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RESEARCH ARTICLE

IMPACT OF CLIMATE CHANGE ON SUGARCANE PRODUCTION IN UTTAR PRADESH, INDIA: A DISTRICT LEVEL STUDY USING STATISTICAL ANALYSIS AND GIS MAPPING

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ABSTRACT

Sugarcane is a cash crop typically cultivated for sugar. Due to climate change, there is a rise in temperature, disruption in the rainfall patterns and cycle of seasons. Such changes in weather parameters affect sugarcane production as well as sugar recovery from the canes. The study was conducted in Uttar Pradesh, India using GIS (Geographic Information System) based models and statistical multiple linear regression from district-wise data on yield and climatic parameters over the study period (1986 to 2015). The GIS models reveal that climatic factors like rainfall, temperature and evapotranspiration changed significantly throughout the study. The multiple linear regression model shows that such changes in climatic parameters have a significant impact on the yield of sugarcane. Graphical analysis of yearly data on temperature and sugar recovery (%) showed that temperature affects the amount of sugar recovered from the canes. The study aims to illustrate the evidence of climate change and its impact on sugarcane production in Uttar Pradesh.

KEYWORDS

Climate change, Remote Sensing, GIS, Multiple linear regression, Sugarcane cultivation

1. INTRODUCTION

Sugarcane (*Saccharum officinarum*) is an important cash crop and the source of raw material for the second largest agro-based enterprise in India. Uttar Pradesh is the largest sugarcane-producing state having an area of about 22.77 lakh ha with the production of 135.64 million-ton canes (Farmer's portal, 2021). Climate change is a severe global environmental issue resulting in rising temperatures, variability in rainfall, and changes in the normal cycle of seasons. The latest scientific researches reveal that the earth's climate has changed significantly over the last fifty years (Balasubramanian and Birundha, 2012). The Intergovernmental Panel on Climate Change has projected that the earth's mean temperature will rise around 1.8 to 5.7 ^{o}C by 2100 (IPCC et al., 2021). These variations in temperature and rainfall patterns severely impact agriculture by exposing the plants to various abiotic stresses and reducing the economic yield. This effect is more adverse in tropical regions like India (Sathaye et al., 2006). To obtain an optimum yield in sugarcane, the maximum temperature should lie between 32-33^{o}C. Very high and low temperatures deteriorate the quality of juice that affects the sugar quality. Very few studies delineate climate change on a regional scale using modern GIS techniques and studying its impact on economically important crops like sugarcane. This study aims to illustrate the changes in maximum and minimum temperature; rainfall patterns over a period of 30 years from 1986 to 2015 using GIS techniques and further statistically analyzes its impact on the productivity of sugarcane and sugar recovery in Uttar Pradesh.

2. MATERIALS AND METHODS

2.1 Study Area

The study area (Figure 1) is the state of Uttar Pradesh located between 23°52'N and 31°28'N latitudes and 77°3' and 84°39'E longitudes (Agriculture mechanization guide for Uttar Pradesh, 2022), comprising 75 districts having a total land area of 240,928 km^2. The state shares boundaries with Rajasthan in the west, Haryana, Himachal Pradesh and Delhi to the northwest, Uttarakhand and Nepal (international border) to the north, Bihar to the east, Madhya Pradesh to the south, and the states of Jharkhand and Chhattisgarh to the southeast. There are three major agro-climatic zones in Uttar Pradesh- Middle Gangetic Plains region; Upper Gangetic Plains region; Central Plateau and Hills region. The climate is primarily subtropical; however, the weather varies significantly in different seasons at different locations. Based on the altitude, the average temperatures range between 12.5–17.5 °C in winter and 27.5–32.5 °C in summer months. The average annual rainfall is around 1,000–2,000 mm in the east to 600–1,000 mm in the west. The maximum amount of rain occurs during the Southwest Monsoon (Agriculture mechanization guide for Uttar Pradesh, 2022). The soil is generally neutral in reaction having moderate proportions of clay as well as low organic carbon content.

2.2 Collection of Data

The geo-climatic informatics of the state of Uttar Pradesh has been developed using GADM, Terra Climate and CHIRPS. Secondary data based on the official statistics published by ICRISAT on the district-wise yearly yield of sugarcane in Uttar Pradesh, precipitation, and temperature for the period 1986 to 2015 has also been used in this study. The data on the percentage of sugar recovery in different years has been obtained from Co-operative Sugar, 2021. Table 1 illustrates the variables and their corresponding data sources used in the present study.

2.3 Multiple Linear Regression Model

Multiple linear regression is a statistical tool used for predicting the

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relationship between a continuous dependent variable and two or more independent variables. The independent variables are either continuous or categorical (dummy). It is helpful in studying the effects or impacts of changes, i.e. it denotes the rate of changes in the dependent variable corresponding to the changes in the independent variables. The model assumes that:

- There should be a normal distribution of the regression residuals.
- The relationship between the dependent variable and the independent variables is linear.
- The residuals are homoscedastic and approximately rectangular-shaped.
- There is the absence of multicollinearity, that is, independent variables are not too highly correlated.

This study considers the major climatic factors affecting the yield of sugarcane, namely annual rainfall and mean annual temperatures (maximum and minimum). District-wise yearly yield of sugarcane was taken as the dependent variable while annual rainfall and annual mean maximum and minimum temperatures were taken as independent variables. A multiple linear regression model was formulated following the ordinary least squares procedure, expressed as:

Yield = f (Max. temperature, Min. temperature, Annual rainfall)

Yield: District-wise annual yield of cotton.
Max. temperature: Average of the monthly maximum temperatures of a district for a year.
Min. temperature: Average of the monthly minimum temperatures of a district for a year.
Annual rainfall: Sum of monthly rainfalls of a district for a year.

Softwares like Microsoft Office Excel and STATA were used to run the model and descriptive statistics. It is evident that even when the independent variables are zero there can be some amount of sugarcane yield due to irrigation and other factors. Thereafter, the model needs a constant. Hence, it becomes:

$$yield = \alpha_0 + \alpha_1 (max.\ temperature) + \alpha_2 (min.\ temperature) + a_3 (rainfall)$$

Where : α_0, is the constant;
α_1, α_2, a_3 are the contribution coefficients to be estimated.
rainfall: annual rainfall
max. temperature: annual maximum temperature
min. temperature: annual minimum temperature
yield: district-wise yield of sugarcane per year

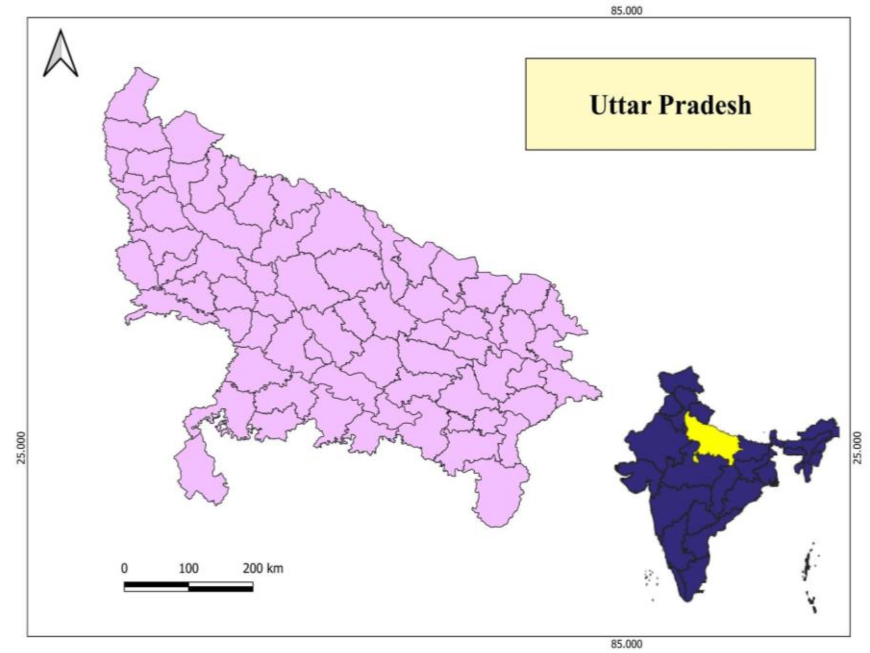

Figure 1: Study area (Uttar Pradesh, India).

Table 1: List of Variables and Data Sources.		
Variables	**Data Source**	**Time Period**
District level map of Maharashtra	GADM (https://gadm.org/)	-
Maximum and Minimum Temperature	Terra Climate (http://climateengine.org/data) ICRISAT [District-wise] (http://data.icrisat.org/dld/src/crops.html)	1986-2015
Precipitation	Terra Climate (http://climateengine.org/data) ICRISAT [District-wise] (http://data.icrisat.org/dld/src/crops.html)	1986-2015
Yield of Cotton	ICRISAT [District-wise] (http://data.icrisat.org/dld/src/crops.html)	1986-2015
Sugar recovery (%)	Co-operative Sugar Vol.53, NOVEMBER 2021 Updated November 2021; Vol. 53, No.3. (Published in Cooperative Sugar)	1986-2015

3. Results and Discussion

Temperature is an important parameter regulating plant growth, development and sugar content of canes. The optimum range of temperature needed for biochemical and metabolic activities in plants is called the thermal kinetic window (TKW) (Burke et al., 1988). Temperatures above or below the TKW result in stress that limit plant growth and yield. The TKW range for sugarcane is 30-34^0 C (Machado, 1987). 32 to 33 °C is optimum for germination of the stem cuttings. It slows down below 25° (Galdos et al., 2009). Figure 2a and Figure 2b illustrate the changes in the temperature in Uttar Pradesh across the study period (1986-2015) by taking into account data obtained from Terra Climate. It is observed that even though there were fluctuations in the maximum and minimum temperatures, it showed an increasing trend.

Besides temperature, rainfall is also an essential factor affecting the yield of crops. The annual rainfall should be 1100-1500 mm for perennial cash crops like sugarcane. Around 1200 mm of evenly distributed rainfall is sufficient for a higher yield (Srivastava and Rai, 1970). The ripening period requires less rainfall in order to have good quality juice hence better sugar recovery, less vegetative growth and reduced tissue moisture. Heavy rainfall may lead to disruptions of these conditions. In course of time, the rainfall has become erratic (Figure 3). In some parts, there is a scarcity of rain leading to moisture stress; in others there are excessive downpours, hampering economic yield.

Statistical analysis of yield and climate data using multiple linear regression reveals the extent of such variability in climatic factors projects on sugarcane production. Table 2 delineates the model output which shows that the F value is about 144.65 and significant at $P < 0.001$. Hence the null hypothesis (H_0) has to be rejected. Therefore, a statistically significant relationship exists between the dependent and the independent variables.

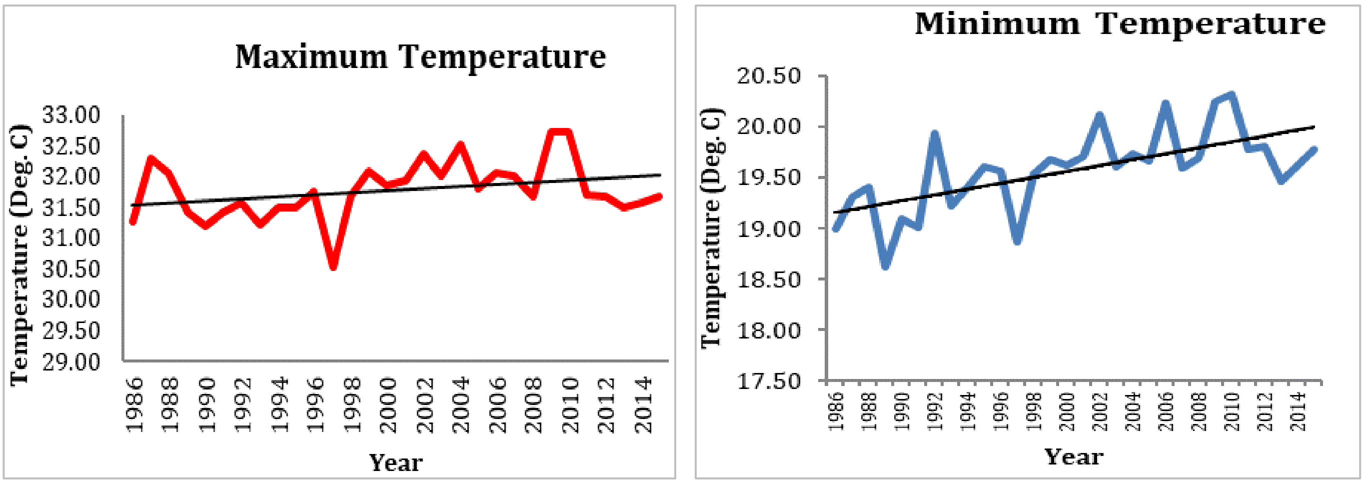

Figure 2: Temperature in Uttar Pradesh from 1986 to 2015 (a) Maximum temperature, (b) Minimum temperature

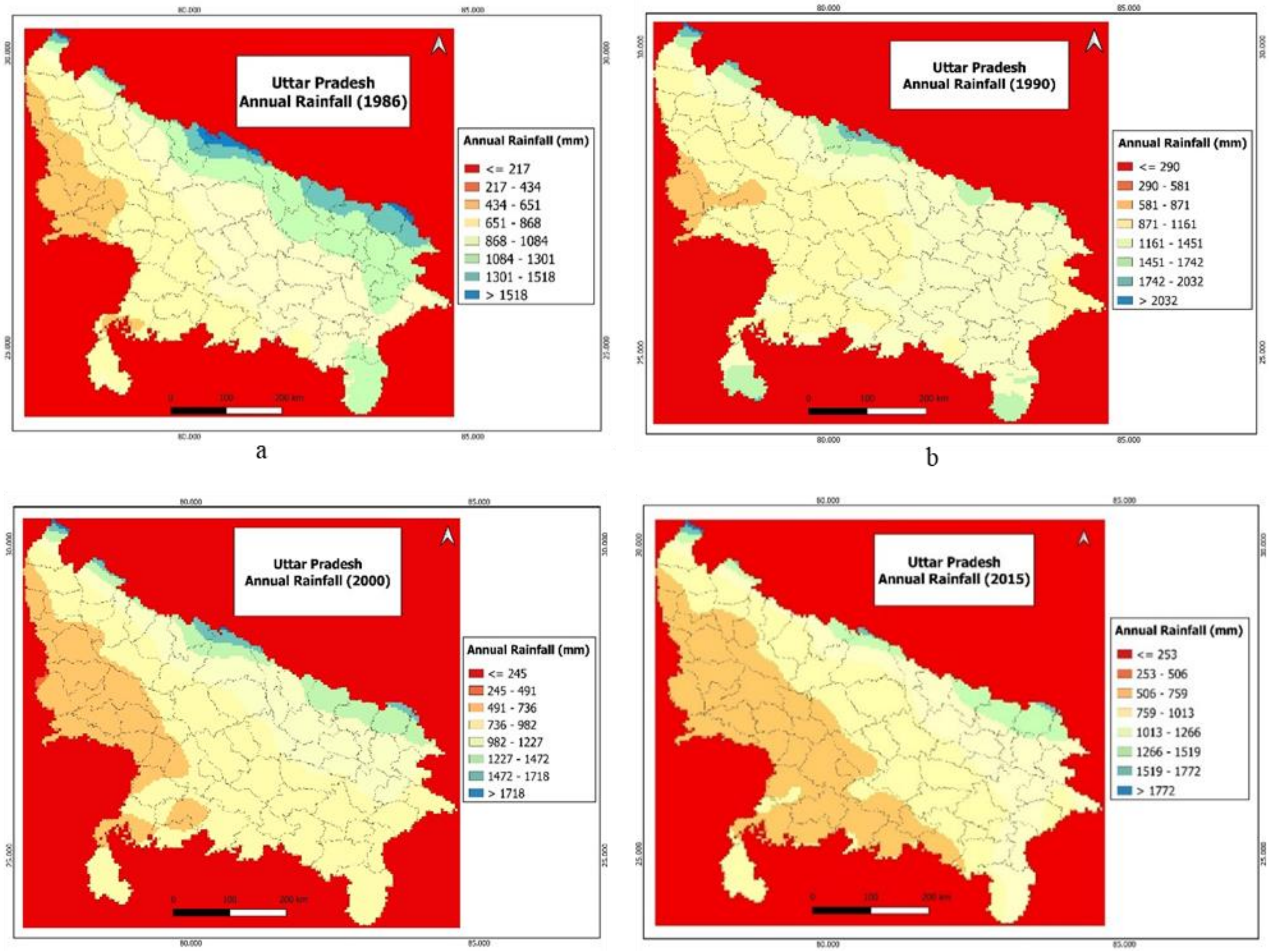

Figure 3: Spatial distribution of annual rainfall in Uttar Pradesh (a) 1986, (b) 1990, (c) 2000, (d) 2015.

Table 2: Model outputs: Relevance of the equation ANOVA[a]

Model	SS	DF	MS	F
Regression	326155295	3	108718432	144.65
Residual	989115596	1,316	751607.596	
Total	1315270891	1,319	997172.776	

a. Dependent variable: Yield of cotton

From Table 3, the value of the multiple correlation coefficients is 0.4980. R≈ 0.50 indicates that the data set is well adjusted to the model so far the study is concerned. The value $R^2 \approx 0.25$ depicts that the independent variables explain around 25% of the variability of the model. The value of adjusted $R^2 \approx 0.25$. It infers the robustness to be about 25% even if another sample from the same population is considered.

Table 3: Model's Output Summary[a]

Number of observations	R	R-squared	Adjusted R-squared	Root MSE
1,320	0.4980	0.2480	0.2463	866.95

a. Dependent variable: Yield of cotton

Table 4: Model outputs: Regression Coefficients.

Model		Non-Standardized Coefficient		Standardized Coefficient	t	P-value
		A	Standard Error	Beta		
1	Max. Temperature	-662.5485	42.24163	-0.6123202	-15.68	<0.001
	Min. Temperature	194.8139	52.63412	0.1426535	3.70	<0.001
	Annual Rainfall	-0.2217234	0.0806665	-0.0673141	-2.75	0.006
	Constant	22570.12	855.8335		26.37	<0.001

From Table 4, the following results can be derived:

The last column implies that all coefficients except that of annual rainfall are significant with a p-value <0.001 and the coefficients for annual rainfall are significant at a p-value of 0.006. Therefore, there is a significant contribution of the independent variables for the explanation of the variability of the model (Pendergrass et al., 2017; Tabari, 2020). The standardized coefficients of "Max. Temperature" and "Annual Rainfall" contribute negatively to the explanation of yield variability with an approximate relative weight of 61.2% and 7 % respectively. On the other hand, the standardized coefficient for minimum temperature contributes positively with a relative weight of 14.3%. As per the non-standardized coefficients (A) the regression line can be reconstructed as

Yield = 22570.12 - 662.5485(max. temperature) + 194.8139(min. temperature) - 0.2217234(rainfall)

The model output confirms the results of previous studies on factors affecting sugarcane yield variability. The residual plots for temperature and rainfall also reveal that the residual values are symmetrical to the origin and close to the line of zero, which suggests that the model fits perfectly (Figure 4a, Figure 4b and Figure 4c). It is to be noted that the model explains more than 61.2 % of yield variability and production, technology explains the rest (Rasheed et al., 2011). From Figure 5a and Figure 5b it is evident that higher temperature corresponds to lesser sugar recovery (Rasheed et al., 2011). This may be because temperatures beyond 32 °C lead to more number of nodes, shorter internodes, higher stalk fiber, therefore, lower sucrose (Bonnett et al., 2006). If night temperature is higher, there is more number of flowering which in turn hampers the internodal vegetative growth resulting in lesser cane yield and sucrose content (Clowes and Breakwell, 1998).

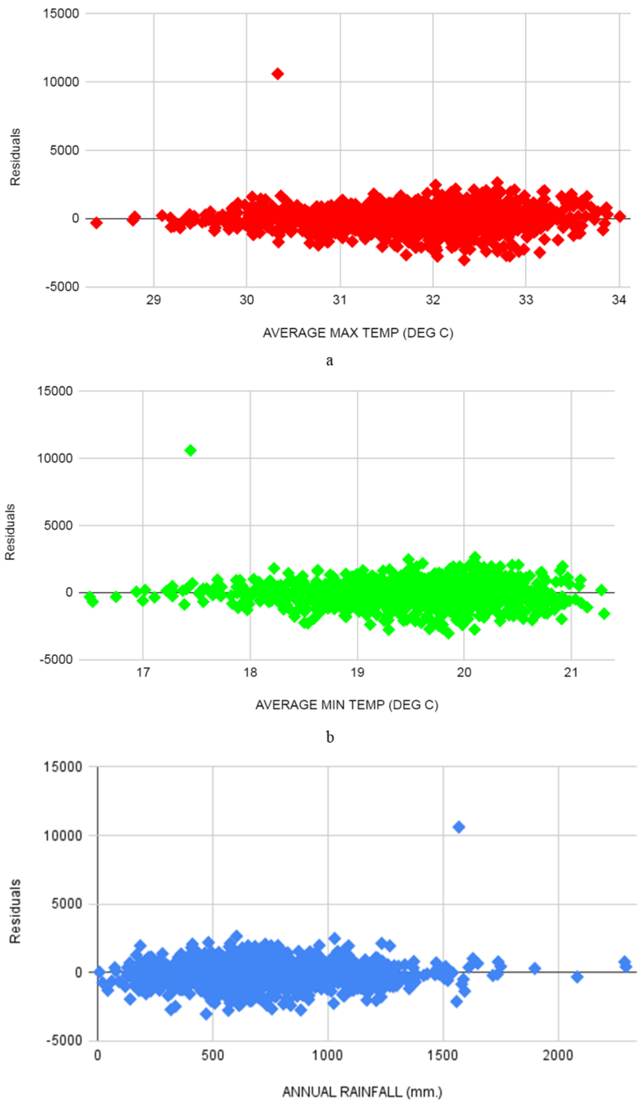

Figure 4: Residual plot (a) Maximum temperature; (b) Minimum temperature and (c) Annual rainfall.

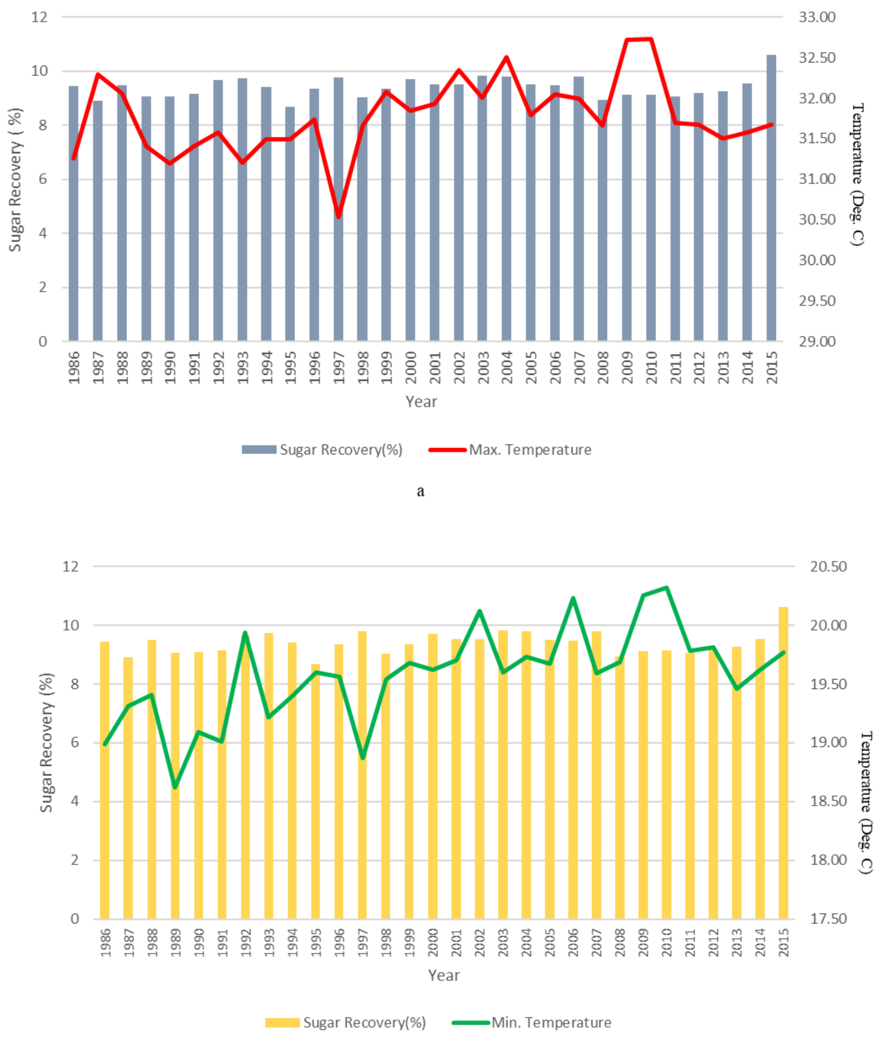

Figure 5: Sugar recovery in relation to (a) Maximum temperature; (b) Minimum temperature.

4. Conclusion

Our earth's climate is changing slowly yet steadily due to both natural and anthropogenic factors. GIS modeling and mapping of a place over a certain period of time provide evidence of changes in the spatial distribution of rainfall and temperature. Such changes affect crop production considerably. Especially the production of cash crops like sugarcane is hampered significantly if temperature and rainfall go beyond the optimum. Higher temperature and higher rainfall during ripening lead to reduced sucrose content. The study reveals that a large section of sugarcane production in Uttar Pradesh, India is affected by the changing climate. The regression analysis shows that the results illustrate a significant linkage between independent variables, such as temperature, rainfall and the dependent variable, sugarcane yield. From the study, it has been found that a 1% rise in maximum temperature may cause a 61.2% decrease in sugarcane yield.

However, 1% rise in minimum temperature might increase the cane yield by 14.2%. Again, higher maximum and minimum temperatures reduce sucrose content thereafter affecting sugar recovery. Furthermore, the result shows that only a 1% increase in rainfall may result in a 7% decrease in yield. The reason behind this observation is that precipitation variability increases with the rise in temperature, which reduces the economic yield of the crop. This means that the incidence of extreme precipitation events increases as global warming increases. Therefore, at some places, there is heavy rainfall while others are experiencing drought. Nevertheless, such differences are not discrete. Temperatures have a higher coefficient than others, suggesting that hot seasons are more frequent and have a greater impact on yield. Hence, it is important to constantly monitor climate variability, minimize anthropogenic factors responsible for global warming. Agriculturists must come up with climate-resilient varieties and promote climate-smart agricultural practices to escalate crop production and ensure economic benefit of the farmers.

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Declaration of Interest Statement

The authors declare that they have no competing interest.

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