J. Mt. Sci. (2016) 13(4): 672-681 e-mail: jms@imde.ac.cn http://jms.imde.ac.cn
DOI: 10.1007/s11629-014-3194-y

Historical temporal variation in precipitation over Western Himalayan Region: 1857-2006

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Citation: Kumar N, Jaswal AK (2016) Historical temporal variation in precipitation over Western Himalayan Region: 1857-2006. Journal of Mountain Science 13(4). DOI: 10.1007/s11629-014-3194-y

Abstract: This study has examined the temporal variation in monthly, seasonal & annual precipitation over the Western Himalayan Region (WHR) and the influence of global teleconnections, like the North Atlantic Oscillation (NAO) and Southern Oscillation (SO) Indices on seasonal & annual precipitation. The Mann–Kendall non-parametric test is applied for trend detection and the Pettitt–Mann–Whitney test is used to detect possible shift. Maximum entropy spectral analysis is applied to find the periodicity in annual & seasonal precipitation. The study shows a non-significant decreasing trend in annual precipitation over WHR for the period 1857-2006. However, in seasonal precipitation, a significant decreasing trend is observed in monsoon and a significant increasing trend in post-monsoon season during the same period. The significant decrease in monsoon precipitation may be due to weakening of its teleconnection with NAO as well as SO Indices mainly during last three decades. It is observed that the probable change of year in annual & monsoon precipitation over WHR is 1979. The study also shows significant periodicities of 2.3-2.9 years and of 3.9-4.7 years in annual & seasonal precipitation over WHR.

Keywords: Monsoon; Precipitation; Western Himalayan region; Temporal Variation

Received: 30 October 2014
Accepted: 6 January 2015

Introduction

The Himalayas plays a vital role in Indian climate and weather, governing the southwest monsoon in summer and Western Disturbances (WDs) in winter. Its mountain chain forces easterly winds associated with monsoon to cause precipitation during June to September; its westerly winds associated with WDs cause snowfall/rainfall mainly during December to March (Kumar et al. 2015). The precipitation climatology of Himalayan region is inconsistent and differs from the rest of the Indian subcontinent (Shreshtha et al. 2000; Barros and Lang 2003). Over India, around 80% of its annual precipitation occurs in monsoon season. In the active phase of monsoon season, above-normal precipitation occurs in central parts of the country and below-normal along the foothills of Himalayas; but in the break phase, the process is reversed (Krishnamurthy and Shukla 2000). In the literature, many studies have been carried out related to precipitation-variation over various parts of Himalayan region (Dhar and Narayanan (1965), Dhar and Farooqui (1973), Shreshtha et al. (2000), Duan and Yao (2003), Archer and Fowler (2004), Basistha et al. (2009) and Bhutiyani et al. (2010), Dimri and Dash (2010), Kumar and Jain (2010), Dimri and Dash (2012) and Yang et al. (2013).

Shreshtha et al. (2000) studied the precipitation fluctuations in the Nepal Himalaya and its vicinity. They found a large inter-annual and decadal variability in the all-Nepal precipitation records. Basistha et al. (2009) explored the changes in rainfall pattern over Uttarakhand during 20th century. They found that most probable year of change in annual as well as monsoon rainfall in the region is 1964. Bhutiyani et al. (2010) studied precipitation variation in northwest Himalayas and found no trend in the winter, but significant decreasing trend in the monsoon precipitation. Kumar and Jain (2010) have analyzed seasonal and annual rainfall & rainy days in Kashmir valley during last century by using data from five stations namely Srinagar, Kulgam, Handwara, Qazigund and Kukarnag. They found decreasing trends in annual and monsoon rainfall during the period 1903-1982 over Srinagar, Kulgam and Handwara. Dimri and Dash (2012) analyzed various climatic indices based on wintertime data for the period 1975–2006 and found slightly decreasing trends in precipitation. Yang et al. (2013) studied spatial & temporal variations in air temperature and precipitation in the Chinese Himalayas during 1971–2007 and found non-significant increasing trend in annual precipitation. They also observed no significant trend in seasonal precipitation during the same period.

Precipitation over the WHR has a very crucial role in agriculture, water resources, horticulture, hydroelectric power generation and economy of the region. River of the WHR is main source of agriculture of plains of northwest India. Any change in precipitation pattern may strongly influence the economy and social well-being of the region. Hence, study of long-term changes in precipitation is essential for the region. In addition, most of studies related to precipitation for WHR are based on limited time period data sets and for specific areas of the WHR only. Therefore, we have carried out a study to examine the temporal variation in monthly, seasonal and annual precipitation over WHR for the period 1857-2006. Kundzewicz and Robson (2004) suggested that at least 50-year of data records is necessary to study the climate change detection. To get into more insight the analysis and precipitation variation, whole period (1857-2006) is divided into three parts viz. 1857-1906 (FY1), 1907-1956 (FY2) and 1957-2006 (FY3).

Further, NAO and SO also influence the precipitation over Indian region and same is studied by various authors over different regions of India (Kane 1998a; Archer and Fowler 2004; Bhutiyani et al. 2010; Sen Roy 2011; Afzal et al. 2013). Precipitation in WHR mainly occurs under the influence of WDs in winter, pre-monsoon & post-monsoon seasons and under the influence of easterlies and or its interaction with westerly systems in monsoon season. WDs are the mid-tropospheric westerlies systems that generated at Mediterranean Sea and Atlantic Ocean. Precipitation variation in Himalayan region may be affected by NAO index (Archer and Fowler 2004; Bhutiyani et al. 2010). In the present study, we also examined the teleconnection between seasonal & annual precipitation with NAO & SO.

1 Study Area

The study area of WHR consists of three states namely, Jammu & Kashmir, Himachal Pradesh and Uttarakhand. It extends from 72°-81° E and latitudes 29°-37° N. Altitudes of the WHR vary from few hundred meters in its southern parts up to 8000 meters in the Karakoram Himalayas in its northern parts (Bhutiyani et al. 2010). The region receives precipitation mainly due to WDs, easterly winds of monsoon or sometimes due to interaction of WDs with easterly winds.

2 Data and Methodology

Monthly precipitation data series for the period 1857-2006 have been obtained from the Indian Institute of Tropical Meteorology (IITM), Pune (http://www.tropmet.res.in/). Detail about the data series is available in Sontakke et al. (2008). In this region, the earliest precipitation record is available for three stations in 1853, four in 1862, five in 1864, six in 1868, seven in 1889, eight in 1891 and ten in 1901. The areal representative series for the period 1901–2006 has been prepared by arithmetic mean of the ten stations. Thereafter, they developed earlier series up to 1900 by following Wigley et al. (1984) and Singh (1994). Monthly NAO (1866-2006) & SO (1876-2006) indices used in study has been obtained from the websites namely, http://www.cru.uea.ac.uk and http://www.bom.gov.au respectively. In order to find the variation in precipitation, standard deviation (SD) and coefficient of variance (CV) for monthly, winter (January and February), pre-monsoon (March to May), monsoon (June to September), post-monsoon (October to December) and annual (January to December) precipitation have been calculated. The percentage (%) contribution of monthly and seasonal precipitation to annual precipitation is also calculated. To test for trends in mean values, time series of anomalies of monthly, seasonal and annual precipitation values are used. % anomaly of time series is calculated as follow:

$$\%\ anomaly = \frac{series\ value}{series\ mean} \times 100 - 100$$

As non-parametric techniques are less affected by non-normality and outliers (Lanzante 1996), Thus, the non-parametric Mann Kendall test (Kendall 1976; Yu et al. 1993; Burn et al. 2004; Bhutiyani et al. 2010; Kumar and Jain 2010; Subash et al. 2011; Kumar et al. 2015) is applied for this study. In Mann-Kendall test, trend analysis is evaluated by using the test statistic 'Z' value (MAKESENS 2002)

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var\ (S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{Var\ (S)}} & if\ S < 0 \end{cases}$$

where, $S = \sum_{k-1}^{n-1} \sum_{j=k+1}^{n} Sgn\left(x_j - x_k\right)$, $j > k, x_j$ & x_k are annual values in year *j* & *k* respectively,

$$Sgn\left(x_j - x_k\right) = \begin{cases} 1 & if\ x_j - x_k > 0 \\ 0 & if\ x_j - x_k = 0 \\ -1 & if\ x_j - x_k < 0 \end{cases}$$ and

$$Var\ (S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=0}^{m} t_I(t_I - 1)(2t_I + 5)\right]$$

Here m is the number of tied groups and t_I is the number of data values in l^{th} group. The statistically significant trend is calculated by Z value. The positive value of Z indicates increasing trend and vice-versa.

Further precipitation time series generally show short-term fluctuations; earlier studies used 11-year running means to remove the short-term fluctuations (Endo 2011; Krishnakumar et al. 2009; Basistha et al. 2009; Naidu et al. 1999). In present study, we also adopted 11-year running means to remove the short-term fluctuations. Thereafter, to identify the change point in the precipitation series, the Pettitt–Mann–Whitney test (Basistha et al. 2009; Kiely et al. 1998) is applied to seasonal & annual precipitation series. In the Pettitt–Mann–Whitney test, every time series with length *n* given by $\left(x_1, x_2, x_3 ----x_n\right)$ considered to have two sample represented by $x_1, x_2, x_3 ----x_m$ and $x_{m+1}, x_{m+2} ----x_n$, the index $V(m)$ and $U(m)$ are defined as

$$V_{m,n} = \sum_{i=1}^{n} Sgn\left(x_m - x_i\right)$$

$$U_{m,n} = U_{m-1,n} + V_{m,n} \text{ for } m = 2, n$$

$$U_{1,n} = V_{1,n}$$

$$Sgn(x) = \begin{cases} 1 & if\ x > 0 \\ 0 & if\ x = 0 \\ -1 & if\ x < 0 \end{cases}$$

$$P(m) = 1 - \exp\left[\frac{-6U_{m,n}^2}{n^3 + n^2}\right]$$

The most significant change-point is that in which $P(m)$ is maximum.

Finally, to see the periodicities in seasonal & annual precipitation, we used maximum entropy spectral analysis method (Ulrych and Clayton 1976; Kane and Teixeira 1991; Kane 1995; Kane 1998b; Tošić and Unkašević 2005; Pardo-Igúzquiza and Rodríguez-Tovar 2006) by using AnClim software (Stepanek 2007).

3 Results and Discussions

3.1 Precipitation characteristics

The mean, SD, CV(%) and % contribution of monthly & seasonal precipitation to annual precipitation for the entire period (1857-2006), FY1(1857-1906), FY2(1907-1956) and FY3(1957-2006) is shown in Table 1. For entire period, the mean annual precipitation is 1569 mm with a SD of 229 mm and CV of 15%. In different 50-year periods, mean annual precipitation for FY1 & FY2

Table 1 Mean, Standard Deviation (SD), Coefficient of Variance (CV(%)) and % contribution to annual precipitation (% cont.) of monthly, seasonal and annual precipitation during 1857-2006

Season/ Month	1857-2006				FY1(1857-1906)				FY2(1907-1956)				FY3(1957-2006)			
	Mean (mm)	SD	CV (%)	% cont.	Mean (mm)	SD	CV (%)	% cont.	Mean (mm)	SD	CV (%)	% cont.	Mean (mm)	SD	CV (%)	% cont.
Annual	1569	229	15	100	1587	242	15	100	1586	228	14	100	1533	217	14	100
Winter	163	66	41	10.4	172	73	43	10.8	157	66	42	9.9	160	58	37	10.4
Pre-Mon	193	75	39	12.4	187	71	38	11.8	174	68	39	11.0	218	79	36	14.2
Monsoon	1127	226	20	72.1	1154	238	21	72.7	1164	210	18	73.4	1063	221	21	69.3
Post-Mon	85	57	67	5.5	74	51	69	4.6	90	64	71	5.7	93	55	60	6.0
January	79	49	63	5.0	85	50	58	5.4	77	53	69	4.9	73	45	61	4.8
February	84	52	62	5.4	87	56	64	5.5	80	53	66	5.1	86	48	55	5.6
March	83	53	64	5.3	77	52	67	4.9	75	51	68	4.7	97	54	56	6.3
April	52	32	61	3.3	50	35	69	3.2	49	29	58	3.1	58	31	55	3.8
May	58	31	54	3.7	60	33	55	3.8	50	27	55	3.2	64	33	51	4.2
June	147	71	48	9.4	159	79	50	10.0	147	73	49	9.3	136	58	43	8.8
July	404	111	27	25.9	417	117	28	26.3	411	107	26	25.9	385	108	28	25.1
August	402	104	26	25.7	421	109	26	26.5	425	100	23	26.8	360	91	25	23.5
September	173	85	49	11.1	157	73	47	9.9	180	102	56	11.4	183	77	42	11.9
October	37	43	118	2.4	30	29	96	1.9	45	62	138	2.8	35	31	88	2.3
November	14	19	139	0.9	10	14	144	0.6	11	17	154	0.7	20	23	115	1.3
December	35	31	90	2.2	34	33	98	2.1	34	30	88	2.1	37	32	86	2.4

are higher than entire period mean and it is much lower than entire period mean in FY3. In season-wise contribution, the monsoon precipitation alone contributes 72.1% of total annual precipitation for entire period and 72.7% in FY1, 73.4% in FY2 & 69.7% in FY3. Thus, the decrease in annual precipitation in FY3 is mainly due to reduction in contribution of monsoon precipitation to its annual precipitation. The contributions of winter, pre-monsoon and post-monsoon to annual precipitation for the entire period are 10.4%, 12.4% and 5.5% respectively. However, the contributions of winter, pre-monsoon and post-monsoon to annual precipitation for FY3 are 10.4%, 14.2% and 6.0% respectively. In month-wise analysis, the rainiest month is July for the entire period; however, it was August in FY1 & FY2 and July in FY3.

3.2 Annual precipitation trends

The annual precipitation trend for entire period is shown in Figure 1, with the Mann Kendall non-parametric test 'Z' values for the entire period, FY1, FY2 & FY3 shown in Table 2. A non-significant decreasing trend is observed for the entire period with a 46 mm decrease in precipitation from its mean. The 11-year running mean of annual precipitation (Figure 1) shows two sharp decrease in precipitation epochs, the first sharp decreasing tendency is during 1899-1909 and second during 1965-1989. Further, the Pettitt–Mann–Whitney test suggests that the most probable change-point year in the annual precipitation is 1979. Analysis of data in 50-year periods, non-significant increasing trends are observed in FY1 & FY2 and significant (confidence level 95%) decreasing trend is observed FY3. So,

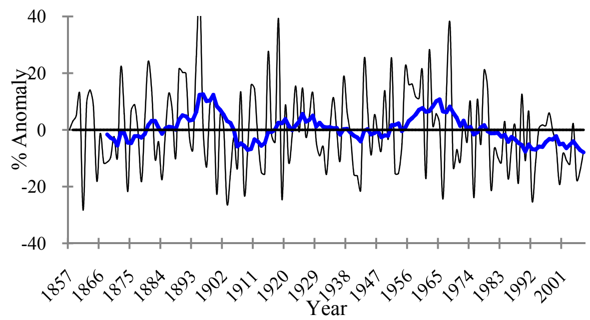


Figure 1 Annual precipitation variation over Western Himalayan Region (WHR) during 1857-2006.

Table 2 Mann Kendall test 'Z' values for Western Himalayan Region (WHR) & All India (AI) monthly, seasonal and annual precipitation

Season/ Month	1857-2006		FY1(1857-1906)		FY2(1907-1956)		FY3(1957-2006)	
	WHR	AI	WHR	AI	WHR	AI	WHR	AI
Annual	-1.50	0.94	0.10	-0.02	0.52	1.84	-2.24*	-0.06
Winter	-0.45	0.15	0.45	0.40	0.10	-0.44	0.99	0.85
Pre-Mon	2.01*	0.91	-0.67	-1.40	-0.18	0.77	2.20*	1.84
Monsoon	-2.64**	0.00	0.35	0.13	-0.02	1.56	-3.33**	-1.14
Post-Mon	1.71	2.32*	-0.07	0.27	0.17	0.47	-1.36	0.43
January	-0.79	-0.51	0.49	0.04	1.20	0.61	-0.21	-0.28
February	0.42	0.46	-0.29	-0.05	-0.46	-0.24	1.49	1.36
March	2.39*	0.69	0.37	0.27	1.44	0.93	1.00	0.60
April	1.17	1.41	-2.13*	-0.66	-1.79	0.82	1.05	2.15*
May	1.12	0.59	-0.31	-0.94	0.12	1.02	2.43*	0.13
June	-1.69	-1.43	-1.10	-0.30	-0.64	-0.77	0.33	2.23*
July	-2.03*	-0.15	-0.49	-0.10	0.25	1.25	-2.81**	-1.36
August	-3.25**	1.66	1.39	0.68	0.20	0.48	-2.41*	-1.76
September	1.63	0.27	1.36	0.54	0.69	1.12	-1.77	-0.81
October	0.49	1.33	-0.27	-0.55	0.61	2.15*	-1.70	0.83
November	2.32*	1.93	-0.12	1.12	-0.85	-0.87	0.14	0.24
December	0.27	1.14	-0.95	2.38*	-0.32	-0.21	-0.48	-0.44

Notes: * Significant at 95% confidence level; ** Significant at 99% confidence level.

maximum variability in annual precipitation mainly occurred during FY3 period. Earlier studies (Basistha et al. 2009; Bhutiyani et al. 2010; Kumar and Jain 2010) also reported decreasing trends in annual precipitation over different parts of the Himalayas in different epochs.

3.3 Seasonal precipitation trends

3.3.1 Winter season

The winter precipitation for the entire period (1857-2006) showed non-significant decreasing trend (Table 2). Fluctuated precipitation is observed during winter season with highest precipitation in the year 1954 and lowest in the year 1902. The 11-year running mean indicated the decreasing tendency in precipitation from 1901 to 1926, 1959 to 1972 and 1981 to 1989 (Figure 2a). In 50-year data analysis, no significant trend is observed in any of the period.

3.3.2 Pre-monsoon season

In pre-monsoon precipitation, a significant (confidence level 95%) increasing trend is observed over WHR for the entire period (1857-2006) (Table 2). The 11-year running mean indicates a sharp increase in precipitation from 1962 to 1991 and thereafter gradual decrease in precipitation from 1991 to 2006 (Figure 2b). The Pettitt–Mann–Whitney test suggests that the most probable change-point year in the pre-monsoon precipitation is 1975. In the 50-year period analysis, a significant (confidence level 95%) increasing trend is observed in FY3, and an increase of 24.8 mm precipitation was noticed in this period as against the whole period normal (193.3 mm).

3.3.3 Monsoon season

In the monsoon precipitation, a significant (confidence level 99%) decreasing trend is observed (Table 2) for the whole period (1857-2006). The monsoon precipitation has decreased by 75 mm from its mean precipitation during the period 1857-2006. Analysis of data by 11-year running mean shows two sharp decreases in precipitation, 1st from 1894 to 1908 and 2nd from 1965 to 1992 (Figure 2c). However, by the Pettitt–Mann–Whitney test, the most probable change-point year in the monsoon precipitation is 1979. Further, in the 50-year period analysis, a highly significant decreasing (confidence level 99.9%) trend is observed in FY3 (Table 2). Kumar and Jain (2010) also observe a decreasing trend in monsoon precipitation during 1903-1982 over Kashmir valley.

3.3.4 Post-monsoon season

In post-monsoon precipitation, a non-significant increasing trend is observed over WHR for the period 1857-2006 (Table 2). Like the winter precipitation, fluctuated precipitation is also observed in the post-monsoon season. The highest post-monsoon precipitation is observed in the year

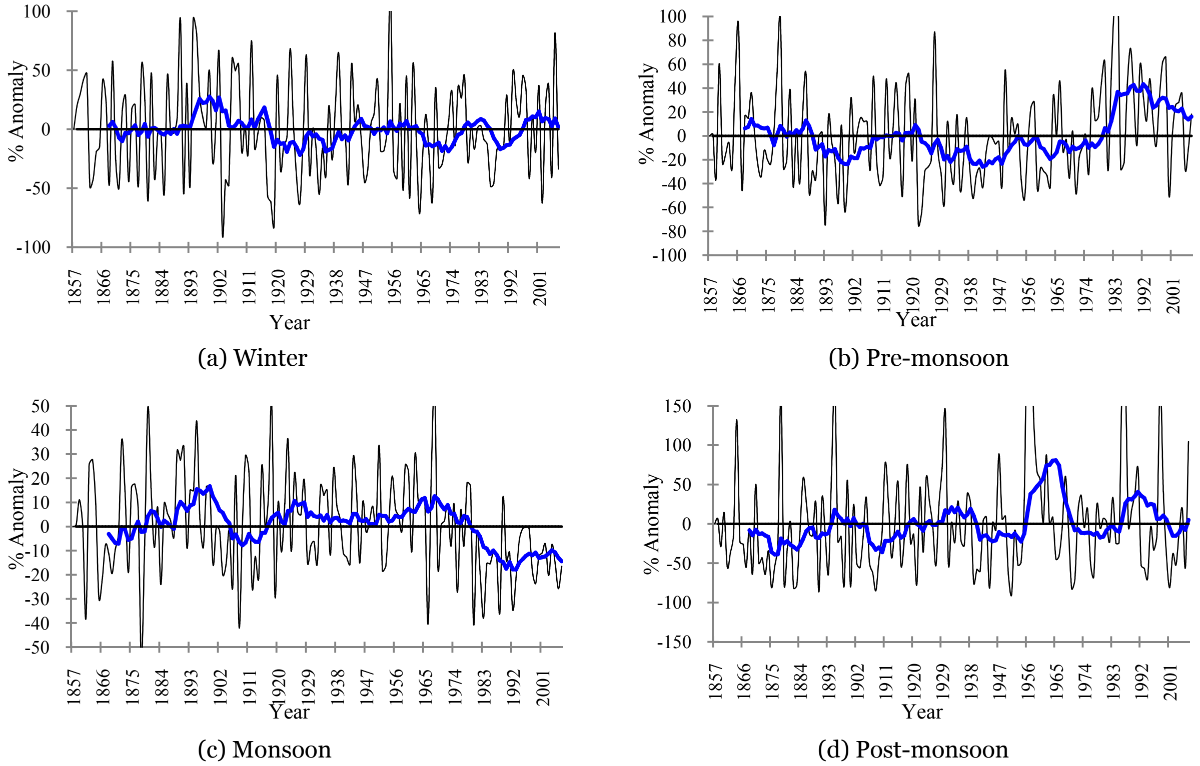


Figure 2 (a) Winter, (b) Pre-monsoon, (c) Monsoon and (d) Post-monsoon precipitation variation over Western Himalayan Region (WHR) during 1857-2006.

1955 and lowest in the year 1950. The 11-year running mean indicated a sharp increase from 1953 to 1964 and thereafter a sharp decrease from 1964 to 1978 (Figure 2d). In the 50-year data analysis, no significant trend is observed in any period (Table 2).

3.4 Monthly precipitation

Over the WHR, significant decreasing trends are observed in July and August during the period 1857-2006 (Table 2). It is found that precipitation decreased by 30 mm and 42 mm from their respective monthly mean precipitation in July and August. Percentage-wise, these are 7.4% and 10.4% of their respective mean precipitation. By 11-year running mean on July precipitation, gradual decreases in precipitation are observed from 1895 to 1913 and from 1968 to 1992. In August precipitation, gradual decrease in precipitation from 1969 to 1989 is observed. Decreasing trends are also observed in January & June over WHR. However, increasing trends are observed over remaining months over the WHR with significant trends in March and November with 17% and 50% increase in precipitation from their respective monthly mean. Considering the 50-year periods, a significant (confidence level 95%) decreasing trend is observed for April precipitation in FY1 over WHR. A significant (confidence level 95%) increasing trend is observed for May precipitation and significant (confidence level 99% for July and 95% for August precipitation) and decreasing trends are observed for July and August precipitation in FY3.

3.5 Decadal annual and seasonal precipitation analysis

Decade wise percentage departure of annual and seasonal decadal mean from normal, excess, deficient precipitation years over WHR from 1857-2006 are shown in Table 3. In the Table 3, annual/seasonal excess and deficient precipitation years are calculated by following way:

Seasonal/annual Excess precipitation = Seasonal/annual mean precipitation + SD

Seasonal/annual Deficient precipitation =

Table 3 Percentage departure of decadal mean from normal (based on 1857-2006) (% dep.), excess (E), deficient (D) precipitation years over Western Himalayan Region (WHR) from 1857-2006

Decade	Annual			Winter			Pre-monsoon			Monsoon			Post-monsoon		
	% dep.	E	D	% dep.	E	D	% dep.	E	D	% dep.	E	D	% dep.	E	D
1857-1866	-0.7	0	2	7.8	3	2	5.2	3	1	-2.3	2	3	-8.4	1	0
1867-1876	-1.2	1	1	-7.7	1	4	-4.2	0	0	3.0	1	0	-37.1	0	1
1877-1886	1.1	1	2	0.5	3	3	13.8	4	2	-0.7	1	2	-3.5	1	3
1887-1896	10.5	5	0	24.8	3	2	-25.1	0	3	14.7	4	0	8.4	1	1
1897-1906	-3.9	0	3	2.4	4	3	-5.3	0	1	-2.7	1	1	-27.9	0	2
1907-1916	-1.2	2	3	3.6	2	1	-1.4	3	2	-1.1	3	3	-10.3	1	1
1917-1926	4.3	3	1	-18.3	2	4	-2.5	3	2	9.0	3	1	0.3	1	1
1927-1936	-0.2	1	1	-11.4	1	1	-18.6	0	3	3.2	1	0	18.4	2	0
1937-1946	-2.2	1	3	5.7	2	2	-21.3	0	2	1.0	1	0	-15.4	1	2
1947-1956	4.8	4	2	3.0	2	1	-4.8	1	2	4.5	2	0	33.0	2	1
1957-1966	5.2	2	2	-9.7	2	3	-8.1	1	2	8.1	4	1	26.4	2	0
1967-1976	-0.3	1	0	-1.5	0	1	-9.0	1	1	2.5	1	1	-15.0	0	2
1977-1986	-3.2	1	2	-10.9	1	2	37.8	6	0	-12.0	0	2	35.2	2	0
1987-1996	-3.7	0	2	13.1	2	0	28.9	3	0	-11.2	0	3	-10.8	1	1
1997-2006	-9.3	0	2	-1.2	1	2	14.7	2	1	-15.8	0	3	6.8	2	1

Seasonal/annual mean precipitation - SD

In the WHR during the decade 1887-1896, the annual percentage departure of decadal mean was highest with 10.5% more precipitation than its annual normal precipitation with maximum number (5) of excess annual precipitation years and 0 deficient year. During the same decade, winter and monsoon precipitation was also highest with 24.8% and 14.7% more than their respective normal precipitation. During the decade 1997-2006, decadal mean was lowest with 9.3% less than its annual normal precipitation with 0 excess and 2 deficient annual precipitation years. Again during the same decade, decadal monsoon precipitation was lowest with 15.8% less than normal monsoon precipitation.

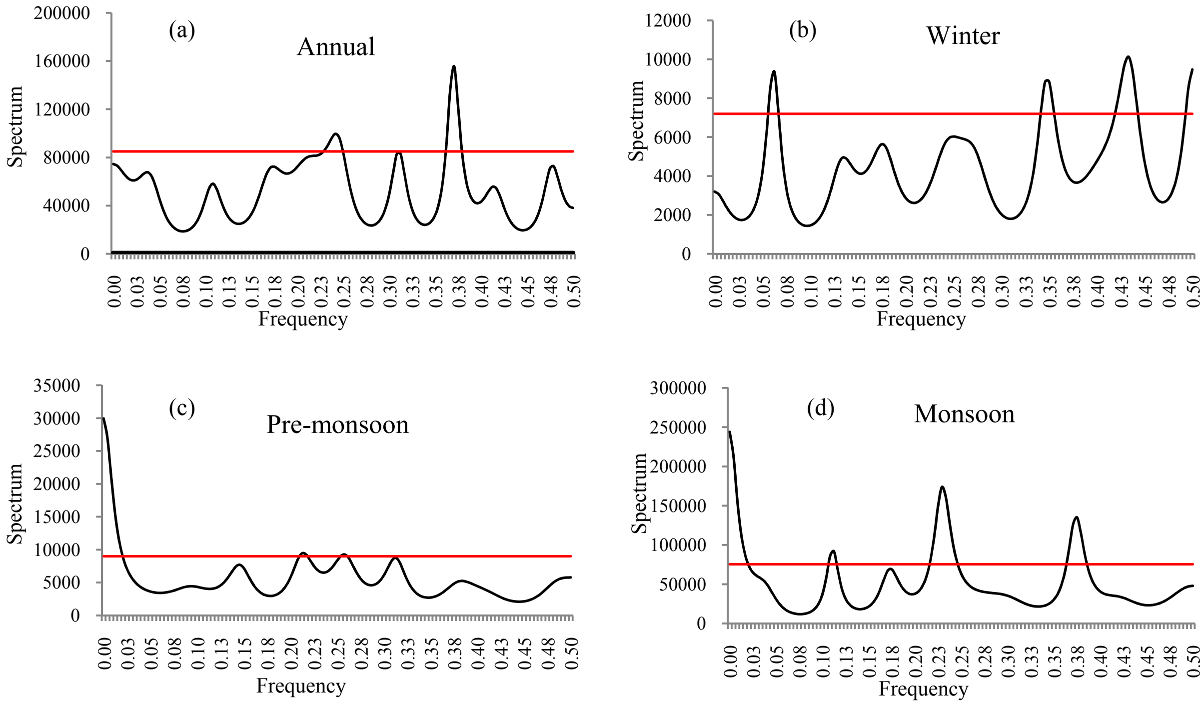
3.6 Comparison with all India precipitation

By comparing monthly, seasonal and annual precipitation trends over WHR with all India precipitation, a lot of dissimilarity in the trends is observed (Table 2). In all India precipitation, no significant trends are observed in FY1, FY2 & FY3, on the other side, significant changes in seasonal and annual precipitation are observed in FY3 over WHR. Considering the entire period (1857-2006), annual precipitation over WHR has decreasing trends, on the other side All India rainfall has increasing trends. In seasonal analysis for the entire period, a significant decrease in monsoon precipitation is observed over WHR, whereas no trend is observed in All India monsoon precipitation. In pre-monsoon season, significant increasing trend is observed over WHR. In monthly data analysis, significant decreasing trends are found in July & August and a significant increasing trend is observed during November over WHR during entire period, whereas, no significant trends are observed in all India rainfall.

3.7 Periodicities of annual & seasonal precipitation

Maximum entropy spectral analyses of annual as well as seasonal precipitation are given in Figure 3. The spectrum analysis shows the periodicities of 2.3-2.9 years in annual, winter & monsoon season precipitation with significance at 95% confidence level. This range of periodicity may be due to quasi-biennial oscillation (QBO). Kane (1995) also observed QBO (2-3 years) in some meteorological sub-divisions of India in monsoon season from 1951 to 1991. Significant periodicities of 3.9-4.7 years are also observed in annual, pre-monsoon & monsoon season. These periodicities in precipitation may be due to El Niño Southern Oscillation (ENSO) cycle. Significant periodicity of 10 & 26.3 years in post-monsoon and isolated periodicity of 15.9 years in winter season precipitation has also been observed.

3.8 Impact of global teleconnections on precipitation



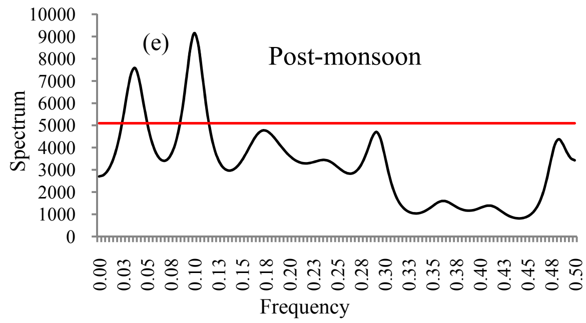


Figure 3 Maximum entropy spectral analysis of (a) Annual, (b) Winter, (c) Pre-monsoon and (d) Monsoon and (e) Post-monsoon precipitation over Western Himalayan Region (WHR) during 1857-2006 and 95% confidence level.

Table 4 Correlation coefficients between annual & seasonal and precipitation and North Atlantic Oscillation (NAO) & Southern Oscillation (SO) Indices over Western Himalayan Region (WHR)

	Index	Annual	Winter	Pre-monsoon	Monsoon	Post-monsoon
1857-2006	NAO	0.108	0.233**	0.133	0.183*	0.164*
1876-2006	SO	0.315**	-0.173*	-0.193*	0.427**	-0.056

Notes: * Significant at 95% confidence level; ** Significant at 99% confidence level.

Correlation coefficients between seasonal & annual precipitation over WHR and NAO & SO Indices are given in Table 4. It is observed that winter, monsoon & post-monsoon precipitation in the WHR during 1857-2006 has a statistically significant (at 95% confidence level) positive correlation with respective seasonal NAO index. Hence, it shows strong teleconnections with winter, monsoon & post-monsoon precipitation in the WHR during 1857-2006. Annual and pre-monsoon precipitation has positive non-significant relationship with the respective annual & seasonal NAO index.

A statistically significant (at 99% confidence level) positive correlation is also observed between annual & monsoon precipitation with respective annual & monsoon SO Indices indicating a strong teleconnection between monsoon precipitation with SO Indices, which is conformity with earlier findings (Kane 1998a; Archer and Fowler 2004; Bhutiyani et al. 2010; Afzal et al. 2013). A statistically significant (at 95% confidence level) negative correlation is observed between winter & pre-monsoon precipitation and respective seasonal SO Indices.

To find the cause of significant decreasing monsoon precipitation during 1857-2006, decadal running correlation coefficients between seasonal precipitation and NAO & SOI have been plotted. It is observed that correlation between monsoon precipitation & NAO and monsoon precipitation & SOI has weakened mainly during last three decades. This shows the weakening of teleconnection between monsoon precipitation with NAO as well as SOI. That would have influenced the monsoon season precipitation over WHR.

4 Conclusions

The study showed a non-significant decreasing trend in annual precipitation and a significant decreasing trend in monsoon precipitation over the WHR for the entire period 1857-2006. This decrease in monsoon precipitation over different parts of the Himalayas has been also reported earlier by many researchers (Duan and Yao 2003; Bhutiyani et al. 2010; Kumar and Jain 2010). According to the Pettitt–Mann–Whitney test, it is observed that the most probable change-point year in the annual as well as monsoon precipitation is 1979. However, an earlier study by Basistha et al. (2009) showed that the most probable year of change in precipitation over Uttarakhand state of WHR is 1964. Winter and monsoon seasons show decreasing trends and pre-monsoon & post-monsoon show increasing trends in precipitation for entire period. This indicates the temporal shifting of the precipitation pattern from winter to pre-monsoon and monsoon to post-monsoon season over the WHR. In monthly precipitation analysis during entire period, significant decreasing trends observed in July & August and increasing trends in all the months of post-monsoon season with significant (confidence level 95%) trend in November. In 50-year periods data analysis, significant changes in the monthly, seasonal and annual precipitation are mainly observed during 1957-2006 (FY3). Further analysis of data by spectrum analysis shows the significant periodicities of 2.3-2.9 years may be due to QBO and 3.9-4.7 years periodicities may be due to the ENSO cycle in annual as well as seasonal precipitation. Strong between winter, monsoon & post-monsoon precipitation and NAO is observed during the period 1857-2006. Strong teleconnections is also observed between annual & monsoon precipitation with SOI during same period. These results conform the earlier finding of Archer and Fowler (2004) and Bhutiyani et al. (2010). The study also reveals that the significant decrease in monsoon precipitation over WHR may be due to weakening of its teleconnection with NAO and SO Indices mainly during last three decades. Study may be used for guidance to see the impact of changing precipitation over WHR on agriculture, horticulture, water resources etc., of the region. However, a more detailed analysis is needed by taking the daily precipitation data of all meteorological observatories located in the region.

Acknowledgements

The authors thank the Director General of Meteorology, India Meteorological Department for his encouragement and support. We sincerely thank the unknown reviewers for their valuable suggestions and comments to improve the quality of the paper.

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