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PROJECTED SUGARCANE YIELD IN DIFFERENT CLIMATE CHANGE SCENARIOS IN INDIAN STATES: A STATE-WISE PANEL DATA EXPLORATION

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Abstract

This study investigates the impact of climatic factors on sugarcane yield in 19 Indian states. Cobb-Douglas production function model was used to estimate the regression coefficients of explanatory variables with sugarcane yield using state-wise panel data during 1970-2017. Thereupon, it estimates the marginal change in sugarcane yield as 1 unit increase in climatic factors using marginal impact analysis technique. It was also projected sugarcane yield across Indian states for different years (i.e. 2040s, 2060s, 2080s and 2100s). Empirical results shows that area sown and value of production per hectare land have a positive implication on sugarcane yield. Climatic factors such as annual average maximum temperature, annual actual rainfall and precipitation show a negative impact on sugarcane yield. Sugarcane yield, therefore, decreases as increase in annual average maximum temperature, and annual actual rainfall and precipitation. Results based on marginal impact analysis technique imply that sugarcane yield is expected to be declined by 1.51% due to one-unit change in climatic factors in India. Estimates demonstrate that marginal impact of climatic factors on sugarcane yield was significantly varied across Indian states due to extreme diversity in climatic factors, geographical location, irrigation facilities, natural resources, farm management practices, use of advance technologies and fertilizer in sugarcane farming, agricultural development policies and agricultural R&D. Results imply that sugarcane yield is likely to be declined by 3.84%, 4.69%, 5.55% and 6.62% in different climate change scenarios in India. Thus, it would create extensive problems for sugarcane farmers, agricultural labours, sugar industries, consumers and government in India.
Keyword: *Agricultural development; Climate change; Food security; Farmers; India; Projection; Rural development.*
JEL Codes: *C23; C53; F64; J43; N50; O13; Q00; Q10; Q18; Q40.*

1. Introduction

Climate change brought a several negative implications on food security, livelihood security, farmer's income, human health and extensive burden on government at world-wide (Zhao & Li, 2015; Kumar, 2015; Weldesilassie, Assefa & Hagos, 2015; Zulfqar et al., 2016; Ali et al., 2017; Kumar, Ahmad & Sharma, 2017; Singh & Jyoti, 2019; Kelkar, Kulkarni & Rao, 2020; Singh & Singh, 2020). Thus, climate change is a biggest challenge in 21st century (Xu et al., 2019). It is also seemed that maximum and minimum temperature, rainfall, precipitation, relative humidity, sun intensity, solar radiation, and incidences of floods, droughts, cyclones, earthquakes, natural disaster are fluctuated due to increase in greenhouses gases (GHGs) emissions in the atmosphere at global level (Chandiposha, 2013; Kumar & Sharma, 2013; Zhao & Li, 2015; Zulfqar et al., 2016; Ali et al., 2017). Furthermore, the impact of climate change is appeared in term of change in mean temperature, rainfall pattern during summer, dry spells and hot extremes which are caused to decrease the quantity and quality of natural resources (i.e. land, water and forestry) (Shukla & Yadav 2017; Kumar, Singh & Sharma, 2020). Furthermore, previous studies have claimed that all sectors of a country are adversely affected due to climate change (Cabas, Weersink & Olale, 2010; Kumar, Ahmad & Sharma, 2017).

Agricultural activities heavily depend upon climatic condition of a geographical region. Therefore, climatic condition plays a significant role to increase the yield of crops (Kumar, 2015; Kumar, Sharma & Ambrammal, 2015; Kumar, Sharma & Joshi, 2015; Singh & Jyoti, 2019; Singh, Issac & Narayanan, 2019; Kumar, Singh & Sharma, 2020). However, high fluctuation in climate factors have a negative impact on crop growth and agricultural production as well. Several studies have found that crop production and yield are negatively associated with climate change across countries. Nevertheless, the impact of climate change on yield varies across crops in different countries or regions or zones or states. Therefore, impact of climate change on yield and production of crops will be unequal at world-wide (Kumar, 2015). As most developing countries have low economic ability to mitigate the negative impact of climate change. These group of countries have high dependency of population on agricultural sector, and illiteracy with low technological skills and extreme poverty, low spending on agricultural R&D, insignificant agricultural development policies and ineffective mechanism towards protection of ecosystem services (Singh et al. 2010; Kumar, 2015; Kumar, Sharma & Joshi, 2016; Kumar Ahmad & Sharma, 2017; Ali et al. 2017; Singh, Issac, and Narayanan, 2019). Thus, it is possible that socio-economic activities of farming community will be in high risk due to climate change in developing economies.

As sugarcane is a most important commercial crop which grow in most economies of the world. Brazil, India, China, Thailand, Pakistan, Mexico, Indonesia, Philippines, Australia and Argentina are in the top ten sugarcane producing countries of the world (Shukla et al., 2017; Singh, Issac & Narayanan, 2019). Brazil have largest cropped area under sugarcane farming and it is a largest sugar producer of the world. Sugarcane crop requires around a year from sowing time to harvesting time and it bears weather impact in all the seasons, thus, this crop is highly climate sensitive (Srivastava & Rai, 2012). High temperature has a significant impact on physiological process and it cause to increase weeds in sugarcane crop (Zulfqar et al. 2016). Lower temperature also has an adverse impact on sugarcane plant. High fluctuation in rainfall pattern during sowing, growing and harvesting time have a negative impact on growth of plant, juice quality and yield of sugarcane crop respectively (Kumar, 2015; Kumar, Sharma & Ambrammal, 2015). In aforesaid perspectives, existing literature have concluded that sugarcane production and yield would be declined due to climate change in most countries. However, the climate change impact on sugarcane farming would be higher in developing economies as compared to developed countries (Singh et al. 2010; Zhao and Li, 2015). Sugarcane yield is likely to be declined due to increase in temperature, precipitation, rainfall, soil moisture, length of growing seasons and extreme variations in drought and floods (Weldesilassie, Assefa & Hagos, 2015).

For instance, Deressa, Hassan and Poonyth (2005) have detected that sugarcane production is decreased due to climate change in South Africa. Binbol et al. (2006) have evaluated the effect of climate change on growth and yield of sugarcane in Nigeria. It is observed that climatic factors have a significant impact on sugarcane yield. Chandiposha (2013) have noticed that climate change has a negative impact on sugarcane crop in Zimbabwe. Marin et al. (2013) have examined the climate change impact on sugarcane yield, water use efficiency and irrigation requirement in Brazil. Zhao & Li (2015) have reported that sugarcane production may be in worsen position after 2050s at world-wide. Weldesilassie, Assefa and Hagos (2015) have found that sugarcane yield is expected to be decreased due to climate change in Ethiopia. Ali et al. (2017) have examined the impact of maximum and minimum temperature, rainfall, relative humidity, and sunshine days on sugarcane yield in Pakistan. It found that maximum and minimum temperature show positive impact, while rainfall and sunshine show a negative impact on sugarcane yield. Khatian et al. (2017) have perceived the positive impact of rainfall and temperature on sugarcane production in Hyderabad (Pakistan). Shukla & Yadav (2017) have claimed that there would be a critical challenge to maintain the sugarcane production in presence of climate change in largely agrarian economies. Taha and Zohry (2018) have witnessed that sugarcane production is projected to be declined by 14% due to climate change and water requirement for irrigation is expected to be increased by 17% by 2040s in Egypt.

In India, several studies have measured the impact of climate change on sugarcane yield, cropped area and production at national, state and district level. For example, Subbaramayya and Kumar (1980) have assessed the impact of maximum and minimum temperature and relative humidity on sugarcane yield in Andhra Pradesh. It perceived that weather factors have a profound effect on sugarcane yield. Kumar (1984) have also noticed that annual average maximum and minimum temperature, and relative humidity show a significant effect on sugarcane yield in Andhra Pradesh. Ramulu (1996) have examined the influence of annual rainfall on cultivated area of sugarcane crop in Andhra Pradesh. It observed that rainfall does not show a significant impact on acreage of sugarcane crop.

Kumar et al. (2004) have examined the relationship of sugarcane production with rainfall in UP, Maharashtra, Gujarat, AP, Karnataka, and Tamil Nadu. It concluded that monsoon rainfall was significantly correlated with sugarcane production. Srivastava & Rai (2012) have found that sugarcane crop is highly sensitive due to change in temperature, rainfall and solar radiation. Further, it is expected that sugarcane yield would be declined due to climate change in future. Samui et al. (2014) have assessed the importance of maximum and minimum temperature, and rainfall in sugarcane farming in Uttar Pradesh and Maharashtra. It found that variation in climatic variables have a significant contribution to increase or decrease sugarcane yield. Chandran and Anushree (2016) have assessed the impact of average rainfall, average maximum and minimum temperature during monsoon, summer, autumn and winter seasons on sugarcane yield in Karnataka. It observed that rainfall in different seasons show a positive impact on sugarcane yield, and maximum temperature in autumn and minimum temperature in summer season have a negative impact on sugarcane yield. Chandran and Anushree (2016) have examined the effect of average rainfall, maximum and minimum temperature on sugarcane yield in Karnataka. It observed that rainfall show a positive, while average minimum and maximum temperature have a negative impact on sugarcane yield. Ramachandran et al. (2017) have stimulated the sugarcane yield in different climate change pathways in Tamil Nadu. It also indicates that sugarcane yield is expected to be decreased by 1.8%, 2.6% and 2.8% for the near, mild and end century periods respectively. Dubey et al. (2018) have predicted the sugarcane yield in 52 districts of India using remote sensing-based approach. Kelkar, Kulkarni & Rao (2020) have examined the influence of annual rainfall, average maximum and minimum temperature on sugarcane production in Maharashtra. It concluded that sugarcane production will be declined under RCP4.5 scenarios of climate change. Further, it found that sugarcane production may be declined by 40–80% in 2040s and by 60-90% in 2080s. Sonkar et al. (2020) have detected that sugarcane yield is projected to be declined due to increase in temperature and water stress in Northern India.

Moorthy, Buermann and Rajagopal (2012) have examined the effect of temperature and precipitation on sugarcane yield in India. It found significant impact of climatic factors on sugarcane yield. Kumar & Sharma (2013) have measured the influence of annual actual rainfall, average maximum and minimum temperature on sugarcane yield in India. It observed that maximum temperature and annual actual rainfall show a negative impact on sugarcane yield. Kumar & Sharma (2014); Kumar, Sharma & Ambrammal (2015) have also examined the influence of climatic and non-climatic factors on sugarcane yield in India. It uses average rainfall, average maximum and average minimum temperature during rainy, winter, and summer seasons. It found that average maximum temperature in summer and average minimum temperature in rainy seasons showed a negative impact on sugarcane yield. Guntukula (2019) have assessed the impact of actual rainfall, average maximum and minimum temperature on sugarcane yield in India. It found that 80% variation in sugarcane yield depends upon climatic factors. Praveen & Sharma (2019) have assessed the impact of climate change on sugarcane yield in India. It observed a positive impact of rainfall and mean temperature on sugarcane yield. Singh, Narayanan & Sharma (2019) have projected the impact of average maximum and mean temperature, and precipitation on sugarcane production and yield during summer, spring, autumn and winter seasons in India. It found that climatic factors in different weather seasons have a negative impact on sugarcane farming. Based on aforementioned review, it can be concluded that climate change has a negative effect on yield and production of sugarcane farming in India. However, previous studies could not estimate the inter-state comparison of climate change impact on sugarcane yield in India. Furthermore, limited studies could estimate the expected sugarcane yield in different climate change scansions at state and national level. Due to aforesaid research gap, the present study is an attempt to identify the answers on following research questions:

- What is impact of climate change on sugarcane yield in Indian states?
- What would be projected sugarcane yield in Indian states in different climate change scansions?
- In which state sugarcane yield is highly vulnerable due to climate change in India?
- What would be the major challenges for farmers and policy maker if sugarcane production decreases due to climate change in India?
- What must be climate policies to mitigate the negative consequences of climate change in sugarcane farming in India?

With significance to above-mentioned research questions, this study is attained following objectives:

- To assess the impact of climatic factors on sugarcane yield in India using state-wise panel data.
- To make inter-state comparison of climate change impact on sugarcane yield in India.
- To examine the projected sugarcane yield in different climate change scenarios across Indian states.
- To provide the effective and practical policy suggestions to mitigate the negative consequences of climate change in sugarcane farming in India.

2. Research Methods and Material

2.1. Introduction of Study Area

This study was compiled the state-wise panel of yield, climatic and non-climatic variables for 19 Indian states during 1970-2017. Andhra Pradesh (AP), Assam, Bihar, Chhattisgarh, Gujarat, Haryana, Himachal Pradesh (HP), Jharkhand, Karnataka, Kerala, Madhya Pradesh (MP), Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh (UP), Uttarakhand and West Bengal were included in this study. These states contribute around 100% cropped area and total production of sugarcane in India. The area sown, production and yield of sugarcane crop for aforesaid states is presented in Table 1. State-wise cane crushed, sugar production, average crushing duration and recovery rate is presented in Table 2.

Table 1. Area sown, Total Production, Value of Production and Yield of Sugarcane in 2014

States	Area sown (in '000 Ha.)	Production (in '000 tonnes)	Yield (in Kg./Ha.)
Uttar Pradesh	2228 (44.79)	134689 (38.36)	60453
Maharashtra	937 (18.84)	76901 (21.90)	82072
Karnataka	420 (8.44)	37905 (10.80)	90250
Tamil Nadu	313 (6.30)	32454 (9.24)	103575
Bihar	258 (5.19)	12882 (3.67)	49916
Andhra Pradesh	192 (3.86)	15385 (4.38)	80130
Gujarat	174 (3.50)	12550 (3.57)	72126
Uttaranchal	104 (2.10)	5940 (1.69)	56971
Haryana	102 (2.05)	7499 (2.14)	73520
Punjab	89 (1.79)	6675 (1.90)	75000
Madhya Pradesh	73 (1.47)	3174 (0.90)	43415
Assam	29 (0.59)	1075 (0.31)	36973
West Bengal	17 (0.34)	1945 (0.55)	114273
Odisha	14 (0.29)	937 (0.27)	65905
Chhattisgarh	9 (0.17)	22 (0.01)	2600
Rajasthan	5 (0.11)	363 (0.10)	68989
Jharkhand	4 (0.08)	463 (0.13)	69215
Himachal Pradesh	3 (0.06)	36 (0.01)	23175
Kerala	2 (0.04)	222 (0.06)	100235
All India	4,974 (100)	351115 (100)	70589

Source: CMIE.

Table 2. Sugar Production, Sugar Factories and Average Crushing Duration in 2012-13

States	Cane crushed ('000 t)	Sugar production ('000 t)	Sugar factories (No.)	Average crushing duration (days)	Recovery (%)
Maharashtra	80223 (32.01)	9054 (36.01)	167	164	11.29
UP	81506 (32.52)	7485 (29.77)	122	129	9.17
Karnataka	33320 (13.30)	3467 (13.79)	60	133	10.41
Tamil Nadu	21457 (8.56)	1906 (7.58)	43	174	8.88
Gujarat	10493 (4.19)	1130 (4.49)	18	145	10.77
AP	10299 (4.11)	993 (3.95)	36	101	9.64
Haryana	5245 (2.09)	512 (2.04)	14	136	9.76
Bihar	5716 (2.28)	506 (2.01)	11	117	8.86
Punjab	4796 (1.91)	438 (1.74)	16	112	9.13
MP	1944 (0.78)	190 (0.76)	12	89	9.78
Odisha	719 (0.29)	62 (0.25)	5	80	8.62
West Bengal	54 (0.02)	5 (0.02)	1	53	9.26
Rajasthan	52 (0.02)	4 (0.02)	1	63	7.69
India	250598 (100)	25141(100)	529	127	10.03

Source: Indian Institute of Sugarcane Research (IISR). **Note:** Values in brackets show the % contribution of each state in corresponding variables in India (in Table 1 and 2).

2.2. Description and Data Sources

Production, yield, and area sown of sugarcane crop for selected states were taken from Centre Monitoring Indian Economy (CMIE) and Indian Institute of Sugarcane Research (IISR) Lucknow. Farm harvest price of sugarcane for each state was taken from Directorate of Economic and Statistics, Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare (GoI). Data of actual annual rainfall was derived from CMIE and Ministry of Statistical Programme Implementation (GoI). Maximum and minimum temperature, and precipitation were taken from GIS online data base and Indian Metrological Department (IMD) (GoI). Daily-wise data on maximum and minimum temperature and precipitation were available at district level for each state. Thus, annual average maximum and minimum temperature, and annual actual precipitation for all districts in a specific state were used for empirical investigation. Interpolation and extrapolation methods were used to complete the time series for those variables which do not had the values in middle years (Kumar, 2015; Kumar, Sharma & Joshi, 2016; Singh & Issac, 2018).

2.3. Formulation of Empirical Model

According to existing literature, crop simulation and statistical models can be used to estimate the climate change impact on crop yield in agricultural production analysis (Kelkar, Kulkarni & Rao, 2020). Crop simulation model assumes that crop growth is a function of climatic factors and soil condition. Statistical technique is based on regression models that measure the association of crop yield with climatic and non-climatic factors (Kelkar, Kulkarni & Rao, 2020). Cobb-Douglas production function approach was used to assess the impact of climatic and non-climatic factors on sugarcane yield in this study (Kumar & Sharma, 2013; Kumar & Sharma, 2014; Kumar, Sharma & Ambrammal, 2015; Singh, Narayanan & Sharma, 2019). This approach assumes that climatic and non-climatic factors may be considered as inputs for sugarcane yield (Kumar & Sharma, 2014; Weldesilassie, Assefa & Hagos, 2015). In this study, sugarcane yield and its association with climatic and non-climatic factors was specified as:

$$(LanPro)_{st} = f\{(AS)_{st}, (ValProPH)_{st}, (AAMaxT)_{st}, (AAMinT)_{st}, (AARf)_{st}, (AAPcp)_{st}, (Lat*AS)_{st}, (Lon*AS)_{st}\} \quad (1)$$

Here, *LanPro* is sugarcane yield; *AS* is cropped area under sugarcane crop; *ValProPH* is value of sugarcane production/hectare land that was calculated based on farm harvest price; *AAMaxT* and *AMinT* are the annual average maximum and minimum temperature respectively; *AARf* and *AAPcp* are actual annual rainfall and precipitation respectively; *Lat* and *Lon* are the latitude and longitude location of associated state; *s* is cross-sectional states and *t* is time period in equation (1). As previous studies have strongly suggested that Cobb-Douglas production model produce better results of regression coefficients of independent variables in crop production analysis (Cabas, Weersink & Olale, 2010; Gupta, Sen & Srinivasan, 2012; Kumar & Sharma, 2013; Kumar & Sharma, 2014; Kumar, 2015; Kumar, Sharma & Joshi, 2016; Singh, Narayanan & Sharma, 2017; Kumar, Singh & Sharma, 2020). Thus, this study was used this model to assess the impact of climatic factors on sugarcane yield. After using Cobb-Douglas production function, the aforesaid equation was used as:

$$log(LanPro)_{st} = \beta_0 + \alpha_1 (YT) + \beta_2 \, log(AS)_{st} + \beta_3 \, log(ValProPH)_{st} + \beta_4 \, log(AAMaxT)_{st} + \beta_5 \, log(AAMinT)_{st} + \beta_6 \, log(AARf)st + \beta_7 \, log(AAPcp)_{st} + \beta_8 \, log(Lat*AS)_{st} + \beta_9 \, log(Lon*AS)_{st}\} + \lambda_{st} \quad (2)$$

Here, *log* is natural logarithm of corresponding variables; *YT* is the time trend factor that was used to capture the impact of technological change on sugarcane yield (Kumar, Sharma & Ambrammal, 2015; Kumar, 2015; Ali et al., 2017; Singh, Narayanan & Sharma, 2017;

Singh & Sharma, 2018); β_0 is the constant term; $\beta_1, \ldots, \beta_9$ are the regression coefficients of associated independent variables; and λ_{st} is the error term in equation (2). The explanation of remaining variables is presented in equation (1).

2.4. Measurement of Projected Sugarcane Yield: Marginal Impact Analysis Technique

Elasticity measures the percentage change in sugarcane yield due to percentage change in a specific factor in sugarcane cultivation. It also examines the marginal change in sugarcane yield due to one-unit change in a climatic factor (Weldesilassie, Assefa & Hagos, 2015; Singh, Narayanan & Sharma, 2017). Elasticity of sugarcane yield was estimated as the regression coefficient of corresponding climatic factor that was multiplied by ratio of mean value of climatic factor with mean value of sugarcane yield (Chen, McCarl & Schimmelpfenning, 2004; Poudel, Chen & Huang, 2014; Kumar, Sharma & Ambrammal, 2015; Singh, Narayanan & Sharma, 2017). Sugarcane yield was projected using marginal impact analysis technique under different climate change scenarios (Singh, Narayanan & Sharma, 2017). For this, it assumes that maximum and minimum temperature are expected to be increased by 0.5, 0.75, 1.0 and 1.5 ^{0}C by 2040s, 2060s, 2080s and 2100s respectively. Rainfall and precipitation are likely to be increased by 4, 5, 6 and 7 mm in aforementioned years respectively (Weldesilassie, Assefa & Hagos, 2015; Kumar, Sharma & Joshi, 2016; Singh, Narayanan & Sharma, 2017; Sharma & Sharma, 2018). The expected sugarcane yield with respect to climatic factors was estimated as (Gupta, Sen & Srinivasan, 2012; Singh & Sharma, 2018):

$$\Delta LanPro = \left[\left(\frac{\delta LanPro}{\delta AAMaxT}\right) * \Delta AAMaxT + \left(\frac{\delta LanPro}{\delta AAMint}\right) * \Delta AAMinT + \left(\frac{\delta LanPro}{\delta AARf}\right) * \Delta AARf + \left(\frac{\delta LanPro}{\delta AAPcp}\right) * \Delta AAPcp\right] * 100 \quad (3)$$

Here, $\Delta LanPro$ is projected sugarcane yield, $\Delta AAMaxT$ and $AAMinT$ are increase in annual average maximum temperature and minimum temperature respectively, $\Delta AARf$ and $AAPcp$ are the change in annual actual rainfall and precipitation respectively. ($\delta LanPro/\delta AAMaxT$), ($\delta LanPro/\delta AAMinT$), ($\delta LanPro/\delta AArf$) and ($\delta LanPro/\delta AAPcp$) are the first differential coefficients of equation (2) with respect to associated climatic factors.

2.5. Process for Selection of Consistent Empirical Model

As this study was based on state-wise panel data which assess the impact of climatic factors on sugarcane yield during 1970-2017. Since, Indian states have a high diversity in socio-economic condition of farmers, geographical location, technological advancement and agricultural development policies. Therefore, it was necessary to select an appropriate form of empirical model to provide the clear justification on regression coefficient of explanatory variables. Following process were used to select a suitable model: existence of panel root test in each series of dependent and independent variables were tested using Im-Pesaran-Shin test (Poudel, Chen & Huang, 2014; Kumar, Sharma & Joshi, 2016). Estimated values under this test were found statistically significant for most variables. Estimates, therefore, show that most variables were found nonstationary. First and second difference of respective variables were considered to make time series stationary (Poudel, Chen & Huang, 2014; Kumar, Ahmad & Sharma, 2017). The Ramsay RESET test was used to identify the appropriate functional form of empirical model (Singh, 2017; Singh & Singh, 2020; Singh & Ashraf, 2020; Jyoti & Singh, 2020). Statistical results of this test were found statistically significant, thus, it proposed that log-linear functional form of empirical model was correctly specified (See Table 3).

OLS/Random and Fixed Effect Model: Ordinary least square estimation was applied to estimate the regression coefficients of explanatory variables as assuming that there was insignificant variation across Indian states (Singh, Narayanan & Sharma, 2017). Random effect model was applied to estimate the regression coefficients, while the suitability of this model was tested using Breusch-Pagan Lagrange multiplier (LM) test (Kumar, Sharma & Ambrammal, 2015; Singh, Narayanan & Sharma, 2017). The Chi^2 value under this test was found statistically significant, thus it implies that random effect model cannot be used to regression coefficients of explanatory variables (See Table 3). The $Prob > Chi^2$ was found less than 0.05, thus, it was significant. It is suggested that random effect model was appeared incorrect to estimate regression coefficients of explanatory variables. Hausman specification test was used to choose the appropriateness of fixed effect model. It basically tests whether the unique error (u_i) were correlated with the regressors or not (Singh, Issac and Narayanan, 2019; Singh & Ashraf, 2020).

Table 3. Hypothesis Testing for Selection of Proper Empirical Model

Applied Test	Sugarcane Yield	Probability
Ramsay RESET test using powers of the fitted values of sugarcane yield	$F(3, 879) = 95.58$	$Prob > F = 0.0000$
Ramsey RESET test using powers of the independent variables	$F(27, 855) = 5.06$	$Prob > F = 0.0000$
Breusch-Pagan Lagrange multiplier (LM) test for random effects model	$Chibar^2(01)=520.85$	$Prob > Chibar^2 =0.0000$
Hausman test for fixed effects model	$Chi^2(8) =77.69$	$Prob>Chi^2 =0.0000$
Pesaran's test for cross-sectional dependence	21.660	$Pr = 0.0000$
Breusch-Pagan LM test of independence	$Chi^2(171) =593.713$	$Pr = 0.0000$
Modified Wald test for heteroskedasticity	$Chi^2 (19) = 690.78$	$Prob>Chi^2 =0.0000$
Wooldridge test for serial-correlation and autocorrelation	$F(1, 18)=7.455$	$Prob > F = 0.0137$

Source: Author's estimation.

Cross-sectional Dependency: Breusch-Pagan LM test of independence was applied to check the existence of cross-sectional dependency in state-wise panel (Kumar, Sharma & Ambrammal, 2015; Singh, Narayanan & Sharma, 2017). The Chi^2 value under this test was found statistically significant at 1% significance level (See Table 3). Thus, it shows the presence of cross-sectional dependency in state-wise panel. Pesaran's test was used to check the presence of cross-sectional independency in in state-wise panel (Singh, Narayanan & Sharma, 2017). The statistical value under this was seemed statistically significant, thus it implies the presence of cross-sectional dependency in in state-wise panel.

Group-wise Heteroskedasticity: Modified Wald test was used to check the presence of heteroskedasticity in state-wise panel (Singh, Narayanan & Sharma, 2017). The *Chi-square* value under this test was found statistically significant, thus it provides a confirmation that state-wise panel have heteroskedasticity (See Table 3).

Autocorrelation: Wooldridge test is considered to recognize the presence of autocorrelation in panel (Poudel, Chen & Huang, 2014; Kumar, Sharma & Ambrammal, 2015). The *F*-value under this test was seemed statistically significant, thus it shows that panel have an autocorrelation (See Table 3).

Final Estimation: As complied state-wise panel data of this study have the cross-sectional dependency, group-wise heteroskedasticity and autocorrelation. So, ordinary square estimation, random effect model and fixed effect models were ineffective to produce the consistent regression coefficient of explanatory variables in the proposed model. For this, previous studies have claimed that Prais Winsten models with panels corrected standard errors estimation (PCSEs) model is highly effective to produce better results in presence of aforesaid statistical problems (Poudel, Chen & Huang, 2014; Kumar, Sharma & Ambrammal, 2015; Singh, Narayanan & Sharma, 2017). SPSS and STATA statistical software were used to run to proposed regression models.

3. Discussion on Descriptive Results

3.1. Statistical Summary of Variables

The statistical summary of dependent and explanatory variables is presented in Table 4. The values of standard deviation for sugarcane yield, area sown and value of production; annual average maximum and minimum temperature, and annual actual rainfall and precipitation, latitude and longitude were found greater than 1. Also, values of skewness and kurtosis for all factors were seemed greater than one. Thus, all factors were not found normally distributed. Therefore, it considered the log of all variables to convert the data in normal form.

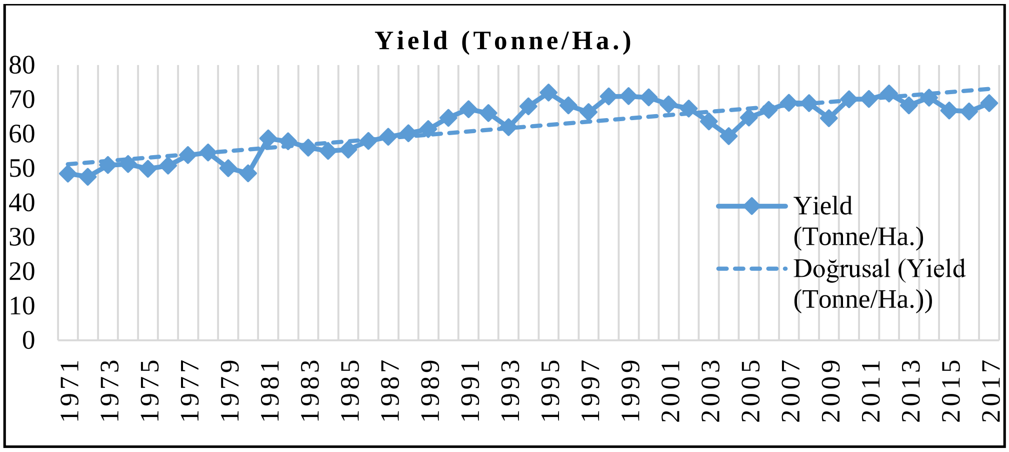
Table 4. Brief Statistical Summary of Variables

Total Obs.		912	No. of Obs./Panel		48	No. of Panels	19
Variable	Unit	Minimum	Maximum	Mean	SD	Skewness	Kurtosis
LanPro	Kg./Ha.	2355.00	134779.0	56684.1	24356.4	0.12	2.79
AS	‘000’ Ha.	1.00	2246.50	196.38	406.76	3.59	15.52
ValProPH	Rs./Ha.	816.00	355761.0	52586.9	59072.8	1.71	5.81
AAMaxT	^{0}C	21.36	34.28	30.83	2.87	-2.04	6.12
AAMinT	^{0}C	10.01	23.22	18.99	3.03	-1.62	4.90
AARf	mm	22.00	25411.00	1276.68	1567.08	10.85	143.29
AAPcp	mm	0.52	8.16	3.22	1.42	0.86	3.55
*Lat*AS*	Degrees	10.00	61554.00	4630.84	10967.8	3.90	17.47
*Lon*AS*	Degrees	76.00	179720.0	15415.3	32358.9	3.65	15.95

Source: Author’s estimation.

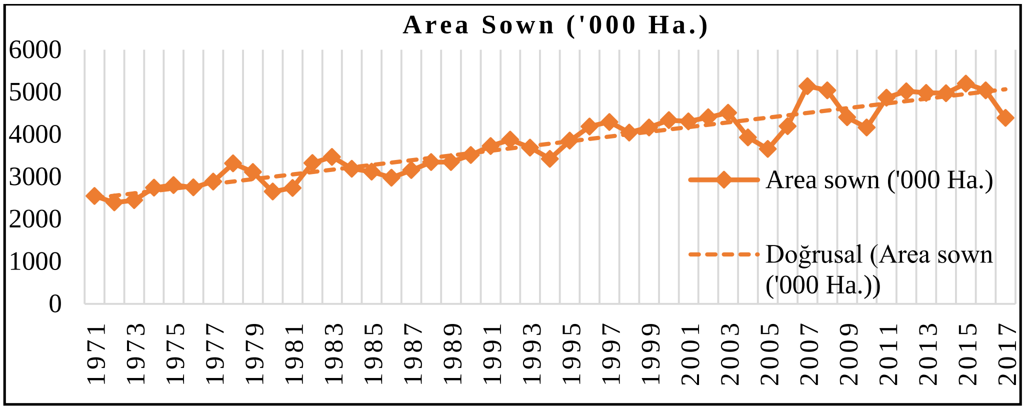
3.2. Trend in Sugarcane Yield and Climatic Factors

The tendency in sugarcane yield, area sown and value of production; annual average maximum and minimum temperature, and annual actual rainfall and precipitation for India during 1970-2017 is presented in Figure 1, Figure 2, Figure 3, Figure 4, Figure 5, Figure 6 and Figure 7 respectively. Based on linear trend in aforesaid factors, it is expected the values of these factors may be increased in India.



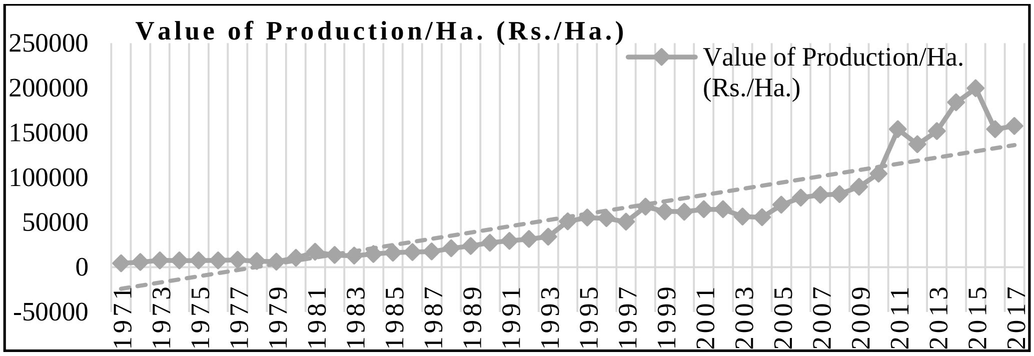
Source: CMIE.

Figure 1. Trend in Sugarcane Yield in India



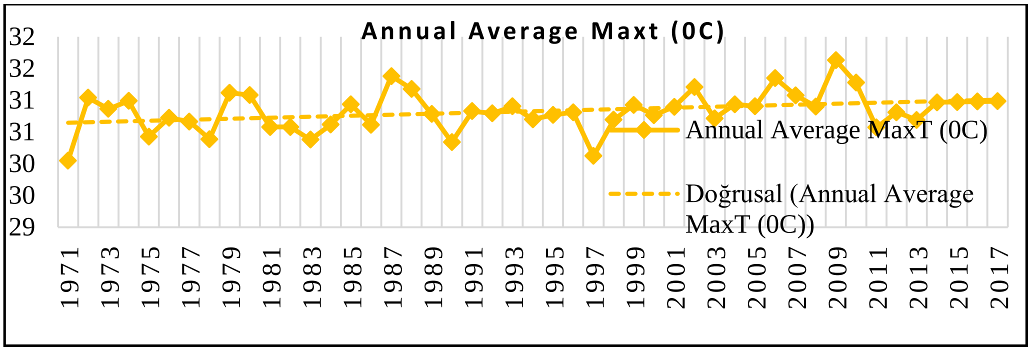
Source: CMIE

Figure 2. Trend in Area Sown of Sugarcane Crop in India



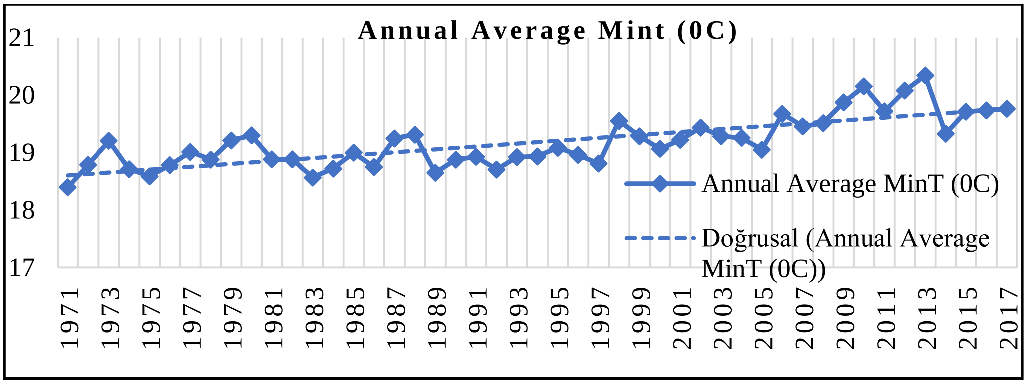
Source: Author's estimation.

Figure 3. Trend in Value of Production of Sugarcane Crop in India



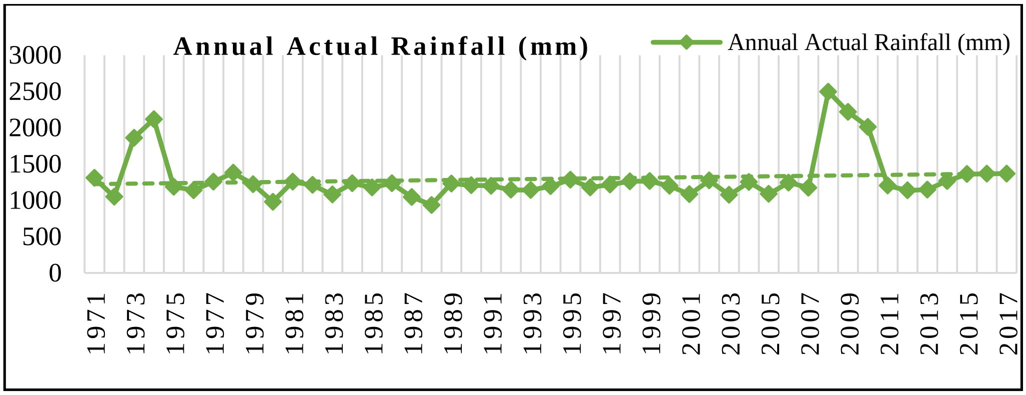
Source: GIS online data base and Indian Metrological Department.

Figure 4. Trend in Annual Average Maximum Temperature in India



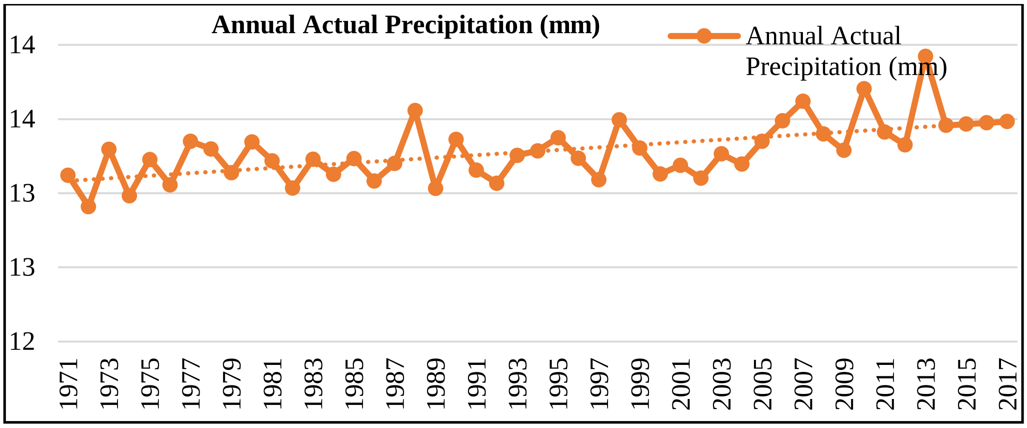
Source: GIS online data base and Indian Metrological Department.

Figure 5. Trend in Annual Average Minimum Temperature in India



Source: GIS online data base and Indian Metrological Department.

Figure 6. Trend in Annual Actual Rainfall in India



Source: GIS online data base and Indian Metrological Department.

Figure 7. Trend in Annual Actual Precipitation in India

4. Discussion on Empirical Findings

4.1. Impact of Climatic Factors on Sugarcane Yield in Indian States

Regression coefficients of time trend factor, area sown, value of production, annual average maximum and minimum temperature, and annual actual rainfall and precipitation with sugarcane yield in Indian states is presented in Table 5. Regression coefficients of time trend factors with sugarcane yield was appeared negative in Andhra Pradesh, Assam, Chhattisgarh, Gujarat, Himachal Pradesh, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Tamil Nadu and Uttarakhand. Estimates suggested that technological advancement produce a negative impact on sugarcane yield in these states. Impact of area sown on sugarcane yield was seemed negative in Andhra Pradesh, Haryana, Jharkhand, Madhya Pradesh, Punjab and Rajasthan. Thus, estimates specify that sugarcane yield was tend to be decreased as increase in area sown under sugarcane crop in these states. Regression coefficients of value of production per hectare land with sugarcane yield was perceived positive in all Indian states. Thus, estimates show that sugarcane yield improves as increase in value of production. Therefore, it is proposed that farmers should get better prices of their production to increase their intension to cultivate sugarcane crop. Further, it would be helpful to increase the economic capacity of farmers to use scientific methods in sugarcane farming. Annual average maximum temperature shows a negative impact on sugarcane yield in Andhra Pradesh, Chhattisgarh, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh and Maharashtra. While, annual average minimum temperature has a negative impact on sugarcane yield in Assam, Bihar, Haryana, Kerala and Uttar Pradesh. Impact of annual actual rainfall on sugarcane is seemed negative in Andhra Pradesh, Chhattisgarh, Haryana, Himachal Pradesh, Jharkhand, and Odisha. Furthermore, annual actual precipitation is also produced negative impact on sugarcane yield in Bihar, Kerala, and Uttar Pradesh. Here, it can be argued that impact of technological change, area sown, value of production, maximum and minimum temperature, rainfall and precipitation on sugarcane yield was varied across Indian states. Therefore, it is suggested that there is requirement to adopt a state specific climate policy to mitigate the negative implication of climate change in sugarcane farming.

Table 5. Regression Coefficients of Climatic Factors with Sugarcane Yield in Indian States

States	*Year*	*as*	*valproha*	*aamaxt*	*aamint*	*aarf*	*aapcp*	*Con. Coef.*
AP	-0.010**	-0.111*	0.180*	-1.154	1.295**	-0.142	0.170**	30.889*
Assam	-0.006**	0.159*	0.118*	1.610*	-1.522*	0.014	0.083	19.530*
Bihar	-0.007	0.110***	0.209*	2.541*	-0.819	0.038	-0.018	15.699
Chhattisgarh	-0.074*	0.031	0.713*	-2.445*	5.298*	-0.442*	0.628*	144.988*
Gujarat	-0.013**	0.173*	0.139**	0.195	0.365	0.015	0.045	33.597*
Haryana	0.004	-0.090***	0.116*	0.487	-0.130	-0.035	0.120**	1.101
HP	-0.030*	0.107	0.368*	-2.34**	2.418*	-0.084	0.119	68.429*
Jharkhand	-0.022**	-0.004	0.381*	0.619	1.422	-0.112	0.168	44.095*
Karnataka	-0.011***	0.137*	0.132**	-1.082	0.646	0.015	0.118**	31.686
Kerala	0.018*	0.023	0.019	-0.504	-116***	0.012	-0.037	-20.02***
MP	-0.010	-0.180**	0.284*	-1.264	1.203	0.183***	0.062	28.178**
Maharashtra	-0.018*	0.034	0.186*	-1.067	1.520**	0.133	0.210**	44.126*
Odisha	0.003	0.085**	0.006	0.241	1.126**	-0.13***	0.211*	1.112
Punjab	-0.013*	-0.100**	0.2307*	0.794	0.269	0.010	0.015	36.260*
Rajasthan	-0.003	-0.099*	0.127*	0.542	0.148	0.038**	0.165*	17.39***
Tamil Nadu	-0.009**	0.225*	0.100***	0.410	0.475	0.016	0.080**	24.608*
UP	0.004***	0.001	0.134*	2.160*	-2.621*	0.334*	-0.250*	0.756
Uttarakhand	-0.005	0.072	0.166*	1.075	0.596	0.010	0.025	17.203*
West Bengal	0.005	0.049	0.082	1.147	0.732	0.120	0.035	1.337

Source: Author's estimation. **Note:** *, **, and *** indicate the regression coefficient of associated independent variables are statistically significant at the 1%, 5% and 10% significance level respectively.

4.2. Impact of Climate Change on Sugarcane Yield in India

Regression coefficients of independent variables with sugarcane yield was estimated using linear regression, correlated panels corrected standard errors (Prais-Winsten) estimations (Table 6). The *Wald Chi*^{2} value was found statistically significant, thus it infers that proposed model was correctly well-defined. *R-squared* value was found 0.8144, thus it exhibits that around 81% variation in sugarcane yield can be explained by undertaken variables. Regression coefficient of time trend factor with sugarcane yield was appeared negative. Thus, use of technological change in sugarcane farming may be ineffective to increase sugarcane yield in India. Kumar, Sharma and Ambrammal (2015) have also found negative impact of technological change on sugarcane yield in India. Regression coefficients of area sown and value of production per hectare land with sugarcane yield were seemed positive. Estimates, therefore suggested that both the factors will be helpful to increases sugarcane yield. However, due to existence of law of diminishing return in agricultural sector, crop productivity is to be declined as increase in cropped area (Kumar, Sharma & Ambrammal, 2015). Further, it is also clear that monetary value per hectare land would be useful for farmers to increase their trust to cultivate those crops which provide them better economic returns (Kumar & Sharma, 2014). Thus, it is essential to provide appropriate prices to farmers for their crop production. Regression coefficients of annual average maximum temperature, and annual actual rainfall and precipitation with sugarcane yield were appeared negative. Thus, sugarcane yield was declined due to increase in maximum temperature, change in rainfall pattern and precipitation. Kumar & Sharma (2013) have also perceived negative impact of maximum temperature and rainfall on sugarcane yield in India. However, few studies such as Guntukula (2019); Praveen & Sharma (2019) have found positive impact of rainfall on sugarcane yield in India. Moreover, minimum temperature shows a positive impact on sugarcane yield in India.

Table 6. Regression Results with Linear Regression, Correlated Panels Corrected Standard Errors Estimation for Sugarcane Yield in India

No. of Observation		892	*R-squared*		0.8144	
No. of States		19	*Wald Chi*^{2}(10)		2207.23	
No. of Obs./States		46	*Prob> Chi*^{2}(10)		0.0000	
Variable	*Reg. Coef.*	*Std. Errors*	*z*	*P* > |*z*|	95% Confidence Interval	
YT (*Year*)	-0.0550	0.0025	-22.21	0.000	-0.0598	-0.0501
logas	0.0412	0.0068	6.08	0.000	0.0279	0.0545
Llogvalproha	0.7385	0.0280	26.41	0.000	0.6836	0.7933
logaamaxt	-2.6125	0.3494	-7.48	0.000	-3.2973	-1.9276
logaamint	1.6295	0.1927	8.45	0.000	1.2517	2.0073
logaarf	-0.0279	0.0233	-1.2	0.231	-0.0736	0.0178
logaapcp	-0.1111	0.0360	-3.08	0.002	-0.1817	-0.0404
Con. Coef.	117.2519	4.5774	25.62	0.000	108.2803	126.2235

Source: Author's estimation.

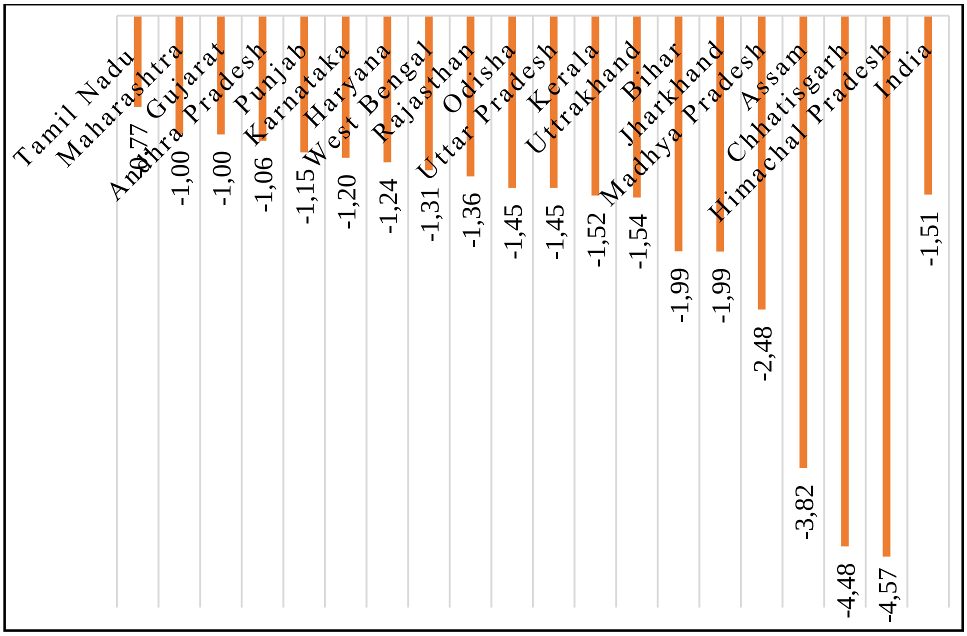
4.2. Validity of Empirical Results

Regression coefficients of explanatory variables with output must be authenticated to increase the unanimity among the existing researchers and academician. Thereafter, regression results of a model can be considered for further purpose. If the error term and its first two lags are positively or negatively correlated with each other's than a model can be valid (Maity & Chatterjee, 2012; Singh, Narayanan & Sharma, 2017). Therefore, correlation coefficients of error-term with its various lags of proposed model was estimated in this study. The auto-correlation and partial auto-correlation coefficients of error term and its various lags were found positive and statistically significant at various significance level (See Table 7). Hence, it is clear that regression results were consistent and these may be used to examine the projected sugarcane yield in different climate change scenarios.

Table 7. Correlation Coefficients Between Error Term and Its Various Lags for Sugarcane Yield

No. of Lags	Auto-correlation coefficients	Partial auto-correlations
1	0.4304*	0.2588*
2	0.3938*	0.1684*
3	0.3226*	0.0599***
4	0.3516*	0.1400*
5	0.2717*	-0.0097
6	0.2806*	0.0313
7	0.2778*	0.0316
8	0.2951*	0.0707
9	0.2450*	0.0284

Source: Author's estimation. **Note:** *, **, and *** values are statistically significant at the 1%, 5% and 10% significance level respectively.



Source: Author's estimation.

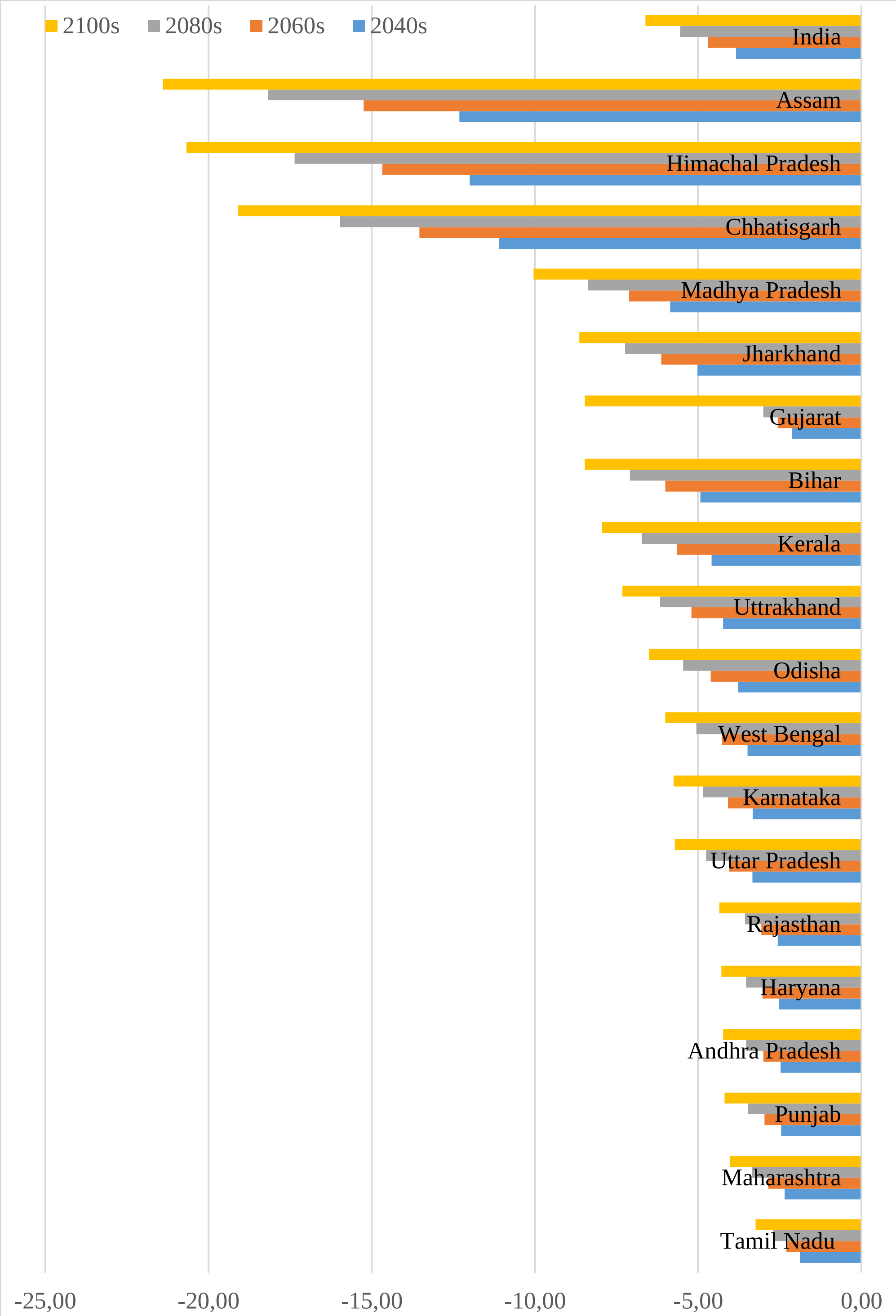
Figure 8. Marginal Impact of Climatic Factors on Sugarcane Yield

4.3. Marginal Impact of Climatic Factors on Sugarcane Yield

Marginal impact of climatic factors on sugarcane yield is presented in Figure 8. The results demonstrate that sugarcane yield was probably to be decreased by 1.51% due to 1% change in annual average maximum and minimum temperature, and annual actual rainfall and precipitation in India. As sugarcane yield was decreased by 4.5% due to marginal increase in climatic factors in Himachal Pradesh. Thus, sugarcane farming was observed highly vulnerable in this state due to climate change. Uttar Pradesh, Maharashtra, Karnataka, Tamil Nadu, Bihar, Andhra Pradesh and Gujarat states were occupied around 88% cropped area of sugarcane and contribute around 87% sugarcane production of India. Sugarcane yield in Uttar Pradesh, Maharashtra, Karnataka, Tamil Nadu, Bihar, Andhra Pradesh and Gujarat were decreased by 1.45%, 1.00%, 1.20%, 0.77%, 1.99%, 1.06% and 1% respectively due to 1% change in aforementioned climatic factors.

4.4. Projected Sugarcane Yield in Different Climate Change Scenarios

The sugarcane yield for India and across states in different climate change scenarios (i.e. 2040s, 2060s, 2080s and 2100s) were projected using marginal impact analysis technique. Sugarcane yield was projected to be declined by 3.84%, 4.69%, 5.55% and 6.62% in India by the aforementioned years respectively (See Figure 9 and Table 8). Results clearly reveal that sugarcane yield may be declined in all states due to climate change. Assam state may be in highly worsen position as sugarcane yield is likely to be decreased by 12.31%, 14.31%, 15.25% and 21.40% by the 2040s, 2060s, 2080s and 2100s respectively. Maharashtra, Uttar Pradesh, Karnataka, Tamil Nadu, Gujarat, Andhra Pradesh, Haryana and Bihar contribute around 99% sugar production of India. The sugarcane yield in these states are likely to be declined in different climate change scenarios.



Source: Author's estimation.

Figure 9. Projected Sugarcane Yield (in %) in Different Climate Change Scenarios

Sugarcane yield is projected to be declined by 2.35%, 2.85%, 3.36% and 4.03% in Maharashtra; 3.84%, 4.05%, 4.76% and 5.72% in Uttar Pradesh; 3.33%, 4.09%, 4.85% and 5.75% in Karnataka; 1.88%, 2.30%, 2.71% and 3.24% in Tamil Nadu; 2.13%, 2.56%, 3.00% and 8.48% in Gujarat; 2.47%, 3.00%, 3.53% and 4.24% in Andhra Pradesh; 2.52%, 3.03%, 3.53% and 4.29% in Haryana; and 2.13%, 2.56%, 3.00% and 8.48% in Bihar by 2040s, 2060s, 2080s and 2100s respectively. Production scale of 471 sugar factories depend upon sugarcane production in aforementioned states. Thus, production activities in sugar industries will be in alarming position due to declining in sugarcane production in this group of states. Consequently, economic capacity of sugarcane farmers and agricultural labours may be decreased in these states. Also, it may adversely affect the employment opportunities of agricultural and industrial workers in sugar factories. Accordingly, food and nutritional security, and social activities of people may be in high risk due to decline in sugarcane production in India. Furthermore, it would also adversely affect the government and agricultural development policies in India.

Table 8. Expected Sugarcane Yield (in %) in Different Climate Change Scenarios

States/Years	2040s	2060s	2080s	2100s
Tamil Nadu	-1.88	-2.30	-2.71	-3.24
Maharashtra	-2.35	-2.85	-3.36	-4.03
Punjab	-2.46	-2.96	-3.47	-4.19
Andhra Pradesh	-2.47	-3.00	-3.53	-4.24
Haryana	-2.52	-3.03	-3.53	-4.29
Rajasthan	-2.57	-3.07	-3.56	-4.35
Uttar Pradesh	-3.34	-4.05	-4.76	-5.72
Karnataka	-3.33	-4.09	-4.85	-5.75
West Bengal	-3.48	-4.27	-5.05	-6.01
Odisha	-3.78	-4.62	-5.46	-6.51
Uttarakhand	-4.24	-5.20	-6.17	-7.32
Kerala	-4.59	-5.66	-6.73	-7.95
Bihar	-4.93	-6.01	-7.09	-8.48
Gujarat	-2.13	-2.56	-3.00	-8.48
Jharkhand	-5.02	-6.13	-7.24	-8.64
Madhya Pradesh	-5.85	-7.12	-8.38	-10.04
Chhattisgarh	-11.10	-13.54	-15.98	-19.09
Himachal Pradesh	-11.99	-14.68	-17.37	-20.68
Assam	-12.31	-15.25	-18.18	-21.40
India	-3.84	-4.69	-5.55	-6.62

Source: Author's estimation.

5. Conclusion, Policy Recommendations and Further Research Direction

Empirical results of this study suggest that climatic factors such as annual average maximum temperature, and annual actual rainfall and precipitation have a negative impact on sugarcane yield in India. Estimates also indicate that 81% variation in sugarcane yield can be explained by aforementioned climatic variables, cropped area and monetary value of sugarcane production per hectare land. Regression results also imply that annual average maximum temperature show a negative impact on sugarcane yield in Andhra Pradesh, Chhattisgarh, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh and Maharashtra. Annual average minimum temperature has a negative impact on sugarcane yield in Assam, Bihar, Haryana, Kerala and Uttar Pradesh. Impact of annual actual rainfall on sugarcane was appeared negative in Andhra Pradesh, Chhattisgarh, Haryana, Himachal Pradesh, Jharkhand, and Odisha. Annual actual precipitation was also produced negative impact on sugarcane yield in Bihar, Kerala, and Uttar Pradesh. While, the association of time trend factor with sugarcane yield was seemed negative in Andhra Pradesh, Assam, Chhattisgarh, Gujarat, Himachal Pradesh, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Tamil Nadu, and Uttarakhand. Hence, estimates imply that impact of climatic factors on sugarcane yield was varied across Indian states. The variation in sugarcane yield exist due to high diversity in climatic factors, geographical location, farm management practices, verities of seed, irrigation facilities, soil quality, use of fertilizer in cultivation, farmer’s understanding towards climate change, economic capacity of farmers to reduce the negative implication of climate change in cultivation, technological advancement, government’s agricultural and rural development policies, training facilities for farmers, agricultural extension services, agricultural cooperative societies across Indian states.

Results based on marginal impact analysis technique show that sugarcane yield is likely to be decreased by 1.51% at national level, and 4.57% in Himachal Pradesh, 4.48% in Chhattisgarh, 3.82% in Assam, 2.48% in Madhya Pradesh, 1.99% in Jharkhand, 1.99% in Bihar, 1.54% in Uttarakhand, 1.52% in Kerala, 1.45% in Odisha, 1.36% in Rajasthan, 1.31% in West Bengal, 1.24% in Haryana, 1.20% in Karnataka, 1.15% in Punjab, 1.06% in Andhra Pradesh, 1.00% in Gujarat, 1.00% in Maharashtra, and 0.77% in Tamil Nadu due to 1% change in climatic factors. Furthermore, sugarcane yield is expected to be decreased by 3.84%, 4.69%, 5.55% and 6.62% by 2040s, 2060s, 2080s and 2100s respectively in India. Here, it is concluded that impact of climate change on sugarcane yield is varied across Indian states. Projected results also clearly indicate that sugarcane yield is predicted to be declined continuously across Indian states in different climate change scenarios.

Maharashtra, Uttar Pradesh, Karnataka, Tamil Nadu, Gujarat, Andhra Pradesh, Haryana, and Bihar have large number of sugar industries and have a significant share in sugar and sugarcane production, and cropped area in sugarcane crop farming in India. Therefore, state specific policies must be started to maintain the sugarcane production. It would be useful for sugar industries to maintain their sugar production scale. Accordingly, it would be helpful for sugarcane growers to cultivate this crop in India. Otherwise, sugarcane farming in these states would be in vulnerable position due to climate change. Thus, it may cause to create several problems such as destruction of existing agricultural development policies, high fluctuation in prices of sugar, and agricultural sector will be unable to meet the requirement of raw material for industries. Furthermore, as livelihood security of 7.5% of rural population that include around 60 million farmers and large number of agricultural labours depend upon sugarcane farming in India (Kumar, Sharma & Ambrammal, 2015; Shukla et al. 2017). Therefore, livelihood security of aforesaid community will be disturbed if sugarcane production declines due to climate change in India.

As sugarcane is the main crop which generates foreign currency in India (Shukla et al., 2017). Therefore, it will create difficulties for rural development if government loss foreign revenue due to decline in sugarcane production in India (Kumar & Sharma, 2014). Also, sugarcane is most dominant cash crop that provide raw material to sugar industries, and 25 different associated industries which produce sugar, brown sugar, khandasari, jiggery, alcohol, papers, electricity, chemicals, and fodder to feed livestock and biofuels (Solomon, 2014; Zulfqar et al., 2016). Most importantly, sugar industry contributes around 6% share in agricultural GDP in India (Shukla et al., 2017). Sugarcane industries would not be in position to contribute their significant share in agricultural GDP if sugarcane production decreases due to climate change in India. Moreover, sugarcane crop is a multi-product originator and it is also a main source of sugar and renewable energy. There may be a high imbalance in supply-side and demand-side components of sugar and associated products due to climate change, consequently it may be caused to increase sugar prices in India (Kumar & Sharma, 2014).

Accordingly, it may create additional burden on government to maintain the prices of sugar and its associated products in India. As India has a largest consumer of sugar in the world (Kumar, Sharma & Ambrammal, 2015). Therefore, price of sugar is expected to be high due to decline in sugar production. Thus, it will reduce the economic capacity of people to acquire sugar as per their requirement. Hence, food and nutritional security of large section of the community will be decreased due to climate change in India (Kumar & Sharma, 2014).

Several policy suggestions can be given to mitigate the adverse impact of climate change in sugarcane farming in India. Sugarcane crop farming requires more water for irrigation as compared to other crops (Shrivastava, Srivastava & Solomon, 2012; Chandiposha, 2013; Taha & Zohry, 2018). Also, irrigated area has a higher productivity than non-irrigated area in cultivation. Thus, appropriate irrigation facilities will be effective to improve sugarcane yield (Singh, Narayanan & Sharma, 2019). Water is a natural resource, and its quantity and quality are diminishing due to overutilization of water in production activities in India. Thus, farmers should use minimum quantity of water in sugarcane farming. For this, farmers can use skip-furrow or alternate furrow irrigation, sprinkler and drip irrigation to conserve water in sugarcane farming (Shrivastava, Srivastava & Solomon, 2012; Shukla et al., 2017). Furthermore, water management policies must be initiated by government to meet the irrigation requirement of agriculture in India. As most farmers avail credit facility from non-formal sources which charge high interest rate (Vyas, 2004). Credit facilities at low interest rate must be provided to the sugarcane growers. It would be helpful for farmers to apply advance technologies to mitigate the negative impact of climate change in sugarcane farming.

India also needs to increase investment in agriculture sector to prevent the impact of natural calamities in crop farming (Vyas, 2004). Crop insurance policies will be helpful for farmers to maintain their economic capacity if crop production is damaged or decreased due to climate change (Shukla & Yadav, 2017; Sihem, 2019). Moreover, scientific research community needs to discover stress tolerant variety of seeds, technique to use of minimum water for irrigation in cultivation and breeding of new varieties of seed to cope with climate change (Chandiposha, 2013; Guntukula, 2019). Furthermore, low cost technologies and discovery of high yielding verities of sugarcane will be effective to mitigate the adverse effect of climate change in sugarcane farming. Change in planting time, planting geometry, fertilizer management, dual cropping pattern, crop diversification, farm management strategies and planting of genotype crop may be useful to mitigate the negative impact of climate change in agriculture (Shukla et al., 2017; Singh, Narayanan & Sharma, 2019; Sonkar et al., 2020).

Aforementioned initiatives may be supportive to maintain the sugarcane production and production activities in sugar industries in India (Chandiposha, 2013; Sonkar et al., 2020). Indian government must be provided small machine or equipment and high yielding varieties of seeds with minimum prices to the small farmers to increase their attention to grow sugarcane crop (Shukla & Yadav, 2017). Also, scientific research community, decision makers and sugarcane growers should work together to discover the modern technologies to mitigate the negative effect of climate change in sugarcane farming (Zhao & Li, 2015).

Agricultural extension services can play a crucial role to disseminate the climate change related information to the farmers on time (Weldesilassie, Assefa & Hagos, 2015; Singh, Narayanan & Sharma, 2019). For this, planning of regular training and institutional support for farmers will be supportive to mitigate negative consequences of climate change in crop farming in India (Kumar et al., 2015). India is also needed to increase public spending in agricultural R&D (Kumar, 2015; Singh & Issac, 2018; Singh, Narayanan & Sharma, 2019). As sugarcane farming is a main source of greenhouse gas (GHGs) emissions, thus there is requirement to maintain the environmental sustainability in India (Zhao & Li, 2015). It is, therefore suggested that farming community must use green harvesting techniques to reduce CO_2 emissions from sugarcane farming. For this, ecosystem-based approach may be effective to abate the CO_2 emissions from agriculture (Pramova et al., 2012; Weldesilassie, Assefa &

Hagos, 2015). Extensive application of fertilizer is useful to increase the agricultural productivity in short term; however, it works as toxic for soil, environment and natural resources in long-term (Kumar, Sharma & Joshi, 2015). It also increases GHGs in the atmosphere and create high possibility for climate change (Pandey, 2009; Gregory, Ingram & Brklacich, 2012). Therefore, farming community must be avoided extensive application of fertilizer and pesticides in cultivation to sustain the quality of ecological services (i.e. water, soil and air) (Kumar & Sharma, 2013; Sharma & Singh, 2016; Kumar, Ahmad & Sharma, 2017; Singh, Issac and Narayanan, 2019).

As this study is assessed the climatic change impact on sugarcane yield across Indian states. It also examines the projected sugarcane yield in different climate change scenarios (i.e. 2040s, 2060s, 2080s, and 2100s). Thus, it is a significant contribution towards existing literature. Also, increase the attention of policy makers, government, farmers and sugar industries to adopt an effective climate action policy to mitigate the adverse impact of climate change in sugarcane farming across Indian states. However, this study could not assess the influence of carbon fertilization, CO_2 emission, solar radiation, sun intensity, and other factors on sugarcane farming. Furthermore, there are several socio-economic and demographical factors (i.e. urbanization, industrialization, population growth) which have significant contribution in sugarcane farming (Sharma & Singh, 2016). These factor, therefore must be considered to examine the expected sugarcane yield in India. Agricultural extension offices (ATO) are providing and facilitating training programmes and other services to the farmers. Thus, ATO also have a positive impact on crop farming. Hence, existing researchers can assess the role of ATO to mitigate the impact of climate change in sugarcane farming using farm level data. It would be effective to formulate a conducive policy to cope with climate change in Indian agricultural sector.

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