



Rainfall variability analysis over north-west India in context to climate change using GIS

Mohan Singh^{1☀}, Ram Niwas²

1. Department of Environmental Science,
Dr. YS Parmar University of Horticulture & Forestry,
Nauni-Solan-173230
India

2. Department of Agricultural Meteorology,
CCS Haryana Agricultural University,
Hisar-125004
India
E-mail: jangra_ms@live.com

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General Note



Article is recommended to print as color version in recycled paper. *Save Trees, Save Climate.*

ABSTRACT

The weather data for the period of more than 30 years 1980 onward of twenty-two meteorological stations located in arid, semi-arid and humid agro-climatic zones in the hills and plains of north-west India were used in this study. The collected rainfall data was computed as normal rainfall for annual, seasonal, decadal at each station, hills, plains and north-west India. For a given location the long period average of rainfall data was considered as normal rainfall. Rainfall trends (seasonal annual, decadal) in north-west India

were evaluated using regression trend analysis. The map of north-west India was digitized and different rainfall zones were delineated using GIS software (ArcMap 10.1). Normal annual rainfall was more than one thousand millimetres at eight stations and ranged between 500-900 mm at eleven stations and between 200 to 500 mm for remaining three stations. Normal rainfall was highest at Palampur and lowest at Ganganagar among the 22 meteorological stations. The coefficient of variation was less than fifty per cent for all the stations. The slope (mm/year) of trend line was negative for nine stations and positive for remaining thirteen stations. The slope 5.51, 1.58 and 5.82 were found in hills, plains and north-west India with standard error of 8.35, 6.12 and 6.73 mm, respectively. The confidence level of significant of correlation coefficient was 41.3, 54.7 and 51 per cent in hills, plains and north-west India, respectively. During effective growing season out of 22 stations the rainfall showed decreasing trend at eight stations and increasing trend at remaining fourteen stations. During dormant season it was decreasing with 57 mm per century in hills, 10.7 mm per 100 years in plains but increasing with 68.6 mm per 100 years in north-west India, respectively.

Key words: rainfall, trend analysis, zoning, meteorological stations, NW India

1. INTRODUCTION

The north-west India includes states of Jammu & Kashmir, Himachal Pradesh, Utrakhand, Punjab, Chandigarh, Haryana, Delhi and parts of Uttar Pradesh and Rajasthan. Punjab and Haryana are not only self-sufficient in food production (wheat & rice) & largest contributor to India's central pool of food grains but also good producer of subtropical fruits (mango, ber, guava, citrus and litchi) and some temperate fruits (pear, peaches, plum, pomegranate etc). Similarly Jammu & Kashmir, Himachal Pradesh, Utrakhand are the largest producer of temperate fruits (apple, apricot, pear, peach, plum and cherry) in India. North-west India with diverse soil and climate comprising several agro-ecological regions provides ample opportunity to grow a variety of horticultural crops which form a significant part of total agricultural produce in the country. The Himalayas provide suitable ecological niches for the prevalence of large number of temperate fruit germplasm. The region also inhabits many *Prunus* species and indigenous edible temperate fruits, which could be exploited for commercial traits (Sharma and Pramanick, 2012). The high value agriculture, particularly horticultural crops are the catalysts for the next wave of growth in the farm sector and be a better tool for the climate-smart agriculture (FAO, 2010).

The spatial data interpolation of temperature and precipitation is increasingly important in the development of agricultural, hydrological, and ecological models; spatially explicit modeling of ecosystem structure, for example requires estimates of variables at un-sampled locations, usually on a regularly spaced grid (Skirvin *et al.*, 2003). A method based on the geographical information system (GIS) was used for spatial climate analysis (Baigorria *et al.*, 2000). Patel *et al.* (2000) used the modern information tools like remote sensing and geographical information system to extend applicability of agro ecological zoning in mountainous areas of Kumaon Himalayas India. Satellite remote sensing and GIS have been providing newer dimension to effectively monitor and manage natural resources. It has been well conceived that remote sensing and GIS have great role to play in agro ecological zoning.

In addition to temperature, rainfall is an important climatic resource, which meets the water requirement of an organism for its survival in its ecosystem. A comprehensive studies carried over NW Himalayas revealed that the change in winter precipitation is minimum but there is significant decrease in monsoon precipitation (Bhutiya, *et al.*, 2007). Jangra and Singh (2011) and Ranbir *et al.*, (2010) observed variability in rainfall in middle and upper Himachal Pradesh. Another analysis with respect to climate of Shimla reveals that total precipitation and snowfall for all the season has a decreasing trend (Bhan & Manmohan, 2011) leaving long term impacts on agriculture horticulture production of the area (Baul and McDonald, 2015; Sen *et al.*, 2015; Emmanuel Mavhura *et al.* 2017). Changing climate results in extreme weather events like heavy downpours, flooding, longer wetter, landslides and during dry season increased evapotranspiration will lead to water scarcity (Sagun, 2009). Climate change is found to be relatively new challenge of global scale however; at a global scale climate change may have negligible impact but severe and substantial at local and regional scale (IPCC, 2007). Hence, with reference to climate change at local, present study was conducted to evaluate rainfall trend and zoning based on spatial distribution and pattern of rainfall in north-west India for efficient use of rain water.

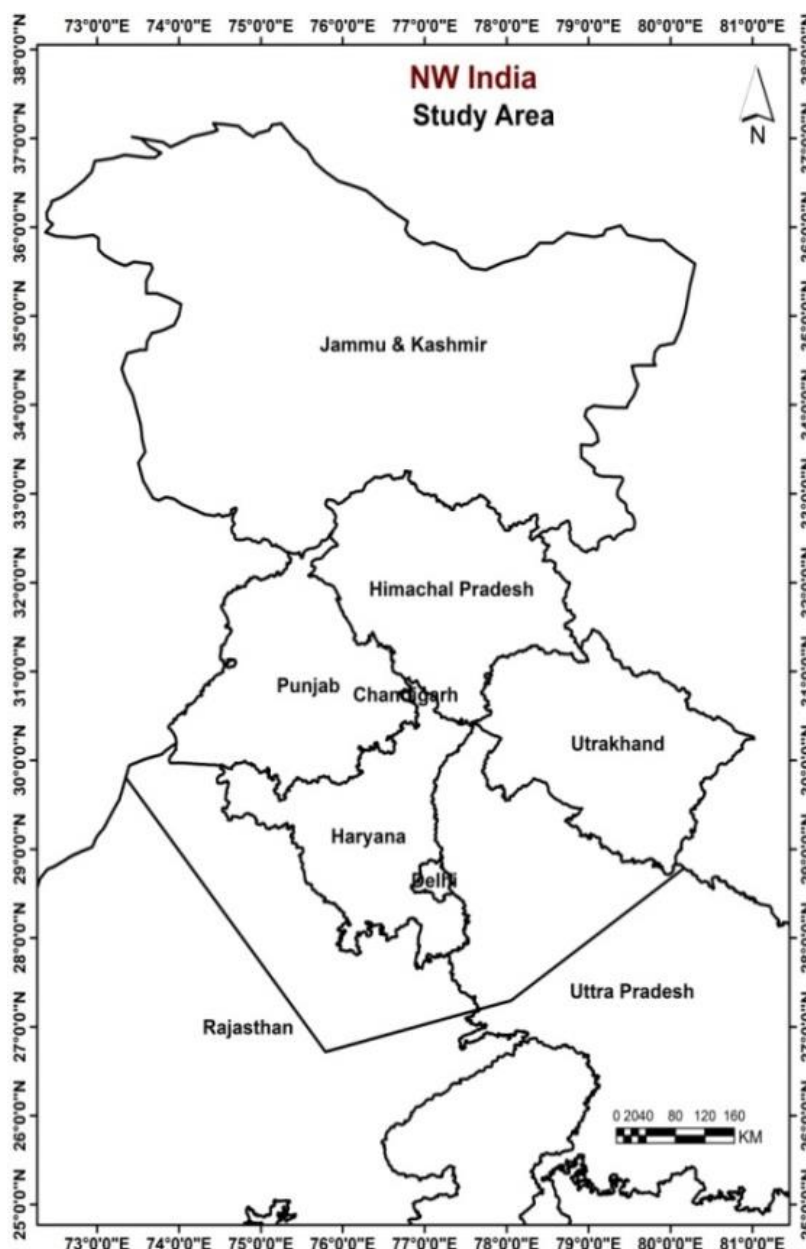
2. DATA AND METHODOLOGY

2.1. 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, Sriganaganagar, 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 2.1) which approximately is located between $26^{\circ}40'$ to $37^{\circ}10'$ N latitude and between $72^{\circ}50'$ and $81^{\circ}00'$ 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 & 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 2.1. 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 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.



Map 2.1 Location of the study area

Table 2.1 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	

The monthly normal (LPA) rainfall at Srinagar varies from 33.2 mm (November) to 116.4 mm (March), at Manali 30.1 mm (November) to 165.7 mm (March), at Shimla 9.3 mm (November) to 305.4 (July), at Palampur 11.8 mm (November) to 614.5 (August), at Solan 9.1 mm (November) to 247.7 mm (August), at Ranichauri 12.1 (November) to 290.5 (July), at Jammu 5.9 mm (November) 333.9 mm (August), at Chandigarh 5.5 (November) to 295.8 (August), at Ambala 9.1 mm (November) to 246.8 mm (July), at Saharanpur 13.3 mm (November) to 292.7 mm (August), at Delhi 4.7 mm (November) to 223.9 mm (August), at Karnal 5.2 mm (November) to 199.2 mm (July), at Patiala 9.1 mm (November) to 275.6 mm (July), at Ludhiana 7.8 mm (November) to 217.7 (July), at Rohtak 5.1 mm (December) 175.0 (August), at Bathinda 6.4 mm (November) to 147.8 (July), at Hisar 3.2 mm (November) to 128.4 mm (July), at Sirsa 2.4 mm (December) to 106.2 mm (July), at Bawal 4.1 mm (November) to 175.4 mm (August), at Narnaul 2.2 mm (November) to 144.7 (July), at Ganganagar 2.9 mm (December) to 78.5 mm (July) and at Jaipur the monthly average rainfall varies from 3.7 mm in November to 195.0 mm in August. It varies from 17.6 mm (November) to 278.0 mm (August), from 5.8 mm (November) to 190.5 mm (July) and from 9.0 mm (November) to 211.7 mm (August) at hills, plains and north-west India, respectively. The lowest rainfall was received in November at all the stations including hills, plains and north-west India except Rohtak, Sirsa and Ganganagar where it was received in December. Similarly the highest rainfall was received in March at Srinagar and Manali, in July at Shimla, Ranichauri, Ambala, Karnal, Patiala, Ludhiana, Bathinda, Hisar, Sirsa, Narnaul, Ganganagar, plains and in August at the remaining stations including north-west India.

2.2. 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 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.

2.3. 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. Statistical measures like normal (long period average) standard deviation, coefficient of variation, slope, standard error, t-values, significance values (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 each station, hills, plains and whole of north-west India.

2.4. Shift analysis

The monthly means of rainfall data were averaged over time periods (decadal) 1985-1994, 1995-2004, 2005-2014 at each station, hills, plains and north-west India. It was further averaged over two time periods viz. previous time period was 1985-2000 (PTP) and the recent time period was 2001-2014 (RTP) to know if there any shifts in rainfall over the time period. The normalized difference in rainfall (NDR) over the time at each station, hills, plains and north-west was calculated with the following formula as: $NDR = ((RTP-PTP)/FTP)*100$.

2.5. Trend analysis

Trends in rainfall 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 rainfall were worked out for all the twenty two stations, hills, plains and whole of the north-west India.

2.6. Spatial distribution

Maps depicting spatial variation in rainfall during different time periods (1985-2000 and 2001-2014), trend in slopes on annual and seasonal basis were prepared using ArcMap 10.1 GIS software by taking followed steps:

- 1) The hard copy of the map of the study area was digitized and shape file was created.
- 2) NW India polygon shape file was selected.
- 3) The latitude-longitude values of each point were find out and converted to degree-decimal format to enter in GIS.
- 4) The coverage file (point) was then generated from the location data in ArcMap (10.1) GIS software.
- 5) The rainfall data entered as attribute table and attached/joined to the point file already generated.
- 6) Then the point file was interpolated by GIS tools and converted to raster format by inverse weighting/krigging/radial basis interpolation function.

3. RESULTS AND DISCUSSIONS

3.1. Annual trend in rainfall

Among the twenty two stations the normal rainfall was recorded highest at Palampur (1965.3 mm) with coefficient of variation of and lowest at for eight stations was more than one thousand millimetres i.e. Patiala (1001.7 mm), Chandigarh (1071.4 mm), Solan (1131.6 mm), Jammu (1145 mm), Manali (1179 mm), Ranichauri (1269.7 mm), Shimla (1311.4 mm) and Palampur (1965.3 mm). Eleven stations (Srinagar, Ambala, Saharanpur, Delhi, Karnal, Ludhiana, Rohtak, Bathinda, Bawal, Narnaul and Jaipur) having normal rainfall between 500-900 mm and rainfall from 200 to 500 mm at remaining three stations (Ganganagar, Sirsa, Hisar). The coefficient was between 40-50 % for two stations (Narnaul and Rohtak) between 30-40% for nine stations (Srinagar, Saharanpur, Delhi, Karnal, Hisar, Sirsa, Ganganagar and Jaipur) between 20-30 % for eight stations (Manali, Shimla, Ranichauri, Chandigarh, Ambala, Patiala, Ludhiana and Bathinda) between 10-20 % for Solan, Palampur and Jammu station (Fig1).

The slope of rainfall trend line was negative at Srinagar, Solan, Jammu, Chandigarh, Saharanpur, Karnal, Ludhiana, Bawal and Ganganagar and positive at Manali, Shimla, Palampur, Ranichauri, Ambala, Delhi, Patiala, Rohtak, Bathinda, Hisar, Sirsa, Narnaul and Jaipur (Map 1). The deceasing trend in rainfall was highest at Chandigarh (-4.62) followed by Srinagar (-4.29) and lowest for

Ganganagar (-0.48) followed by Jammu (-0.9/year). The value of increasing trend in rainfall was highest at Palampur 13.84mm per year and was lowest at Rohtak (0.31mm/year). The normal rainfall computed was 1288.5, 687.8 and 851.6 mm with coefficient of variation of 22.2%, 32.6% and 29.7%, respectively and increasing trend in rainfall of 5.51, 1.58 and 5.82mm per year at hills, plain and whole of north-west India, respectively (Fig 1).

Rainfall during effective growing season was highest at Manali with coefficient of variation of 144.3 per cent and lowest at Ganganagar with coefficient of variation of 44.3 percent. Shimla showed a highest increasing trend of 13.72 mm/years followed by Palampur (13.08mm/years). Probability (p) value at five stations (Jammu, Saharanpur, Ludhiana, Rohtak and Ganganagar) was 0.70 four stations had less than 0.40 and rest of the stations had between 0.40 and 0.70, respectively. The normal rainfall during effective growing season was 973.5 mm for hills 634.5 mm for plains and 726.9 mm for north-west India with coefficient of variation of 26.4 %, 35.3 % and 32.1 % and slope values of 3.38, 2.77 and 4.56mmfor hills, plains and north-west India, respectively (Map2). Similarly, the long period average of rainfall during dormant season was 319.6 mm, 54.9 mm and 122.7 mm with coefficient of variation 31%, 29.9% and 36 per cent in hills, plains and north-west India, respectively. The rainfall trend during this season was negative in hills and plains but it was positive in north-west India. Rainfall was decreasing with a rate of 0.571 mm per year in hills and 0.107 mm per year in plains but increasing with a rate of 0.686 mm per year in north-west India (Map 3).

The increasing trend in annual rainfall at most of the stations might be due to regional warming which resulted in high convection currents (Fitsum Bekele et al. 2017). Increase in water vapors in atmosphere due to flood irrigation facilities in most of Haryana might cause more local rains. Kaur and Hundal (2006) confirmed these results and they reported an increase in rainfall (10.5 mm/year) in Ludhiana, Punjab. Geethalakshmi *et al.* (2011) projected the climate change over Cauvery basin of Tamil Nadu scenario using regional climate models for A1B and showed an increasing trend for maximum, minimum temperatures and rainfall.

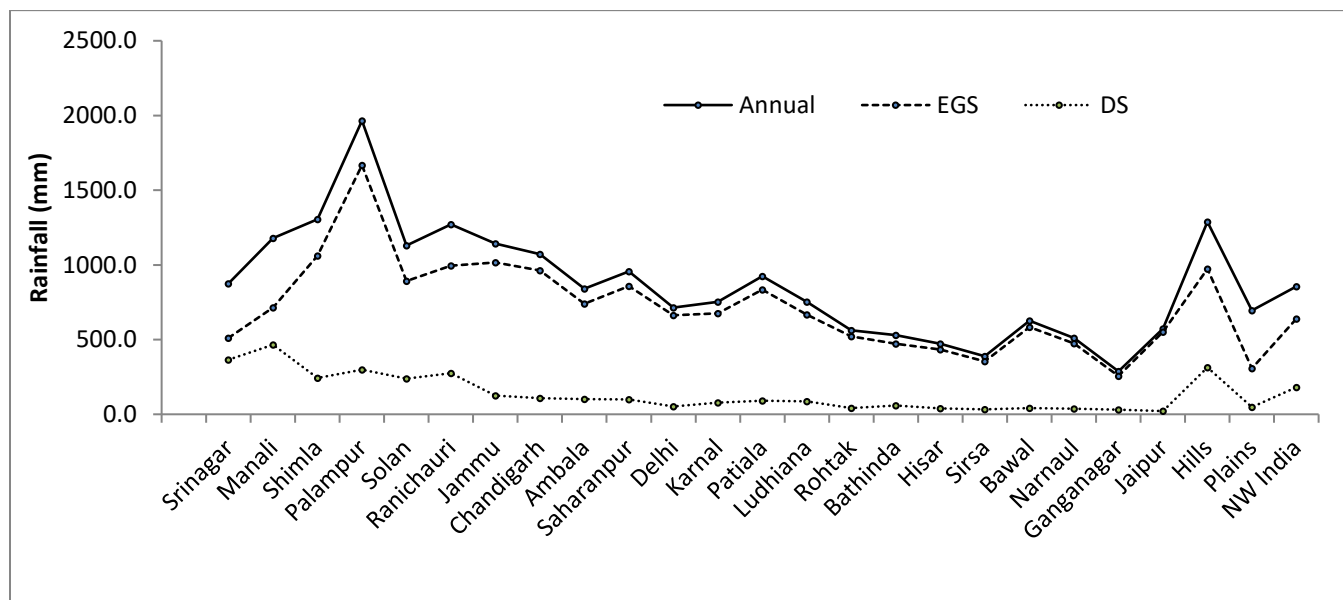
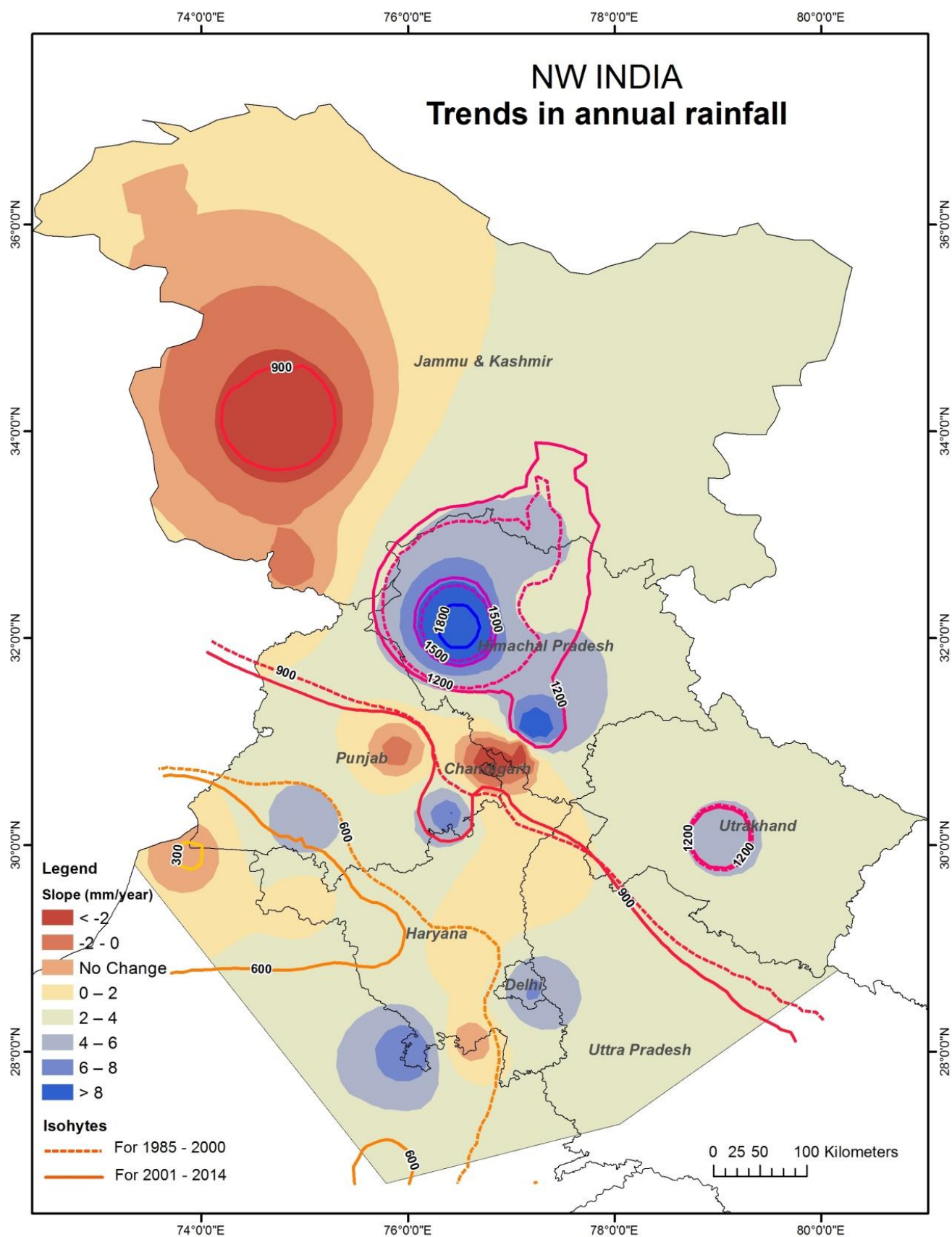
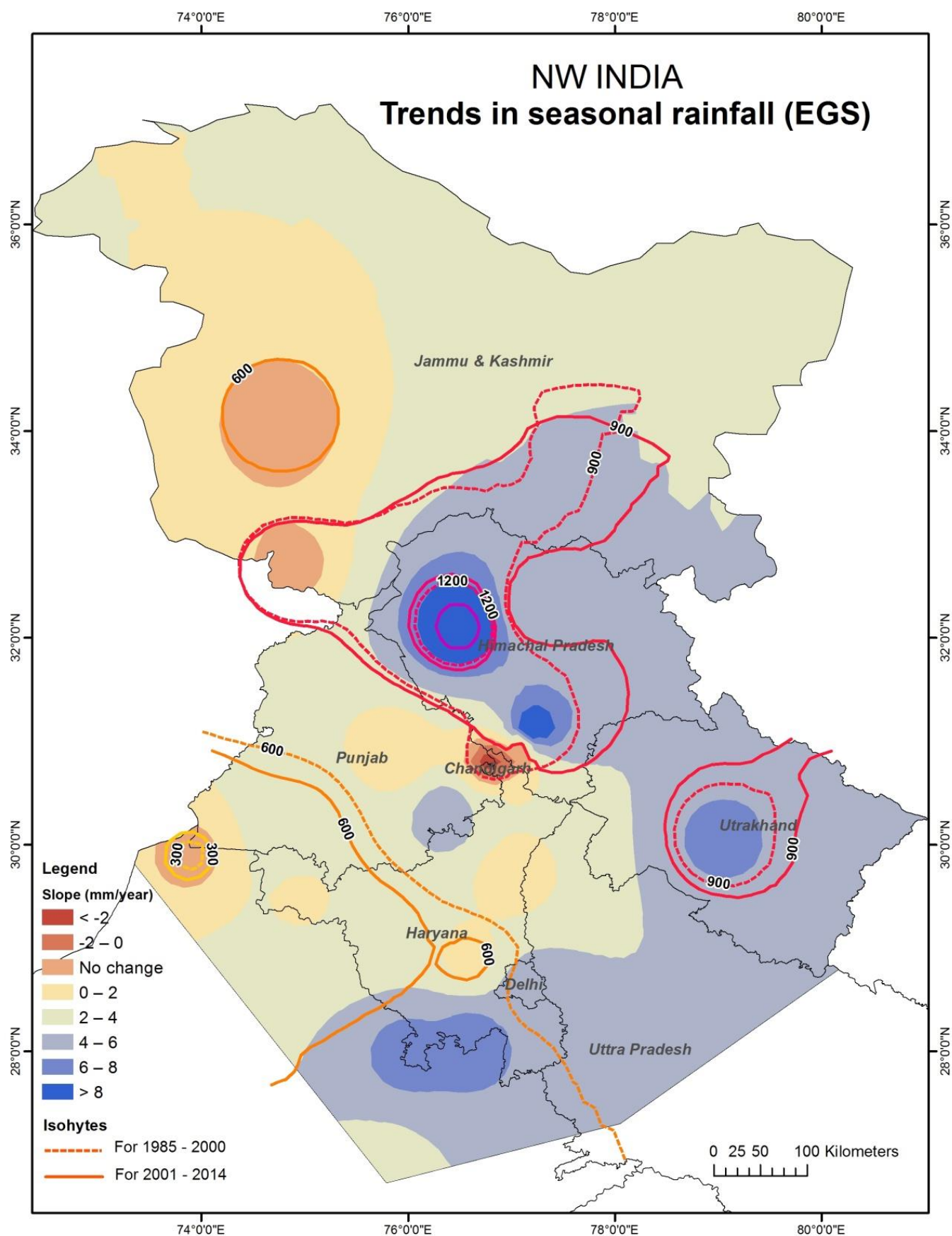


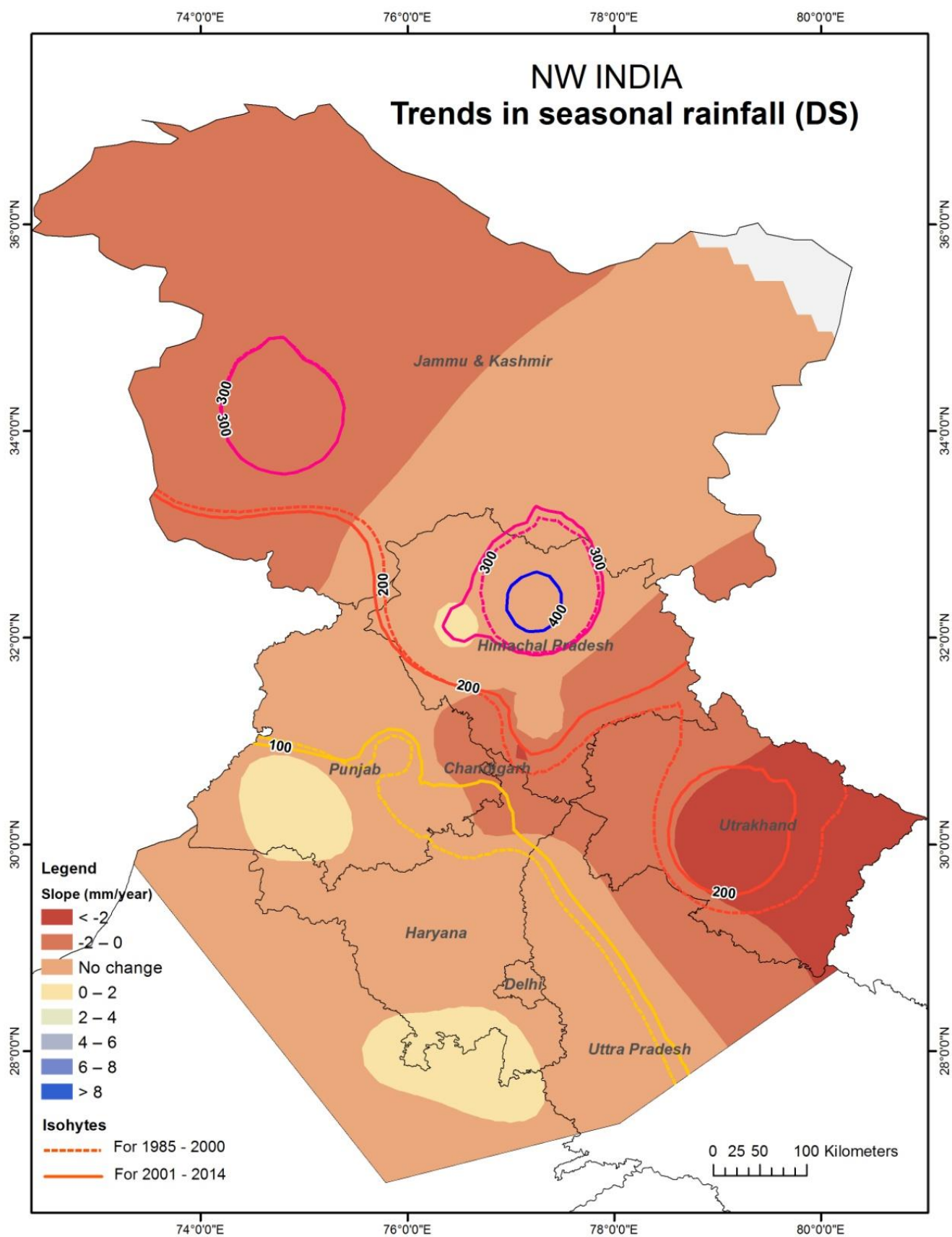
Figure 1 Annual and seasonal rainfall in north-west India



Map 2 Spatial distribution of annual rainfall in NW India



Map 3 Spatial distribution of rainfall during effective growing season in NW India



Map 4 Spatial distribution of rainfall during dormant season in NW India

3.2. Decadal trend in rainfall

The rainfall decreased in second decade (D2) over first decade (D1) in January, March, April, May and December, in all the months at Manali, in November at Shimla, in January, February, March, April, May, July, August, September and December at Palampur, in March, May, August, November and December at Solan, in March, May, July, November and December at Ranichauri and increased in rest of the months at these stations (Table 1). It was decreased in January, February, March, May, July and December and increased in rest of the months at hills. During the third decade in comparison with first decade the rainfall was increased in January, February, March, April, June, September and November at Srinagar, in all the months except November at Manali, in February, July, September and December at Shimla, in January, February, March, May, June, July, September, October and December at Palampur, in February, June, September, November and December at Solan, in January, February, March, April, May, June, July, September, and December at Ranichauri and decreased at rest of the months at these stations, respectively. The pooled rainfall for hills increased in January, February, March, April, May, June, July, September, and December in D3 over D2. Decade to decade progressive increased was observed in February, June, September and November at Srinagar, in February at Manali, in February and September at Shimla, in June & October at Palampur, in February, June & September at Solan, in February, June, August & September at Ranichauri and only in June & September for (pooled) hills (Table 1). The decade to decade progressive decreased in May & December at Srinagar, in November at Manali & Shimla, in April & August at Palampur, in March & August at Solan, in March & November at Ranichauri and no such progressive decrease in pooled rainfall for hills.

TABLE 1

Decadal average of rainfall (mm) at different stations in hills

Years	Decade	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Srinagar													
1985-94	D1	70.2	75.1	167.3	105.2	85.4	37.4	95.5	95.7	41.6	28.4	19.5	81.1
1995-04	D2	57.4	90.0	96.0	93.2	82.6	71.7	107.1	98.9	58.6	43.7	36.4	44.4
2004-14	D3	86.2	103.4	106.2	101.3	71.7	60.2	66.6	67.2	69.4	40.6	38.2	40.5
Manali													
1985-94	D1	83.9	130.6	211.2	119.9	86.2	48.2	171.9	153.9	110.6	42.7	33.0	63.4
1995-04	D2	60.6	97.8	114.5	82.1	63.6	89.9	122.1	150.2	100.8	32.1	31.5	34.8
2004-14	D3	144.6	158.0	155.7	96.9	102.1	110.9	176.8	186.0	118.3	32.3	21.3	54.5
Shimla													
1985-94	D1	46.4	72.1	47.4	30.2	52.3	120.8	275.2	227.2	104.4	21.9	11.1	33.1
1995-04	D2	68.0	80.0	84.2	66.4	80.8	216.5	309.7	332.2	147.4	40.0	10.8	19.6
2004-14	D3	48.0	87.9	75.3	39.0	71.1	210.0	353.5	301.4	180.8	20.6	6.3	23.0
Palampur													
1985-94	D1	104.8	113.6	125.2	66.5	68.9	155.6	575.3	648.5	203.8	3.7	9.7	36.0
1995-04	D2	65.2	59.9	56.0	34.9	40.4	193.6	416.8	622.0	203.3	36.0	15.0	19.7
2004-14	D3	95.2	135.6	144.7	33.1	128.5	319.8	588.2	561.9	233.4	48.7	5.6	30.8
Solan													
1985-94	D1	49.6	58.5	81.8	26.6	79.9	154.1	201.4	286.5	119.6	26.9	12.9	66.8
1995-04	D2	71.6	72.4	64.3	51.4	63.7	174.1	258.8	236.7	130.8	41.9	7.7	13.2
2004-14	D3	50.5	78.0	62.6	25.6	47.7	101.4	204.6	213.7	177.4	24.8	6.2	12.7
Ranichauri													
1985-94	D1	51.4	79.9	83.1	41.2	99.2	111.8	286.5	244.2	125.8	32.0	19.8	66.0
1995-04	D2	72.0	109.1	75.5	58.6	53.3	118.2	236.1	272.3	142.3	58.3	11.1	20.1
2004-14	D3	46.2	112.9	50.6	36.3	67.1	149.0	349.0	316.6	168.3	20.6	5.4	20.5
Hills													
1985-94	D1	67.7	88.3	119.3	64.9	78.7	104.7	267.6	276.0	117.6	25.9	17.7	57.7
1995-04	D2	65.8	84.9	81.8	64.4	64.1	144.0	241.8	285.4	130.5	42.0	18.8	25.3
2004-14	D3	78.5	112.6	99.2	55.4	81.4	158.6	289.8	274.5	157.9	31.3	13.8	30.3

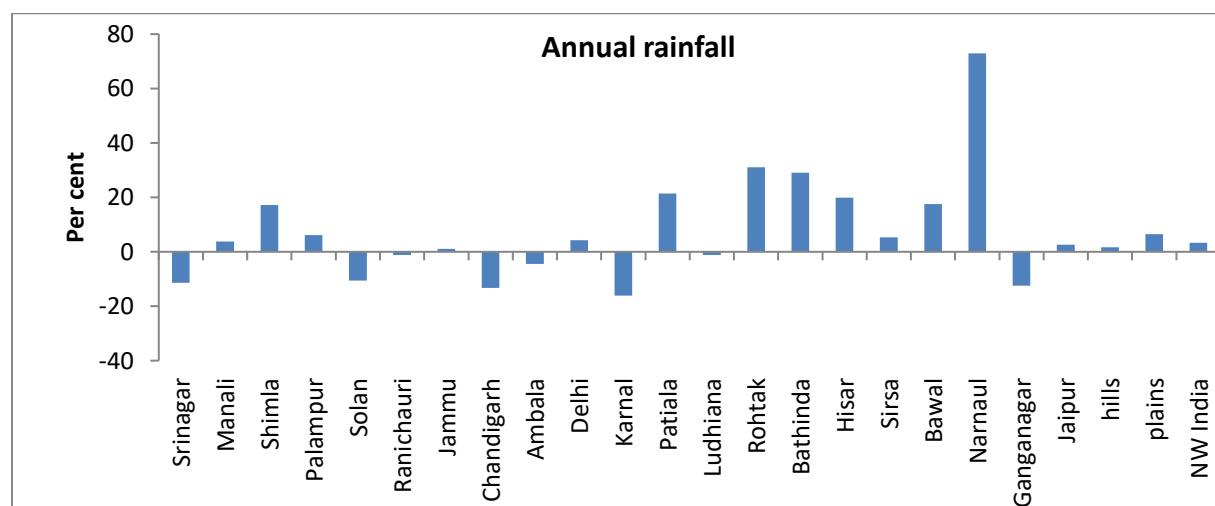
TABLE 2

Decadal average of rainfall (mm) at different stations in plains

Years	Decade	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jammu													
1985-94	D1	53.8	54.7	104.3	31.4	12.9	53.6	352.7	286.7	186.6	7.6	3.6	35.1
1995-04	D2	42.5	43.0	41.0	21.1	18.7	100.3	307.2	353.2	131.4	31.6	9.3	9.8
2004-14	D3	53.0	53.5	40.6	20.9	22.6	114.8	294.7	352.4	153.8	14.6	4.4	20.0
Chandigarh													
1985-94	D1	29.3	43.0	26.2	12.1	28.7	107.5	295.7	302.1	159.0	12.8	9.3	30.8
1995-04	D2	50.5	40.5	23.4	19.3	37.0	177.8	240.2	353.5	158.7	43.6	4.2	19.4
2004-14	D3	19.9	40.5	42.4	16.9	30.6	149.6	238.5	226.9	165.1	8.9	3.2	21.2
Ambala													
1985-94	D1	19.1	49.2	20.0	8.8	28.8	87.9	222.9	182.5	134.3	12.9	8.3	32.4
1995-04	D2	30.0	39.4	27.0	21.5	27.4	132.9	250.6	195.5	109.0	16.8	9.0	16.5
2004-14	D3	21.7	35.9	26.4	18.1	53.8	110.5	241.3	175.1	134.0	9.2	2.2	15.8
Delhi													
1985-94	D1	17.1	19.5	13.1	6.9	19.8	51.7	185.6	225.3	104.7	8.6	6.1	9.9
1995-04	D2	25.6	19.1	11.6	7.8	31.0	95.9	171.0	208.8	99.9	29.5	5.7	11.2
2004-14	D3	8.6	32.4	18.7	8.1	44.9	65.9	190.3	237.8	145.1	14.3	2.8	4.6
Karnal													
1985-94	D1	14.7	39.5	18.8	8.6	26.1	88.9	223.4	214.4	105.9	8.6	3.9	21.5
1995-04	D2	45.2	30.9	20.6	16.1	30.8	121.2	157.0	214.0	116.8	33.3	4.5	12.4
2004-14	D3	23.2	49.0	20.7	11.2	29.5	83.6	144.2	146.0	153.8	9.4	2.2	5.5
Patiala													
1985-94	D1	24.9	33.2	17.9	4.8	19.5	95.1	230.9	239.7	93.1	7.9	3.6	11.6
1995-04	D2	35.8	22.1	122.3	34.7	68.8	58.6	294.7	212.5	94.1	20.3	15.2	31.0
2004-14	D3	26.1	43.8	36.9	14.2	21.3	80.5	296.6	260.5	143.0	24.2	5.1	18.4
Ludhiana													
1985-94	D1	28.7	25.7	33.9	26.5	25.8	45.6	250.8	171.6	108.4	12.6	13.7	28.7
1995-04	D2	33.3	34.4	19.1	13.4	17.2	72.4	223.9	207.8	120.8	21.1	6.8	33.3
2004-14	D3	28.0	36.8	18.9	22.0	31.9	101.7	174.0	191.7	73.7	9.1	2.4	28.0
Rohtak													
1985-94	D1	18.5	9.2	30.8	13.2	20.7	23.2	137.5	154.8	19.8	5.1	0.2	18.5
1995-04	D2	17.3	14.8	13.0	13.1	40.2	69.6	128.0	174.4	39.7	18.1	12.0	17.3
2004-14	D3	6.6	22.2	14.9	17.7	39.8	65.0	133.5	161.5	158.7	10.8	3.6	6.6
Bathinda													
1985-94	D1	11.8	18.1	14.7	10.7	18.8	48.8	129.1	149.0	40.5	5.5	4.7	3.3
1995-04	D2	14.8	23.4	32.6	8.4	23.2	75.2	171.7	89.5	100.2	13.4	11.7	15.2
2004-14	D3	24.4	37.9	6.5	15.8	12.1	69.0	142.7	143.6	72.4	21.7	2.8	6.4
Hisar													
1985-94	D1	13.0	17.2	15.0	19.2	28.0	43.4	166.4	129.5	53.4	2.6	6.8	5.0
1995-04	D2	11.2	15.0	6.0	7.3	13.8	50.1	128.7	102.7	75.3	3.2	0.1	3.6
2004-14	D3	14.6	17.3	13.2	10.8	42.9	63.6	112.5	106.6	44.8	29.0	1.0	5.2
Sirsa													
1985-94	D1	8.6	22.4	7.5	7.9	22.1	47.1	115.7	59.6	60.0	3.1	3.3	3.0
1995-04	D2	12.7	12.9	11.7	7.7	28.4	55.5	123.8	63.8	52.0	18.6	2.9	2.8
2004-14	D3	4.0	27.5	16.8	9.5	18.2	54.0	78.3	104.0	91.5	1.6	1.3	1.3
Bawal													

1985-94	D1	12.4	16.2	10.4	12.1	20.2	50.1	141.3	146.4	67.6	14.3	1.9	6.5
1995-04	D2	16.2	11.7	6.9	10.9	29.9	65.5	166.7	208.7	104.0	13.1	4.5	6.8
2004-14	D3	5.6	39.1	24.0	9.6	60.0	106.2	164.5	166.6	136.4	10.9	6.9	2.7
Narnaul													
1985-94	D1	7.2	8.9	3.0	2.8	18.6	57.1	128.1	72.5	14.5	7.2	1.3	4.3
1995-04	D2	25.6	14.9	10.0	4.6	46.4	63.6	121.3	86.0	72.6	16.3	3.5	5.2
2004-14	D3	10.6	30.6	9.1	18.3	41.4	162.1	134.8	192.5	118.8	13.4	1.9	2.8
Ganganagar													
1985-94	D1	8.7	16.9	7.5	15.9	6.6	32.2	90.2	73.8	40.0	4.0	0.8	3.7
1995-04	D2	8.7	9.8	4.9	10.3	19.0	38.7	85.8	33.9	25.1	11.9	3.0	1.9
2004-14	D3	7.5	20.8	15.3	7.5	16.3	52.2	51.0	60.0	74.8	3.6	1.9	3.6
Jaipur													
1985-94	D1	6.6	12.9	1.6	14.5	10.2	87.4	151.9	198.4	44.0	7.0	1.6	2.8
1995-04	D2	3.7	6.7	2.3	10.6	16.5	50.7	161.6	204.5	52.4	46.6	3.0	5.3
2004-14	D3	2.8	8.1	9.7	8.8	15.0	83.3	153.1	226.2	94.4	4.4	9.3	1.9
Plains													
1985-94	D1	18.3	25.8	21.6	13.0	20.5	61.3	188.1	173.8	82.1	8.0	4.6	14.5
1995-04	D2	24.9	22.6	23.5	13.8	29.9	81.9	182.1	180.6	90.1	22.5	6.4	12.8
2004-14	D3	17.1	33.0	20.9	14.0	32.0	90.8	170.0	183.4	117.4	12.3	3.4	9.6

In plains decadal to decade progressive increased in decadal average rainfall was observed in June at Jammu, in July, September & October at Patiala, in February at Rohtak, in January, February & October at Bathinda, in June at Hisar, in March at Sirsa, in May & June at Bawal, in February, April, June, August, September and October at Narnaul, in April, May, August, September at plains for pooled data. The highest increased in D3 over D1 was in July (79.2 mm) at Karnal followed by July (58.0 mm) at Jammu. Decadal to decade progressive decreased was observed in July at Jammu, in July & November at Chandigarh, in November at Delhi and Ludhiana, in July at Karnal, in January & December at Rohtak, in July at Hisar and Ganganagar, in January, April & September at Jaipur and in July & December at plains. The highest increased in D3 over D1 was observed in August (120.0 mm) followed by September (104.3 mm) at Narnaul (Table 2).



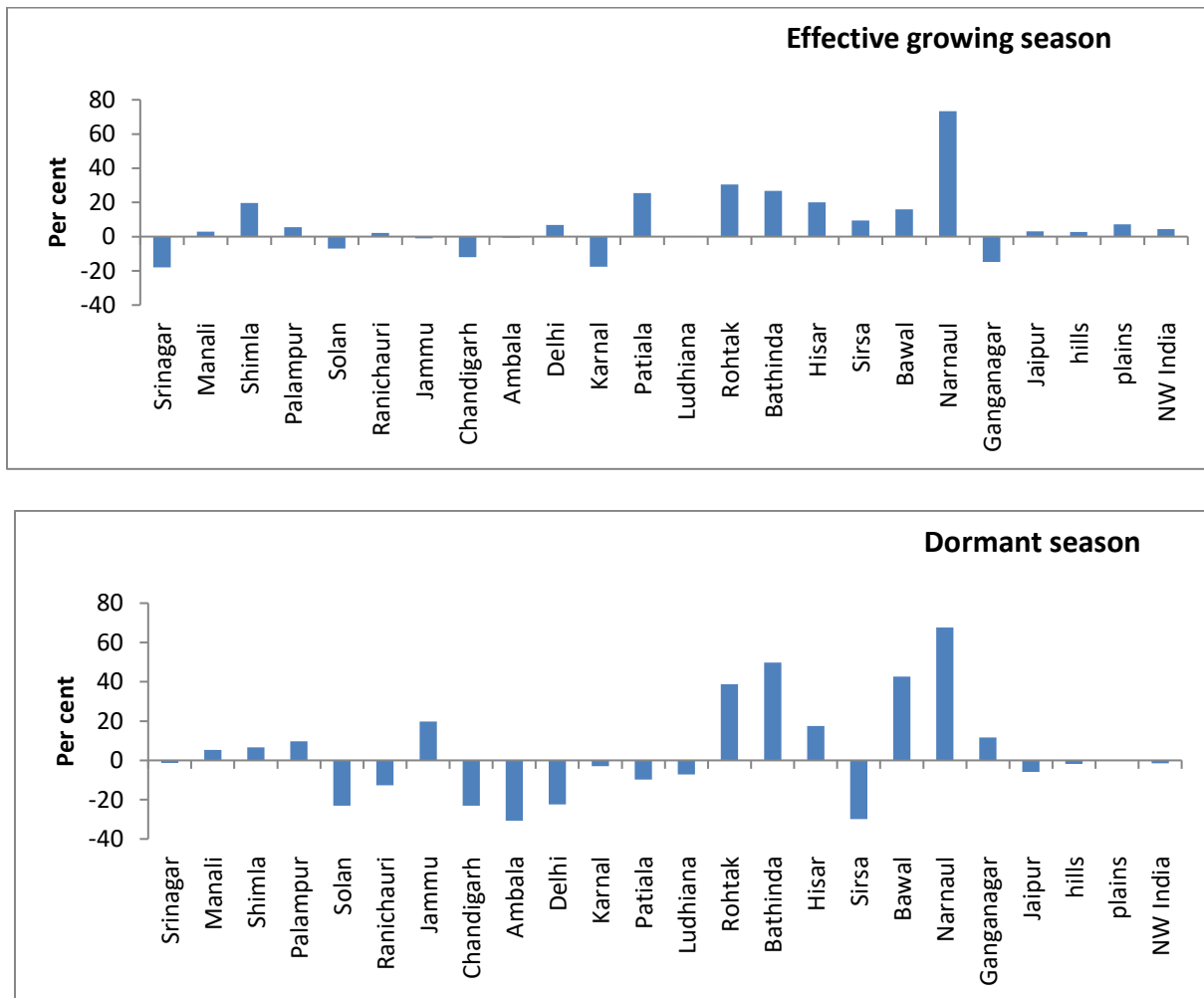


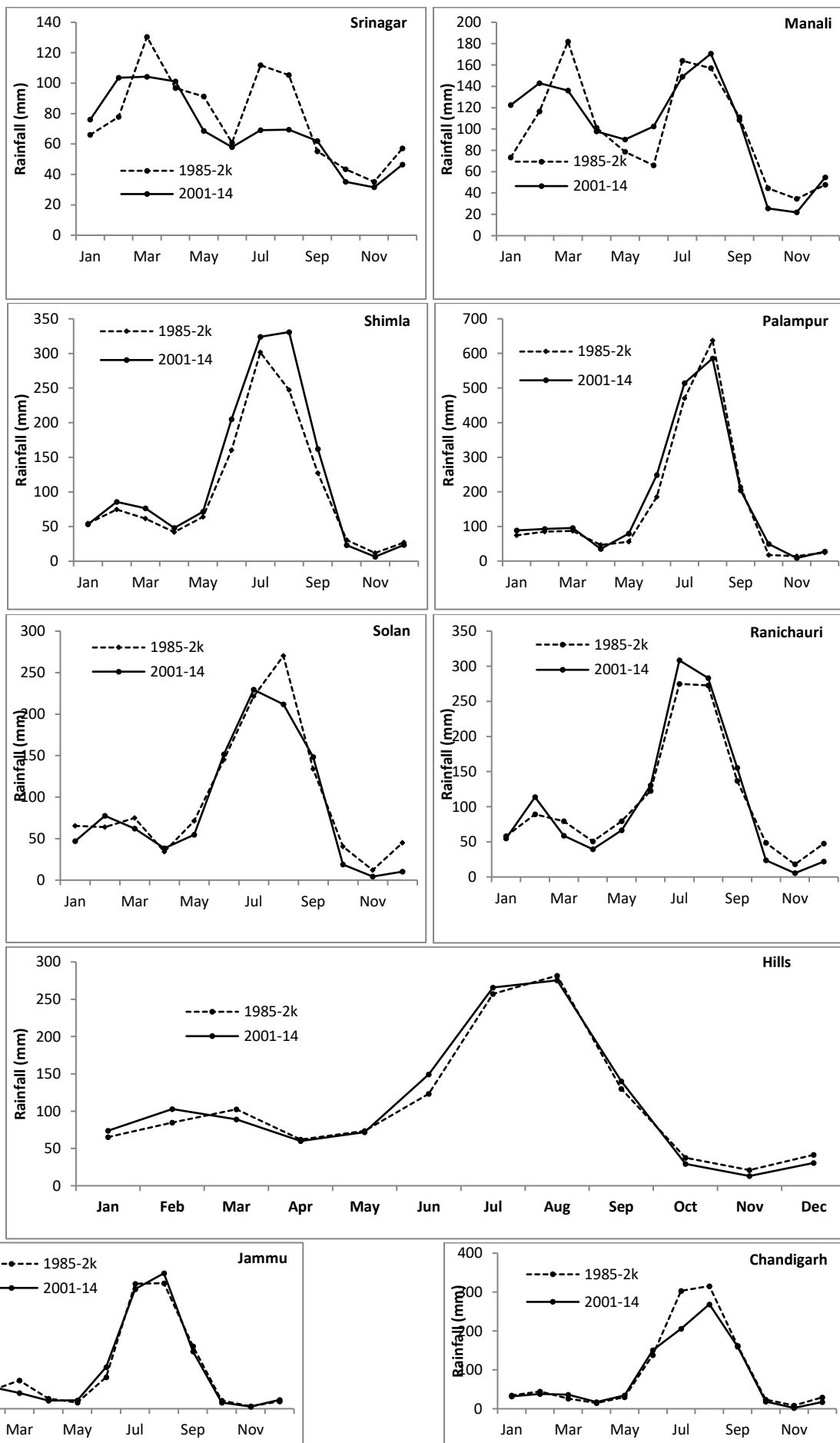
Figure 2 Annual and seasonal normalized rainfall recent time scale over previous

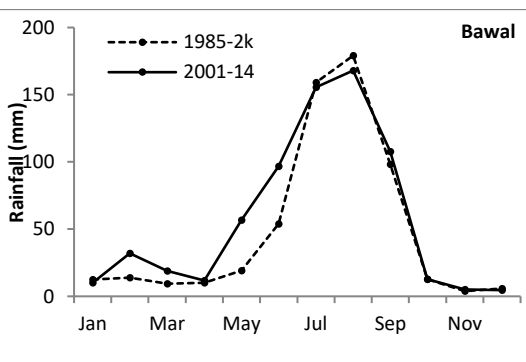
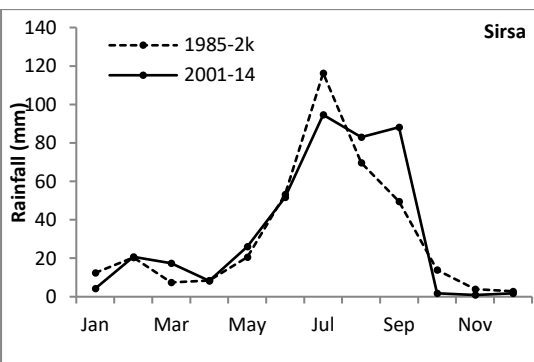
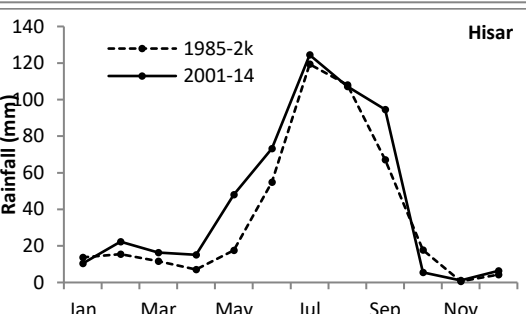
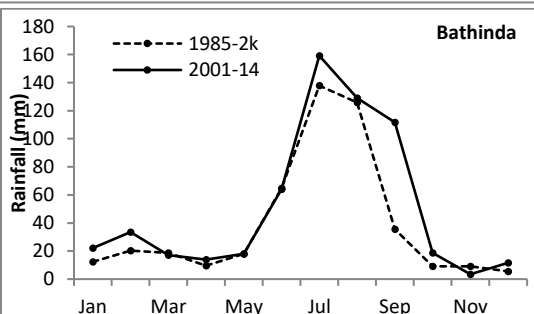
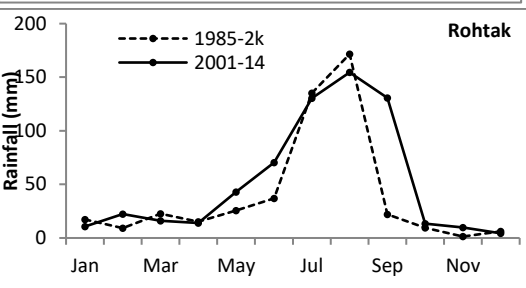
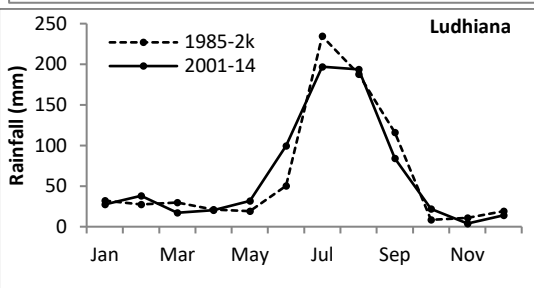
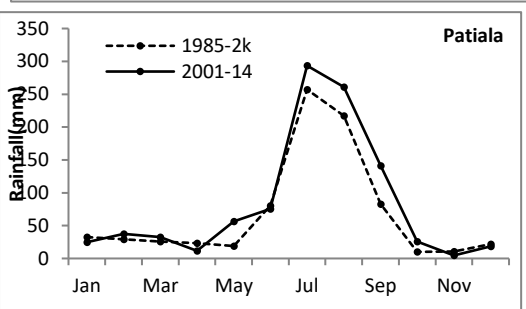
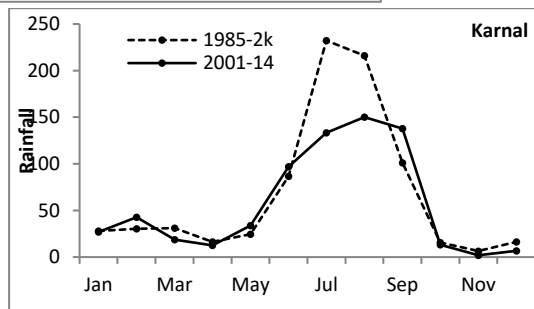
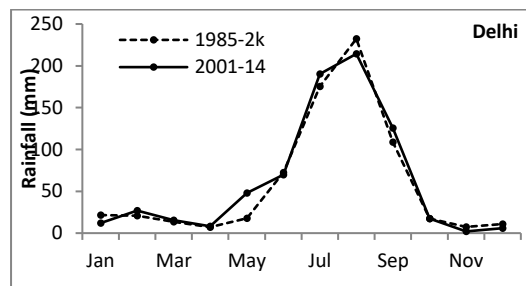
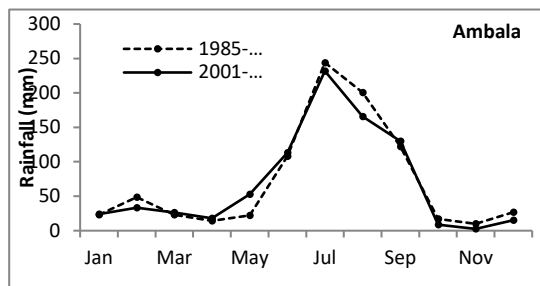
3.3. Normalized difference in recent time scale

The percent normalized difference in recent time scale (2001-14) over the previous time scale (1985-2000) for annual and seasonal rainfall was depicted in Fig 2. For annual rainfall it was negative for eight stations (Srinagar, Solan, Ranichauri, Chandigarh, Ambala, Karnal, Ludhiana, Ganganagar) and positive for the thirteen remaining stations with highest negative value (-16.1%) at Karnal and highest positive value (73.0 %) at Narnaul. During effective growing season it was negative for seven stations (Srinagar, Solan, Jammu, Chandigarh, Ambala, Karnal, Ludhiana and Ganganagar) and positive for remaining fourteen stations with highest value (-17.9 %) at Srinagar and highest positive value (73.4%) at Narnaul (Fig 2). Similarly during the dormant season eleven stations had negative and ten had positive value with highest negative value (-30.7 %) at Ambala and highest positive value (67.6%) at Narnaul.

3.4. Shift in rainfall

The plot of monthly rainfall at different stations, hills, plains and northwest India revealed that no shift in the month of peak rainfall at hills (pooled data) and northwest India (Fig. 3) but, shift from July to August at plains (pooled data) during present time scale (2001-14) compared to the previous time scale (2001-14). The shift was observed from July to March at Srinagar, from July to August at Manali, Shimla, Jammu, Chandigarh, Narnaul and Karnal from August to July at Ranichauri and Ganganagar and no shift in the month of peak rainfall at the remaining stations (Fig 3). The curve of recent time scale was almost above the curve of the previous time scale at Shimla and Palampur in hills and Patiala, Rohtak, Hisar, Bathinda, Bawal and Narnaul in plains which showed an increasing trend. No much difference in both the curves was observed at Jammu, Ambala, Delhi, Palampur, Bawal, Jaipur, hills and northwest India indicates less variability in rainfall during the recent time scale over the previous one. The steepness in curve was decreasing at Srinagar, Manali, Solan, Ranichauri, Karnal, Sirsa and Ganganagar indicate that the good distribution of rainfall among the months is increasing but, opposite to this the steepness had increased at Jammu, Chandigarh, Patiala, Bathinda, Narnaul and Ganganagar which indicate skewed distribution among months.





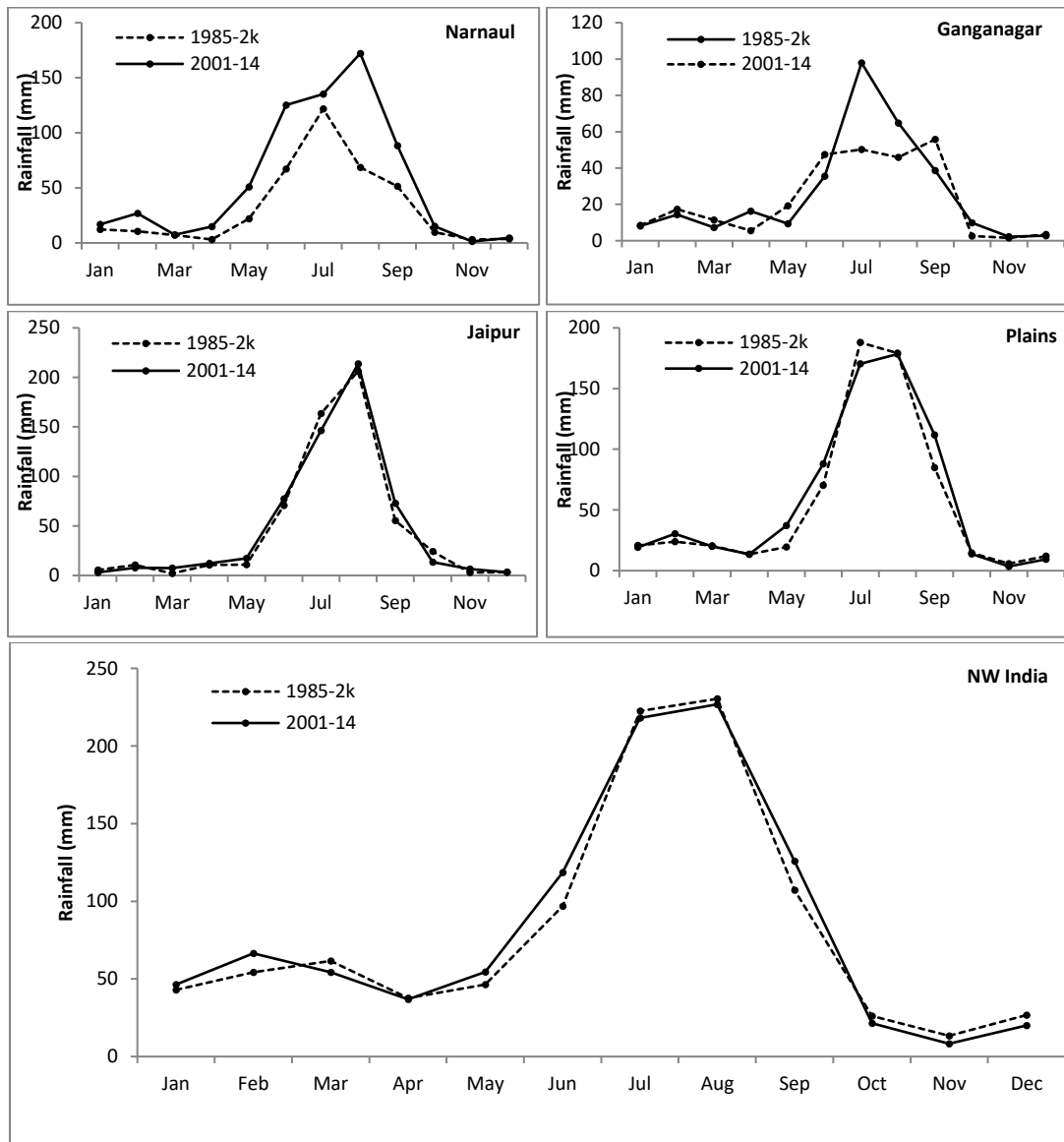


Figure 3 Shift in rainfall at plains

The isohyets of higher rainfall was spreading for annual as well as in effective growing season (Map 2 & 3) but during the dormant season it was contracting towards north of the study area (Map 4). The annual rainfall showed an increasing trend in eastern part, decreasing trend in western part and almost no change in central part of the study area (Map 2). Similar trend was observed during effective growing season with more pronounced increasing trend in eastern part (Map 3). During the dormant season it showed decreasing trends in eastern and western part with almost no change in the central part of the study area (Map 4).

4. CONCLUSIONS

Important conclusions drawn from long-term analysis of rainfall at twenty two locations and at hills, plains and north-west India area:

1. The isohyets of higher rainfall was spreading for annual as well as in effective growing season but it was contracting towards north during the dormant season of the study area.
2. The annual and effective growing seasonal rainfall showed an increasing trend in eastern part, decreasing trend in western part and almost no change in central part of the study area.
3. During the effective growing season rainfall was increasing with the rate of 3.38 mm/ years, 2.77 mm/ years and 4.56 mm per year in hills, plain and north-west India, respectively.

4. During the dormant season it showed decreasing trends in eastern and western part with almost no change in the central part of the study area
5. No shift in the month of peak rainfall at hills and northwest India but, shift from July to August at plains during present time scale compared to the previous time scale.
6. Steepness in monthly rainfall decreased and distribution among the months toward smoothing trend.

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