



Spatio-temporal variability in climatic parameters in trans-gangetic plains of India

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Abstract

In the present study analysis of Spatio-temporal variations in climatic parameters in trans-gangetic plains was carried out. Long term data (1971-2016) on climatic parameters of the trans-gangetic region were employed for the investigation. Variability and trends in climatic data were analyzed using Mann Kendall and Sen's slope statistics and spatial interpolations were carried out using the Inverse Distance Weighted (IDW) method. It was concluded that maximum and the minimum temperature had increased over trans-Gangetic plains. However; minimum temperature increased at a significant trend in all states of trans-Gangetic plains. Rainfall followed an erratic behavior.

Keywords: climatic variability, temperature, rainfall, ArcGIS, TGP

Introduction

Climate change affected food security due to warming, changing precipitation patterns, and greater frequency of some extreme events. It is an unprecedented threat to the food security. Average global temperature has increased about $1.1 \pm 1^\circ\text{C}$ since the late 19th century largely due to increased CO₂ and other human-made emissions into the atmosphere (WMO, 2018). The hottest year recorded was 2016 followed by 2017 without El-nino influence (NASA, 2018). The annual mean temperature in India has increased at the rate of 0.42°C (Arora *et al*, 2009) but temperature rise is likely to be much higher during *rabi* season than *kharif* season. Moreover, it is predicted that the mean temperature in India will rise by $0.4\text{-}2.0^\circ\text{C}$ in *kharif* and $1.1\text{-}4.5^\circ\text{C}$ in *rabi* by 2070 (Khan *et al*, 2009). Any significant change in climate may affect agriculture at larger scale. Several climatic factors affecting agriculture productivity are heat waves, high temperature (Ciais *et al*, 2005; Van der Velde *et al*, 2012), heavy and prolonged precipitation (Rosenzweig *et al* 2002; Pathak *et al*, 2011 and Thakur *et al*, 2010) and excess cold. The agricultural productivity in developing countries is expected to decline by 9-21% because of global warming (Cline, 2008). In India, 70% of the population depends on agriculture for their livelihood and 23% of India's Gross National Product representing agriculture sector alone, which plays a major role in the country's development and shall continue to hold an important place in the national economy (Khan *et al*, 2009). Indian agriculture system is based upon south-west and north-east monsoon. Any fluctuations and uncertainties in long range rainfall pattern may affect agriculture sector and also lead to increase the frequency of droughts and floods at regional scale (Jain and Kumar, 2012). These factors have positive as well as negative effects on crop production. Almost every year India faces several weather events due to changes in such climatic parameters in various regions which reduce crop yield. Reduction in potential yield of crops is linked to negative trends in solar radiation and increasing trends

in minimum temperature in IGP (Pathak 2003). As TGP is important in Indian economy due to high agricultural production, climate change could pose a great threat to the agriculture. A study therefore, has been planned to look into the climate variability in trans-gangetic plain region by using statistical procedures.

Methodology

Study area

The study has been carried out at Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana and Punjab Remote Sensing Center, Ludhiana for different locations of trans-gangetic plains of India (Fig, 1).

The climate of trans-gangetic plain (TGP) is of three types: arid, semi-arid and sub-humid in different districts. The heat waves and dust storms are common. This region has three seasons i.e. winter (November- March), summer (April-June) and rainy (July-October). The variation in rainfall is between 190 and 1150 mm. For irrigation purpose, the rivers like Beas, Ravi, Sutlej, Yamuna and Ghaggar are important in this zone. The major types of soils covered by this region are the deep loamy alluvium-derived soils with occasional saline and soalaic phases as well as deep loamy to grey brown and deep loamy desert soils (Verma and Singh 2004).

Weather data

The weather data of the TGP from 1971 to 2016 was collected from India Meteorological Department and National Innovations in Climate Resilient Agriculture. The data of trans-gangetic plains was analyzed followed by state wise and the zones in a state. Punjab was divided into three zones: Sub-mountainous zone, central zone and south-western zone; Haryana was divided into two zones: eastern and western zone based on topography and climate of the region.

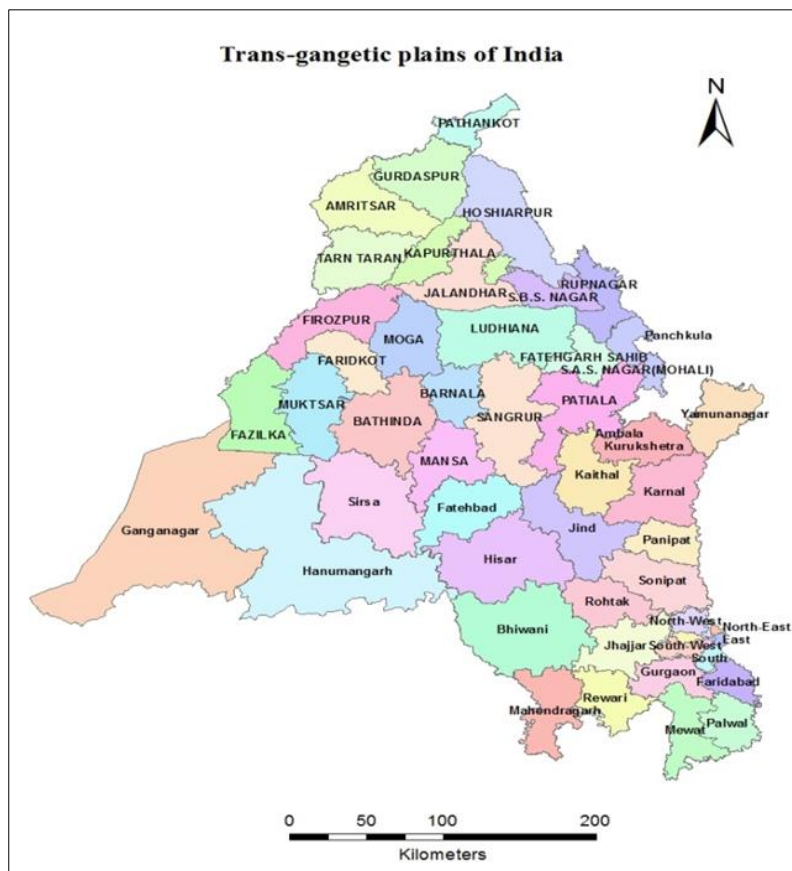


Fig 1: Location of study area

Statistical analysis

Non-parametric statistics

Mann-Kendall test was used to find the annual and seasonal trends in maximum temperature, minimum temperature and rainfall e. The Mann-Kendall test analyzes the sign of the difference between later-measured data and earlier-measured data (Meals *et al.*, 2011). Each later-measured value is compared to all values measured earlier; resulting in a total of $n(n-1)/2$ possible pairs of data, where n is the total number of observations. In this test, the difference between the later-measured value and all earlier-measured values, $(y_j - y_k)$, where $j > i$, is calculated. The test statistic, S, is then computed as the sum of the integers

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n sgn(y_j - y_k)$$

Where, $sgn(y_j - y_k)$ is equal to -1, +1 or 0. The variance associated with S is calculated from the following equations

$$V(S) = \left\{ n(n-1)(2n+5) - \sum_{k=1}^m t_k(k-1)(2t_k+5) \right\} / 18$$

Where, m is the number of tied groups and t_k is the number of data points in group k. The standardized Mann- Kendall test statistic Z which follows the standard normal distribution with mean of zero and variance of one is given by:

$$Z = \frac{S - 1}{\sqrt{V(S)}} \text{ for } S > 0$$

$$0 \text{ for } S = 0$$

$$\frac{S + 1}{\sqrt{V(S)}} \text{ for } S < 0$$

When the Z values computed by above equations are greater than the critical values of Z at a given level of significance, the null hypothesis (no trend in the data) is rejected. The positive values of S indicate an increasing trend, the negative values a decreasing trend and the smaller values no trend. If a significant trend is found, the rate of change can be calculated using the Sen slope estimator (Helsel and Hirsch, 1992) for all $i < j$ and $i = 1, 2, \dots, n-1$ and $j = 2, 3, \dots, n$.

$$Q = \text{median} \left\{ \frac{y_j - y_i}{X_j - X_i} \right\}$$

The median of those slopes is the Sen's slope estimator.

Spatial interpolation

The spatial patterns in rainfall, maximum and minimum temperature were studied by taking the average of five years for

the period 1971-2016 using Inverse Distance weighted (IDW) method in ArcGIS 10.2. IDW determine cell values using a linearly weighted combination of a set of same points. The assigned values to unknown points are calculated with a weighted average of the values available at the known point.

Results

Annual and seasonal climatic variability

Maximum temperature increased by 0.056 °C and 0.038 °C per year during *kharif* and *rabi* respectively, at $p=0.001$ level of significance. Minimum temperature increased by 0.055 °C and 0.025 °C per year during *kharif* and *rabi* respectively, at $p=0.001$ level of significance. On annual basis, minimum temperature increased at the rate of 0.046 °C per year significant at 0.1% level of significance. There was no trend observed in rainfall in TGP of India (Table 1). In state of Punjab, no trend was observed in maximum temperature whereas minimum temperature showed increasing trend. During *kharif* and *rabi* season, it increased at the rate of 0.031 °C and 0.037 °C per year at 0.1% level of significance whereas on annual basis, it increased at the rate of 0.035 °C per year at 0.1% level of significance. No trend was observed in rainfall over Punjab region. In Haryana, maximum and minimum temperature increased to the tune of 0.063 °C and 0.045 °C during *kharif*, at the rate of 0.045 °C and 0.041 °C per year during the *rabi* season and annually at the rate of 0.054 °C and 0.050 °C, respectively at $p=0.001$ level of significance. However, no significant trend was observed in rainfall. In Rajasthan, maximum and minimum temperature increased significantly at the rate of 0.049 °C and 0.056 °C per year, respectively at 0.1% level of significance during *kharif* season and at the rate of 0.034 °C and 0.06 °C per year at 0.1% level of significance annually. During *rabi* season, rainfall followed increased to the tune of 0.133 mm per year at 1% level of significance and annual increase in rainfall was 0.20 mm per year significant at 5% significance level. In Delhi, maximum and minimum temperature increased at the rate of 0.04 °C (0.01% significance level) and 0.05°C (0.1% level of significance) per year, during *kharif* season and at the rate of 0.02 °C and 0.04 °C per year significant at 1% and 0.1% level of significance annually. No trend was observed in rainfall. In three zones of Punjab (sub-mountainous, central and south-western zone), minimum temperature increased at the rate of 0.039 °C, 0.050 °C and 0.042 °C per year during *kharif*, *rabi* and annually; respectively at 0.1% significance level in sub-mountainous zone of Punjab. In central zone, minimum temperature increased at the rate of 0.036 °C per year, 0.051 °C per year and 0.044 °C per year during *rabi*, *kharif* and annually at 0.1% level of significance. In south-western zone, minimum temperature increased at the rate of 0.025 °C per year in *Kharif*, 0.034 °C per year in *rabi* and 0.031 °C per year annually at $p=0.001$ level. No significant trend

observed in rainfall in all the three zones of Punjab. In eastern zone of Haryana, maximum temperature increased at the rate of 0.03 °C per year in *kharif* season at 5% level of significance, 0.05 °C per year in *rabi* season at 1% level of significance and of 0.03 °C per year annually at 1% level of significance. In western zone, it increased at the rate of 0.04 °C ($p=0.001$), 0.02 °C (0.05) and 0.04 °C (0.001) per year in during *kharif*, *rabi* and annually. Minimum temperature increased at the rate of 0.05°C ($p=0.001$) in eastern zone and 3.20 °C ($p=0.01$) in western zone during *kharif* season. During *rabi* season, it increased at the rate of 0.04 °C and 3.20 °C per year at 0.1% and 1% level of significance respectively in eastern and western zone. Annually minimum temperature increased at the rate of 0.05°C per year in eastern zone and 3.52 °C per year in western zone both significant at 0.1% level of significance. No significant trend was observed in rainfall. The increase in minimum temperature was higher than maximum temperature which is congruous with the results revealed by Alexandar *et al* 2006; Paul *et al* 2015; Kaur and Prabhjot-Kaur 2015. Rainfall is becoming highly variable and unpredictable along with potential increase in temperature, causing extreme events like floods and droughts. This indicated the erratic nature of rainfall over the region and the changes in rainfall are less significant than those for temperature. The results are consistent with the findings of study by Kling *et al* (2013), Kingra *et al* (2017). This erratic behavior of rainfall will impact the crop productivity significantly as revealed by studies of Gitayet *et al* 2001.

Similar patterns of climatic parameters have been depicted by spatial interpolation conducted using IDW (Inverse Distance Weighted) method in ArcGIS 10.2 (Figs. 2-4). During the pentad 1971-75, lower range of maximum temperature (27-28 °C) was observed sub-mountainous Punjab which increased in central Punjab (29-30 °C) and southern Punjab (30-31 °C). In eastern Haryana and Delhi, maximum temperature prevailed in the range of 31-32 °C during 1971-75. In northern Rajasthan and western Haryana highest range of maximum temperature was observed *i.e.* 32-33 °C during the corresponding time period. During the period of 1976-80, high range of maximum temperature (31-32 °C) shifted towards western Haryana and Delhi. The area under low temperature (27-28 °C) declined. During the pentads 1981-85 to 2011-16, slight variations in maximum temperature were observed.

Spatial interpolation of minimum temperature over TGP in different pentads from 1971-2016 (1971-75, 1976-80, 1981-85, 1986-90, 1991-95, 1996-00, 2001-05, 2006-10 and 2011-16) revealed that area under low minimum temperature decreased significantly. Spatio-temporal variability as interpolated spatially indicated that total amount of rainfall over the trans-gangetic plain region is declining. Area under highest amount of rainfall is reduced continuously from 1971-2016 (Fig. 4).

Table 1: Annual and seasonal climatic variability over trans-gangetic plains of India

Region	Test	Tmax			Tmin			Rainfall		
		Kharif	Rabi	Annual	Kharif	Rabi	Annual	Kharif	Rabi	Annual
TGP	Z									
	Sen's slope	0.056***	0.038***	0.046***	0.055***	0.025***	0.046***	0.016	0.013	0.006
Punjab	Z	0.3	0.56	0.75	3.39***	3.73***	0.05	-0.29	0.05	-0.31
	Sen's slope	0.004	0.006	0.006	0.031***	0.037***	0.023	-0.039	0.023	-0.059
a) Sub-mountainous Zone	Z	0.88	-0.54	0.22	4.18***	4.84***	5.03***	-0.82	-0.66	-1.65
	Sen's slope	0.007	-0.004	0.002	0.039***	0.050***	0.042***	-0.467	-0.129	-0.349
b) Central Zone	Z	-0.02	0.85	0.6	4.14***	4.93***	5.13***	-0.07	-0.15	-0.17
	Sen's slope	0	0.0008	0.004	0.036***	0.051***	0.044***	-0.055	-0.016	-0.035

c) South-Western zone	Z	0.27	-0.14	0.17	3.02***	3.77***	3.91***	0.94	-0.05	0.74
	Sen's slope	0.003	-0.0044	0.002	0.025***	0.034***	0.031***	0.23	-0.005	0.104
Haryana	Z	4.24***	3.91***	4.40***	5.12***	5.50***	5.65***	0.43	1.7	0.9
	Sen's slope	0.063***	0.045***	0.054***	0.045***	0.041***	0.050***	0.184	0.119	0.166
a) Eastern Zone	Z	2.46*	3.18**	2.87**	5.60***	5.62***	6.20***	0.14	1.11	1.03
	Sen's slope	0.03*	0.05**	0.03**	0.05***	0.04***	0.05***	0.002	0.01	0.01
b) Western zone	Z	3.99***	2.45*	4.32***	5.60***	1.71**	5.89***	0.92	-1.59	-0.6
	Sen's slope	0.04***	0.02*	0.04***	3.20**	3.20**	3.52***	0.01	-0.02	-0.02
Northern Rajasthan	Z	3.90***	0.36	4.02***	5.61***	0.64	5.43***	1.55	2.95**	2.06*
	Sen's slope	0.049***	0.00	0.034**	0.056***	0.01	0.06***	0.267	0.133**	0.20*
Delhi	Z	3.82***	0.00	3.10**	5.72***	1.63	6.31***	-1.51	-0.08	-1.71
	Sen's slope	0.04***	0.00	0.02**	0.05***	0.015	0.04***	-0.36	-0.006	-0.22

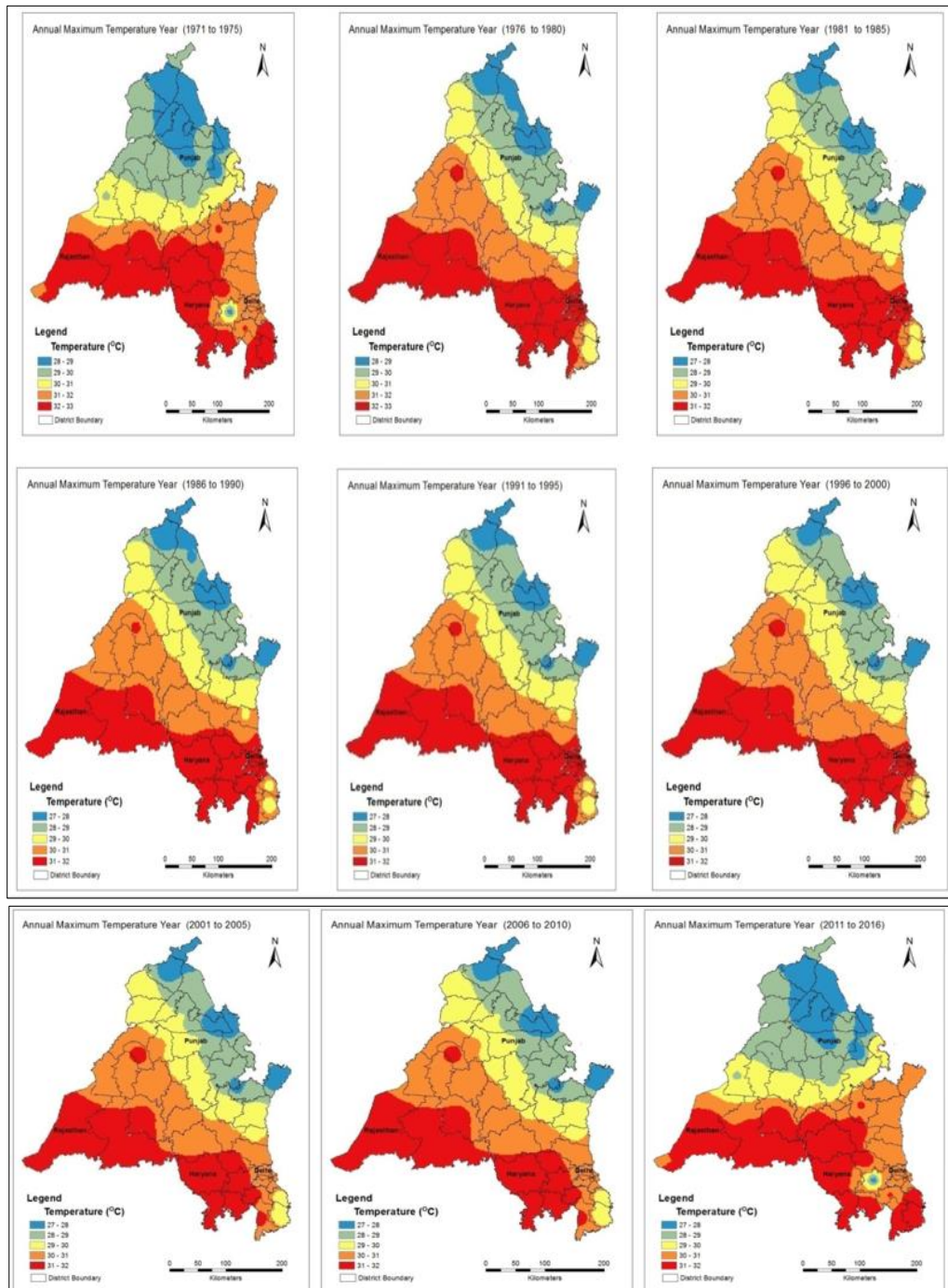


Fig 2: Spatio-temporal variability in maximum temperature during pentads 1971-75 to 2011-2016

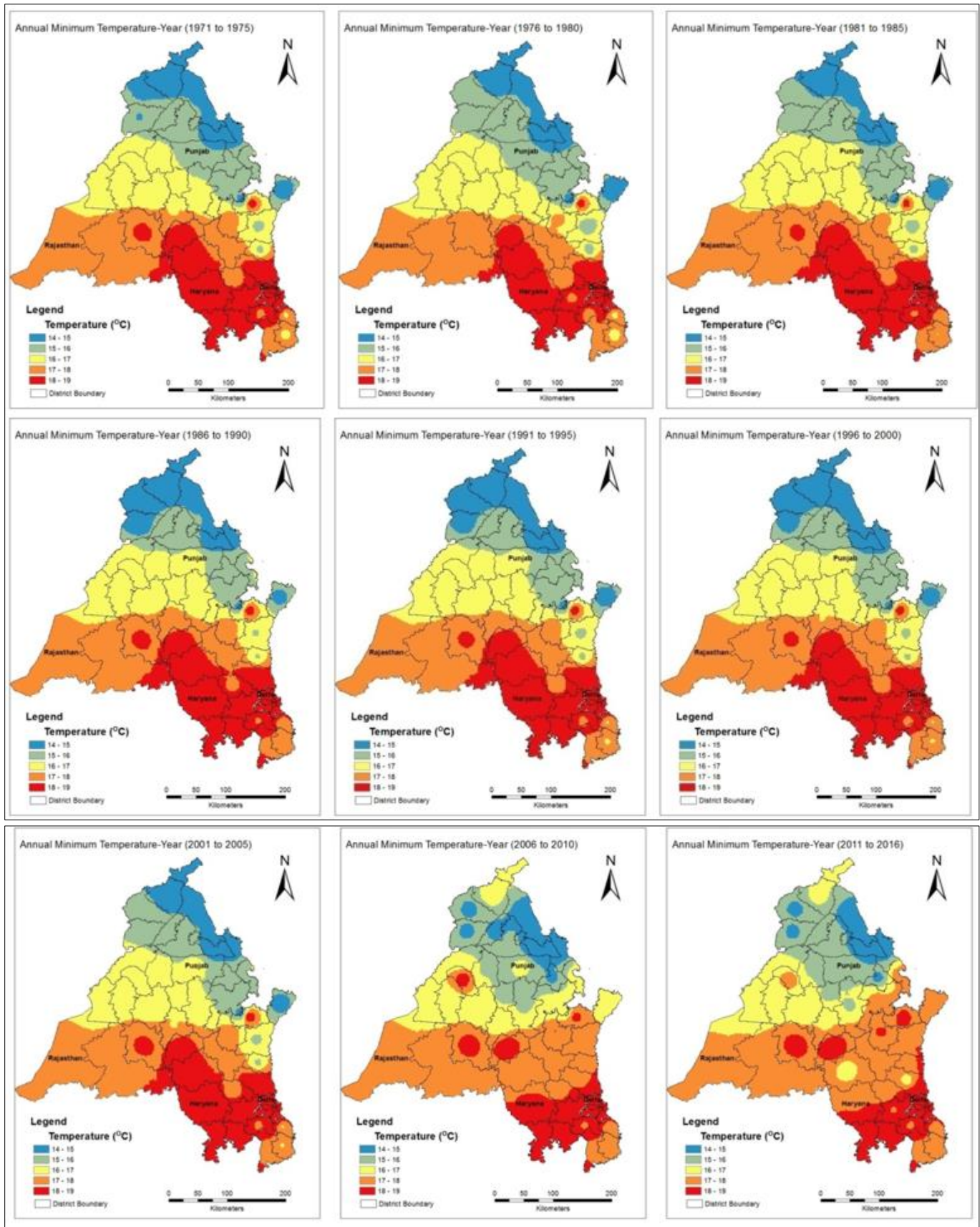


Fig 3: Spatio-temporal variability in minimum temperature during pentads 1971-1975 to 2011-16

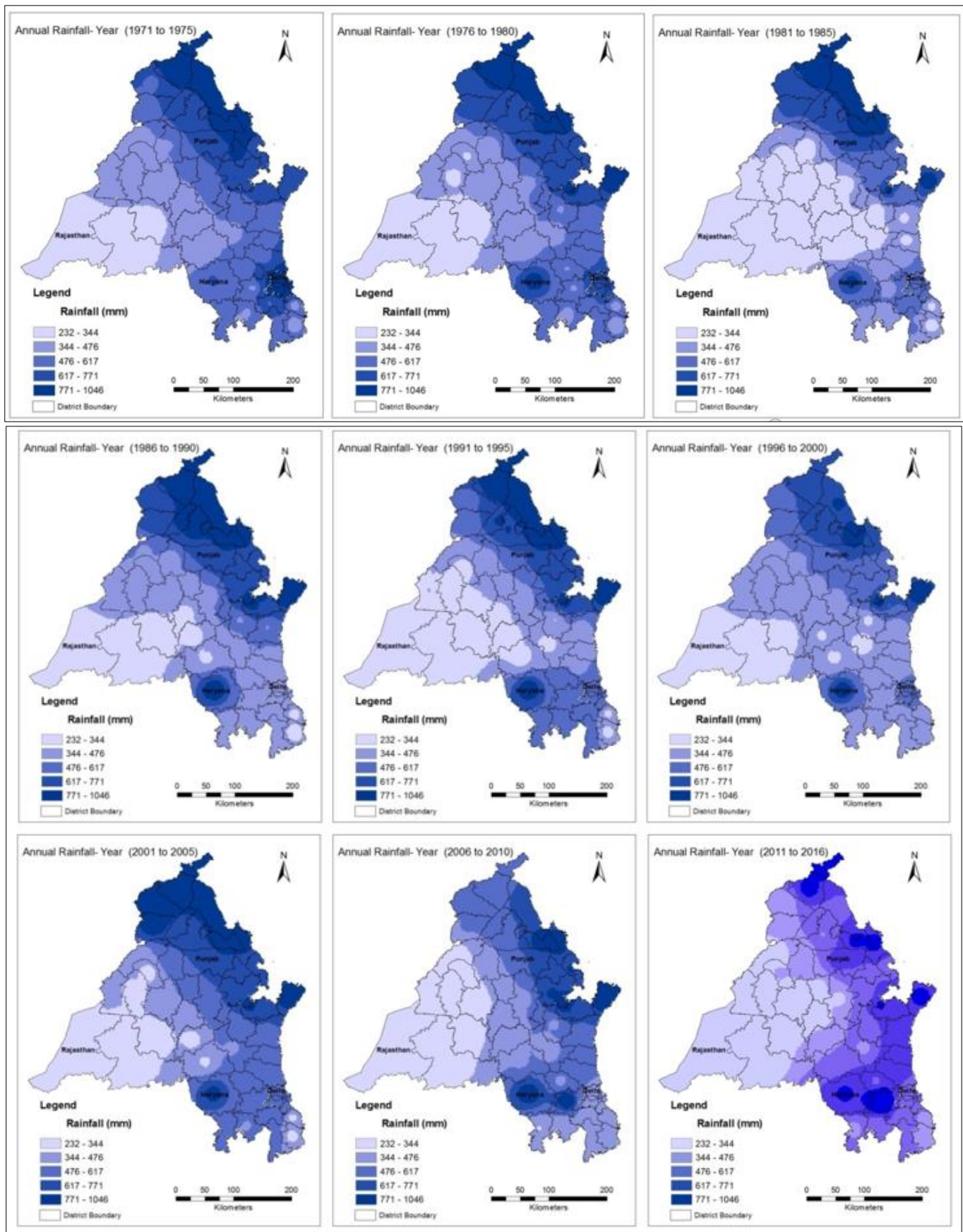


Fig 4: Spatio-temporal variability in rainfall during pentads 1971-1975 to 2011-2016

Conclusion

It is concluded based on the above discussion that that maximum and the minimum temperature had increased over trans-Gangetic plains. However; minimum temperature increased at a significant trend in all states of trans-Gangetic plains. Rainfall followed an erratic behavior. Thus, policymakers, researchers, farmers, and agro-based industries need to understand the changing scenario of climate so that, proper planning and development of suitable agronomic and cropping practices, as per the shifting condition and its intensity to affect the crop, becomes possible.

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