Response of Maize Yield in Future Climate of Namakkal District with Reference to HADGEM-ES and GFDL-CM3 Climate Models, Tamil Nadu, India

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Abstract
Understanding the effects of climate change on maize yield in a semi-arid area of Namakkal district is the goal of this study. This study determined the microclimate of the study area using IMD's gridded rainfall data at 0.25 x 0.25-degree precision and temperature data at 1 x 1 degree resolution. Future climate and yield change were evaluated using simulations utilizing the HadGEM2-ES and GFDL-CM3 climate models. The rainfall trend was determined using the Mann-Kendall and Sen's estimate of the slope. The annual mean maximum temperature will increase from 2.39 to 4.130C and from 2.95 to 4.300C, respectively, according to HadGEM2-ES and GFDL-CM3. Both the HadGEM2-ES analysis and the GFDL-CM3 analysis indicate an increase in rainfall of between 23.83 and 47.77 percent and between 11.60 and 38.23 percent, respectively. The rainfed maize productivity in the research area was predicted using the DSSAT crop model, and the results show a negative influence. According to the HadGEM2-ES and GFDL-CM3 models, the region of Kumarapalayam experiences the greatest yield drop, going from 3997 kilograms per hectare in the baseline to 3358 kilograms per hectare by the midcentury to 2682 kilograms per hectare by Rasipuram. The yield variations from baselines through the end century ranged from -3 to -18 percent for HadGEM2-ES and GFDL-CM3. In order to better comprehend the need for crop development and improved management techniques used to boost yields for future generations.

Keywords: HADGEM-ES, GFDL-CM2, Namakkal.

Introduction

Due to climate change, agriculture is one of the major sectors vulnerable to risks (Smith and Skinner, 2002). Depending on climatic behavior, crop production in any region is directly or indirectly affected. The various researchers around the world are highly concentrated to increase cereal production in developing countries (Godfray et al., 2010). In recent years, there is notable attention has been made to meet the demand of food production in changing climate and identified adaptation as a key factor (Lobell et al., 2008). In response to climate change, agriculture and food production in India is highly sensitive to climate change and considered as the vulnerable sector (Dubey and Sharma, 2018). Lobell et al., (2011) pointed out that every one-degree increase of temperature above the threshold value of 300C leads to a reduction in maize yield by 1 percent during the favorable condition and in the unfavorable condition, it is 1.7 percent. Maize is one of the alternate and value-added crops in the upland Tamil Nadu state from the common crop of rice and wheat (Muthu Meenal, 2017). However, maize is one of the major crops in Namakkal district, it is necessary to assess the productivity in changing climate. Therefore, this study aimed to assess the impact of climate change on maize production during near, mid and century in the rainfed Namakkal district of Tamil Nadu at a micro-level. The study area is a Namakkal district of Tamil Nadu that extends between 11000’ to 11036’10” north latitudes and 77040’ to 78030’ east longitudes. The total geographical area of the district is 3429.3sq.km (Fig.1).

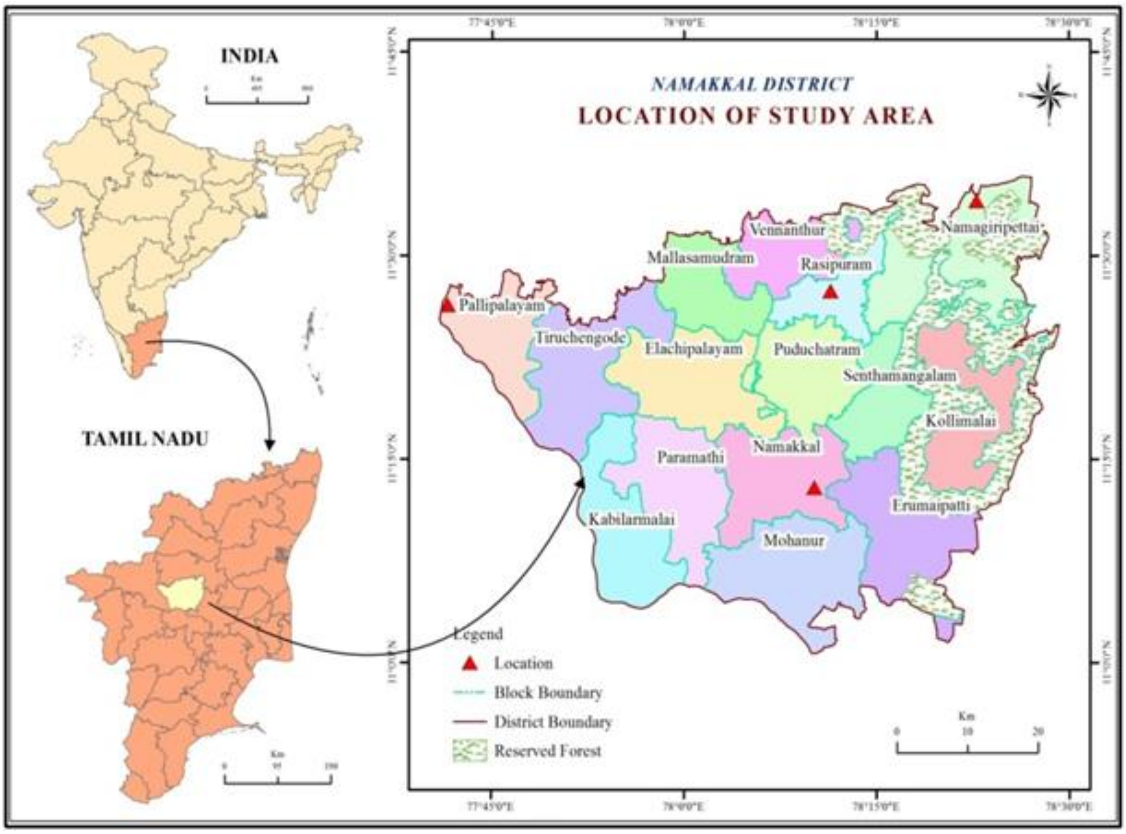

Fig. 1 Location of study area – Namakkal district.

Materials and Methods

This study considers the administrative setup as a boundary for assessing the climate and also yields of crops. The base map has been prepared using Survey of India, Toposheets. There are no Indian Meteorological Department (IMD) stations in the study area so, gridded interpolated data rainfall data from IMD with a resolution of 0.25^{o} X 0.25^{o} and for temperature with 1^{o} X 1^{o} for temperature were used to understand the baseline climatic condition (1980 - 2010). Trend assessments were studied using Mann-Kendall and Sen’s slope. The dynamically downscaled approaches using the regional climate model such as HadGEM2-ES and GFDL-CM3 for RCP 8.5 scenario have been employed in this study for annual. Among the 29 climate models, two climate models for Hot/wet and Hot/dry conditions were selected using the scatter plot method in R for near (2010 - 2039), mid-century (2040 - 2069), and end century (2070 – 2099). The yield assessments were studied using a crop simulation model for annual using Decision Support System for Agrotechnology

Transfer (DSSAT). The interpolation technique has been used to create the spatial map using Arc GIS software. The relative yield change is calculated using the following formula,

Relative Yield Change = [(Projected yield – Observed yield) / Projected yield] × 100 Eq. (1)

Projected climate study period: The future scenario data could be generated to near century (2010 – 2039); midcentury (2040 – 2069) and end century (2070 – 2099) using the climate models.

Using R script to project the future climate: The procedures outlined by climate modeling team of Agricultural Model Inter comparison and Improvement Project (AgMIP) for Climate scenario data generation was followed in the current study (Cynthia et al., 2013; Hudson and Ruane, 2015).

Running R Scripts: R scripts and GCM files for RCP 8.5 as well as the latitude and longitude files required to properly read the GCM files were download from https://webdrive.gsfc.nasa.gov/longauth/600/alexander.c.ruane/hWono4C. The following scripts were run under R console as per the guidelines given in AgMIP (www.agmip.org). R scripts utilize the baseline data and GCM data files for future climate projection. The script used is named as run_agmip_simple_mandv.R.

Climate projection approach: Future climate projections were created by utilizing "mean and variability" approach, in which the mean monthly changes as well as the magnitude of variability (from baseline) under RCP 8.5 for Mid Century time slices, centered around 2055 was applied to the daily baseline weather series as described by Villegas and Jarvis (2010). These scenarios of future projections were referred to as "mean and variability change scenarios".

Following four parameters were retrieved from future scenario simulations.

1. Maximum Temperature (^oC)
2. Minimum Temperature (^oC)
3. Rainfall (mm)
4. Solar radiation (W/m^2)

From the future climate data, annual and seasonal averages of maximum temperature, minimum temperature and rainfall for the respective periods were worked out. To understand the future change projected, annual and seasonal metrics of climate variables were derived. The future data was worked out grid wise to understand the magnitude of change and spatial variability of climate impacts.

Impact of climate change on maize and paddy productivity – A case study: A case study has been made to find out the impact of climate change on rainfed maize and paddy productivity by using DSSAT, a dynamic crop simulation model for the future.

Decision Support System for Agro technology Transfer (DSSAT): DSSAT- crop simulation models have been used for many applications ranging from one farm and precision management to regional assessments of the impact of climate variability and climate change. It has been in use for more than 20 years by researchers, educators, consultants, extension agents, growers, and policy and decision makers in over 100 countries worldwide (Jones et al., 2003; Hoogenboom et al., 2015).

CERES –Maize: The CERES (Crop Estimation through Resources and Environment Synthesis) model embedded in DSSAT (Jones and Kiniry, 1986) was used to assess the impact of climate change on maize and paddy. The CERES – model is a simulation model with individual module for maize and paddy that describes daily Phenological developments and growth response to environmental factors. To simulate the maize and paddy yield DSSAT requires data sets of daily weather data, soil data and crop management details.

Results

Trend analysis: Annual trend analysis through Mann-Kendall analysis among the rain gauge location in the district, two stations had a significant decreasing trend in annual and rest of the station had no trend at a 5% significant level. Based on Sen's estimator of slop, the magnitude of trend is varied in nature for annual (Table 1).

Table 1 Annual Summary of the Mann-Kendall analysis and Sen's estimator of slope.

S. No	Station	Mann-Kendall	Sens Estimator	
		Annual	Slope	Constant
1.	Kumarapalayam	-1.5244	-0.55	2490
2.	Mangalapuram	-1.7224	0.24	350.28
3.	Namakkal	-2.9102	-0.67	20966.4
4.	Rasipuram	-0.3365	-6.77	21266.4

The magnitude of trend in annual and seasonal rainfall as determined by the Mann-Kendall test is given in Table 3.7. Among the rain gauge location in the district, one stations had a significant decreasing trend in annual and rest of the station had no trend. The increase in annual rainfall is not noted in all of the locations studied. The decrease was maximum in Namakkal rain gauge station (-2.91 mm/yr) and minimum of -0.34 mm/yr in Rasipuram rain gauge station. During annual the magnitude of trend is varied in nature while assessing the Sen's Slope estimator. The maximum increase out of 4 stations was experienced in Mangalapuram (0.24 mm/yr) (Table 1). There is a significant reduction in noticed in Rasipuram (-6.77 mm/yr). The decrease in trend is varied between -0.55 mm/yr to -6.77 mm/yr. The magnitude of annual trend is shown in the fig. 2a, b.

Projected Maximum Temperature: Maximum temperature was projected to increase by both the models studied for all the locations over Namakkal. The climate models HadGEM2-ES and GFDL-CM3 projected with a mean of 2.27 and 2.38°C for the near century. A mean maximum temperature of 2.4 to 4.12°C and 2.95 to 4.3°C rise by HadGEM2-ES and GFDL-CM3 during mid and end century. HadGEM2-ES projected a mean of 2.24, 2.20 to 3.94°C and GFDL-CM3 by 3.0, 3.29 to 5.34°C for near, mid and end century respectively (Table 2). The lowest increase was projected over Kumarapalayam and Mangalapuram by HadGEM2-ES. While highest increase was also noted over Kumarapalaym, Namakkal and Rasipuram (Fig. 3).

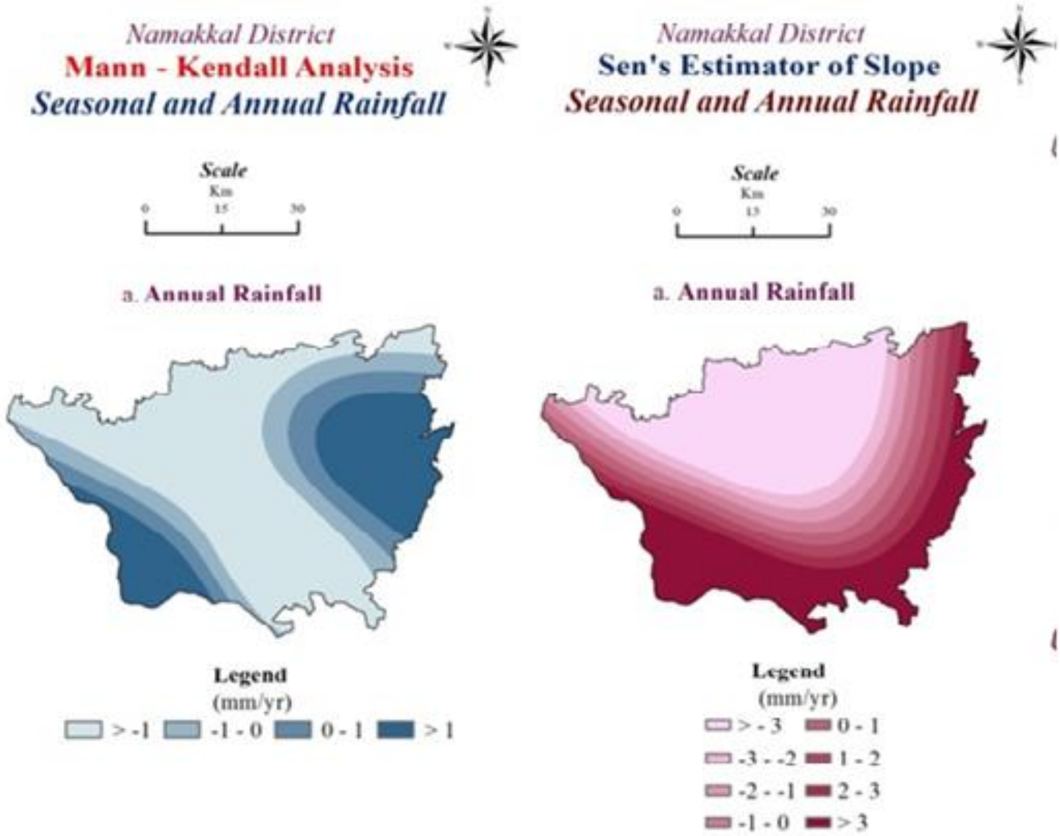

Fig. 2 Trend Analysis a) Mann – Kendall Analysis and b) Sen's Estimator of Slope.

Table 2. Projected changes in Annual mean maximum temperature (°C) during different season.

	Locations	Hot / Wet	Hot / Dry	Hot / Wet	Hot / Dry	Hot / Wet	Hot / Dry
		HadGEM2-ES	GFDL-CM3	HadGEM2-ES	GFDL-CM3	HadGEM2-ES	GFDL-CM3
1	Kumarapalayam	2.27	2.39	2.44	2.96	4.13	4.30
2	Mangalapuram	2.27	2.38	2.39	2.95	4.12	4.30
3	Namakkal	2.28	2.39	2.39	2.96	4.13	4.30
4	Rasipuram	2.28	2.39	2.39	2.96	4.13	4.30

(Source: Compiled by investigator based on secondary data)

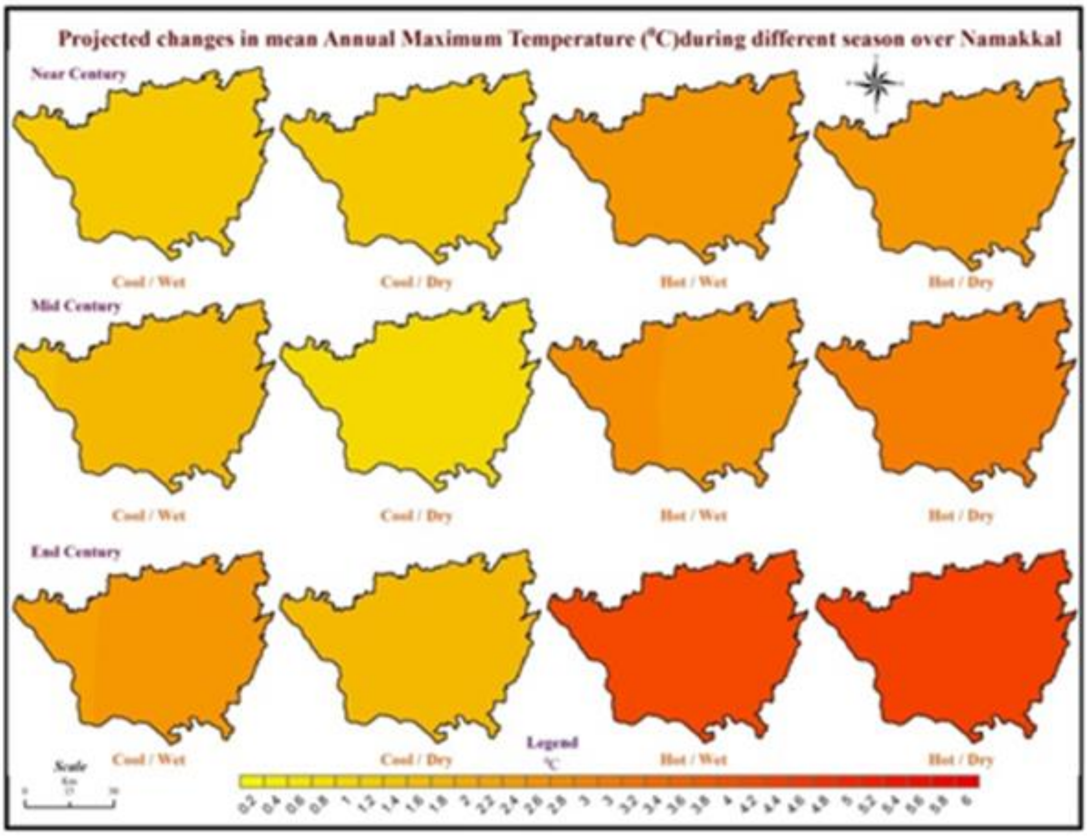

Fig. 3 Projected Mean annual Maximum Temperature for Near, Mid and End Century.

Projected Minimum Temperature: Annually, the district projected an increase of 2.9°C of temperature during the near century by both models. But in mid-century, HadGEM2-ES projected 3°C and GFDL-CM3 projected 2.9°C. During the end century, mean temperature rise was projected as 5.2°C and 4.7°C by HadGEM2-ES and GFDL-CM3 respectively (Fig. 4).

Projected Rainfall: Annual rainfall was projected to vary between increases of 8.38 percent (GFDL-CM3) to an increase of 35.46 percent (HadGEM2-ES) by RCP 8.5. HadGEM2-ES (Hot-Wet) had above 30, 20 and 47 percent increase over all the grids during near, mid and end centuries. During hot dry (GFDL-CM3) had above 10, 10 and 30 percent increases in all the grids during near, mi mid and end century (Fig.5).

DSSAT yield projection: The maize yield deviation is drastically changed and shows a negative deviation during Hot/Dry conditions in all the locations and the deviation was - 16 to - 1 with an average of - 8 percent. Forcing Hot/Wet scenario model showed a deviation in maize productivity by - 10 to + 8 percent at different locations with an average of - 3 percent for near-century (Table 3.). The deviation is negative in all the locations during Hot/Dry and Hot/Wet periods for the mid and end century (Fig.6).

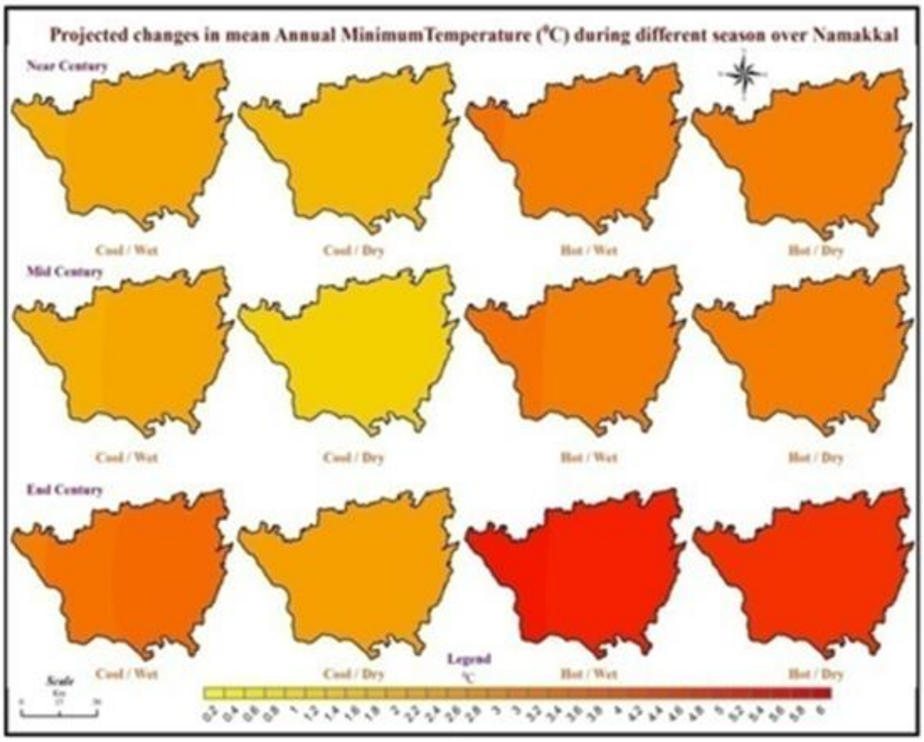

Fig. 4 Projected Mean annual Minimum Temperature for Near, Mid and End Century.

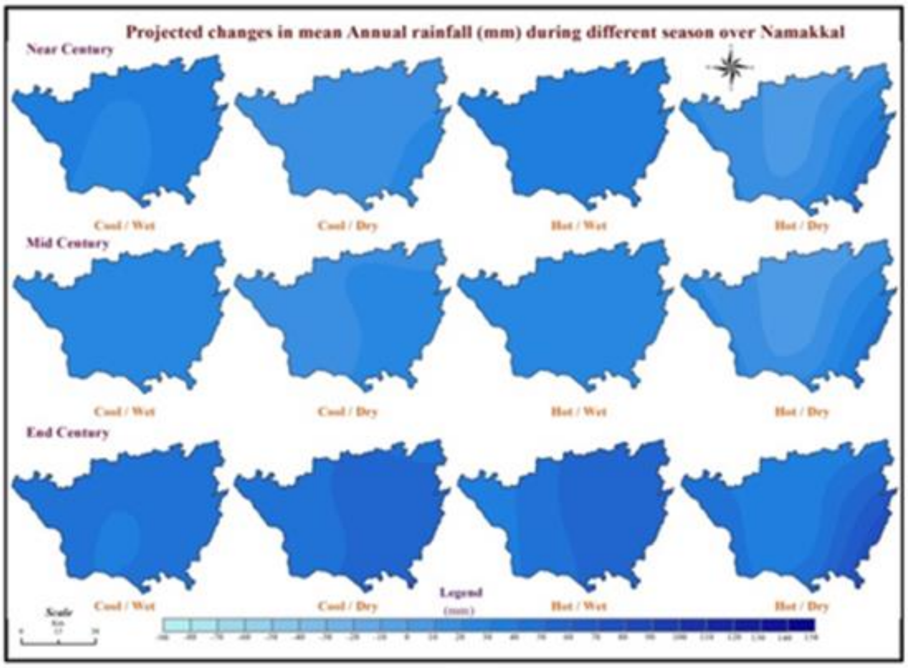

Fig. 5 Projected Mean rainfall for Near, Mid and End Century.

Table 3 Annual Projected Temperature, Rainfall and Maize yield over Namakkal district.

Century	Climate Models	Max. T°C	Min. T°C	Rainfall (%)	Yield (%)
Near	HadGEM2-ES	2.28	2.94	34.95	-2.75
	GFDL-CM3	2.39	2.9	13.66	-8.0
Mid	HadGEM2-ES	2.40	2.99	23.83	-9.25
	GFDL-CM3	2.96	2.85	11.60	-14.75
End	HadGEM2-ES	4.13	5.19	47.77	-18.0
	GFDL-CM3	4.30	4.65	38.23	-22.5

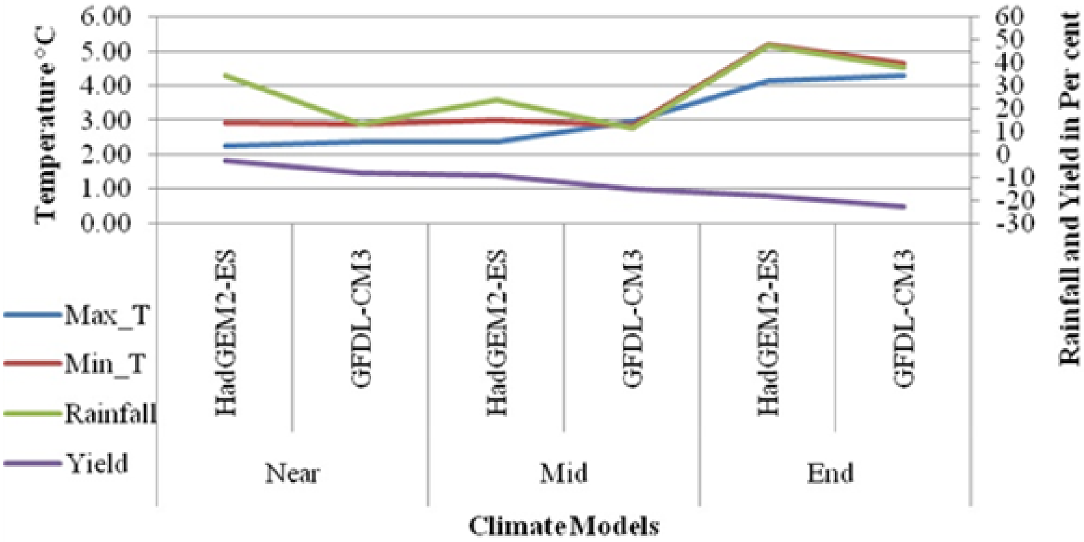

Fig. 6 Graphical representation of Yield with respect to climate models.

Conclusion

The future climate of the district and its impact on maize crops are studied using HadGEM2-ES and GFDL-CM3 climate models. The results are projected for annual, indicating that, ups and downs are noticed during near and mid-century annual rainfall over the study area. There is a steady-state increase in temperature is predicted by both the models for maximum and minimum temperature over the district annually. The influence of climatic conditions over maize crops indicates a negative impact in all the locations and the rainfed maize is adversely affected by the changing climate. Change of sowing date based on the local condition to be addressed. Crop rotation diversity, appropriate fertilizer application (Split application) should be carried out effectively. Climate resilient hybrid varieties should be developed to adopt the future changing climate. A micro-level study will be much helpful to the department of agriculture officials for planning the better sowing window to achieve better yield in rainfed maize cultivation.

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