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Research Journal of Agricultural Sciences
An International Journal

P- ISSN: 0976-1675
E- ISSN: 2249-4538

Volume: 12
Issue: 06

Res. Jr. of Agril. Sci. (2021) 12: 2007–2011

CARAS

Res. Jr. of Agril. Sci. (Nov-Dec 2021) 12(6): 2007–2011
www.rjas.org

Full Length Research Article

The Relationships of Climate Variability and Crop Production: An Analysis of the Cachar District of Assam, India

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Received: 05 Aug 2021 | Revised accepted: 15 Oct 2021 | Published online: 10 Nov 2021

ABSTRACT

The primary goal of this research is to explore the impact of climate change on major crop production in Assam's Cachar district. The study examines the trends of rainfall and temperature in the district over the period of 1981-2019. The study also investigates the trends in the major crop production over the period 1981-2017. Mann-Kendall test has been used to detect the trend in the series and Sen's slope test has been performed to evaluate the magnitudes of trends. The strength of the relationship between agricultural output and climate variability was measured using Pearson's correlation coefficient. The study finds that average annual temperature maximum is showing a significant decreasing trend whereas average temperature minimum and rainfall series are showing significant positive trends. Rice production and maize production are showing significant positive trends whereas rapeseed and mustard production is showing a significant negative trend. Climate variables have distinct effects on the production of different crops, according to the study. The rice and maize production are negatively correlated with temperature maximum whereas rapeseed and mustard production is positively correlated. The minimum temperature has a significant positive correlation with rice and maize productivity. Average rainfall has significant positive correlation with rice and maize productivity, but a significant negative correlation with rapeseed and mustard production.

***Key words*: Climate variability, Crop production, Rainfall, Temperature, Trend analysis**

Climate change, according to the Inter-Governmental Panel on Climate Change, is defined as a change in climate that can be recognized by changes in the mean and/or variability of its properties over a long period of time, generally decades or longer [7]. Climate variability refers to changes in the climate's mean state and other statistics at all spatial and temporal scales, not just individual weather occurrences [15]. Because of their relationship and impact on agriculture and related industries, climate change and variability are crucial. Agriculture is the most sensitive economic sector to climate change [12- 13]. It is susceptible to climate change because all agriculture depends on acceptable temperature ranges and rainfall patterns for raising crops and livestock. Climate change reduces agricultural production in two ways: directly by causing harm to standing crops and indirectly by influencing cropping decisions [18]. Climate change impacts on agriculture have received considerable attention because it has a close relation to the food security and poverty status of a vast majority of the world [3]. It is expected to contribute significantly to future food insecurity by raising food costs and lowering food production.

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The two most important and prominent variables in climate and hydrological studies are rainfall and temperature. Any change in these two components will have a significant impact on the hydrological cycle, streamflow, and the corresponding water demand by various sectors [8]. Thus, trend detection analysis of the time series behaviour of rainfall and temperature pattern is important to understand the climate dynamics. Employing correlation analysis, a study indicates that any significant change in climatic conditions (Rainfall and temperature) will not only challenge the food production of North West India but also challenge the country's food security situation [1]. Using regression analysis, another study shows that rainfall variability is harmful to autumn and winter rice yield in Assam, India. For summer rice, it is positive but statistically insignificant [14]. Based on a systematic review, a study finds that unpredictable and decrease in rainfall reduces agricultural production in the worldwide [9]. Employing Multivariate regression analysis, it has been shown by a study that due to increase in minimum temperature during vegetative phase on observed rice yield trend is positive whereas its impact during reproductive phase is negative in Brahmaputra Valley of Assam [2]. Using OLS technique, it has been observed by a study that there is a significant negative impact of temperature on rice yield in India over the period 1966-1999 [4].

To understand the susceptibility and adaptation of regional agricultural production to climate change requires an understanding of seasonal and yearly climate patterns and their impacts on crop yield at regional scales [17]. Here, we systematically investigated climate– crop production trends and their relationships over the last few decades for major five crops in the Cachar district of Assam (a state of India). The purposes of this study are (i) To look at the trends in meteorological variables (Rainfall and temperature) and key crop production in Assam's Cachar district. (ii) To examine the district's climate-crop production correlations.

MATERIALS AND METHODS

Climatic data

Data on monthly maximum temperatures (°C), monthly minimum temperatures (°C) and monthly total rainfall (mm) for period 1981-2019 has been collected from https://power.larc.nasa.gov/data-access-viewer/ which is free to access (Retrieved on 26 July 2021). Single point dataset has been downloaded for the Cachar district (latitude: 24.8333° N, longitude: 92.7789° E).

Agricultural data

Rice, maize, wheat, sugarcane, rapeseed and mustard were chosen for this study because, according to ICRISAT data, these crops account for more than 80% of total grain output in the Cachar district. These crops' production figures (in 1000 tonnes) for the years 1981 to 2017 were collected from http://data.icrisat.org/dld/ (Retrieved on 2 September 2021).

Trend analysis

Mann-Kendall (MK) approach [11;10] was used to determine a statistically significant trend in the series. It's a rank-based non-parametric approach that works well with skewed variables and is resistant to extremes [5]. When dealing with non-normally distributed data, outliers, and non-linear trends, this technique can be used [6]. The MK test compares the null hypothesis of no trend against the alternative hypothesis of a rising or falling trend. Equation (1) calculates the MK test statistic (S).

$$S = \sum_{k-1}^{n-1} \sum_{j=k+1}^{n} sign\ (x_j - x_{k)} \qquad \text{……..……… (1)}$$

Where n is the time series length, x denotes the data point at times j and k (k>j), and equation denotes the sign function (2).

$$\text{sign}\,(x_j - x_k) = \begin{cases} +1, if\ (x_j - x_k) > 0 \\ 0, \text{ if } (x_j - x_{k)} = 0 \\ -1, if\ (x_j - x_k) < 0 \end{cases} \qquad \text{…….…. (2)}$$

If n is less than 10, the value of [S] is directly compared to Mann Kendall's theoretical distribution of S. The statistic S is considered to be asymptotically normal for n=10 or greater, with a mean E(S)= 0 and variance as follows:

$$\text{Variance: } Var(S) = \frac{1}{18}[n(n-1)(2n+5) - \Sigma_t\, t(t-1)(2t+5)] \quad \text{… (3)}$$

Where t is the size of a specific tie, and Σ_t denotes the total number of ties. A tie occurs when two samples of data have the same value, and the summation is applied to all ties. Equation (4) calculates the standard normal deviation Z.

$$Z = \begin{cases} \frac{s-1}{\sqrt{var(s)}}\ , & if\ S > 0 \\ 0, & if\ S = 0 \\ \frac{s+1}{\sqrt{var\ (s)}}, & if\ S < 0 \end{cases} \qquad \text{……..……… (4)}$$

Positive Z (c) and negative (c) represent an upward and decreasing trend during the time, respectively, where Z (c) follows a normal distribution. If [Z]> $Z_{a/2}$, at a level of significance, the null hypothesis Ho should be accepted in a two-sided trend test.

The null hypothesis is tested at a 95% confidence level in this study.

A simple non-parametric approach proposed by Sen was also used to assess the magnitude of a time series trend (Sen 1968). Equation (5) is used to calculate the trend.

$$\beta = median\left(\frac{x_j - x_k}{j-i}\right), j > i \qquad \text{……..……… (5)}$$

where β is Sen's estimate of the slope. A time series with β >0 shows an upward trend. The data series, on the other hand, shows a declining tendency with time.

Statistical software package 'XLSTAT' was used to perform the tests which works as ad –on to MS Excel.

Climate-crop production relationship

Using the XLSTATS programme, correlation coefficient analysis was used to determine the climate-crop production relationships. The strength of the link between agricultural production and climate variability was measured using Pearson's correlation coefficient. This resulted in a linear relationship. Correlation coefficients have values ranging from −1 to +1. The perfect correlation (complete dependency) between two variables is represented by −1 or +1, while 0 denotes full independency between the variables. Equation (6) is used to calculate the correlation coefficient, where x represents the independent variable and y represents the dependent variable.

$$r = \frac{\Sigma(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\Sigma(x_i - \bar{x})^2\, \Sigma(y_i - \bar{y})^2}} \qquad \text{……..…. (6)}$$

r = coefficient of correlation
xi = values independent variable
$\bar{x}$ = mean value of x variable
yi = values dependent variable
$\bar{y}$ = mean value of x variable

RESULTS AND DISCUSSION

The trends of average annual maximum temperature (T max), average minimum temperature (T min) and average precipitation (rainfall) for the Cachar district of Assam during the period 1981-2019 have been obtained by Mann-Kendall (MK) test. In addition, the Sen's slope test is performed to determine their magnitudes. Crop production trend is also is also obtained by MK test for the period 1981-2017 as per availability of secondary data. Accordingly, climate-crop production relationships were analyzed for the period 1981-2017.

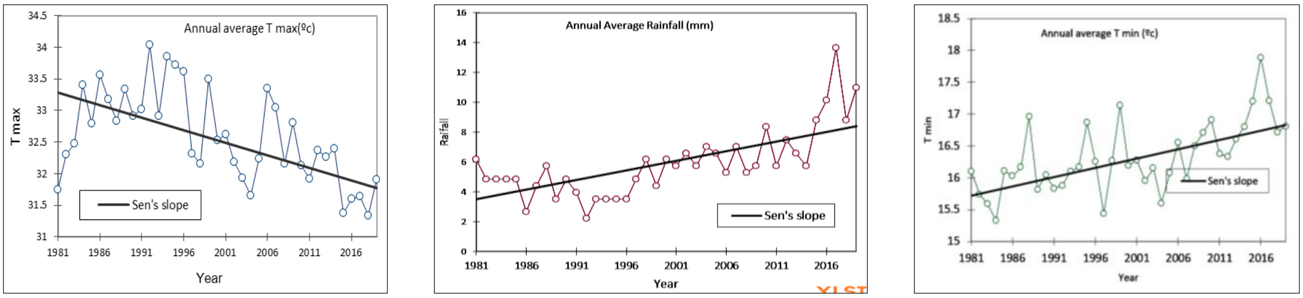
Trends in climatic variables

Trend analyses of annual average T max, T min and rainfall for the period 1981-2019 have been performed using XLSTAT software. Average annual T max is showing a significant decreasing trend whereas average T min and rainfall series are showing a significant positive trend (Table 1). The magnitudes of the trends can be seen from Sen's slope test, -0.040, 0.029 and 0.128 for T max, T min and rainfall respectively. The observed time series graph along with linear trend line is represented by (Fig 1).

Table 1 Result of the statistical test for climatic variables

Parameters	Mann- Kendall Test			Sen's slope
	S	Z	P value	
T max	-295	-0.398*	0	-0.040
T min	367	0.495*	<0.0001	0.029
Rainfall	399	0.546*	<0.0001	0.128

*Indicates values are statistically significant at 95% confidence level (α= 0.5)

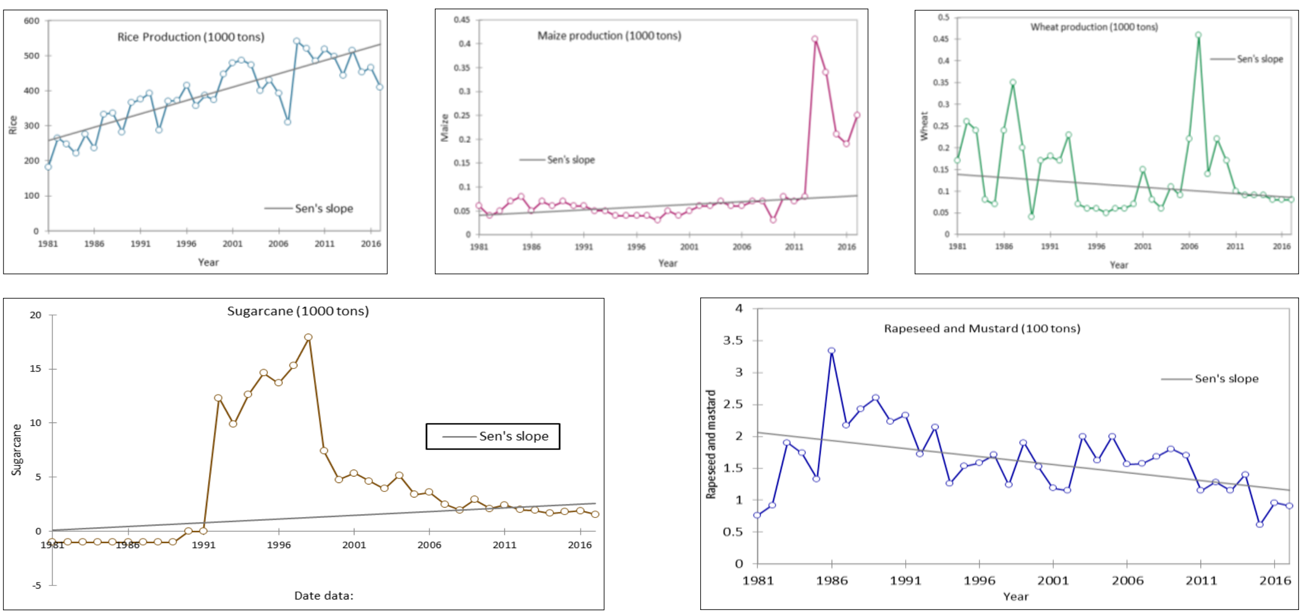


Source: Author's own calculation using secondary data from https://power.larc.nasa.gov/data-access-viewer/ (Retrieved on 26-07- 2021)

Fig 1 Observed trend line and time series graph for average climatic variables

Crop production trends

Trend analyses of rice, wheat, maize, sugarcane and rapeseed and mustard production for the period 1981-2017 have been performed using XLSTAT software. According to the statistical result rice, maize and sugarcane are showing positive trends whereas wheat and rapeseed and mustard are showing negative trends (Table 2). But trends are statistically significant only for rice, maize and rapeseed and mustard. The observed time series graph along with linear trend line is represented by (Fig 2).



Source: Author's own calculations using secondary data from http://data.icrisat.org/dld/ (accessed on 2nd September, 2021)

Fig 2 Observed trend line and time series graph for crops production 1981-2017

Table 2 Result of the statistical test for crops production

Crops	Mann- Kendall Test			Sen's slope
	S	Z	P value	
Rice	426	0.640*	<0.0001	7.621
Wheat	-93	-0.144	0.227	-0.001
Maize	211	0.339*	0.005	0.001
Sugarcane	45	0.070	0.562	0.070
Rapeseed and Mustard	-221	-0.333*	0.004	-0.025

*Indicates values are statistically significant at 95% confidence level (α= 0.5)

Climate-crop production relationship

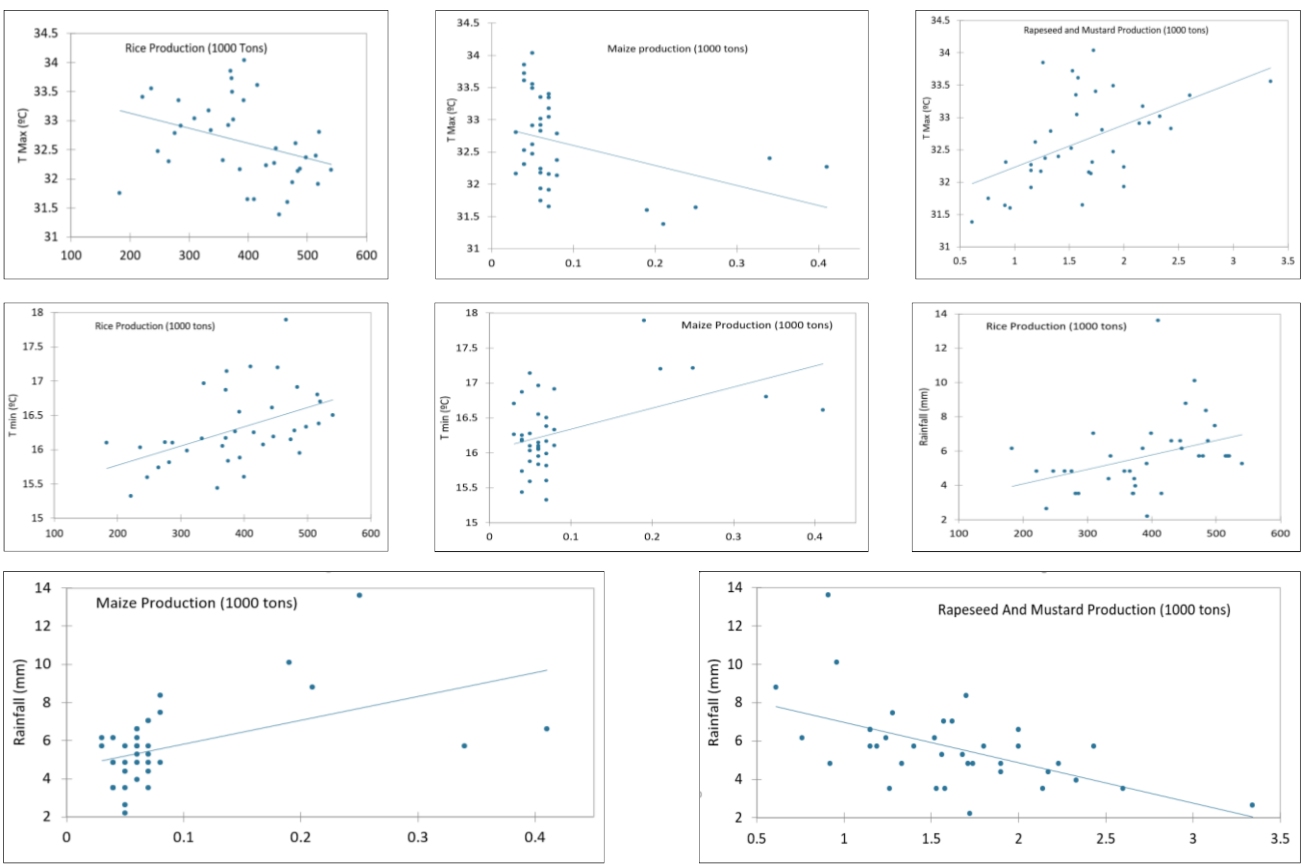
A correlation (Pearson) analysis was used to investigate the relationship between climatic variability and main crop production (Table 3). The findings show that temperature maximum has a negative link with rice and maize output, but a positive relationship with wheat, sugarcane, rapeseed and mustard production. The relationships of temperature minimum with rice and maize production are positive whereas the relationships of temperature minimum with wheat, sugarcane and rapeseed and mustard production are negative. Rainfall has positive relationships with rice and maize production whereas relationship is negative for wheat, sugarcane and rapeseed and mustard. A strong positive correlation between temperature maximum and rapeseed and mustard production (r= +0.521) and strong negative relationship between rainfall and rapeseed and mustard production (r= -0.547) are observed. The relationships of temperature maximum with rice, temperature maximum with maize, temperature maximum with rapeseed and mustard, temperature minimum with rice, temperature minimum with maize, rainfall with rice, rainfall with maize and rainfall with rapeseed and mustard production are found statistically significant (Table 3). The observed scatter plots with regression lines (which are statically significant) are presented in the (Fig 3).

Table 3 Correlation matrix (Pearson)

Variables	Rice production (1000 tons)	Wheat production (1000 tons)	Maize production (1000 tons)	Sugarcane production (1000 tons)	Rapeseed and mustard production (1000 tons)	T max (°C)	T min (°C)	Rainfall (mm)
Rice production (1000 tons)	1							
Wheat production (1000 tons)	-0.326	1					-	-
Maize production (1000 tons)	0.286	-0.195	1					
Sugarcane production (1000 tons)	0.176	-0.341	-0.248	1				
Rapeseed and mustard production (1000 tons)	-0.298	0.267	-0.353	-0.146	1			-
T max (°C)	-0.350	0.191	-0.377	0.264	0.521	1		
T min (°C)	0.478	-0.177	0.461	-0.024	-0.306	-0.253	1	
Rainfall (mm)	0.369	-0.131	0.490	-0.243	-0.547	-0.753	0.535	1

Values in bold are statistically significant with 5% significance level (alpha=0.05)

Source: Author's own calculation using secondary data from https://power.larc.nasa.gov/data-access-viewer/ and http://data.icrisat.org/dld/



Source: Author's own calculation using secondary data from https://power.larc.nasa.gov/data-access-viewer/ and http://data.icrisat.org/dld/

Fig 3 Scatter plots and regression lines of the statistically significant relationships of climatic variables and crop production

As shown in the (Fig 3), when temperature maximum decreases over the period, rice and maize production increases whereas for rapeseed and mustard production the relationship is positive. If temperature minimum increases, rice and maize production also increases. when average rainfall increases over the period of time, rice and maize production also increases whereas rapeseed and mustard production decreases. These relationships are found statistically significant at 5% level of significant (Table 3).

CONCLUSION

The variability and long-term trends of average annual temperature maximum, minimum, and rainfall for the Cachar district of Assam are examined in this research study. Rice, maize, wheat, sugarcane, rapeseed, and mustard cultivation are among the five principal crops grown in the area. Pearson's correlation analysis was used to examine the association between climate variability and main crop production. The average annual temperature maximum shows a substantial decreasing tendency, whereas the average annual temperature minimum and rainfall series indicate a significant positive trend, according to the study. For crop production trends, rice production and maize production are showing significant positive trends whereas rapeseed and mustard production is showing a significant negative trend. The results from Pearson's Correlation test indicates that temperature maximum has significant negative relationship with rice and maize production whereas a positive relationship with rapeseed and mustard production over the period 1981-2017. The temperature minimum has significant positive relationship with rice and maize production. The average rainfall has significant positive relationship with rice and maize production but a significant negative relationship with rapeseed and mustard production over the period. The findings of this study show that climatic variables have distinct effects on the production of different crops in Assam's Cachar district.

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