MAUSAM, **66**, 4 (October 2015), 841-846

551.581 : 551.524.36 : 631

Temperature trend in different agro-climatic zones in India

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सार – 1901 से 2002 तक की अवधि में जलवायु आँकड़ों का उपयोग करके भारत के चार कृषि-जलवायविक क्षेत्रों में औसत मासिक तापमान की प्रवृत्तियों का इस शोध पत्र में अध्ययन किया गया है। चार कृषि-जलवायविक क्षेत्रों के पिछले वर्षों में प्रवृति की विशेषताओं की जाँच करने के लिए गैर-प्राचलीय, मान-केंडल परीक्षण किया गया। इससे प्राप्त परिणामों की स्पीअरमैन रैंक सांख्यिकीय और निर्धारणात्मक प्रवृत्ति विश्लेषण से प्राप्त परिणामों के साथ परस्पर जाँच की गई। जाँच से पता चला है कि सभी क्षेत्रों में, वार्षिक औसत तापमान में महत्वपूर्ण रूप से वृद्धि हो रही है। वार्षिक औसत तापमान में अधिकतम वृद्धि क्षेत्र 3 में हुई है जो पिछली शताब्दी में 0.3° सेंटीग्रेड तक रही। परिणाम से यह भी पता चला है कि सभी चारों कृषि जलवायविक क्षेत्रों में सर्दी के महीने, अर्थात् नवम्बर से जनवरी, पहले के मुकाबले गर्म हो रहे हैं। क्षेत्र 1 और 3 के लिए मासिक माध्य तापमान सभी महीनों में बढ़ रहा है और दूसरी ओर क्षेत्र 2 और 4 में जून से सितम्बर में कम तथा अन्य महीनों में बढ़ रहा है।

ABSTRACT. Trends in mean monthly temperature in four agro-climatic zones of India have been studied using climate data for the period of 1901 to 2002. The Non-Parametric, Mann-Kendall Test has been applied to investigate the significance of trend over the years for four agro-climatic zones. The results were cross-checked with those obtained from Spearman's rank statistic and deterministic trend analysis. The investigation reveals that in all the zones, annual mean temperature is significantly increasing. The maximum increase in annual mean temperature is in zone 3 with a tune of 0.3° centigrade in the last century. The results also reveal that the winter months, *i.e.*, November to January are becoming hotter in all four agro-climatic zones. The monthly mean temperature for zone 1 and 3 is increasing in all the months; on the other hand it is decreasing in June-September in zone 2 and 4 and increasing in other months.

Key words – Climatic zones, Mann-Kendall test, Temperature, Trend analysis.

1. Introduction

Climate change affects the variability and seasonality of temperature and humidity. Impact of climate change on Indian agriculture could be amplified because of the warmer temperature of the Indian sub-continent. Since climate is an important input in agricultural production, studying the trends of temperature and rainfall is important. Also in its fourth assessment report, the Intergovernmental Panel on Climate Change (IPCC, 2007) has projected adverse climate effects for the Asian continent. Various studies have been done to examine the trends in climate variables. The study by Srivastava *et al*. (1992) on decadal trends in climate over India gave the first indication that the diurnal asymmetry of temperature trends over India is quite different from that over many other parts of the globe. Pant and Rupa Kumar (1997) analysed seasonal and annual air temperature series for 1881-1997 and showed that there is a significant warming trend of 0.57 °C per 100 years. Bhutiyani *et al*. (2007) found increasing trend in maximum, minimum, mean and diurnal temperature range over the north western Himalayan region during the 20th century. Kothawale *et al*. (2010) studied trends in pre-monsoon temperature in India by dividing the country into homogeneous parts and studied the time series of extreme temperature events. An increasing trend in hot days and nights was observed for some regions and a decreasing trend in cold nights for some other regions. Sarkar *et al*. (2012) studied climate trend in the Brahmputra Basin for the last three decades & concluded that mean temperature shows a rising trend in monsoon and winter season. Attri and Tyagi (2010) reported strong temperature variations in different seasons in India ranging from mean temperature of about 10 °C in winter to about 32 °C in summer season. Paul *et al*. (2014) reported the structural break in mean temperature at around 1970s.

Dhorde *et al*. (2009) investigated long term temperature trends at four largest cities of India during the twentieth century. Jain and Kumar (2012) reported that most of the sub-divisions in the south, central and western parts of India have a rising temperature trend. Some stations located in the north and north eastern India

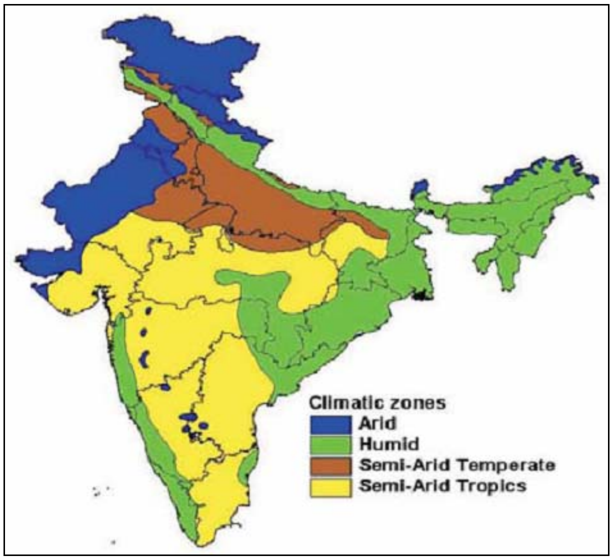

Fig. 1. Agro-Climatic Zones of India

showed a falling trend in annual mean temperature. Kumar *et al*. (2004) studied the crop-climate relationship in India for various crops. Using a regression forecasting model it was found that aggregate production is strongly related with monsoon rainfall. Therefore it is of prime importance to examine changes in climate as extreme weather events can have a great impact on the socio-economic life of people. Also, if a climate signal can be detected it would help to formulate policies to prepare for the after-effects. In our study, trends in temperature have been investigated for all parts of the country using the Mann-Kendall non parametric test, and the spearman's rank statistic is used to cross check the result.

2. Data and methodology

States are generally considered as the unit of analysis. But since Indian states lack homogeneity in terms of Agro-ecological conditions, there is a need to define areas which are more homogeneous and divide them into different zones. ICRISAT (Rao *et al*., 2005) has divided India into four zones (Fig.1). These zones are arid, humid, semi-arid temperate and semi-arid tropic. Zone-3 or Semi-Arid Tropics covers the largest geographical area while Zone-4 or the Arid Zone has the least area under it. The dataset that is used for this work, is the publicly available Climate Research Unit (CRU) generated by the Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, United Kingdom. The CRU TS 2.0 is a widely used long-term data set for climatic variables. This data product consists of climate variables gridded on 0.5° × 0.5° (50 × 50 km^2) and the product is based on surface meteorological observations. The district wise monthly mean surface temperature data from 1901 to 2002, for the Indian subcontinent was extracted from this data set. The annual area weighted mean temperature series for each of the 4 agro-climatic zones were prepared by assigning the district area as the weight for each meteorological station in that agro-climatic zone. In each agro-climatic zone, 63 stations data was considered.

For trend analysis, a non-parametric Mann-Kendall test is used. The advantage of a non-parametric test is that fewer assumptions are used and the problems of skewed data can be avoided. The magnitude of trend in the series is determined using regression analysis is conducted with time as the independent variable and temperature as the dependent variable. A brief description of both the test is given below.

2.1. *Mann-Kendal test*

The Mann-Kendal test is a rank based non-parametric test which is used to detect the existence of a linear trend (Jayawardene *et al*., 2005). The null hypothesis (H_0) for this test is that there is no trend in the series. The first step is replacing the observations (x_i's) by their ranks k_i's. Next calculate N_i, as the number of k_j preceding it such that $k_j > k_i$. The test statistic for the Mann-Kendall test is computed by the following formula $t_m = \frac{4\sum_i^{n-1} N_i}{n(n-1)} - 1$ Next define a range r_m for a desired probability point r_g as $r_m = \pm r_g \sqrt{\frac{4n+10}{9n(n-1)}}$. If t_m lies outside the range of $\pm r_g$ it is said that a significant trend exists, on the other hand if t_m lies within the range of $\pm r_g$ then trend doesn't exist. To find the direction of the trend *i.e.* to see if the trend is increasing or decreasing, the S statistic is used. S is calculated as $S = \sum_k^{n-1} \sum_{j=k+1}^{n} \text{sgn}\,(x_j - x_k)$. Where, sgn is the signum function. If S is greater than zero, trend is said to be increasing otherwise if S is less than zero trend is decreasing. Spearman's rank statistic is also computed to confirm the result obtained from the Mann-Kendall test. The ranks (k_i's) are arranged in increasing order of magnitude. Next calculate d_i as $d_i = k_i$-1. The test statistic is given as $\rho_s = 1 - 6\frac{\sum_j^n d_i^2}{n(n-1)}$. Significance of ρ_s can be tested by calculating t_S, where t_S is given as $t_s = r_s \sqrt{\frac{n-2}{1-r_s^2}}$. Trend is absent if t_s lies within the desired limits.

TABLE 1

Monthly normals of mean temperature for different agro-climatic zones

Month	Zone-1		Zone-2		Zone-3		Zone-4	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
January	18.53	0.49	15.10	0.73	20.83	0.62	16.51	0.59
February	20.66	0.59	17.87	1.06	22.97	0.67	19.10	0.89
March	24.13	0.62	23.32	1.15	26.71	0.70	23.75	0.93
April	26.85	0.60	29.34	1.08	29.95	0.62	28.92	0.94
May	28.08	0.60	33.04	1.23	31.41	0.70	31.98	1.21
June	27.25	0.57	33.35	0.93	29.38	0.83	32.28	0.86
July	25.78	0.40	30.44	0.91	26.83	0.52	30.27	0.78
August	25.51	0.26	29.21	0.55	26.04	0.39	29.38	0.61
September	25.56	0.29	28.87	0.55	26.47	0.49	28.81	0.65
October	24.54	0.39	26.37	0.70	26.15	0.52	26.13	0.65
November	21.76	0.64	21.16	0.87	23.53	0.84	21.57	0.67
December	18.99	0.55	16.36	0.62	21.13	0.62	17.46	0.62
Annual	24.25	0.28	25.15	0.39	25.58	0.32	24.55	0.41

SD stands for standard deviation, temperature in °C, data used from 1901-2002

TABLE 2

Estimates of mean temperature trend in Zone 1 and 2

Month	Zone-1				Zone-2			
	S	t_m	t_s	b	S	t_m	t_s	b
January	797	-0.1547*	2.319*	0.0048*	397	-0.077	1.107	0.0030
February	1633	-0.3170*	5.378*	0.0114*	1021	-0.198*	3.123*	0.0123*
March	881	-0.1710*	2.485*	0.0070*	538	-0.104	1.648	0.0068
April	465	-0.0902	1.337	0.0050	625	-0.121	1.893	0.0090*
May	491	-0.0953	1.483	0.0023	149	-0.028	0.526	0.0018
June	105	-0.0203	0.380	0.0011	-671	0.130	-1.948	-0.0068
July	185	-0.0359	0.630	0.0007	-571	0.110	-1.773	-0.0057
August	741	-0.1438*	2.240*	0.0012	-609	0.118	-1.660	-0.0034
September	559	-0.1085	1.854	0.0020*	-809	0.157*	-2.335*	-0.0045*
October	1139	-0.2211*	3.404*	0.0049*	429	-0.083	1.154	0.0020
November	1885	-0.3659*	6.135*	0.0122*	1535	-0.298*	4.805*	0.0138*
December	2143	-0.4160*	7.335*	0.0119*	1875	-0.364*	5.999*	0.0123*
Annual	2091	0.4060*	7.056*	0.0050*	893	0.173	2.573*	0.0030*

*denotes significance at 5% level.

2.2. *Deterministic trend*

The regression analysis can be carried out directly on the temperature series. A linear equation, $Y_t = \beta_0 + \beta_1 t + \varepsilon_t$ defined by β_0 (the intercept) and trend β_1 (the slope), can be fitted by regression. Here, ε_t is the error term which follows IID Normal $(0, \sigma^2)$. The linear trend value represented by the slope of the simple least-square regression line provided the rate of rise/fall in the temperature.

3. Results and discussion

Mann-Kendall test has been applied to monthly mean temperature data for the period of 1901 to 2002. The descriptive statistics for zone-wise monthly mean temperature and annual mean temperature have been computed and are reported in Table 1. A perusal

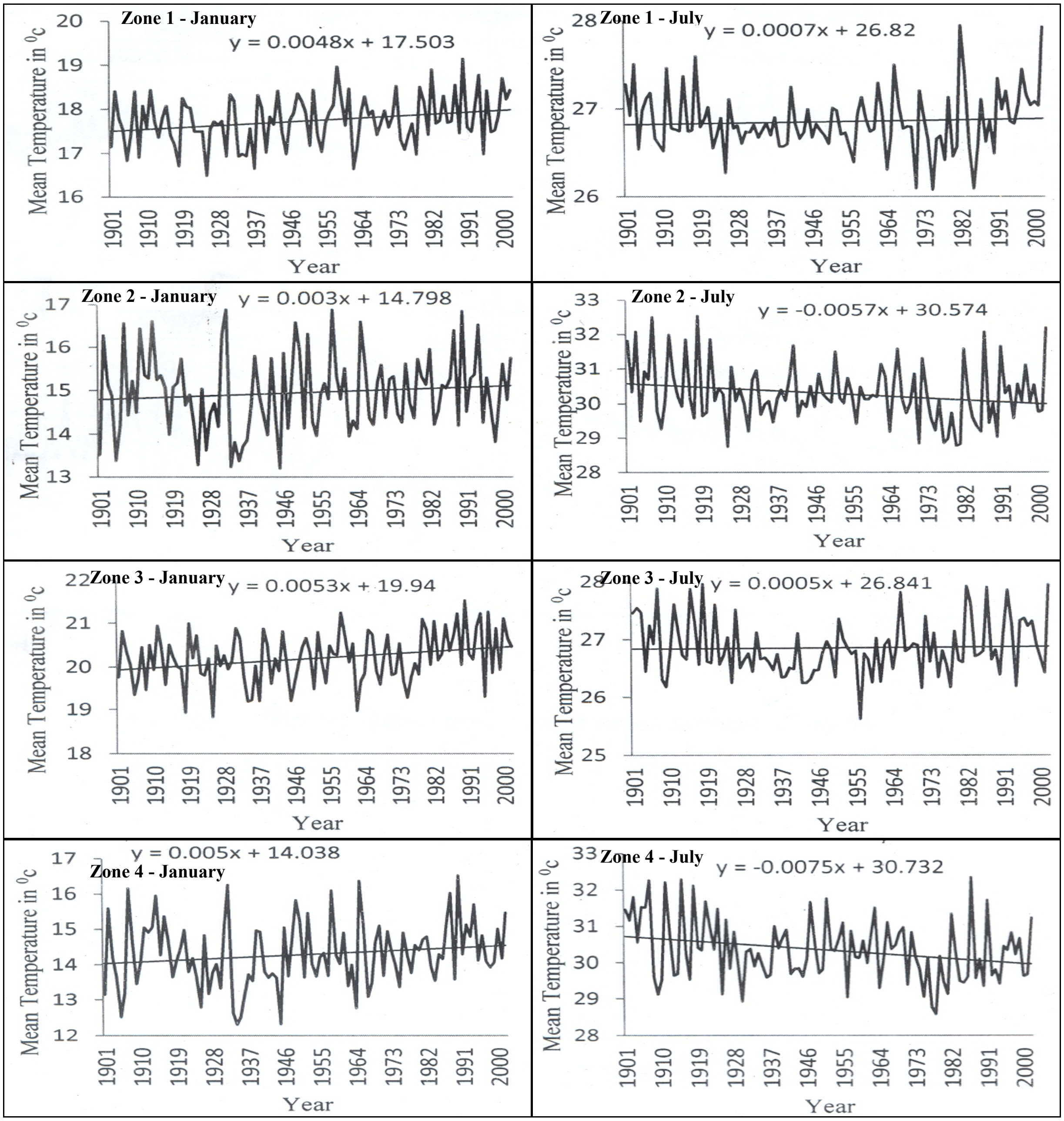

Fig. 2. Monthly mean temperature trends for January and July in different zones

of Table 1 reveals that irrespective of zone, the minimum mean temperature is observed in the month of January. The zone-wise result of mean monthly temperature trend along with the annual mean temperature trend analysis has been reported in Tables 2 and 3. Three methods namely, Man Kendall trend test, Sperarman's rank test and linear regression have been used for the present analysis. In the Tables 2 and 3, *S* denotes direction of trend as determined by Mann Kendall test, and t_m are the calculated test statistic and critical value for Mann Kendall test, t_s is the calculated test statistic for Spearman's test and b denotes the least square estimate of the slope. For zone-1, temperature trend for January, February, March, October, November and December comes out to be significant and is increasing. From the least square estimate of slope it can be found that in the last century, mean temperature for January has increased by 0.48 °C; for February 1.14 °C; for March 0.7 °C and for August it is 0.12 °C. For the months of August and September there is a discrepancy in the results obtained from Mann-Kendall test, Spearman's

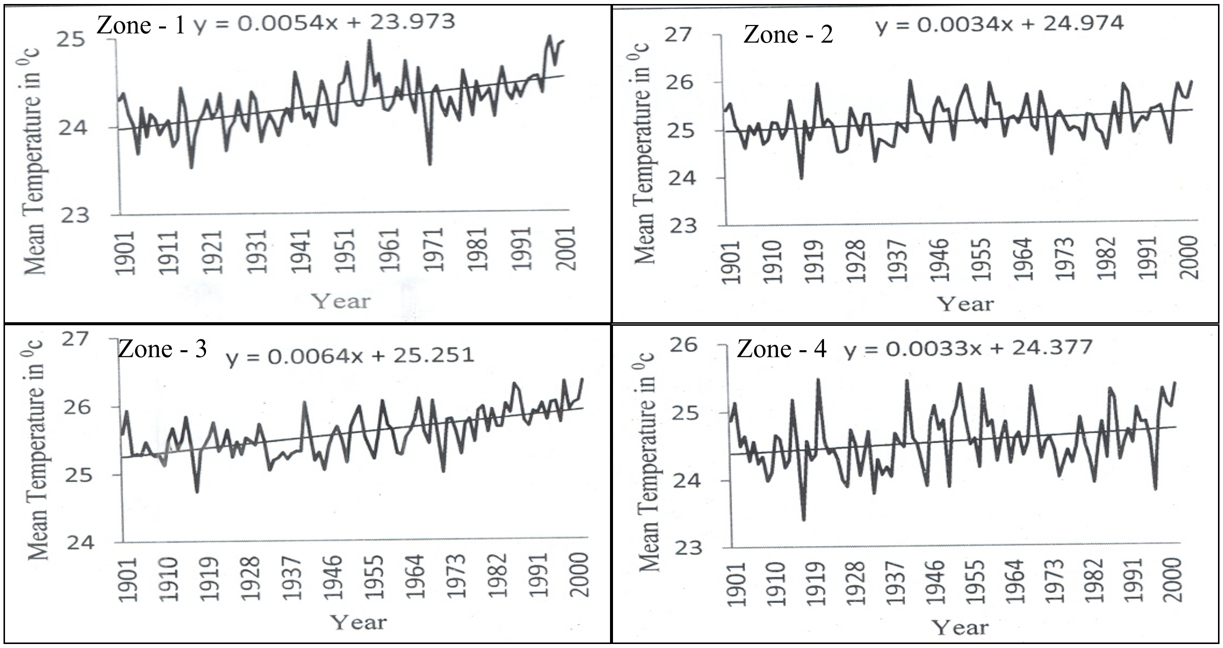

Fig. 3. Annual mean temperature trends in different zones

TABLE 3

Estimates of mean temperature trend in Zone 3 and 4

Month	Zone-3				Zone-4			
	S	t_m	t_s	*b*	*S*	t_m	t_s	*b*
January	883	-0.1714*	2.5785*	0.0053*	575	-0.1116	1.6856	0.0050
February	1685	-0.3271*	5.4806*	0.0117*	963	-0.1869*	2.8702*	0.0118*
March	1325	-0.2572*	4.0260*	0.0093*	571	-0.1108	1.7484	0.0081
April	871	-0.1690*	2.6704*	0.0070*	937	-0.1819*	2.8721*	0.0127*
May	479	-0.0929	1.3452	0.0029	473	-0.0918	1.3559	0.0057
June	41	-0.0079	0.0894	0.00002	-343	0.0665	-1.0384	-0.0045
July	195	-0.0378	0.5120	0.0004	-823	0.1597*	-2.5240*	-0.0075*
August	83	-0.0161	0.2070	0.0006	-561	0.1089	-1.6248	-0.0048
September	969	-0.1881*	3.0497*	0.0042*	-581	0.1127	-1.6928	-0.0040
October	1271	-0.2467*	3.9539*	0.0068*	-325	0.0630	-0.9165	-0.0029
November	1837	-0.3566*	6.2598*	0.0151*	1123	-0.2180*	3.3240*	0.0097*
December	2093	-0.4063*	7.5797*	0.0131*	1317	-0.2556*	3.8608*	0.0084*
Annual	2135	0.4140*	7.6732*	0.0060*	803	0.1560*	2.4932*	0.0030*

*denotes significance at 5% level.

test and regression method. This is due to the fact that regression estimates are very sensitive to extreme observations whereas Mann-Kendall test is a non-parametric test and is not much affected by an extreme observation. So the presence of extreme observations or outliers has affected the estimate of slope by least squares and thus we get opposite result as compared to Mann Kendall and Spearman's test. SAS software 9.3 and R software version 2.15.0 have been used for statistical analysis.

For Zone-2, there is a significant increase in temperature for February, November and December. The least square estimate of slope indicates that during the last century, the increase in mean temperature for February is 1.23 °C, November is 1.38 °C and for December it is

1.23 °C. Temperature in September shows a decreasing trend and the decrease is 0.45 °C. Discrepancy in the results obtained from Mann-Kendall test and regression method is observed in the month of April. For Zone-3, the mean temperature for January-April and then from September-December comes out to be significantly increasing (Table 3). In the last century, during the months of January, February, March, April, September, October, November and December the mean temperature has increased by 0.53 °C, 1.17 °C, 0.93 °C, 0.70 °C, 0.42 °C, 0.68 °C, 1.51 °C and 1.31 °C increase respectively. The trend estimate for Zone 4 shows an increasing trend in temperature for February, April, November and December and in the last century, increase in temperature in these months is 1.18 °C, 1.27 °C, 0.97 °C and 0.84 °C respectively. On the other hand, mean temperature of July is decreased by 0.75 °C in the same period.

The monthly mean temperature trend for January, July over the years for different agro-climatic zones has also been depicted in Fig. 2. A perusal of Fig. 2 reveals that the mean temperature varies a lot over the years irrespective of the agro-climatic zones. The increase in temperature for January and July is rapid after 1970s. The annual mean temperature for all four zones has also been plotted in Fig. 3. A perusal of Fig. 3 indicates that irrespective of zones, the annual mean temperature is increasing over the years. The rate of increase in mean temperature is maximum in zone 3 at 0.64 °C and least in zone 4 at 0.33 °C for 100 years as evident from the least square estimate of slope depicted in equation in the Fig. 3.

4. Conclusions

Agricultural production in India is highly sensitive to climate; therefore any change in temperature will influence the crop growth and productivity. For any particular crop, the effect of increased temperature will depend on the crop's optimal temperature for growth and reproduction. In some areas, warming may benefit the types of crops that are typically planted there. However, if warming exceeds a crop's optimum temperature, yields can decline. The present study is based on analysing mean monthly temperature along with mean annual temperature trend in four homogenous agro-climatic zones in India. The investigation reveals that annual mean temperature for all zones is significantly increasing. Agro-climatic zone wise mean monthly temperature analysis showed that in zone 1 and 3 mean temperature is increasing in all the months whereas in zone 2 and 4 the mean temperature is increasing in January to May and October to December and decreasing in June-September. Further studies might help in understanding the behaviour of climate and better assessment of its impact.

Acknowledgements

Authors are thankful to the anonymous reviewers for providing useful comments which helped improve the paper.

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