

Spatio-temporal variability of climatic parameters across different altitudes of North-Western Himalaya

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ABSTRACT

Climate change impact varies across different altitudinal ranges and demands local specific management strategies for water resource and farming system management. The present study analyses spatio-temporal climate parameters across different altitudes of Himachal Pradesh a hilly state of India. Analysis shows that annually, minimum temperature has significantly decreased by -0.09°C at altitude I (350 - 400 m) while maximum temperature has significantly increased by 0.05°C at altitudes I and II (1400-1500 m) and decreased significantly by -0.08°C at altitude III (2000- 2100 m). Higher regions Altitude – IV (2900-3000 m) received lowest rainfall (746.1 mm) with 30.2 % variation. Seasonal rainfall variability was higher in post monsoon (102 - 174%) and least in monsoon (21 - 57%). Annual rainfall at altitude I is strongly irregular (PCI 20.1 to 22.3), followed by altitude – IV (PCI 15-25); altitude – II irregular (PCI 15-20) and altitude – III moderate to irregular (PCI 12 -19) rainfall. Seasonal Index values for four altitudes fall between 0.91-0.96 revealed that rainfall is irregular and markedly seasonal with longer drier season. Higher wavelet powers in altitude - I and II after 2005 suggests frequency of extreme rainfall occurrence had increased.

Key Words: Altitude, precipitation concentration index, rainfall, seasonality index, temperature, wavelet analysis

Climate change is inevitable; however, it is imperative to know the variability of climate change so that necessary measures can be taken at local levels for adapting to such changes. Indian economy is largely agricultural based. Agriculture is a climate sensitive sector and any change in climate will have direct or indirect impact on agricultural productivity by affecting the crop yield, water availability and associated drought stress, pest-diseases *etc* affecting economy of the country. Cropping intensity and cropping area are also greatly influenced by the climatic variability (Kotera *et al.* 2014). Extreme temperature and rainfall variability have significant negative impacts on crop production. It was observed that temperature have more significant positive or negative impact on crop production as compared to rainfall (Lobell *et al.* 2011). Other impacts of climate change include higher runoff from the fields and increased soil erosion due to more frequent intense rainfall events. Piao *et al.* (2010) opined that the impact of climate change plays a pivotal role for future agricultural planning and crop production in the world, including India.

North Western (NW) Himalayan region of India covers

states of Jammu and Kashmir, Himachal Pradesh and Uttarakhand. About 1.6 degree of temperature rise in the NW Himalayan region was reported in the last century (1901-2002) by Bhutiyan *et al.* (2007). Significant increasing trend of $0.06^{\circ}\text{C year}^{-1}$ on annual mean maximum temperatures and $0.02^{\circ}\text{C year}^{-1}$ on annual mean temperatures for the 1951–2010 time period were observed for Himachal Pradesh (Rathore *et al.* 2013). Increasing trend over the central India region for the period 1950-2000 was also observed for number of rainfall events per year with precipitation greater than 100 mm whereas number of moderate rainfall events had shown decreasing trend in the same period (Goswami *et al.* 2006). Decreased number of rainfall events but increasingly common high rainfall events was reported by Dourte *et al.* (2012). The impacts of such extreme events in hills will leads to migration of species towards higher altitudes, loss/drying of traditional water sources, changes in planting time and dates, reduced crop yields and increased vulnerability of farming communities to climatic changes.

It is therefore, important to know trends of temperature and rainfall in space and time at local levels so that region

specific interventions can be advocated for adaptation under changing climatic conditions. Pawar *et al.* (2019) have analysed trends of rainfall and temperature at Shimla and Dharmshala. In this paper we aim to analyse the temperature and rainfall trend and pattern over different altitude of Himachal Pradesh on monthly, seasonal and annual timescale.

MATERIALS AND METHODS

Study area

Himachal Pradesh is located between 30°22'40" N to 33°12'40" N latitudes and 75°45' 55" E to 79°04' 20" E longitudes. The state has a hilly terrain and complex topography with the altitude ranging from 350 meters to 7000 meters above sea level. The annual rainfall of the state varies from 2909 – 3800 mm and temperature ranges from -4°C (minimum) to 42°C (maximum). Based on its altitude, precipitation and varied cropping patterns, the state is divided into four agro climatic zones : Low-hill subtropical zone, mid-hill subhumid zone, high-hill temperate wet zone and high hill temperate dry zone. One station from each of the four agro-climatic zones was selected for the study.

Data source

Different stations located at varying altitudes were selected for study (Table 1). Monthly temperature (minimum and maximum) and rainfall data of selected stations of Himachal Pradesh for years 1980–2015 were collected from India Meteorological Department (IMD), Regional Research Station Shimla. Four Principal seasons observed in the state are winter (December, January, February), pre monsoon (March, April, May), monsoon (June, July, August, September) and post monsoon (October, November).

Trend analysis

Monthly, annual and seasonal trends of temperature and rainfall were computed using non-parametric Mann-Kendall (MK) statistic (Mann, 1945; Kendall, 1975). This MK test is recommended by the World Meteorological Organization and has been widely used to test for trends in hydrological and meteorological data, including precipitation, temperature and runoff (Li *et al.* 2008; Zang and Liu, 2013). The change in trend per unit time was calculated using non parametric Sen's slope estimator (Sen, 1968). The Sen's slope estimator is computed by choosing the median of the slopes of all lines through pairs of points as follows:

$$b = \text{median} \left[\frac{x_j - x_i}{j - i} \right] \text{ for all } i < j$$

The direction of change and the rate of increase or decrease in the annual and seasonal trend is revealed through the slope (Choudhury *et al.* 2012).

Precipitation concentration index (PCI)

Long-term total variability in the amount of rainfall was assessed using Precipitation Concentration Index (Oliver, 1980). It is taken as an indicator of rainfall concentration and rainfall erosivity (Michiels *et al.* 1992). PCI was calculated on an annual and seasonal scale as follows:

$$PCI(\text{annual}) = \frac{\sum_{i=1}^{12} p_i^2}{(\sum_{i=1}^{12} p_i)^2} * 100$$

where p_i is the monthly precipitation in i^{th} month.

$$PCI(\text{seasonal}) = \frac{\sum_{i=1}^n p_i^2}{(\sum_{i=1}^n p_i)^2} * \frac{n}{12} * 100$$

Where n is the no. of the months in a season.

PCI was computed on five yearly basis. PCI values are interpreted differently by different studies (Table 2).

Seasonality index

Seasonality comparison for different altitudes in a state or over different locations in a larger region is possible only when there is some quantitative tool for accounting for rainfall regimes (Adejuwon, 2012). Rainfall regimes are important to know the degree of variability in monthly rainfall throughout the year (Walsh and Lawer, 1981). Seasonality Index (SI) is a function of mean monthly and annual rainfall and was estimated using the following formula:

$$SI = \frac{1}{R} \sum_{n=1}^{12} \left| X_n - \frac{R}{12} \right|$$

Where X_n is the mean rainfall of month n and R is the mean annual rainfall. The SI values ranges from zero (if all the months have equal rainfall) to 1.83 (if all the rainfall occurs in one month). Different rainfall regimes with respect to SI values (Kanellopoulou, 2002) is given in Table 3.

Change point analysis

Change-point analysis is a powerful tool for detecting a change in the time series. Abrupt changes occurring in the climatic records are evaluated using non- parametric Pettitt's test, developed by Pettitt (1979). The Pettitt's test affectability to breaks in the middle of any time series make it the most commonly used test for change point detection (Winingaard *et al.* 2003). The exact time of the change can be easily obtained

Table 1: Selected stations, their altitude and zonation

S.No.	Station	Altitude (metres amsl*)	Agroclimatic Zone
I	Altitude I	369	Sub montane, Low Hills, Sub tropical Zone
II	Altitude II	1453	Mid Hills, Sub Humid Zone
III	Altitude III	2050	High Hills, Temperate Wet
IV	Altitude IV	2960	High Hills, Temperate Dry

* above mean sea level

Table 2: Interpretation of PCI values by different authors.

Oliver (1980)		de Luis <i>et al.</i> (2011)	
PCI	Precipitation distribution	PCI	Precipitation distribution
<10	uniform distribution or low precipitation concentration	8.3	the perfect uniformity in precipitation distribution (i.e., that same amount of precipitation occurs in each month)
11-15	a moderate precipitation	16.7	total precipitation was concentrated in 1/2 of the period
16-20	irregular distribution	25	total precipitation occurred in 1/3 of the period (i.e., total annual precipitation occurred in 4 months)
>20	a strong irregularity or high precipitation concentration		

Table 3: Rainfall regimes and their respective SI values

Rainfall regime	Seasonality index (SI)
Very equable	≤0.19
Equable but with a definite wetter season	0.20-0.39
Rather seasonal with a short drier season	0.40-0.59
Seasonal	0.60-0.79
Markedly seasonal with a long drier season	0.80-0.99
Most rain in three months or less	1-1.19
Extreme almost all rain in 1±2	≥1.2

by detecting a significant change in the mean of a time series. Many studies have explained the test statistics used in Pettitt's test (Jana *et al.* 2017; Dhorde and Zarenistanak, 2013; Kang and Yusof, 2012; Gao *et al.* 2011).

RESULTS AND DISCUSSION

Spatial temperature and rainfall distribution

Analysis of temperature reveals that annual minimum and maximum temperature varied from 4.5 – 15.6 °C and 15.9 – 30.0 °C respectively. Minimum temperature was in Altitude-IV with 19.6 % variation and maximum temperature was in

Altitude- I with 6.3 % variation. The annual rainfall varied from 746.1 – 1398 mm with an average of 1075.8 mm. Higher region (Altitude – IV) received lowest rainfall (746.1 mm) with 30.2 % variation and Altitude – II received highest (1398 mm) rainfall with 17.9 % variation. For minimum temperature, maximum temperature and rainfall higher variation was 36.9 %, 13.7 % and 42.0 % respectively in altitude-III (Table 4).

Monthly and seasonal distribution

Monthly temperature distribution pattern indicates

Table 4: Statistical results on monthly, annual and seasonal weather parameters of Altitude I-IV

Statistics	Pre- monsoon												Post Monsoon					
	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Winter	Pre- monsoon	Monsoon		
Altitude I	Minimum temperature (°C)	4.0	6.7	9.7	13.5	18.5	21.6	22.3	22.6	20.5	14.4	8.5	4.6	15.6	3.0	14.3	11.4	
	CV(%)	34.2	23.2	16.7	11.7	9.2	7.6	8.3	7.2	8.3	12.1	19.8	36.3	17.8	87.7	13.5	7.2	
	Maximum temperature (°C)	19.7	23.0	28.4	34.3	38.0	38.0	33.9	33.1	33.1	31.2	27.1	22.1	30.0	19.0	33.8	34.8	29.2
	CV(%)	6.8	8.2	8.4	5.9	4.6	4.9	4.4	2.2	2.1	2.9	3.3	6.6	6.2	22.7	5.4	4.7	2.4
Altitude II	Minimum temperature (°C)	44.1	45.6	44.7	24.1	27.4	89.4	271.1	295.8	121.1	19.0	12.8	26.9	1022.2	116.6	96.3	777.5	31.8
	CV(%)	79.5	76.2	97.5	114.9	123.1	70.9	41.7	34.3	72.7	154.7	240.1	136.9	25.2	45.8	63.6	31.7	135.2
	Maximum temperature (°C)	2.8	5.4	8.9	12.8	16.9	20.0	21.6	21.6	18.5	12.0	6.3	3.0	12.5	3.8	12.9	20.4	9.2
	CV(%)	39.0	21.2	10.4	7.4	7.2	4.4	5.3	1.9	6.3	8.4	14.1	36.5	3.3	19.7	5.5	3.0	10.0
Altitude III	Minimum temperature (°C)	17.6	19.8	24.6	29.9	33.9	34.0	30.9	30.3	30.2	28.5	24.5	19.7	27.0	19.1	29.5	31.4	26.6
	CV(%)	8.3	10.0	10.3	7.1	5.5	5.1	3.6	2.5	2.1	3.7	3.6	6.2	2.7	5.3	6.0	2.0	3.4
	Maximum temperature (°C)	61.1	76.1	74.5	46.9	80.8	175.4	352.3	332.0	134.5	23.0	8.8	34.5	1398.0	169.6	202.4	994.2	31.8
	CV(%)	74.4	57.6	66.9	72.6	67.5	49.8	36.0	34.4	57.7	163.0	157.2	130.6	17.9	40.3	32.5	21.7	127.9
Altitude IV	Minimum temperature (°C)	-1.1	0.0	2.8	6.0	9.0	12.5	15.6	15.5	12.1	6.1	2.2	0.1	6.9	-0.3	6.1	13.8	4.2
	CV(%)	-125.3	-	61.0	23.4	11.9	10.5	8.3	9.6	11.6	15.8	37.3	1191.0	36.9	-317.8	17.3	10.2	23.0
	Maximum temperature (°C)	10.2	11.5	16.1	20.9	24.7	26.6	25.7	25.3	24.4	21.7	17.5	13.2	20.1	9.9	20.8	25.6	19.6
	CV(%)	17.5	20.8	17.0	14.1	7.1	7.2	5.2	3.7	4.5	7.0	7.8	13.0	13.8	36.6	9.3	4.3	6.9
Altitude V	Minimum temperature (°C)	83.6	117.4	157.9	81.7	68.1	68.4	184.6	174.8	98.7	27.3	23.4	50.9	1137.0	252.0	307.8	526.6	50.7
	CV(%)	94.0	75.9	72.6	85.6	90.3	79.3	60.4	58.7	83.3	157.0	151.8	108.0	42.0	58.7	57.2	46.4	102.6
	Maximum temperature (°C)	-4.0	-3.1	0.1	3.8	6.9	10.3	13.0	12.7	9.3	4.3	1.2	-1.4	4.6	-2.7	3.8	11.4	2.8
	CV(%)	-46.8	-58.2	760.1	31.3	21.2	11.0	6.9	6.9	12.6	25.5	91.5	-83.5	19.6	-47.0	40.2	7.3	39.3
Altitude VI	Minimum temperature (°C)	4.9	6.1	11.0	16.5	20.4	22.7	22.7	22.2	21.1	18.3	14.4	9.0	15.9	6.3	16.0	22.2	16.3
	CV(%)	52.8	39.4	23.8	10.8	8.0	4.0	4.5	4.0	4.6	6.6	9.6	26.2	5.6	32.5	8.9	2.5	7.8
	Maximum temperature (°C)	81.5	109.7	125.6	70.5	63.2	53.3	47.1	47.5	56.9	21.1	15.1	49.6	746.1	233.1	259.2	213.3	40.5
	CV(%)	67.9	57.2	97.9	66.2	79.1	196.4	71.6	63.4	95.8	210.9	209.9	98.6	30.2	40.6	56.8	57.0	174.6

Table 5: Sen's estimator of slope for climatic parameters in different altitudes of Himachal Pradesh.

Month	Altitude I			Altitude II			Altitude III			Altitude IV		
	Min temp (°C)	Max temp (°C)	Rainfall (mm)	Min temp (°C)	Max temp (°C)	Rainfall (mm)	Min temp (°C)	Max temp (°C)	Rainfall (mm)	Min temp (°C)	Max temp (°C)	Rainfall (mm)
January	-0.054	-0.022	-0.125	-0.007	0.065*	-0.367	-0.023	-0.063	2.356*	-0.035	0.057	2.222*
February	-0.038	0.021	0.140	0.035	0.063*	-0.489	0.012	-0.089	2.173	-0.042	0.021	2.409
March	-0.034	0.125*	-0.417	0.010	0.131*	-0.541	0.050	0.007	0.157	-0.001	0.102*	-1.779
April	-0.035	0.045	0.047	0.012	0.064	0.989	0.008	-0.086*	0.124	-0.009	0.059*	-0.771
May	-0.027	0.097**	0.263	-0.036	0.059	-0.702	0.022	-0.043	0.062	-0.012	0.060*	-1.145
June	-0.061	0.001	1.608	-0.007	-0.028	1.375	0.011	-0.107**	1.637*	-0.024	-0.006	0.731
July	-0.089*	0.044	-0.226	0.012	0.033	-1.739	-0.020	-0.048	0.389	0.015	0.025	0.578
August	-0.076*	0.033	2.999	0.007	0.024	1.136	-0.005	-0.067**	2.418	0.002	0.006	0.617
September	-0.072	0.026	1.605	0.010	0.013	1.469	0.004	-0.085**	1.110	-0.012	0.030	1.002
October	-0.071	0.043*	0.210	0.022	0.031*	0.000	0.058**	-0.100**	0.170	-0.013	0.048*	0.000
November	-0.070	0.027	0.000*	-0.007	0.033**	0.031	0.053**	-0.085**	0.138	0.004	0.062*	-0.184
December	-0.116**	0.033	0.000	-0.041*	0.040*	0.035	-0.007	-0.094*	0.258	-0.006	0.096*	-1.956
Annual	-0.096*	0.047*	0.362	-0.002	0.050**	0.018	-0.002	-0.080**	0.636	-0.026	0.028	0.042
Winter	0.000	0.053	-0.080	-0.011	0.054**	-0.574	-0.014	0.024	1.460	-0.051*	0.105**	1.315
Pre-monsoon	-0.056	0.119*	-0.242	-0.001	0.098*	-0.291	0.006	-0.052*	-0.635	-0.012	0.097**	-0.972
Monsoon	-0.095	0.027	1.514	-0.001	0.013	-0.071	0.012	-0.086**	1.330	-0.015	0.011	0.801*
Post Monsoon	-0.067	0.036*	-0.125	0.006	0.031**	0.079	0.057**	-0.093**	0.209	-0.001	0.049**	-0.465

** and * denotes significance of trends at 1% and 5% level of significance respectively based on Mann Kendall's Z statistics

mean minimum temperature was lower in January in all four altitudes ranging from $-4.0 - 4.0$ °C. Mean maximum temperature was higher in the month of June ($22.7 - 33.9$ °C) in altitude II, III and IV whereas, it was higher (38.1 °C) in altitude – I in May. Variation for minimum temperature was higher (-125.4 %) for altitude – III in January. Maximum temperature variability was higher (53.0 %) in January for altitude – IV. Mean monthly rainfall was higher in July in altitude - II (352.3 mm) and altitude – III (184.6 mm). Rainfall variability was higher (240.1 %) in November at altitude – I (Table 4).

Seasonal temperature analysis implies that average minimum temperature was higher ($11.4 - 21.7$ °C) in monsoon and least ($-2.6 - 3.7$ °C) in winter season. Average maximum temperature was higher ($22.2 - 34.8$ °C) in monsoon season. Variation of minimum temperature was higher (-317.8 %) in winter and for maximum temperature it was also higher (36.6 %) in winter in altitude – III. Seasonal rainfall variability was higher in post monsoon ($102.6 - 174.6$ %) and least in monsoon ($21 - 57$ %) (Table 4).

Monthly trends

Minimum temperature has significantly decreasing trend during July, August and December by 0.09 °C, 0.08 °C and 0.12 °C respectively for the altitude I. Significant decreasing trend in minimum temperature (0.04 °C) was found for December in altitude II. Minimum temperature of October and November had significant increasing trend of 0.06 °C and 0.05 °C respectively for Altitude III (Table 5)..

Significant increase in maximum temperature by 0.12 °C, 0.1 °C and 0.04 °C was observed during the months of March, May and October, respectively for lowest Altitude I. However, significant increase in maximum temperature by 0.1 °C, 0.06 °C, 0.06 °C, 0.05 °C, 0.06 °C and 0.1 °C was observed during March, April, May, October, November and December, respectively in Altitude - IV. No significant trend in rainfall was observed for Altitude I and II (Table 5). At altitude - III, rainfall showed significant increase by 2.36 mm and 1.64 mm during the months of January and June, respectively. Significant increase in rainfall by 2.22 mm in the month of January was also observed for the altitude - IV.

Seasonal and annual trends

Magnitude of seasonal temperature and rainfall trend was analyzed and is presented in Table 5. Maximum temperature showed a significant increasing trend in most of the seasons. Minimum temperature had a decreasing trend in

most of the season. However, significant decrease was (-0.051 °C) was observed for altitude - IV during winter season. Monsoon rainfall in altitude-IV had a significant increasing trend. Decreasing trend of winter rainfall in lower altitudes (altitude – I and II) and its increasing trend in higher altitudes (altitude – III and IV) are cause of concern and requires contingency planning. At lower altitude, which is agricultural production areas, rainfall trends show increased concentration in monsoon and its decrease in other all seasons. Such changes on one hand will hamper winter cropping and on the other creates flood like situation during rainy season. Annual trend shows significant increase in maximum temperature in lower altitudes.

Seasonal rainfall concentration

Pattern of rainfall distribution was assessed using PCI on 5 yearly bases. Annual and seasonal PCI values varied from lower than 10 in the monsoon season to higher than 30 in the post-monsoon season (Fig 2). Annual rainfall at altitude I is strongly irregular (PCI 20.14 to 22.37), followed by altitude – IV with PCI moderate to strongly irregular (PCI 15-25); altitude – II irregular (PCI 15-20) and altitude – III moderate to irregular (PCI 12 -19) rainfall. This shows that annual rainfall is unevenly distributed among the months and is concentrated more in one third of the year.

Seasonal PCI showed mixed rainfall distribution in pre-monsoon, post-monsoon and winter rainfall with PCI values varying from 9 to 46. This shows highly irregular and unpredictable nature of rainfall during the seasons. This uncertainly in rainfall affects the *pre-kharif* and *rabi* crop sowing and management (Jana *et al.* 2017). Monsoon season shows relatively stable and uniform rainfall concentration with PCI in a range of 9-15. Highest PCI values were for post monsoon season in all altitudes with highest PCI values in altitude – I.

Seasonality index

Seasonal Index values for four altitudes fall between $0.91 - 0.96$ (Fig. 2). Decadal trend of rainfall is decreasing for all altitudes except for altitudes I and II for the decade of 1980-89 which had an increasing trend. Over all decreasing trend agrees with the fact that monsoon rainfall is decreasing and on the other hand pre- and post-monsoon rainfall is increasing which in fact reduces the rainfall concentration disparity. This suggests that there a relative shifting in rainfall pattern with passing time with inconsistency in rainfall. Similar observations were made for the state of Kerala by Nair *et al.* (2014), Bundelkhand by Jana *et al.* 2017 and Thomas and

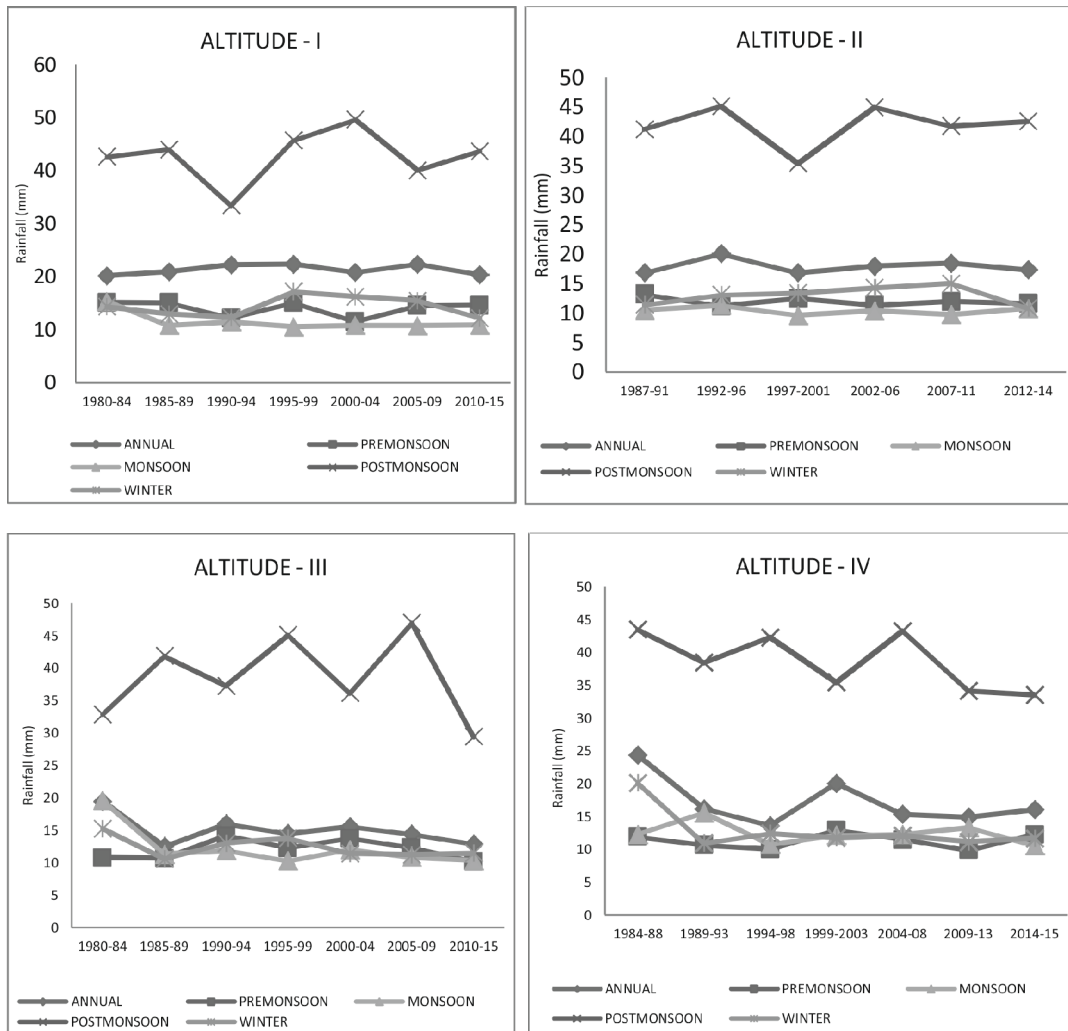


Fig. 1: Annual and seasonal PCI over four different altitudes

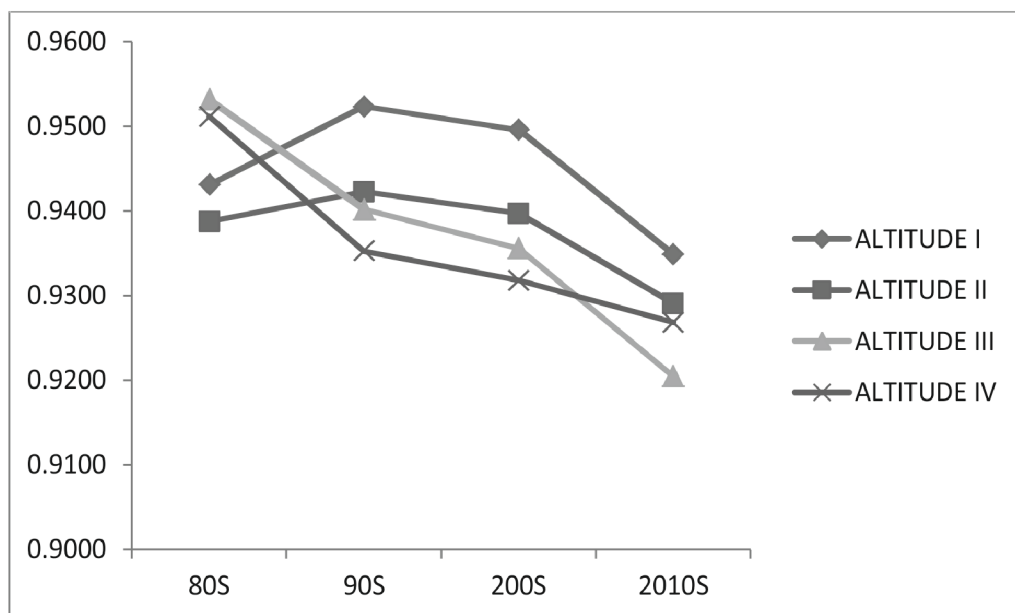


Fig. 2: SI values for different altitudes

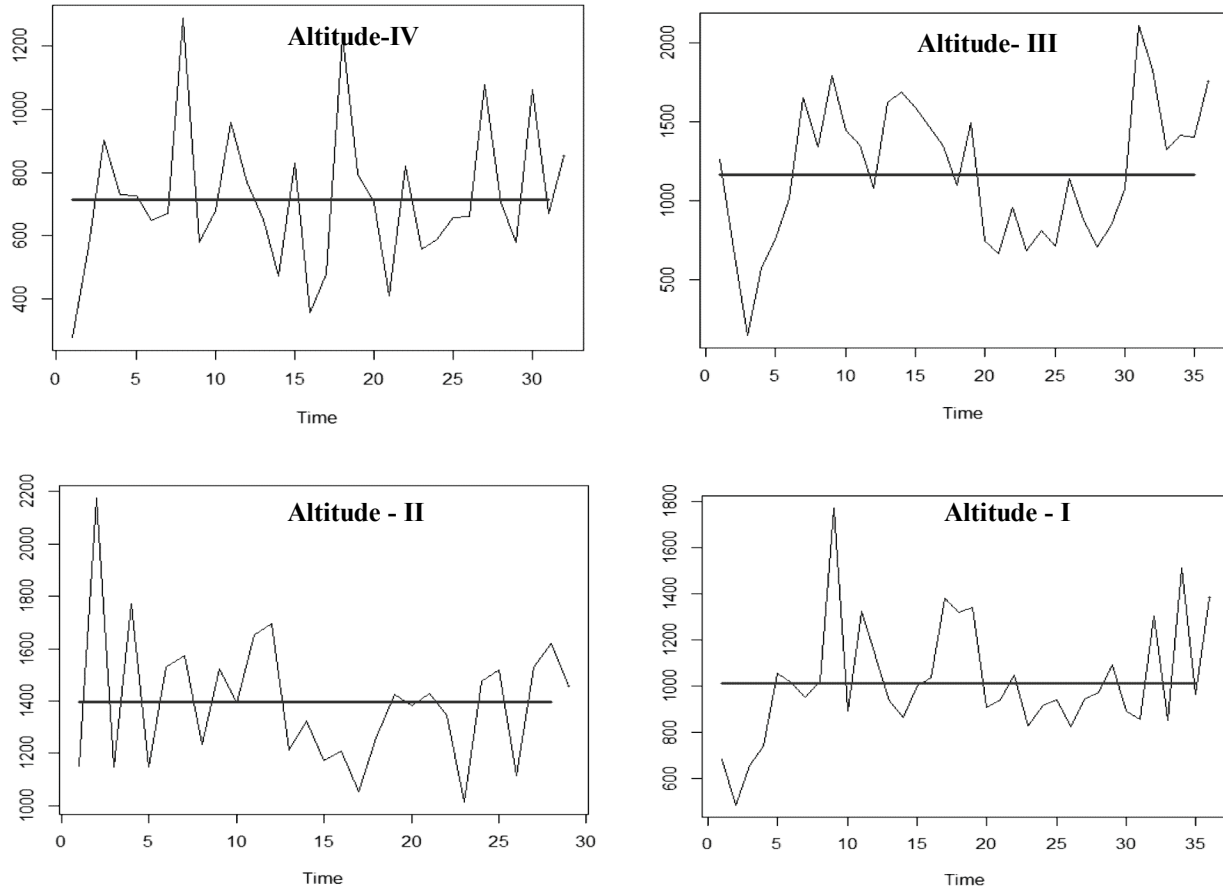


Fig. 3: Time series along with change year using Pettitt change point analysis for annual rainfall

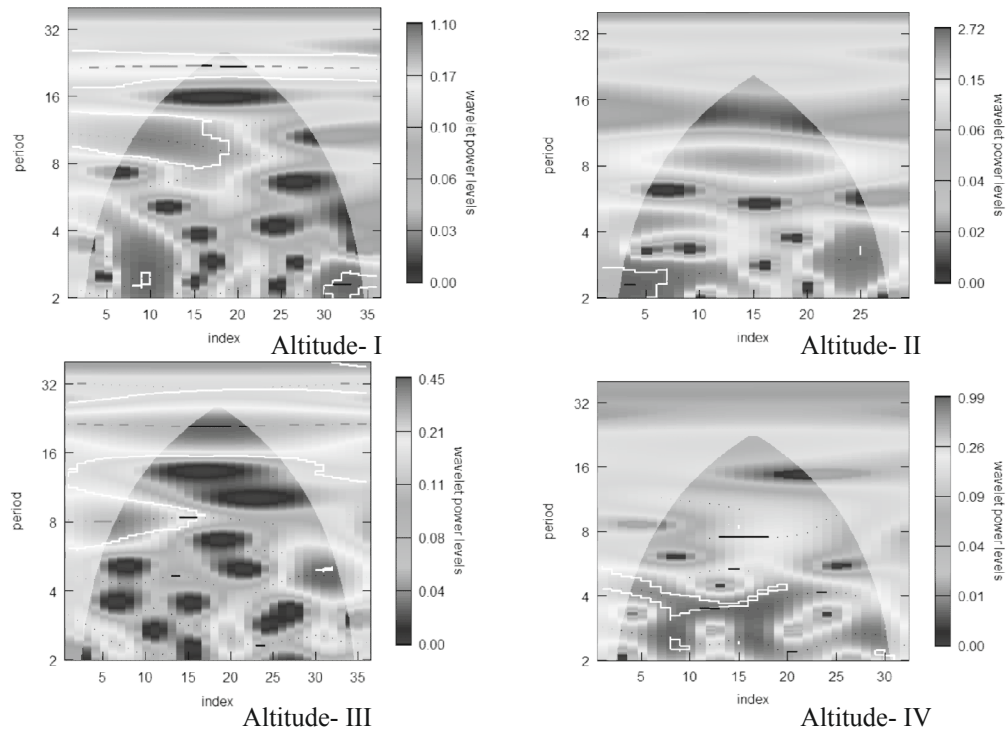


Fig. 4: Wavelet analysis for annual rainfall for four altitudes

Prasannakumar, 2016 who had reported mixed but slight decreasing trend in the time series.

Change point analysis

Annual series of rainfall was analyzed using Pettitt's test for change detection analysis. Time series of annual rainfall with the change points is presented in Fig. 3. The change point analysis on time series of annual rainfall indicated that significant change points in all the altitudes was in year 2014 from where above average rainfall was observed. The significant change points in the series observed during 2014 may be attributed to the growing commercial activities in the region (Jaiswal *et al.* 2015). Besides 2014, change point was also found in 1998 (showing decreased rainfall), 1983 (showing increased rainfall) and 2009 (showing decreased rainfall) for altitude-II, altitude-I and altitude-III, respectively. Change point in 1990's was also observed for Agra district, India (Jana *et al.* 2016)

Rainfall periodicity

Wavelet analysis for annual rainfall periodicity is given in Fig. 4 for all the four altitudes. It was found that periodicity of rainfall in altitude – I had decreased and remained almost similar in other altitudes. Higher wavelet powers in altitude - I and II after 2005 suggests frequency of extreme rainfall occurrence had increased. Dash *et al.* (2012) while analysing rainfall characteristics over nine agrometeorological divisions also found that heavy intensity rainfall spells are increasing. In altitude III the periodicity of such extreme events has also increased from 7 – 24 years (during 1980 to 1995) to 4 – 24 years (during 2006 to 2015). A periodicity of 2–8 years was found in annual and seasonal rainfall patterns in Kerala state, India (Thomas and Prasannakumar, 2016).

CONCLUSIONS

The study reveals that annual variability was more for minimum temperature (19.6%) in higher altitude and for maximum temperature in lower altitude. Winter season showed maximum variation for both minimum and maximum temperature in altitude – III. Monsoon rainfall is the major contributor to the annual rainfall and has higher consistency compared to other seasons. Rainfall variability was higher in post-monsoon (102 – 145 %). At lower altitude, which is agricultural production areas, rainfall trends show increased concentration in monsoon and its decrease in other seasons. Maximum PCI values also confirm that annual rainfall amount is highly variable and is concentrated in the 2–3 months of the monsoon season. PCI values were higher for post-monsoon in

altitude – I. High seasonal index values (0.91-0.96) revealed that rainfall is irregular and markedly seasonal with longer drier season. Higher wavelet powers in altitude - I and II after 2005 suggests frequency of extreme rainfall occurrence had increased.

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