Delineation of maize growing areas vis-à-vis climate and technology using statistical and geospatial techniques in Punjab

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ABSTRACT

In the present investigation, maize growing areas in Punjab were delineated with respect to climate and technology variables using statistical and geospatial techniques. The effect of the climate (maximum temperature, minimum temperature and rainfall) and technology variables (fertilizers, irrigation) on maize yield was studied in spatio-temporal domain in maize growing areas of Punjab. Long-term data on climate and technology variables as well as maize productivity was collected for maize growing districts of the state. The maximum temperature during maize growing season was highest (35.7°C) in Amritsar, the minimum temperature was highest (25.3°C) in Ludhiana, whereas rainfall was highest (765.4 mm) in Gurdaspur. The results of Mann-Kendall test showed significant increase in maximum temperature @ 0.03°C year^{-1} in Hoshiarpur, Kapurthala, Patiala and Roopnagar and minimum temperature @ 0.04°C year^{-1} in Gurdaspur, Hoshiarpur, Kapurthala and Roopnagar, @ 0.03°C year^{-1} in Jalandhar and @ 0.05°C year^{-1} in Ludhiana and Patiala districts. Analysis indicated that the maize yield was significantly higher in Ludhiana than other districts. Spatial variability in maize yield, climate and technology was studied using Geographic Information System (GIS). The integration of the layers of climate parameters with yield in GIS demarcated four major maize growing zones in Punjab.

Key words : Climate variability, technology, maize yield, GIS

Maize is one of the most important cereal crops after wheat and rice. It is used both as a food and feed crop as well as it is used as an industrial raw material such as alcoholic beverages, pharmaceuticals, gums, textiles, oil, proteins, food sweeteners and in paper and packaging industries etc (Kumar *et al.,* 2018). Maize has highest genetic potential which allows it to grow in tropical, sub-tropical and temperate climates (Rathod *et al.,* 2017). In order to feed the increasing world's population it is important that the production of three important cereal crops (rice, wheat and maize) be increased by 70% by 2050. But due to climate change agricultural production is likely to be adversely affected, which may hinder the capability of many areas to attain the required goals for future food security (Lobell *et al.,* 2008). ln India area under maize crop is 9.63 million hectares with a production of 25.89 million tonnes and yield of 10.76 q acre^{-1} in the year 2016-17. Punjab occupied an area of about 114 thousand hectares, with a production of 423 thousand tonnes and average yield was 15.01 q acre^{-1} during the year 2017-18 (Anonymous, 2019).

Depending on the locations, the increased temperature due to increased CO_2 will have a great impact on food grain production. In tropical and sub-tropical countries like India, temperature is likely to rise by 1.0-2.0°C which may decrease the food production up to 30% (IPCC, 2014 and Johkan *et al.,* 2011). Warming temperature reduces the crop growth periodby increasing phenological development and thus decreases the period of photosynthesis and biomass accumulation (Xiao *et al.,* 2013 and 2015). Warming along with drought reduces greater yield due to the impact of higher vapour pressure deficit (VPD) on yield (Lobell *et al.,* 2014). Maize growth and yield also reduces due to the decrease in precipitation and solar radiation (Mo *et al.,* 2009; Liu *et al.,* 2010; Tao and Zhang, 2011).

The state of Punjab is also suffering from the climatic variation during the last many decades. Geospatial technology offers many advantages over the traditional methods to collect, manipulate, evaluate and retrieve abundant spatially referenced data collected from different sources (Aronoff, 1991). In view of above the present study was conducted to show how the productivity of maize varies among different districts of Punjab and to see how the changing climate and technology variables affect the maize productivity.

MATERIALS AND METHODS

Data Collection

Long term data (1971-2017) on maize productivity, fertilizer application and irrigation were collected from statistical abstracts of Punjab. Long term (1971-2017) climate data (maximum, minimum temperature and rainfall) during the maize growing season (June to September) was collected from Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University (PAU) Ludhiana, different research stations of PAU, India Meterological Department and different websites.

Statistical Analysis

Long term weather and crop yield data were analyzed for the maize growing districts of Punjab *viz.*, Gurdaspur, Hoshiarpur, Roopnagar, Amritsar, Jalandhar, Kapurthala, Ludhiana and Patiala by using statistical techniques like mean, standard deviation, coefficient of variation, Mann-Kendall test and correlation.

Spatial interpolation

Spatial interpolation of maize yield and climate parameters (maximum, minimum temperature and rainfall) was done using Inverse Distance Weighted (IDW) method in ArcGIS 10.4 by taking the average from 1971 to 2017. The characterization of the maize growing districts of Punjab was then done by overlaying the interpolated layers of maize yield, technology and climate parameters.

RESULTS AND DISCUSSION

Spatial and temporal variations in maize yield

The highest average maize yield was noticed in Ludhiana (2873.6±1286.9 kg ha^{-1}) followed by Kapurthala (2762.5±1274.8 kg ha^{-1}) and lowest in Gurdaspur (1828±647.1 kg ha^{-1}). The coefficient of variation was highest in Patiala (53.7%) which indicated high variability and less consistency in maize yield in this district followed by Kapurthala (46.1%) and lowest in Gurdaspur (35.4%) which showed high consistency and low variability in maize yield in this district. The rate of increase (74.3 kg ha^{-1} year^{-1}) was highest for Patiala and the value of R^2 was observed to be highest for Hoshiarpur (0.84) (Table 1). Spatial variability showed that maize yield at Gurdaspur remained between 1800-2000 kg ha^{-1}, at Roopnagar, it remained between 2000-2200 kg ha^{-1}, at Hoshiarpur and Patiala, it remained between 2200-2400 kg ha^{-1}, at Amritsar, it remained between 2400-2600 kg ha^{-1}, at Jalandhar and Kapurthala, it remained between 2600-2800 kg ha^{-1} and at Ludhiana it

remained between 2800-3000 kg ha^{-1} (Fig. 1).

Variations in climatic parameters during maize growing season

The highest average maximum temperature during maize growing seasons (35.7±0.9°C) was noticed in Amritsar, followed by Kapurthala (35.2±1.3°C) and lowest in Gurdaspur (33.3±1°C). However, the variability in maximum temperature was highest in Roopnagar (5.4%) which indicated low consistency and high variability in maximum temperature in this district, followed by Hoshiarpur (3.7%) and lowest in Ludhiana (2.1%) which indicated high consistency and low variability in maximum temperature in this district. The rate of increase in maximum temperature was highest at Roopnagar (0.08°C year^{-1}) and the value of R^2 was observed to be highest for Roopnagar (0.39) (Table 2). The highest average minimum temperature during maize growing seasons (25.3±1°C) was observed in Ludhiana, followed by Kapurthala (24.6±1.1°C) and lowest in Gurdaspur (23±1.5°C). The variability in minimum temperature was highest in Roopnagar (7.3%) which indicated high variability and less consistency in minimum temperature in this district, followed by Gurdaspur (6.5%) and lowest in Amritsar (3.3%) which indicated low variability and high consistency in minimum temperature in this district. The rate of increase in minimum temperature was highest at Roopnagar (0.09°C year^{-1}) and the value of R^2 was observed to be highest for Ludhiana (0.70). Kingra *et al*. (2017) also reported significant climatic variations in different agroclimatic regions of Punjab.

The highest average rainfall during maize growing seasons was observed in Gurdaspur (765.4±239.8 mm), followed by Jalandhar (760.5±544.7 mm) and lowest in Amritsar (549.3±193.1 mm). The coefficient of variation was highest in Jalandhar (71.6%) which indicated high variability and less consistency in rainfall in this district, followed by Patiala (41.1 %) and lowest in Roopnagar (31 %) which indicated low variability and high consistency in rainfall in this district. The rate of increase in rainfall was highest at Jalandhar (15.58 mm year^{-1}) and the value of R^2 was observed to be highest for Jalandhar (0.15). Similarly, Mann-Kendall test was performed to see the variability in maximum temperature. Gurdaspur showed significant increase in mean minimum temperature @ 0.04°C year^{-1}. Hoshiarpur showed significant increase in maximum and minimum temperature @ 0.03 and 0.04°C year^{-1} respectively. Jalandhar showed significant increase in minimum temperature @ 0.03°C year^{-1}. Kapurthala showed increase in maximum and minimum

Table 1: Temporal variability in maize yield in different districts of Punjab from 1971-2017

Station	Yield ± S.D. (kgha⁻¹)	CV (%)	Rate of change (kg ha⁻¹ year⁻¹)	R²
Gurdaspur	1828±647.1	35.4	36.8	0.61
Hoshiarpur	2352.2±932.3	39.6	62.3	0.84
Roopnagar	2079.9±862.8	41.5	56.8	0.81
Amritsar	2502.8±1022.4	40.8	59.2	0.63
Kapurthala	2762.5±1274.8	46.1	71.4	0.59
Jalandhar	2640.3±939.1	35.6	61.6	0.81
Ludhiana	2873.6±1286.9	44.8	70.8	0.57
Patiala	2364±1268.9	53.7	74.3	0.64

Table 2: Temporal variability (1971-2017) climatic parameters in Punjab

District	Test	Maximum temperature	Minimum temperature	Rainfall
Amritsar	Mean±SE	35.7±0.1	24.5±0.1	549.3±28.2
	Z	-0.33	1.63	0.42
	Q	0.00	0.01	0.19
Gurdaspur	Mean±SE	33.3±0.2	23.0±0.2	765.4±35
	Z	1.28	5.52***	-0.42
	Q	0.01	0.04	-0.31
Hoshiarpur	Mean±SE	34.3±0.2	23.9±0.2	709.5±32.5
	Z	3.32***	5.78***	0.16
	Q	0.03	0.04	0.07
Jalandhar	Mean±SE	34.6±0.2	24.5±0.1	760.5±79.5
	Z	-0.24	5.59***	0.85
	Q	0.00	0.03	0.53
Kapurthala	Mean±SE	35.2±0.2	24.6±0.2	643.4±32.9
	Z	3.15**	6.07***	-0.03
	Q	0.03	0.04	0.00
Ludhiana	Mean±SE	34.7±0.1	25.3±0.1	593.0±33.4
	Z	-0.50	6.86***	0.15
	Q	0.00	0.05	0.08
Patiala	Mean±SE	33.8±0.2	24.0±0.2	616.6±37
	Z	3.25**	6.02***	-0.01
	Q	0.03	0.05	-0.02
Roopnagar	Mean±SE	33.5±0.3	23.4±0.2	748.8±33.9
	Z	3.37***	5.65***	1.79+
	Q	0.03	0.04	1.04

Z: Mann-Kendall test, Q: Sen's slope estimator **Statistically significant at the 1% significance level, ***Statistically significant at the 0.1% significance level, + Statistically significant at 10% significance level

Table 3 : Correlation of maize yield with climate and fertilizer and irrigation variables in different districts of Punjab

Districts	Maximum temperature	Minimum temperature	Rainfall	Fertilizers	Gross irrigated area
Amritsar	0.049	0.123	0.052	0.026	-0.718**
Gurdaspur	0.147	0.563**	-0.172	0.699**	-0.511**
Hoshiarpur	0.67**	0.812**	-0.088	0.773**	0.822**
Jalandhar	0.182	0.648**	0.447**	0.294*	-0.804**
Kapurthala	0.579**	0.689**	-0.171	0.608**	-0.643**
Ludhiana	-0.045	0.52**	-0.08	0.39**	-0.466**
Patiala	0.629**	0.856**	-0.041	0.481**	-0.515**
Roopnagar	0.685**	0.766**	0.106	0.345*	0.365*

* Correlation is significant at 5% significance level (2-tailed)

 ** Correlation is significant at 1% significance level (2-tailed)

temperature @ 0.03 and 0.04°C year^{-1} respectively. Ludhiana showed significant increase in minimum temperature @ 0.05°C year^{-1}. Patiala showed significant increase in maximum and minimum temperature @ 0.03 and 0.05°C year^{-1} respectively and Roopnagar showed significant increase in maximum and minimum temperature @ 0.03 and 0.04°C year^{-1} respectively (Table2).

Spatial interpretation showed variability showed that maximum temperature at Gurdaspur, Roopnagar and Patiala remained between 33-34°C, at Hoshiarpur, Jalandhar and Ludhiana, it remained between 34-35°C and at Amritsar and Kapurthala it remained between 35-36°C (Fig.1). Minimum temperature at Gurdaspur and Roopnagar remained between 23.0-23.5°C, at Hoshiarpur, it remained between 23.5-24.0°C, at Patiala, it remained between 24.0-24.5°C, at Amritsar, Jalandhar and Kapurthala, it remained between 24.5-25.0°C and at Ludhiana minimum temperature remained between 25.0-25.5°C (Fig. 1). Similarly, rainfall at Amritsar remained between 500-550 mm, at Ludhiana, it remained between 550-600 mm, at Kapurthala and Patiala, it remained between 600-650 mm, at Hoshiarpur and Roopnagar, it remained between 700-750 mm and at Gurdaspur and Jalandhar rainfall remained between 750-800 mm (Fig. 1). Acquah and Kyei (2012) showed that average maize yield is positively related to crop area and negatively related to rainfall and temperature. Furthermore, increase in crop area and temperature will enlarge maize yield variability while rainfall increase will decrease the variability in maize yield.

Effect of climate and technology variables on maize yield

A significantly positive relationship was observed between maize yield and gross irrigated area at Amritsar

(r= -0.718). At Gurdaspur yield was significantly correlated with minimum temperature (r=0.563), fertilizers (r=0.699) and Gross irrigated area (r= -0.511). At Hoshiarpur, yield was significantly correlated with maximum temperature (r=0.67), minimum temperature (r=0.812), fertilizers (r=0.773) and gross irrigated area (r= 0.822). At Jalandhar, yield was significantly correlated with minimum temperature (r=0.648), rainfall (r= 0.447), fertilizers (r= 0.294) and gross irrigated area (r= -0.804). At Kapurthala, yield was significantly correlated with maximum temperature (r=0.579), minimum temperature (r= 0.689), fertilizers (r= 0.608) and gross irrigated area (r=-0.643). At Ludhiana, yield was significantly correlated with minimum temperature (r=0.52), fertilizers (r= 0.39) and gross irrigated area (r= -0.466). At Patiala, yield was significantly correlated with maximum temperature (r= 0.629), minimum temperature (r=0.856), fertilizers (r=0.481) and gross irrigated area (r= -0.515). At Roopnagar, yield was significantly correlated with maximum temperature (r= 0.685), minimum temperature (r=0.766), fertilizers (r=0.345) and gross irrigated area (r= 0.365) (Table 3). Ogada and Nyangena (2015) also reported that inorganic fertilizers and improved maize varieties significantly improve yields when adopted as a package rather than as individual elements.

Delineation of maize growing regions of Punjab

The interpolation of different layers of climatic parameters and maize yield divided the maize growing areas into four zones. The first zone covering the districts of Gurdaspur and Roopnagar having maximum temperature range of 33-34°C, minimum temperature range of 23-24°C, rainfall range of 600-900 mm and maize yield of 1000-2000 kg ha^{-1}. Second zone comprised of Hoshiarpur having maximum temperature range of 34-37°C, minimum
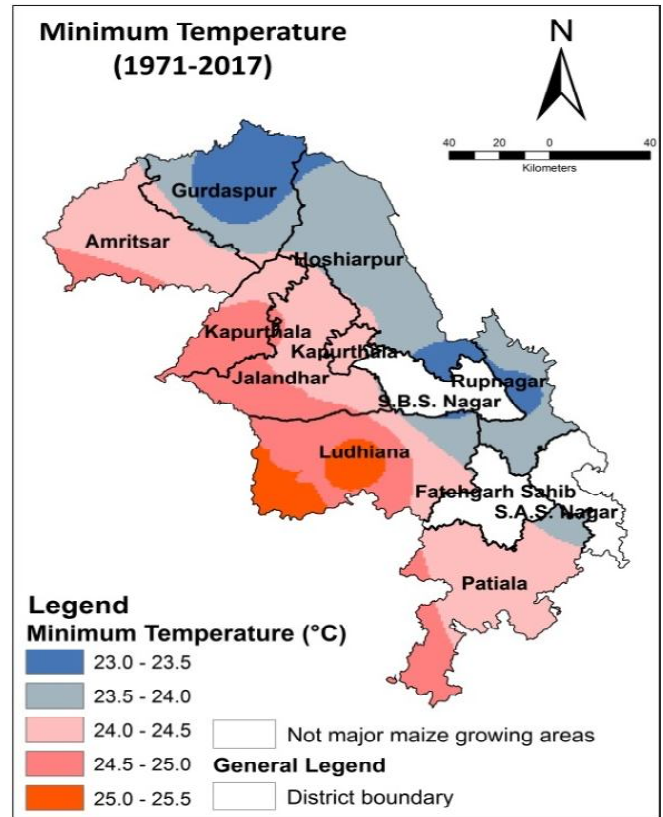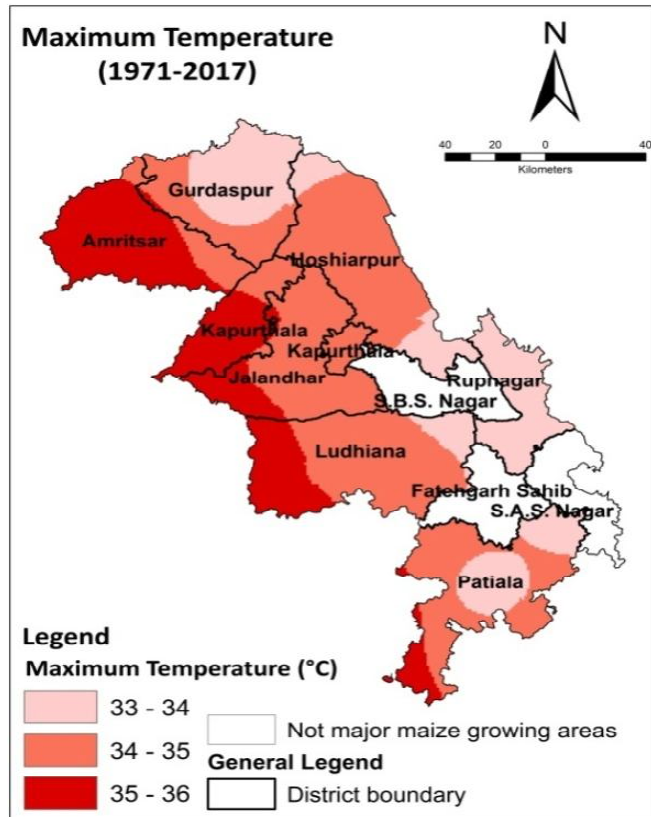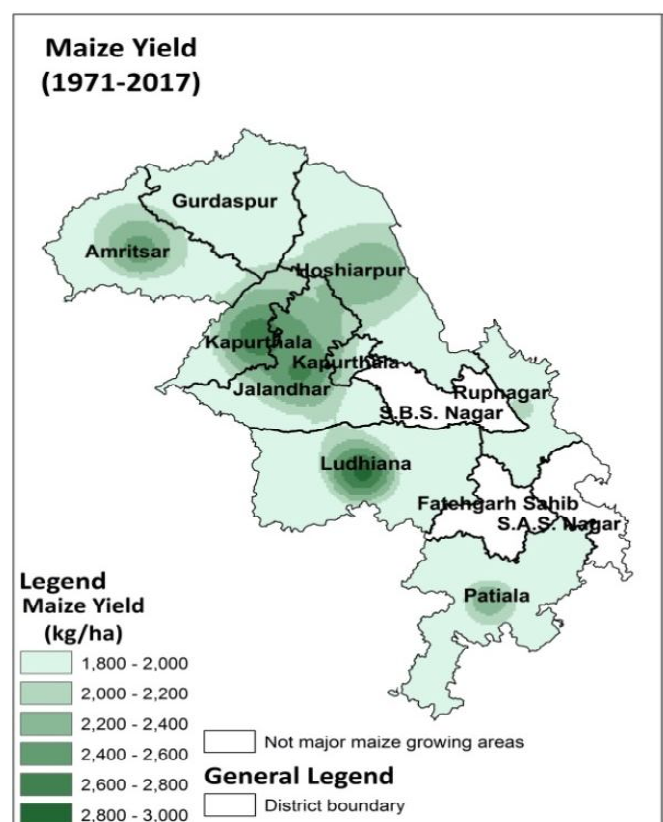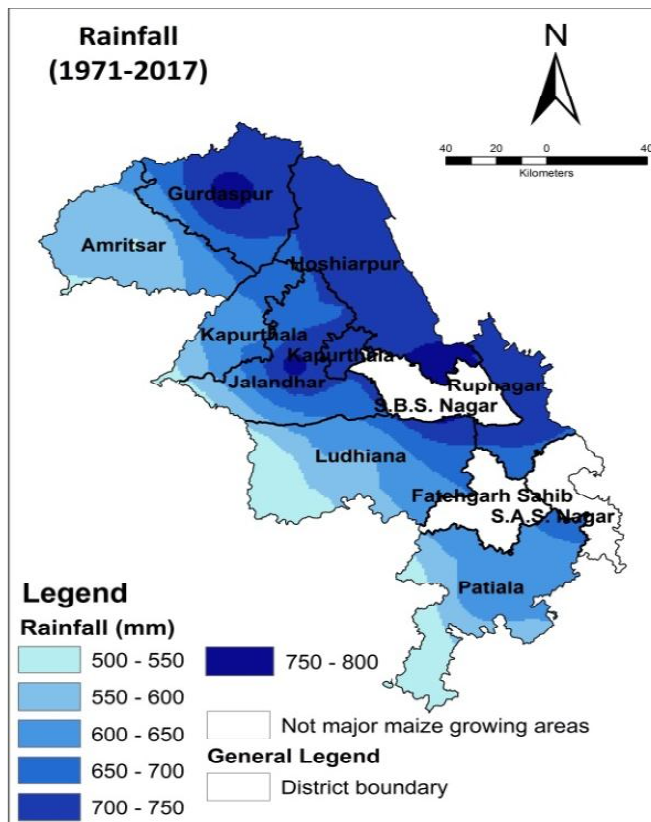
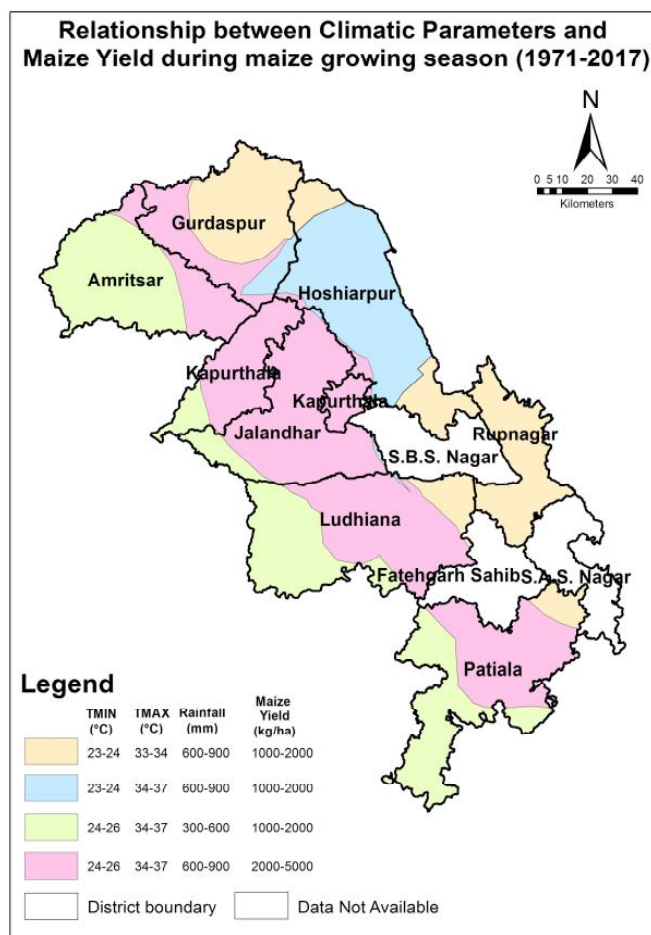Fig 1 Spatial variability in climatic parameters and its relations with maize yield

Fig 2 Demarcation maize growing regions of Punjab

temperature range of 23-24°C, rainfall range of 600-900 mm and maize yield of 1000-2000 kg ha^{-1}. Third zone comprises of Amritsar having maximum temperature range of 34-37°C, minimum temperature range of 24-26°C, rainfall range of 300-600 mm and maize yield of 1000-2000 kg ha^{-1} and fourth zone comprised the districts of Kapurthala, Jalandhar, Ludhiana and Patiala having maximum temperature range of 34-37°C, minimum temperature range of 24-26°C, rainfall range of 600-900 mm and maize yield of 2000-5000 kg ha^{-1} (Fig 2). It has been observed that the effect of the different climate parameters and technology variables (fertilizer and irrigation) are variable in spatio-temporal scale. Lobell and Field (2007) reported 8.3% decrease in maize yield for 1°C rise in temperature without considering the effect of water stress. Hu (2003) reported the technology and climate parameters impact on maize. Genetic variability and availability of nutrients affect the maize yield potential (Huff and Neill, 1982). Kumar *et al*. (2018) also suggested that maize research has a crucial role to play in enhancing adaptation and mitigation of climate change while also enhancing food security.

CONCLUSION

The study concluded that maize yield is significantly affected by climate and technology variables. In view of the changing climatic conditions, there is a dire need to adopt the suitable technological innovations to increase crop yield. Under the changing climatic conditions, geospatial technology can be used quite successfully to evaluate their impacts on crop yield and delineation of crop growing areas using geospatial techniques can be of great help to implement various crop productiontechniques at the zone level.

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