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Zoning and Trend Analysis of Temperatures for Fruit Crops in North-West India Using GIS

Mohan Singh[1], Ram Niwas[1], M.L. Khichar[1] and A.K. Godara[2*]

[1]Department of Agricultural Meteorology, CCS Haryana Agricultural University, Hisar, Haryana, India
[2]Department of Fruit Science, CCS Haryana Agricultural University, Hisar, Haryana, India

**Corresponding author*

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A B S T R A C T

Study was conducted to quantify trend in temperatures, its variability and spatial distribution and its influence on fruit production in north-west India for this purpose more than 30 years data on maximum and minimum temperatures of twenty two different agrometeorological stations of Jammu & Kashmir, Himachal Pradesh, Utrakhand, Punjab, Haryana, Chandigarh, Delhi, Uttar Pradesh and Rajasthan were used in this study. The temperature data was analyzed for computation of annual normal temperature and the coordinates were converted (into decimal system) for each meteorological station, for spatial analysis. Temperature trends for different meteorological stations in hills, plains of north-west India were evaluated using trend analysis. The map of north-west India was digitized and different temperature zones for maximum, minimum and mean temperature were delineated using GIS. Out of 22 stations, half of the stations showed a significant positive trend and another half negative trend in maximum temperature. A significant positive trend in minimum temperature of twenty stations but negative trend at Srinagar and Ranichauri was observed. Mean temperature showed significant positive trend at seventeen but negative at five stations. In north-west India as a whole a significant positive trend in annual maximum temperature (0.1 to 3.0°C/100 years), annual minimum temperature (1.5 to 1.6°C/100years) and in mean temperature (1.1 to 2.5°C/100 years) was observed. The North-west India was divided into six zones of maximum temperature, seven zones of minimum temperature and five zones of mean temperature by taking a class interval of 2.5°C. The study can be further refined by including the historical temperatures data of more and more meteorological stations located in the study area for better results.

Introduction

Temperature has a direct effect on all forms of life on earth, affecting a wide range of processes and activities ranging from human comfort and consequent energy supply and demand for heating and cooling, to crop and domestic animals responses, the incidence of insects-pests, diseases and also rates of evapotranspiration. Temperature is a basic climatological parameter frequently used as an index to the energy status of an environment (De Jager and Schulze, 1977). The increased concentration of carbon dioxide (CO_2) and

other trace GHG in the atmosphere, over the last century due to rapid industrialization and population pressure resulted in global warming. At present rate of CO_2 emission is projected to be in the range of 500–1000 ppm by the end of this century, which will potentially increase global temperature by 1.8–5.8^{o}C (IPCC, 2007). In case of 4^{o}C rise in mercury level, there would be a 30% probability of temperature so high that even a moderate outdoor work cannot be carried out during the hottest month in north India. There will also be 40% chances that individual in north India will not be able to participate in competitive outdoor activities, if global temperature goes by average 1^{o}C (PTI, 2015).The Himalaya extending 3000 km in length and covering nearly 750,000 sq km of northern Pakistan, Nepal, Bhutan and North-western and North-eastern states of India forms wall which protect the lands area to its south from the scorching cold winds coming from Siberia and a source of eight major rivers of Asia and is known as "water tower of Asia" (IPCC, 2007; Xu *et al.,* 2009).

The Himalayas region is one of the most complex young mountains systems in the world and is extremely vulnerable to global warming (Bandyophadhyay and Gyawali, 1994). Evidence of climate change in north-west India as in other parts of the world was reported (Kumar *et al.,* 2015; Pathak *et al.,* 2010; Sharma *et al.,* 2009). Limited studies on temperature at few places in Himalayan region showed three times higher warming than the global average (Xu *et al.,* 2009; Shrestha *et al.,* 2012; IPCC, 2007). Some other studies also showed much higher warming in the last hundred years (Du *et al.,* 2004 and IPCC, 2007). Though Himalayas are vulnerable to climate change (Xu *et al.,* 2009) and undergoing rapid environmental change (Bawa *et al.,* 2010), there is no systematic analysis of climate change in this region (Sharma *et al.,* 2009; Shrestha *et al.,* 2012). First and foremost research gap identified by Sharma *et al.,* (2009) is the lack of knowledge on rate climate change at regional and local levels. Lack of daily weather data for more number of years and locations in the region is the main constraint for assessment of climate change and related extreme climatic events. So, the present study was panned to evaluate temperature trend in relation to fruit production in north-west India.

Materials and Methods

Location of the study area

Twenty two meteorological stations, Srinagar, Jammu (Jammu & Kashmir), Manali, Shimla, Palampur, Solan (Himachal Pradesh), Ranichauri (Utrakhand), Ludhiana, Bathinda Patiala (Punjab) Chandigarh, Ambala, Karnal, Rohtak, Sirsa, Hisar, Bawal, Narnaul (Haryana) Delhi, Sriganganagar, Jaipur (Rajasthan) Saharanpur and in Uttar Pradesh located in north-west India were selected for the study. The experimental site was the north-west India (Map 1) which approximately is located between $26^{0}40'$ to $37^{0}10'$ N latitude and between 72^{0} 50′ and 81^{0} 00′ E longitudes. The altitude of area varies between 200 to 8600 meters above mean sea level. Total area of the site is approximately 5 lakh square km out of this 1000 thousand hectare is covered under the fruit crops. It has geographic features like the cold desert, the coldest place on the earth (Akbar *et al.,* 2013), the Higher Himalaya, the Middle Himalaya, the Lower Himalaya, the Shiwalik hills, semi desert sandy plain and the Aravali range and the hot Thar Desert. The latitude, longitude and altitude of all the stations, along with their climatic types are given in Table 1. Based on the altitude, the study area was divided hills >1000 meters (Srinagar, Manali, Shimla, Palampur, Solan and Ranichauri) and Plains (Jammu, Chandigarh, Ambala, Saharanpur, Delhi, Karnal, Patiala, Ludhiana, Rohtak,

Bathinda, Hisar, Sirsa, Bawal, Narnaul, Ganganagar and Jaipur) <1000 meters. Similarly, the whole year was divided into two seasons namely effective growing season (EGS) and dormant season (DS) for regional and seasonal of data analysis. EGS for hills was considered from April to October and for plains from March to October, similarly DS for hills was considered from November to March and for plains from December to February, respectively.

Data collected

Monthly maximum and minimum temperature data of twenty two locations, *viz.*, Manali, Shimla, Solan, Chandigarh, Ambala, Saharanpur, Delhi, Karnal, Patiala, Ludhiana, Rohtak, Bathinda, Hisar, Narnaul, Ganganagar and Jaipur for the year from 1980 to 2014 and at Srinagar, Palampur, Ranichauri, Ranichauri, Sirsa, Bawal for the year from 1985 to 2014, respectively were used for the study. These data were collected from India Meteorological Department), Central Research Institutes for Dry Land Agriculture (CRIDA), revenue departments state agricultural universities (SAUs), Regional Research Stations (RRS), Regional Horticultural Research Stations etc.

Calculation of statistical measures

Annual means of maximum, minimum and mean temperature were calculated by averaging over 365 days of each year. Similarly, seasonal and monthly means of temperatures were calculated by averaging over the days of respective season or month of each year. Keeping the growth behaviour of fruit crops in mind the two seasons considered in this paper: effective growing season (EGS) and dormant season (DS) for regional and seasonal comparison of data analysis. EGS for hills was considered from April to October and for plains from March to October, similarly DS for hills was considered from November to March and for plains from December to February, respectively. The monthly means of temperature data were further averaged over time periods (decadal) 1985-1994, 1995-2004, 2005-2014 at each station. Statistical measures like normal (long period average) standard deviation, coefficient of variation, slope, standard error, t-values, and significance (probability) and regression coefficient were computed using 'OP Stat" software from daily temperature data of more than 30 years at each station. Annual, seasonal and decadal statistical measures were computed at hills, plains and whole of the north-west India.

Analysis of data

Trend in temperatures were assessed through simple linear regression between weather parameters (Annual, monthly, seasonal and decadal) at hills, plains and north-west India. Significance of regression (or trends) was assessed through *F*-test and *P*-levels. Student's *t-test* was used to test the significance of difference between decadal means of weather parameters. Descriptive statistics like, arithmetic mean, standard deviation, coefficient of vitiation, t-values, probability (p) in maximum and minimum temperatures were worked out for all the twenty two stations, hills, plains and whole of the north-west India. Percent share of a station in normal temperature (PST) was worked out by dividing the normal temperature of a station by the summation of all the normals and multiplied by hundred as:

PST = Normal temperature of the station x100/∑Normal temperatures.

Shift analysis

The monthly means of temperatures data were averaged over three time periods (decadal) 1985-1994 (D1), 1995-2004 (D2), 2005-2014 (D3) at each station, hills, plains and north-west

India and D1 and D3 were compared to know if there were any shifts in temperatures over these time period.

Spatial analysis

Maps depicting spatial variation in annual and seasonal temperature were prepared using ArcMap 10.1 GIS software by taking followed steps:

The hard copy of the map of the study area was digitized and shape file was created.

North-west India polygon shape file was selected.

The latitude-longitude values of each point were find out and converted to degree-decimal format to enter in GIS.

The coverage file (point) was then generated from the location data in ArcMap (10.1) GIS software.

The thermal and LGP data entered as attribute table and attached/joined to the point file already generated.

Then the point file was interpolated by GIS tools and converted to raster format by krigging/radial basis interpolation function.

Results and Discussion

Normal maximum temperature

The share in long period average (normal) of maximum and minimum temperatures worked out on annual & seasonal basis for each station was given in Tables 2a, 2b, 3a and 3b. Among the six stations comes under hills (Srinagar, Manali, Shimla, Palampur, Solan and Ranichauri) the monthly mean maximum temperature was lowest at Srinagar (19.4^{o}C) followed by Shimla (19.6^{o}C) and Ranichauri (19.7^{o}C) and highest at Solan (25.4^{o}C) and followed by Palampur (23.7^{o}C) with PST of 3.11, 3.14, 3.15, 4.07 and 3.79%, respectively (Table 2a). The mean minimum temperature was lowest at Srinagar (6.7^{o}C) followed by Ranichauri (10.2^{o}C) and Manali (10.4^{o}C), highest was at Palampur (13.5^{o}C) followed by Solan (11.4^{o}C) with PST of 1.99, 3.02, 3.08, 4.00 and 3.38%, respectively (Table 3a).The mean normal temperature was lowest at Srinagar (13.1^{o}C) followed by Ranichauri (14.9^{o}C) and Shimla (15.3^{o}C), highest was at Palampur (18.6^{o}C) followed by Solan (18.4^{o}C) with PST of 2.73, 3.10, 3.19, 3.87 and 3.83%, respectively.

In plains the monthly mean maximum temperature was lowest at Ludhiana (29.7^{o}C) followed by Jammu (29.9^{o}C) and Karnal (29.9^{o}C) and highest at Ganganagar (32.9 ^{o}C) followed by Jaipur (32.1 ^{o}C) with PST of 4.75, 4.79, 4.79, 5.27 and 5.14, respectively (Table 2a). The monthly mean minimum temperature was lowest at Saharanpur (14.6^{o}C) followed by Hisar (16.3^{o}C) and Jammu (16.7^{o}C) and highest at Jaipur (19.2 ^{o}C) followed by Ganganagar (16.9 ^{o}C) with PST of 4.33, 4.83, 4.95, 5.69 and 5.34, respectively (Table 3a).

Seasonal maximum temperature

The PST of mean maximum temperature was 26.49, 38.37and 35.15% for annual, 27.90, 37.31 and 34.79 for effective growing season, 27.53, 37.63 and 34.84% for dormant season at hills, plain and north-west India, respectively (Table 2a). The corresponding value of PST for minimum temperature was 24.65, 39.77 and 35.58 for annual, 27.41, 37.82 and 34.87 (Table 3a). The annual maximum temperature was most variable at Shimla (CV 5.6%) followed by Manali (CV 4.7%) and Srinagar (CV 4.6%) and comparably less variable at the remaining stations (CV of 1.1 to 3.6%). During the effective growing season the average

maximum temperature was between 25.6°C and 34.8°C in the study area (Table 2a). The coefficient of variation was highest (9%) for Manali followed by Shimla (4.5%) and Srinagar (4.2%). The coefficient for variation varied from 1 to 4 per cent for rest of stations being lowest for Chandigarh (1.55) and Karnal (1.6%). The normal maximum temperature for dormant season varied from 10-15^{o}C for Srinagar, Manali, Shimla, Ranichauri with coefficient of variation 7 to 12.2%, from 15-20^{o}C for Palampur, Ludhiana and from 20-25^{o}C for Solan, Jammu, Chandigarh, Ambala, Saharanpur, Delhi, Karnal, Patiala, Rohtak, Bathinda, Hisar, Sirsa, Bawal, Narnaul, Ganganagar, Jaipur with coefficient of variation less than 7% (Table 2a). The standard error for maximum temperature was almost at par for annual as well as on seasonal basis but was somewhat higher during the dormant season (Table 2b).

The annual maximum temperature for hills (includes Srinagar, Manali, Shimla, Palampur, Solan and Ranichauri) was 21.4°C ± 0.84, for plains (includes rest 16 stations) was 31.0°C± 0.65 and for the whole of north-west India it was 28.4°C± 0.70. The coefficient of variation was 4.0, 2.1 and 2.6% for hills, plains and north-west India, respectively. The standard error and t-value were higher for the hills as compared to the plains but the significance (p) was higher for plains (3.85 %) as compared to hills and the north-west India (Table 2b). During effective growing season the maximum temperature for hills was 25.5°C, for plains 34.1°C and for north-west India it was 31.8°C with the coefficient of variation 4.2%, 2.1% and 2.6% for hills, plains and north-west India, respectively.

Normal minimum temperature

For annual normal minimum temperature the coefficient of variation was found highest (16.0%) for Manali followed by Srinagar (7.8%) and Ranichauri (6.6%) and lowest for Saharanpur (1.8%) followed by Patiala (1.8%). Its value for Sirsa, Shimla and Solan varied from 5.3 to 5.7 for Narnaul, Bawal and Jammu varied from 4.2 to 4.5 per cent and for the remaining stations Saharanpur, Patiala, Karnal, Delhi, Bathinda, Chandigarh, Ganganagar, Ludhiana, Ambala, Hisar, Rohtak and Jaipur it was between 1.8 and 3.7 per cent (Table 3a). During the effective growing season the normal minimum temperature was between 20.1°C and 22.3°C for Chandigarh, Ambala, Delhi, Karnal, Patiala, Ludhiana Bathinda, Sirsa, Bawal, Narnaul, Ganganagar and Jaipur and varied between 11.5 and 19.7°C for Srinagar Manali, Shimla, Palampur, Solan, Ranichauri, Jammu and Saharanpur. The slope was negative for Srinagar, Shimla, Palampur and Ranichauri and positive for remaining eighteen stations (Table 3a). Significance level (p) of R^2 was at 0.970 for Saharanpur and it was less than 0.602 for all the remaining twenty one stations (Table 3b).The normal minimum temperature during dormant season varied from 0-5^{o}C for Srinagar, Manali, Solan and Ranichauri and from 5-10^{o}C for Shimla, Palampur, Jammu, Chandigarh, Ambala, Saharanpur, Delhi, Karnal, Patiala, Ludhiana, Rohtak, Bathinda, Hisar, Sirsa, Bawal, Narnaul, Ganganagar and Jaipur. The normal value of annual minimum temperature was 10.6°C ± 0.73 for the hills 17.1°C ± 0.57 for plains and for whole of north-west India it was 15.3°C ± 0.62. The coefficient of variation was 7.3%, 3.3% and 4.4% for hills, plains and for north-west India, respectively (Table 3a). The standard error was higher for hills as compared to plains and significance (p) was higher in hills than plains and whole of north-west India (Table 3b). During effective growing season the normal minimum temperature for the hills was 14.8°C for plains was 20.5°C and for north-west India it was 18.9°C with coefficient of variation of 6.2%, 3.3% and 4.0%, respectively.

Trends in temperatures

Out of twenty two stations, half showed the decreasing trend and another half increasing trend in maximum temperature. It was increasing with a rate of 0.0-10.5°C per 100 years at Srinagar, Manali, Shimla, Palampur, Solan, Ranichauri, Saharanpur, Ludhiana, Rohtak, Ganganagar and Jaipur whereas it was decreasing at the remaining eleven stations with a very low rate of 0.0-2°C per 100 years (Table 2a). The slope was positive for hills (0.030), plains (0.001) and north-west India (0.009) and was higher for hills compared to plains and the north-west India. The maximum temperature was increasing with 3.0°C/100 years in hills, 0.1°C/100 years in plains and 0.9°C per 100 years in north-west India. This reflects the regional warming as reported by IPCC 5th reports (IPCC, 2014). Similar trend was observed by Negi*et al.,* (2012) and Jain and Kumar (2012).

The slope of minimum temperature was positive for all the stations except Srinagar, Palampur and Ranichauri where it was negative. The warming rate of 12.1°C per 100 year was observed at Manali which was highest and the lowest rate was observed at Shimla. The slope was positive for hills (0.016), plains (0.015) and 0.016 for north-west India (Table 3a).

The minimum temperature showed an increasing trend for hills, plains and north-west India which was also reported by Jangra & Singh (2011). The increasing rate was 1.6°C/100 years for hills, 1.5°C/100 years for plains and 1.6°C per 100 years for north-west India. An increase in minimum temperatures (0.07°C/year), decrease in maximum temperatures (0.02°C/year) also reported by Kaurand Hundal (2006) in Ludhiana, Punjab and by Vinod (2015) for different meteorological stations in Haryana.

Table.1 Geographical information of different meteorological stations

S. No.	Station	Latitude	Longitude	Altitude (m)	Division
1	Srinagar	34.09	74.79	1600	Hills
2	Manali	32.27	77.17	2050	
3	Shimla	31.11	77.17	2397	
4	Palampur	32.12	76.53	1219	
5	Solan	30.92	77.12	1600	
6	Ranichauri	30.06	78.99	1950	
7	Jammu	32.73	74.87	327	Plains
8	Chandigarh	30.75	76.78	321	
9	Ambala	30.38	76.78	264	
10	Saharanpur	29.96	77.54	268	
11	Delhi	28.62	77.21	216	
12	Karnal	29.69	76.98	245	
13	Patiala	30.34	76.38	350	
14	Ludhiana	30.91	75.85	244	
15	Rohtak	28.89	76.57	220	
16	Bathinda	30.23	74.95	201	
17	Hisar	29.15	75.71	215	
18	Sirsa	29.53	75.01	205	
19	Bawal	28.08	76.58	266	
20	Narnaul	28.01	76.01	308	
21	Ganganagar	29.92	73.88	178	
22	Jaipur	26.91	75.81	431	

Table.2a Statistical measures for annual maximum temperatureat different stations

Stations	PST (%)			Standard deviation			CV (%)			Slope (rate)		
	Annual	EGS	DS	Annual	EGS	DS	Annual	EGS	DS	Annual	EGS	DS
Srinagar	3.11	3.66	2.45	0.88	1.1	1.3	4.55	4.2	12.2	0.022	0.02	0.05
Manali	3.31	3.61	3.29	0.98	2.1	2.1	4.72	9.0	9.0	0.025	0.01	0.04
Shimla	3.14	3.29	3.38	1.10	1.0	1.4	5.60	4.5	9.7	0.100	0.09	0.12
Palampur	3.79	3.89	4.27	0.52	0.7	1.0	2.20	2.6	5.5	0.070	0.03	0.12
Solan	4.07	4.11	4.70	0.90	0.9	1.6	3.55	3.3	7.6	0.105	0.06	0.17
Ranichauri	3.15	3.31	3.36	0.64	0.6	1.1	3.24	2.5	7.2	0.005	0.00	0.01
Jammu	4.79	4.72	4.63	0.77	1.0	1.1	2.57	2.9	5.4	-0.027	-0.02	-0.06
Chandigarh	4.85	4.75	4.90	0.55	0.5	1.1	1.80	1.6	4.9	-0.001	0.01	-0.03
Ambala	4.82	4.75	4.72	0.61	0.6	1.0	2.01	1.7	4.9	-0.005	0.01	-0.04
Saharanpur	4.87	4.72	5.00	0.34	0.6	0.9	1.13	1.8	4.1	0.060	0.07	0.04
Delhi	4.96	4.88	4.95	0.53	0.6	1.0	1.72	1.8	4.6	-0.017	-0.01	-0.05
Karnal	4.79	4.72	4.70	0.55	0.5	0.9	1.85	1.6	4.4	-0.002	0.01	-0.03
Patiala	4.87	4.74	4.75	0.73	0.6	0.7	2.40	1.8	3.5	-0.009	-0.01	-0.01
Ludhiana	4.75	4.71	4.52	0.56	0.7	0.8	1.90	2.0	4.2	0.013	0.02	0.00
Rohtak	5.09	4.98	5.15	0.60	0.7	0.9	1.89	1.9	4.0	0.004	0.01	-0.01
Bathinda	5.03	4.98	4.90	0.56	0.8	0.9	1.78	2.3	4.3	-0.024	-0.02	-0.18
Hisar	5.03	4.97	4.88	0.72	0.7	0.9	2.28	2.1	4.3	-0.011	-0.01	-0.03
Sirsa	5.01	4.97	4.81	0.67	0.7	1.2	2.13	2.1	5.6	-0.007	0.01	-0.06
Bawal	5.09	5.04	4.86	0.69	0.8	1.1	2.16	2.2	5.3	-0.003	-0.01	0.00
Narnaul	5.09	4.98	5.13	0.98	1.0	1.2	3.09	2.9	5.5	-0.023	-0.02	-0.04
Ganganagar	5.27	5.21	5.13	0.80	0.9	0.9	2.42	2.5	4.1	0.032	0.05	-0.01
Jaipur	5.14	4.98	5.50	0.81	0.9	1.0	2.51	2.5	4.3	0.024	0.02	0.02
Hills	26.49	27.90	27.53	0.84	1.1	1.4	3.98	4.2	9.0	0.030	0.03	0.04
Plains	38.37	37.31	37.63	0.65	0.7	1.0	2.10	2.1	4.6	0.001	0.01	-0.02
NW India	35.15	34.79	34.84	0.70	0.8	1.1	2.61	2.6	5.5	0.009	0.01	-0.003

PST: Percent share of a station in normal temperature

Table.2b Statistical measures for annual maximum temperature at different stations

Stations	S. E.			't'			'p'			R^2		
	Annual	EGS	DS	Annual	EGS	DS	Annual	EGS	DS	Annual	EGS	DS
Srinagar	0.023	0.02	0.03	0.96	0.70	2.02	0.327	0.474	0.045	0.032	0.017	0.128
Manali	0.016	0.02	0.02	1.53	0.70	2.10	0.135	0.489	0.043	0.064	0.015	0.118
Shimla	0.011	0.01	0.02	9.52	8.63	6.94	0.000	0.000	0.000	0.745	0.706	0.609
Palampur	0.030	0.03	0.04	2.34	0.99	3.17	0.023	0.309	0.003	0.255	0.058	0.385
Solan	0.019	0.02	0.03	5.61	2.63	6.76	0.000	0.011	0.000	0.570	0.223	0.656
Ranichauri	0.015	0.01	0.02	0.34	0.05	0.52	0.730	0.960	0.592	0.004	0.000	0.010
Jammu	0.020	0.02	0.02	-1.39	-0.76	-2.47	0.175	0.453	0.020	0.067	0.022	0.190
Chandigarh	0.010	0.01	0.02	-0.11	0.54	-1.40	0.912	0.595	0.171	0.000	0.009	0.059
Ambala	0.010	0.01	0.02	-0.54	0.88	-2.63	0.595	0.384	0.013	0.008	0.022	0.165
Saharanpur	0.069	0.06	0.10	0.87	1.07	0.36	0.357	0.262	0.695	0.087	0.125	0.016
Delhi	0.011	0.01	0.02	-1.55	-0.70	-2.39	0.132	0.492	0.023	0.076	0.016	0.164
Karnal	0.006	0.01	0.01	-0.34	0.71	-2.62	0.737	0.480	0.012	0.003	0.012	0.144
Patiala	0.011	0.01	0.02	-0.81	-0.64	-0.93	0.423	0.528	0.363	0.022	0.014	0.029
Ludhiana	0.014	0.01	0.02	0.91	1.49	-0.15	0.370	0.147	0.885	0.030	0.076	0.001
Rohtak	0.008	0.01	0.01	0.54	1.14	-0.76	0.594	0.260	0.453	0.007	0.032	0.015
Bathinda	0.014	0.02	0.08	-1.75	-0.90	-2.30	0.081	0.359	0.024	0.098	0.028	0.158
Hisar	0.007	0.01	0.01	-1.54	-0.76	-2.58	0.131	0.453	0.013	0.052	0.013	0.134
Sirsa	0.015	0.02	0.02	-0.45	0.47	-2.46	0.644	0.628	0.016	0.007	0.008	0.178
Bawal	0.014	0.02	0.02	-0.24	-0.32	-0.08	0.809	0.752	0.940	0.002	0.003	0.000
Narnaul	0.014	0.02	0.02	-1.69	-1.10	-2.58	0.091	0.267	0.012	0.073	0.032	0.156
Ganganagar	0.014	0.02	0.02	2.25	2.99	-0.49	0.031	0.005	0.626	0.141	0.223	0.008
Jaipur	0.013	0.01	0.02	1.82	1.68	1.34	0.077	0.103	0.189	0.092	0.079	0.052
Hills	0.019	0.02	0.02	3.38	2.28	3.59	0.203	0.374	0.114	0.257	0.170	0.318
Plains	0.016	0.02	0.03	0.25	0.36	-1.38	0.385	0.386	0.278	0.001	0.045	0.092
NW India	0.017	0.02	0.03	0.74	0.89	-0.03	0.335	0.382	0.234	0.046	0.079	0.153

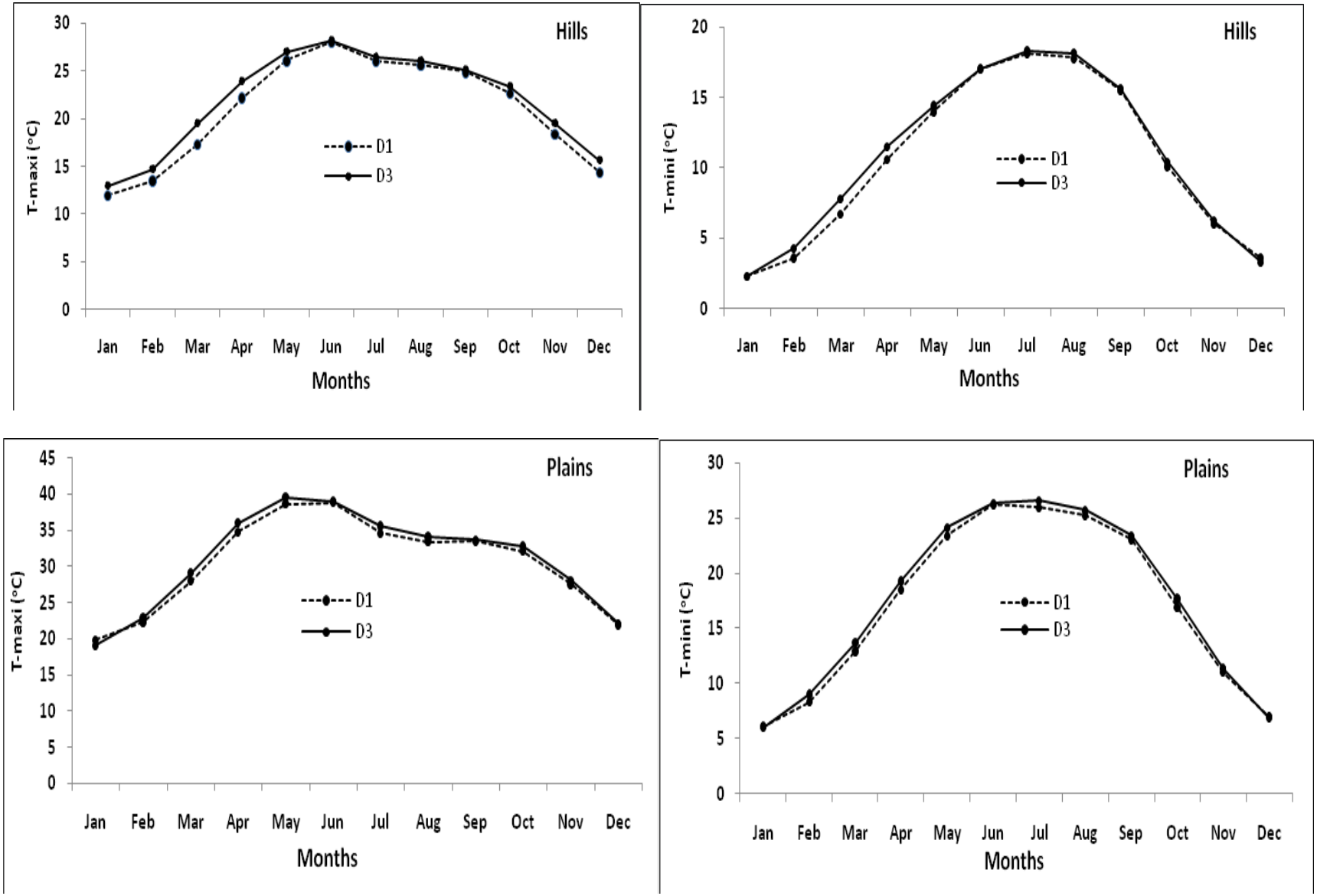
Table.3a Statistical measures for annual minimum temperatureat different stations

Stations	PST (%)			Standard deviation			CV (%)			Slope (rate)		
	Annual	EGS	DS	Annual	EGS	DS	Annual	EGS	DS	Annual	EGS	DS
Srinagar	1.99	2.76	0.01	0.52	0.8	0.61	7.75	6.7	8945	-0.034	-0.04	0.00
Manali	3.08	3.56	3.10	1.67	1.7	1.7	15.98	11.7	38.8	0.121	0.12	0.12
Shimla	3.29	3.53	4.25	0.59	0.6	0.8	5.36	4.1	13.2	0.000	-0.01	0.01
Palampur	4.00	4.23	5.54	0.30	0.5	0.5	2.25	2.8	6.8	-0.008	-0.02	0.00
Solan	3.38	3.92	3.31	0.65	1.0	0.8	5.69	6.2	16.7	0.025	0.02	0.04
Ranichauri	3.02	3.36	3.24	0.67	0.9	0.9	6.60	6.4	19.4	-0.034	-0.04	-0.03
Jammu	4.95	4.73	5.47	0.76	1.1	1.0	4.52	0.5	1.3	0.036	0.06	-0.02
Chandigarh	5.22	4.97	5.83	0.53	0.6	0.7	3.04	2.9	8.2	0.022	0.03	0.00
Ambala	5.13	4.93	5.47	0.55	0.6	0.8	3.19	3.1	10.5	0.013	0.01	0.01
Saharanpur	4.33	4.30	3.24	0.26	0.4	0.8	1.80	2.5	17.4	0.023	0.00	0.09
Delhi	5.22	5.05	5.33	0.47	0.5	0.6	2.68	2.6	8.4	0.013	0.02	-0.01
Karnal	5.04	4.83	5.26	0.39	0.4	0.7	2.28	2.0	9.2	0.012	0.01	0.01
Patiala	5.16	4.95	5.40	0.32	0.4	0.6	1.82	2.1	8.6	0.013	0.01	0.02
Ludhiana	4.98	4.85	4.90	0.53	0.6	0.8	3.12	2.9	11.2	0.049	0.06	0.04
Rohtak	5.31	5.07	5.54	0.66	0.8	0.8	3.71	3.7	11.1	0.015	0.01	0.03
Bathinda	5.01	4.88	4.46	0.48	0.9	0.9	2.82	4.3	13.9	0.000	0.02	0.04
Hisar	4.83	4.76	4.10	0.60	0.6	0.8	3.65	3.3	14.9	0.013	0.01	0.01
Sirsa	5.16	5.02	5.04	0.93	1.1	1.0	5.34	5.3	13.9	0.069	0.07	0.05
Bawal	4.86	4.83	3.74	0.70	0.7	1.1	4.28	3.6	21.0	0.027	0.03	0.03
Narnaul	5.01	4.90	4.54	0.71	0.8	0.8	4.23	3.9	12.2	0.008	0.01	0.00
Ganganagar	5.34	5.19	5.18	0.55	0.7	0.7	3.09	3.0	9.5	0.022	0.03	0.01
Jaipur	5.69	5.36	7.05	0.75	0.8	0.8	3.91	3.7	8.3	0.028	0.03	0.01
Hills	24.65	27.31	25.28	0.73	0.9	0.9	7.27	6.2	19.4	0.016	0.01	0.02
Plains	39.77	37.82	39.33	0.57	0.7	0.8	3.34	3.3	11.5	0.015	0.02	0.01
NW India	35.58	34.87	35.39	0.62	0.8	0.8	4.42	4.0	13.0	0.016	0.02	0.01

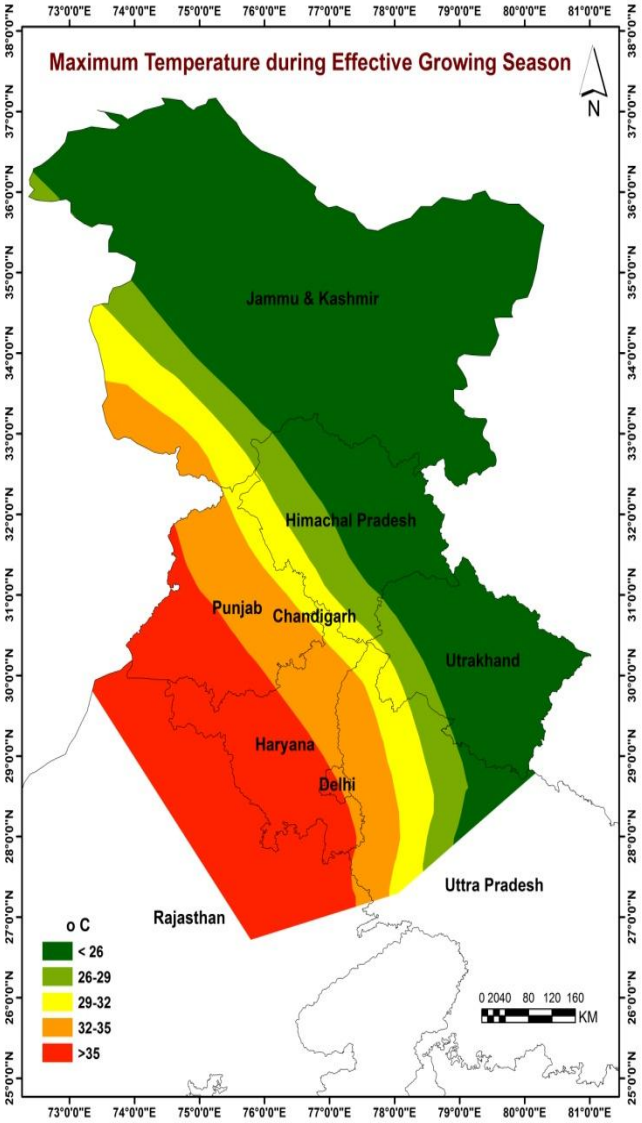
Table.3b Statistical measures for annual minimum temperature at different stations

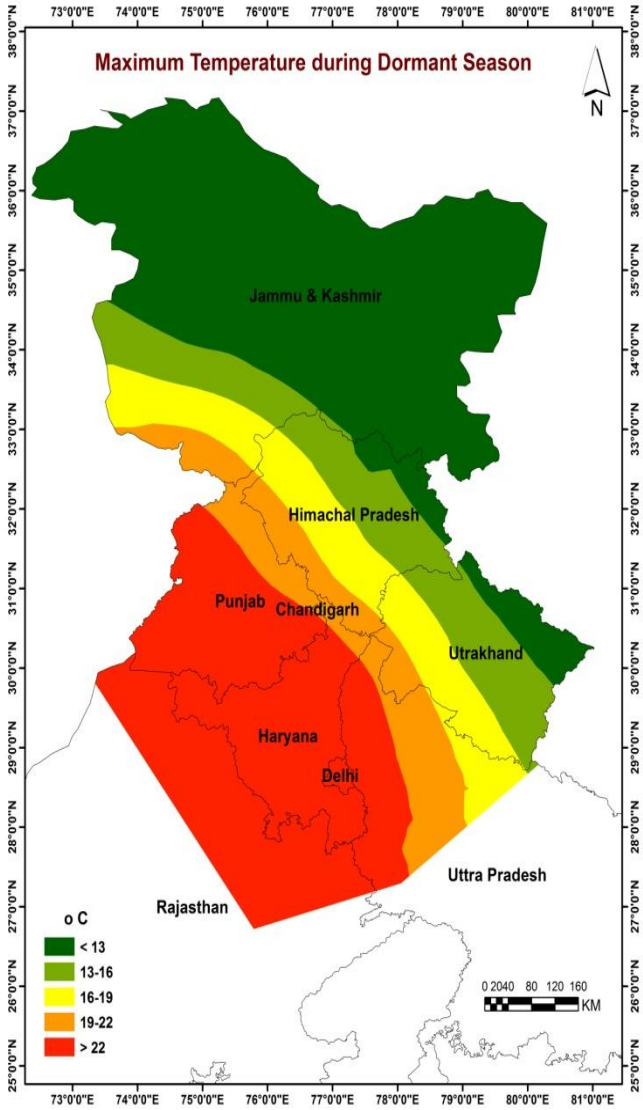
Stations	S. E.			't'			'p'			R^2		
	Annual	EGS	DS	Annual	EGS	DS	Annual	EGS	DS	Annual	EGS	DS
Srinagar	0.015	0.02	0.01	-2.27	-2.81	-0.25	0.025	0.007	0.799	0.156	0.220	0.002
Manali	0.019	0.02	0.02	6.51	6.09	6.22	0.000	0.000	0.000	0.566	0.529	0.539
Shimla	0.011	0.01	0.02	-0.02	-0.53	0.46	0.982	0.602	0.650	0.000	0.009	0.007
Palampur	0.021	0.02	0.03	1.48	-0.67	0.05	0.135	0.485	0.956	0.120	0.028	0.000
Solan	0.020	0.03	0.02	1.27	0.67	1.96	0.199	0.490	0.052	0.063	0.019	0.138
Ranichauri	0.016	0.02	0.02	-2.10	-2.00	-1.77	0.037	0.047	0.077	0.137	0.125	0.101
Jammu	0.019	0.02	0.02	1.91	2.62	-0.94	0.067	0.014	0.358	0.120	0.209	0.033
Chandigarh	0.010	0.01	0.01	2.29	3.05	-0.19	0.029	0.005	0.848	0.144	0.231	0.001
Ambala	0.009	0.01	0.01	1.37	1.31	0.94	0.181	0.198	0.352	0.051	0.047	0.025
Saharanpur	0.056	0.05	0.09	0.41	-0.04	1.01	0.662	0.970	0.288	0.020	0.000	0.113
Delhi	0.010	0.01	0.01	1.35	1.90	-0.37	0.189	0.067	0.711	0.059	0.111	0.005
Karnal	0.005	0.01	0.01	2.66	2.75	1.33	0.011	0.009	0.192	0.148	0.156	0.041
Patiala	0.008	0.01	0.01	1.63	1.09	1.85	0.114	0.284	0.074	0.084	0.039	0.106
Ludhiana	0.009	0.01	0.02	5.16	7.05	2.83	0.000	0.000	0.008	0.497	0.648	0.229
Rohtak	0.010	0.01	0.01	1.57	1.13	2.33	0.125	0.263	0.025	0.059	0.032	0.122
Bathinda	0.012	0.02	0.02	-0.02	1.12	2.06	0.982	0.257	0.041	0.000	0.043	0.132
Hisar	0.007	0.01	0.01	1.86	1.70	1.46	0.069	0.097	0.151	0.075	0.063	0.047
Sirsa	0.017	0.02	0.02	3.96	3.75	2.99	0.000	0.001	0.004	0.359	0.335	0.242
Bawal	0.013	0.01	0.02	1.99	1.91	1.54	0.055	0.065	0.133	0.117	0.109	0.074
Narnaul	0.010	0.01	0.01	0.76	0.76	0.39	0.443	0.440	0.690	0.016	0.016	0.004
Ganganagar	0.010	0.01	0.01	2.27	2.42	0.66	0.030	0.021	0.517	0.142	0.159	0.014
Jaipur	0.012	0.01	0.01	2.33	2.62	0.88	0.026	0.013	0.387	0.141	0.173	0.023
Hills	0.017	0.02	0.02	0.81	0.13	1.11	0.230	0.272	0.422	0.148	0.080	0.155
Plains	0.014	0.01	0.02	1.97	2.17	1.17	0.186	0.179	0.299	0.230	0.349	0.045
NW India	0.015	0.02	0.02	1.65	1.63	1.16	0.198	0.197	0.332	0.238	0.317	0.091

Fig.1 Shift in maximum & minimum temperatures at hills and plains in D3 (2005-2014) over D1 (1985-94)

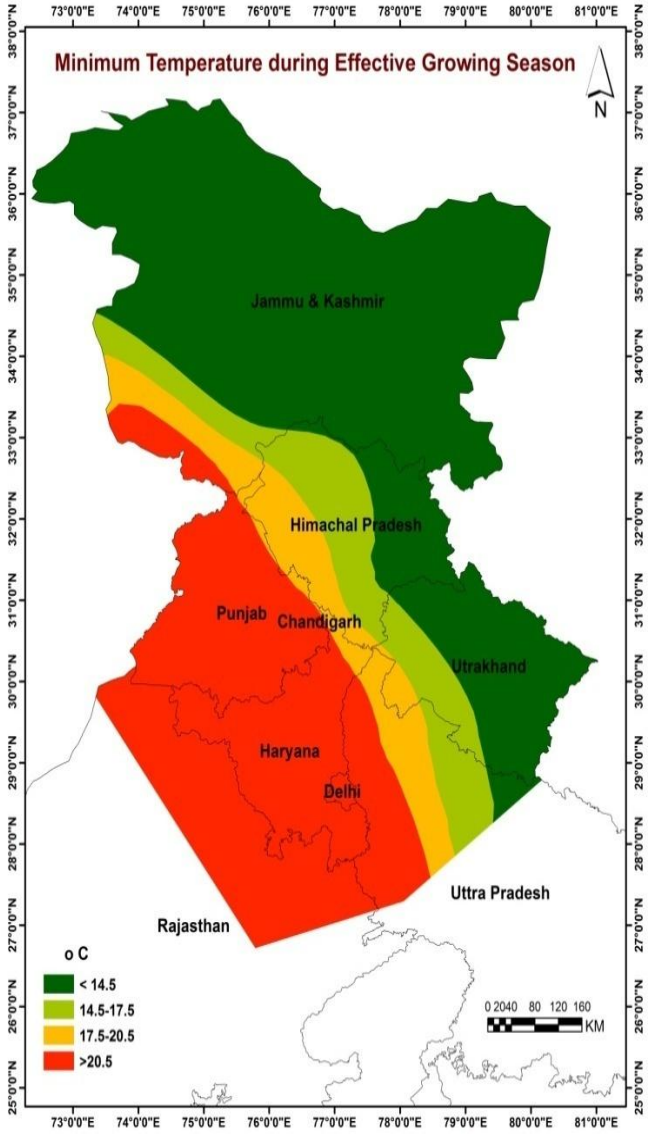


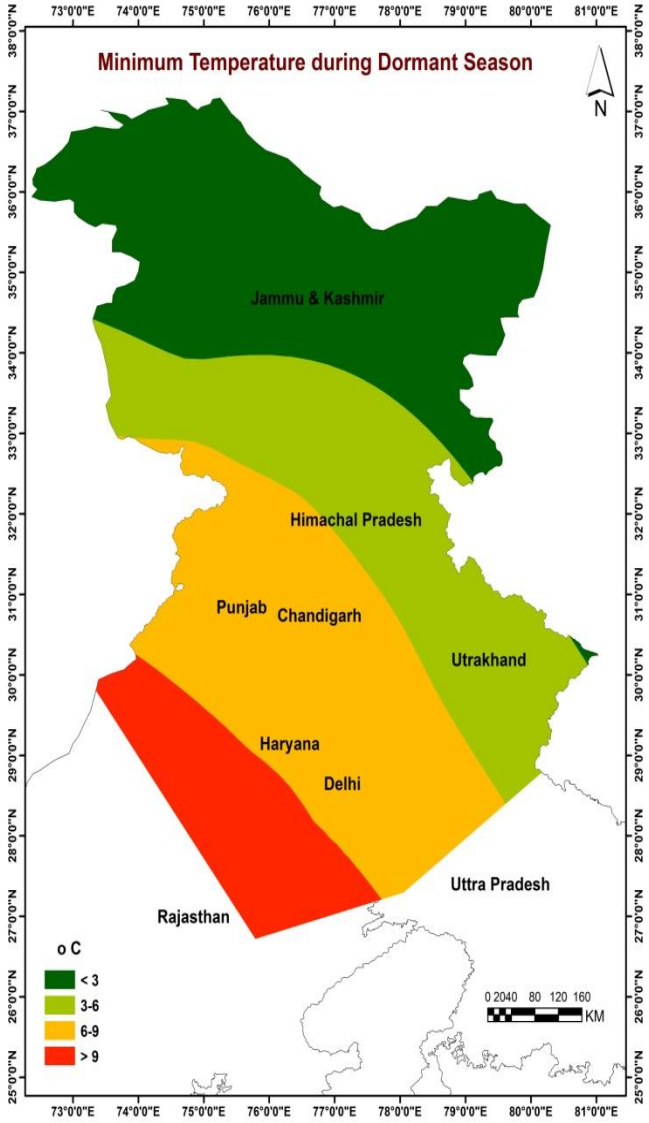
Map.2 Spatial distribution of maximum temperature during effective growing season.
Map.3 Spatial distribution of maximum temperature during dormant season





Map.4 Spatial distribution of minimum temperature during effective growing season.
Map.5 Spatial distribution of minimum temperature during dormant season





Map.1 Location of the study area

Shift in decadal temperatures

At hills no shifts in the month of occurrence of peak average maximum and minimum temperatures were observed during the present time scale (D3) compared to previous one (D1) and similar trend was observed at plains (Fig. 1). Average maximum and minimum temperatures of March-April during the present time scale was significantly higher than the average maximum and minimum temperature during its previous time scale at both hills and plains. Same is the case with average maximum temperature of January, February, May, November and December at hills, average minimum temperature at hills, average maximum temperature of May, July, August at plains and average minimum temperature of all the months except January, June and December at plains (Fig. 1). These shifts in temperature are in the conformity of the perception of farmers in western Himalayas (Vedwan and Rhoades, 2001).

Temperature zones

The temperature constraints in crop ecological zoning are related to the length of the temperature growing period, i.e. number of days with a mean daily temperature above 5^{o}C. Spatial variation in temperature (maximum and minimum) is depicted in Maps 2-5. During effective growing season north-west India was divided into five zones based on maximum temperature (<26^{o}C, 26-29^{o}C, 29-32^{o}C, 32-35 and >35^{o}C) and four zones based on minimum temperature (<14.5^{o}C, 14.5-17.5^{o}C, 17.5-20.5^{o}C, >20.5^{o}C) taking a class interval of 3^{o}C. The normal maximum temperature during effective growing season ranged from 25.6^{o}C to 36.4^{o}C and minimum temperature from 11.5^{o}C to 22.3^{o}C, showing an increasing trend from north-east to south-west (Map 2& 4).

Similarly during dormant season north-west India was divided into five zones based on

maximum temperature (<13^{o}C, 13-16^{o}C, 16-19^{o}C, 19-22^{o}C and >22^{o}C) and four zones based on minimum temperature (<3^{o}C, 3-6^{o}C, 6-9^{o}C, >9^{o}C) taking a class interval of 3^{o}C. The normal maximum temperature during dormant season ranged from 10.8^{o}C to 24.1^{o}C and minimum temperature from 0.01^{o}C to 9.8^{o}C, showing an increasing trend from north-east to south-west (Map 3 &5). This might be because of topography relief, which increased from SW to NE of study area. Similar results also repotted by IPCC (2014); Singh *et al.*, (2010) and Gautam *et al.*, (2014).

Normal annual maximum temperature was increasing 3.0°C/100 years, 0.1°C/100 years and 0.9°C per 100 years and minimum temperature was increasing at the rate of 1.6°C/100 years, 1.5°C/100 and 1.6°C per 100years for hills, plains and north-west India, respectively.

The normal seasonal maximum temperature during effective growing season was increasing with the rate of 2.1°C/100 years, 0.4°C/100 years and 0.9°C/100 years minimum temperature at the rate of 1.2°C/100 years, 2.0°C/100 years and 1.8°C/100 years in hills, plains and north-west India, respectively.

During dormant season the normal seasonal maximum temperature was showing a decreasing trend of 2^{o}C/100 year in plains, 0.3^{o}C/100years in north-west India but an increasing trend of 4.4 ^{o}C per 100years in hills but, minimum temperature for was increasing with the rate of 2/100years, 0.8/100year and 1.22^{o}C/100year in hills, plains and north-west India, respectively.

No shifts in the month of occurrence of peak average maximum and minimum temperatures were observed. North-west India was divided into six and seven zones based on spatial distribution of annual maximum and minimum temperatures and into five and four zones during effective growing and dormant seasons.

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