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Climate Change Impacts During Near, Mid and End Century Over Rice Bowl of Tamil Nadu, India

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A B S T R A C T

The study utilized two downscaled climate model (GFDL-ESM2M and HadGEM2-ES) outputs from Agro Climate Research Centre, Tamil Nadu for the Representative Concentration Pathways 4.5 and 8.5 using regional climate model namely RegCM 4.4. The model output was fed into DSSAT crop simulation for assessing vulnerability of rice crop to projected climate change for near, mid and end of century. The study revealed an increase of maximum temperature for near (0.8 to1.2 ^{0}C) mid (1.3 to 2.5^{0}C) and end (1.5 to 4.2^{0}C) of century while increase of minimum temperature for near (0.7-1.2^{0}C) mid (1.3 to 2.6^{0}C) and end (1.6-4.5^{0}C) century. The rainfall projected was highly variable as indicated by high RMSE value of 117.06 and also showed that rainfall was more for GFDL-ESM2M model and less for HadGEM2-ES model over the time period. The relative difference of rice yield indicated that in RCP 4.5, highest reduction was observed for end of century (-8.6 to -22.1%) followed by mid (-2.2 to 21.1%) and near (+0.1 to -9.1%) while for RCP 8.5, highest reduction was seen during mid (-17.7 to -20.5%) followed by end (-11.9 to -16.3%) and near (-9.6 to 13.6 %) century.

Introduction

Crop production systems are often largely controlled by environmental factors, thus being vulnerable to climate change (IPCC, 2013). Thanjavur district of Tamil Nadu is popularly known as rice bowl of Tamil Nadu.

The studies on projecting the future climate under projected climate change scenarios and its impacts on rice productivity over Thanjvaur district is much important for arriving adaptation strategies in view of better rice production and food security of Tamil Nadu state.

Study area

Thanjavur bounded by 10.99^{0}N latitude, 79.47^{o}E longitude and11.02^{o}N latitude, 79.49^{o}E longitude (Figure 1). The soils of Thanjavur district are potentially productive.

Study period

For projecting future climate change and its impact on rice yield, the dynamically downscaled historic base line data for the period 1971-2005 and future data for the period 2010-2100, under two Representative Concentration Pathway (RCP) scenarios such as RCP 4.5 and RCP 8.5 were used.

Regional climate model (RegCM4.4)

The dynamical downscaling was done at Agro Climate Research Centre (ACRC), Tamil Nadu Agricultural University (TNAU), Coimbatore, employing Regional Climate Model (RCM) RegCM4.4 and the products were used for the study.

Calibration of CERES rice crop simulation model

CERES Rice model was calibrated for popular rice variety CO (R) 50 by iteration method for assessing the impact of projected climate change on yield of *Samba* rice crop in Thanjavur district of Tamil Nadu. The genetic coefficient estimated is given in the Table 1.

Climate change impact assessment

Impact assessment of climate change on rice production was carried out by downscaling of two GCM models GFDL-ESM2M, HadGEM2-ES using regional climate model namely RegCM4.4. The downscaling for future climate change was done for the period 2006-2100 under 4.5 and 8.5 RCP scenarios. A historical run was also carried out for above two models for obtaining base year data for the period of 1971-2005.

The daily weather variables such as maximum temperature, minimum temperature, rainfall and solar radiation were used for the historical run whereas for the future period, three time scales such as near century(2010-2039), mid (2040-2069)century and end century(2070-2100) derived from model output under two RCP scenarios were fed into DSSAT 4.6 crop simulation model. The carbon dioxide concentration for climate scenarios and time period prescribed for use in crop simulation model by Rosenzweig *et al.,* (2016) is given Table 2.

Verification of climate data

Verification of climate data was done using CRU gridded data with the following statistical techniques.

The error statistics *viz.* Mean absolute Deviation (MAD), Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE) along with correlation coefficient (r) were estimated for verification CRU with projected data and the equations used for the analysis is given below.

Mean Absolute Deviation (MAD)

$$MAD = \frac{\sum_{i=1}^{n}(Oi - Pi)}{n}$$

Root Mean Squire Error (RMSE)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Oi - Pi)^2}{n}}$$

Mean Absolute Percentage Error

$$MAPE = \frac{\sum_{i=1}^{n} \frac{|Oi - Pi|}{|Oi|}}{n} \; x100$$

Correlation coefficient (r)

$$r = \frac{\sum PiOi \frac{\sum Pi . \sum Oi}{n}}{\sqrt{\sum Pi^2 - \frac{(\sum Pi)^2}{n}} . \sqrt{\sum Oi^2 - \frac{(\sum Oi)^2}{n}}}$$

Where,

P_i is the predicted data, O_i represent observed data. n is the number of observation

Percentage relative difference (R.D. %)

Percentage relative difference from base year (1971-2005) for rice productivity was worked out for near century (2010-2039), mid-century (2040-2069) and end of century (2070-2100) using the following formula.

$$\text{R.D. \%} = \frac{\text{Average predicted future years} - \text{Average predicted base years}}{\text{Average predicted base years}}$$

Results and Discussion

Validation of climate change projection

Monthly mean downscaled baseline data (1971-2005) were validated with climatic research Unit (CRU) observed data using statistical techniques *viz.*, Mean Absolute Difference (MAD), Root Mean Squire Error (RMSE), Mean Absolute Percentage Error (MAPE) and correlation coefficient (Table 3). The results inferred that, for maximum and minimum temperature the statistical results was appreciable and indicated prediction was valid. The high level of correlation coefficients irrespective of models suggested its reliability. In the case of rainfall, the model variability was high with lower correlation (0.32) and higher RMSE (172.51) and while analysing the data it was revealed that, GFDL models overestimated rainfall in this region whereas HadGEM2 underestimated rainfall. This result goes in tally with Dash *et al.*, 2014 where he founded out HadGEM2 underestimated rainfall over most parts of India except Western Ghats and Arunachal Pradesh.

Climate projections

The downscaled daily data (maximum temperature, minimum temperature and rainfall) of two GCM models GFDL-ESM2M, HadGEM2 were averaged to grid point pertaining to Thanjavur district and time period was classified for near (2011 - 2039), mid (2040-2069) and end (2070-2099) century and the deviation from the timescales to that of base years (1971-2005) were worked out to understand the projected change.

Deviation of maximum temperature for Thanjavur district

The maximum temperature over Thanjavur district was projected to be increasing by the two models used for the study. The results also revealed that, increase of temperature was more in HadGEM2 projection compared to GFDL-ESM2M and maximum increase was noted for end of the century (2070-2100) for both RCP 4.5 and RCP 8.5 scenarios. For HadGEM2 during end of century, an increase of 2.5^{0}C and 4.2^{0}C was projected for RCP 4.5 and RCP 8.5 respectively while the GFDL-ESM2M projected increase for the same period was 1.5^{0}C and 2.8^{0}C for RCP 4.5 and RCP 8.5 respectively. Geethalakshmi *et al.*, (2011) also found out impacts of climate change on in Cauvery delta basin of Tamil Nadu for A1B scenario and concluded an increasing trend for maximum, minimum temperatures and rainfall (Table 4).

Deviation of minimum temperature for Thanjavur district

The projection of minimum temperature over Thanjavur district of Tamil Nadu showed a grater increase of night temperature from near to end of century. Similar to maximum temperature, HadGEM2 projected higher minimum temperature than GFDL-ESM2M. For RCP 4.5 and 8.5 scenarios, the HadGEM2 projected an increase of minimum temperature from near to end of century as 1.0^{0}C to 2.5^{0}C and 1.2^{0}C to 4.4^{0}C respectively whereas for GFDL-ESM2M projected increase for the same period was 0.7^{0}C to 1.6^{0}C and 1.0^{0}C to 3.1^{0}C (Table 5).

Fig.1 Location map of Kuttanad region

Fig.2 Percent relative difference of rice yield over Thanjavur under RCP 8.5 scenario

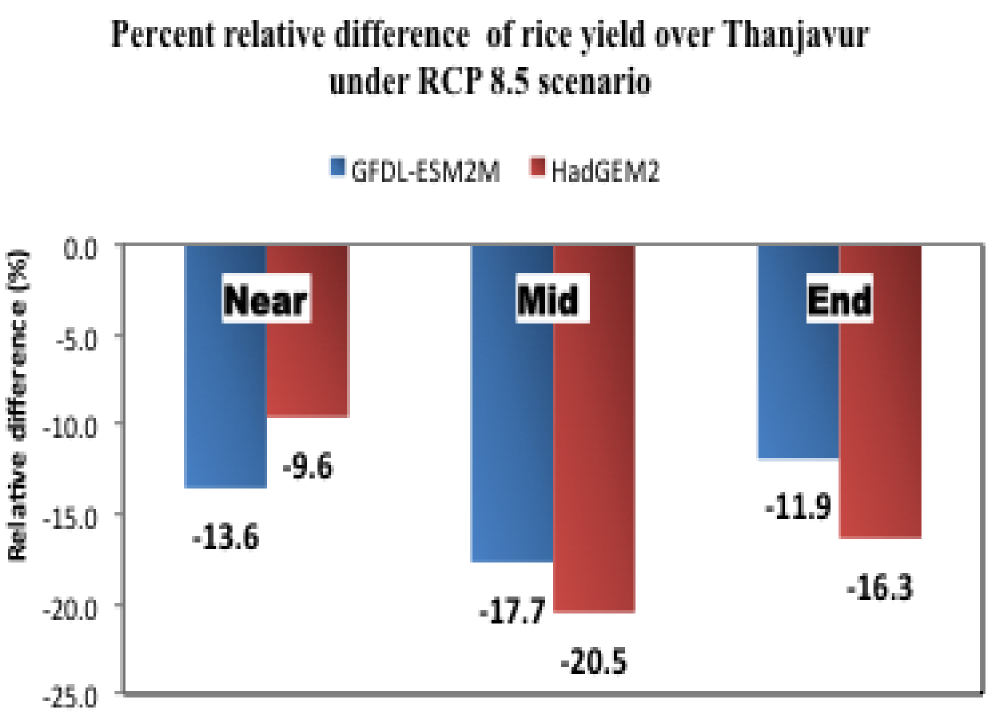

Fig.3 Percent relative difference of rice yield over Thanjavur under RCP 4.5 scenario

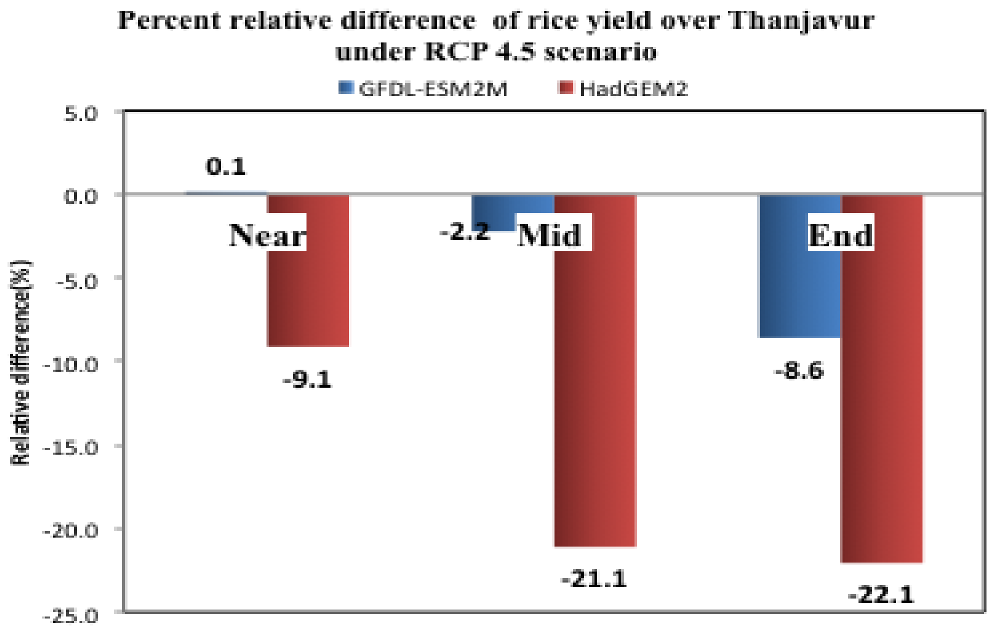

Table.1 Genetic coefficient for CO(R) 50 rice variety for CERES rice model

P1	P2R	P5	P20	G1	G2	G3	G4
550.7	83.4	315.3	12	58	0.02	1	1

Table.2 The CO_2 increment in ppm over the study period

Scenario	Time Period	[CO_2]
Current	1971-2005	380
RCP4.5 Near-term	2010-2039	423
RCP8.5 Near-term	2010-2039	432
RCP4.5 Mid-Century	2040-2069	499
RCP8.5 Mid-Century	2040-2069	571
RCP4.5 End-of-Century	2070-2100	532
RCP8.5 End-of-Century	2070-2100	801

Table.3 Validation of climate change projections

Model		MAD	MAPE	RMSE	R
GFDL-ESM2M	Maximum temperature	2.26	6.88	2.54	0.88
	Minimum temperature	5.20	21.04	19.60	0.91
	Rainfall	113.66	229.97	172.51	0.32
HadGEM2-ES	Maximum temperature	1.17	3.55	1.34	0.86
	Minimum temperature	4.65	18.70	4.72	0.89
	Rainfall	78.10	121.80	117.06	0.38

Table.4 Deviation of maximum temperature projection for Thanjavur district

	RCP 4.5		RCP 8.5	
	GFDL-ESM2M	HadGEM2	GFDL-ESM2M	HadGEM2
2010-2039	0.8	1.1	0.90	1.2
2040-2069	1.3	1.9	1.9	2.5
2070-2100	1.5	2.5	2.8	4.2

Table.5 Deviation of minimum temperature projection for Thanjavur district

	RCP 4.5		RCP 8.5	
	GFDL-ESM2M	HadGEM2	GFDL-ESM2M	HadGEM2
2010-2039	0.7	1.0	1.0	1.2
2040-2069	1.3	1.9	2.0	2.6
2070-2100	1.6	2.5	3.1	4.4

Table.6 Deviation of rainfall projection for Thanjavur district

	RCP 4.5		RCP 8.5	
	GFDL-ESM2M	HadGEM2	GFDL-ESM2M	HadGEM2
2010-2039	75	-86	101	18
2040-2069	118	-83	43	-125
2070-2100	119	-71	98	-243

Deviation of rainfall projection for Thanjavur district

The tri-decadal rainfall projection for Thanjavur district of Tamil Nadu inferred that, the two models projected rainfall differently. The GFDL-ESM2M projected an increase of rainfall for near, mid and end century for both RCPs while in HadGEM2, the rainfall was decreasing for all the time scales for RCP 4.5 and for RCP 8.5 scenarios, showed an increase for near century after that it was decreasing (Table 6).

Impact of rice production to future climate change

DSSAT crop simulation model was used to assess the impact of rice to future climate change and the results were shown in Figure.

The percent deviation of rice productivity from base year (1971-2005) in Thanjavur district of Tamil Nadu revealed a yield reduction for all the time period under RCP 8.5 scenario (Figure 2). The results also indicated that reduction in yield was maximum for mid-century at which a decrease of 17.7% and 20.5 % was noticed for GFDL-ESM2M and HadGEM2 respectively. The yield reduction was maximum for HadGEM2 model except during near century. The reduction in yield was decreased during in end of century for both models.

The percent relative difference of Thanjavur rice yield for RCP 4.5 revealed reduction from near century to end of century (Figure 3). The highest yield reduction was observed during end century followed by mid-century and near century. In this period, the reduction in rice yield when compared to baseline period (1971-2005) was -22.1% for HadGEM2 and -8.6 % for GFDL-ESM2M while variability during mid-century varied between -21.1% for HadGEM2 and -2.2 % for GFDL-ESM2M. The relative difference for near century was negligible (+1%) for GFDL-ESM2M when compared HadGEM2 (-9.1%). Rajalakshmi *et al.,* (2015) also assessed influence of projected climate on rice yield over Tamil Nadu using PRECIS and RegCM4 Regional Climate Models (RCMs) for the period from 2011 to 2100 and revealed a 10 % decline in rice productivity by the end of the 21st century, relative to the average yield during the base period 1971-2009.

The study predicted significant decline in rice productivity over rice bowl of Tamil Nadu state. The yield reduction varied over time scale and scenario used and yield reduction up to 22% was observed. The study also gave an insight of a significant increase of maximum and minimum temperature and variability of rainfall under the projected climate change scenarios.

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