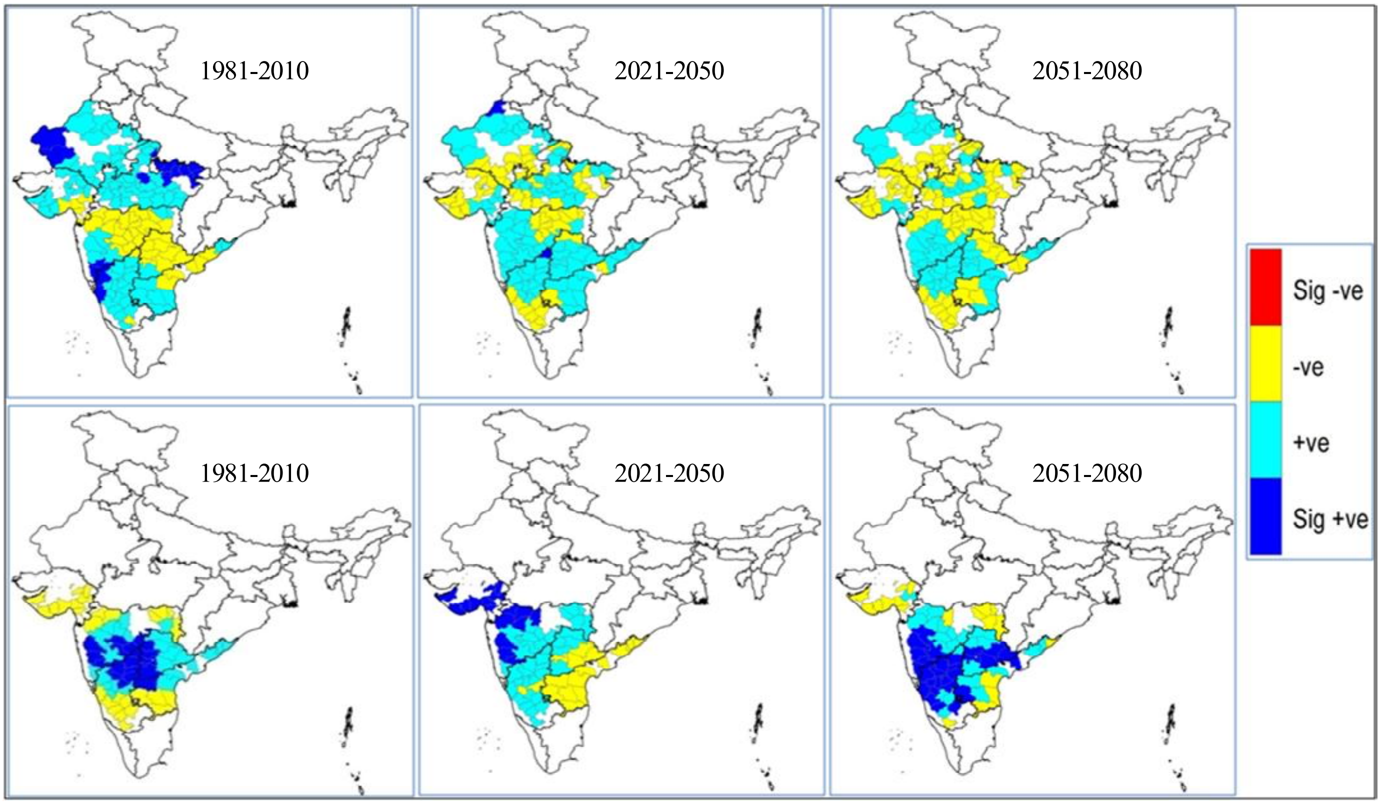

Fig. 6: Spatial variability of trend in ET_c during *kharif* (upper pane); *rabi* (lower pane) crop growing seasons during baseline (1981-2010) and future climatic scenarios (2021-2050 and 2051-2080).

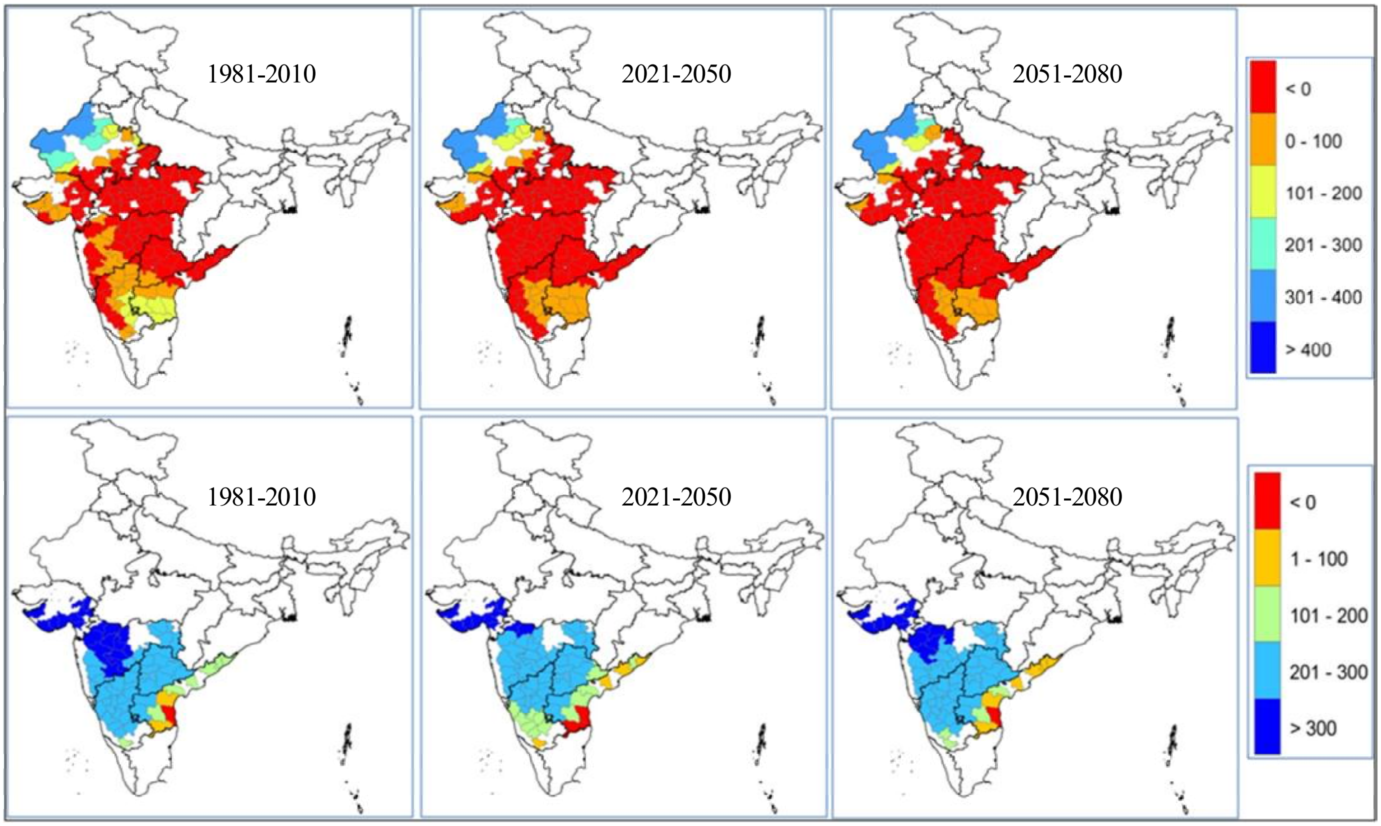

Fig. 7: Spatial distribution of I_r (mm) during *kharif* (upper pane); *rabi* (lower pane) crop growing seasons during baseline (1981-2010) and future climatic scenarios (2021-2050 and 2051-2080).

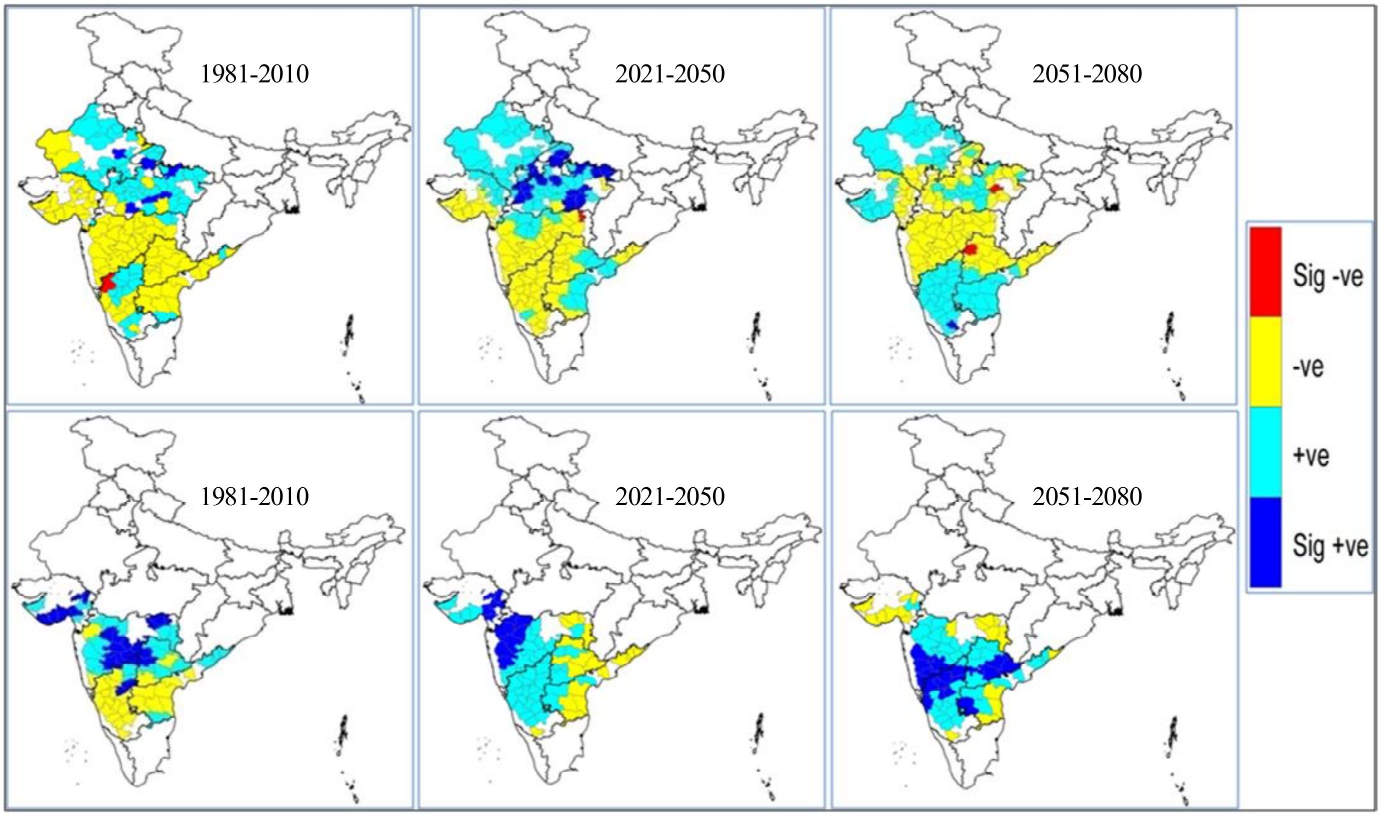

Fig. 8: Spatial variability of trend in I_r during *kharif* (upper pane); *rabi* (lower pane) crop growing seasons during baseline (1981-2010) and future climatic scenarios (2021-2050 and 2051-2080).

sorghum growing regions are likely to experience an increasing trend in seasonal rainfall during 2051-2080 with significant increase in Central India except in some regions in the southern parts. Parts of central India may experience an increase to a magnitude of 6.6 mm^{-1} year during 2051-2080. The *rabi* season rainfall is not exhibiting significant increasing/decreasing trends, except a few pockets during baseline and future climatic scenarios

Crop water requirement (ET$_c$)

Crop water requirement (ET$_c$) during *kharif* season ranged between 320-450 mm in majority of the growing areas during baseline period (Fig.5). It exceeded 450mm over small regions in north western parts and it is projected to increase further during future climates over these regions. During *rabi* season ET$_c$ ranged between 340-400 mm over majority of the crop growing areas. Climate projections did not show large changes in average ET$_c$ during 2021-2050, however, it is projected to rise over substantial area in central Maharashtra and northern parts of Karnataka during 2051-2080.

There was an increasing trend in ET$_c$ during *kharif* season in the baseline period over large area and this is likely to continue during 2021-2050 but area may likely to decline during 2051-2080 (Fig.6). A significant increase was noticed in *kharif* season ET$_c$ over northern (0.42 mmyear^{-1}), northwestern (0.48 mmyear^{-1}) and western regions (0.36 mmyear^{-1}) during baseline (1981-2010) period. The core area of the *rabi* sorghum growing regions indicated significant increasing trend in ET$_c$ during baseline and future periods, which may become more prominent during 2051-2080. The average rate of increase in ET$_c$ during *rabi* season over the areas, where a significant increasing trend was noticed, are of the order of 0.39 mmyear^{-1} during baseline, 0.34 mm^{-1} year during 2021-2050 and 0.53 mmyear^{-1} during 2051-2080.

Irrigation requirement (I$_r$)

It is observed that during base line period I$_r$ values hovered around 0 mm during *kharif* season over more than 50 per cent of the area. Rayalaseema region of Andhra Pradesh, eastern and northeast Karnataka, central Maharashtra, Gujarat and Rajasthan regions showed I$_r$ values ranging from 10 to 350 mm (Fig. 7). The I$_r$ values of *rabi* season are low over east coast and gradually increased towards west since east coast areas receive some amount of rainfall during northeast monsoon season. Projected scenarios did not indicate large change in area for I$_r$ during *kharif* season. However *rabi* season I$_r$ values were in the rage of 200-300 mm over majority of the area during the baseline period. This is projected to continue in the future climate scenarios as well. The *kharif* season I$_r$ shows increasing trend over northern regions and a decreasing trend in central and western parts of the crop growing regions during baseline and future climatic scenarios (Fig. 8). The core area of the *rabi* sorghum growing regions exhibited increasing trend in I$_r$ during baseline and future periods, which is likely to become more significant during 2051-2080. The significant increasing trend in I$_r$ during 2051-2080 is noticed over central Maharashra, northern Karnataka and Telangana regions. Thus there is a need to minimize the vulnerability of *rabi* season crop to moisture stress through better water management practices.

CONCLUSIONS

Due to the significant positive influence on yield over majority of the growing regions during both *kharif* and *rabi* seasons, it is identified that rainfall plays a significant role in sorghum productivity. Large areas showing negative association with ET$_c$ and I$_r$ are indicative of moisture stress the crop has experienced during growing season. Majority of the sorghum growing regions, yields are inversely related with ET$_c$ during both seasons and more than 50 per cent area during *kharif* season showed significant impact.

Even though increasing trend in rainfall is noticed in the coming decades the intraseasonal variability in rainfall needs to be considered to quantify the moisture stress. Further studies can be carried out in order to get more insight on water requirement of sorghum in the future climates by considering the above factors with more number of projected scenarios.

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