

Long term rainfall variability and trend analysis in lower *Shivaliks* of Punjab, India

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सार – इस शोध पत्र में रैखिक समाश्रयण निदर्श, मान केंडल परीक्षण और सेन की ढलान का उपयोग करके पंजाब के निचले शिवालिकों क्षेत्रों में तीन स्थानों, पटियाला-की-राव (1982-2015), बलोवाल सौंखरी (1987-2015) और सालेरान (1984-2017) के लिए मासिक, वार्षिक और ऋतु के आधार पर वर्षा के ऐतिहासिक आंकड़ों का प्रवृत्ति विश्लेषण किया गया है। इसके अलावा, 1986-2000 और 2001-2015 की अवधि के लिए वार्षिक और ऋतुनिष्ठ वर्षा और वर्षा के दिनों के आंकड़ों का भी पंचवर्षीय आधार पर विश्लेषण किया गया है। आंकड़ों के विश्लेषण से पता चला है कि इस क्षेत्र में वार्षिक वर्षा 1000 से 1150 मिमी तक होती है। आंकड़ों की प्रवृत्ति विश्लेषण से पता चलता है कि पटियाला-की-राव और सालेरान में मासिक वर्षा में कमी हो रही है, हालांकि यह प्रवृत्ति पटियाला-की-राव में मई में और सालेरान में मार्च और नवंबर में महत्वपूर्ण थी। बलोवाल सौंखरी में, मई से अक्टूबर तक गिरावट की प्रवृत्ति देखी गई है, हालांकि यह प्रवृत्ति केवल अगस्त में महत्वपूर्ण रही है। पंजाब के निचले शिवालिक में तीन स्थानों पर वार्षिक और मॉनसूनी वर्षा में कमी क्रमशः 13 से 17 मिमी और 12 से 13 मिमी प्रति वर्ष रही है। संपूर्ण अध्ययन अवधि के दौरान उच्चतम वार्षिक वर्षा (1600-2000 मिमी) और मॉनसून वर्षा (1500-1800 मिमी) वर्ष 1988 में तीन स्थानों पर दर्ज की गई थी। आंकड़ों के दशकीय विश्लेषण से पता चलता है कि अप्रैल से अक्टूबर के दौरान सामान्य से कम वर्षा हुई। 15 वर्ष के मासिक, वार्षिक और ऋतुनिष्ठ औसत वर्षा के आधार पर वर्षा और वर्षा के दिनों के विश्लेषण से पता चला है कि वर्ष की सभी ऋतुओं में 1986-2000 की तुलना में 2001-2015 के दौरान वर्षा और वर्षा के दिनों में कमी आई है।

ABSTRACT. The trend analysis of historical rainfall data on monthly, annual and seasonal basis for three locations in lower *Shivaliks* of Punjab, viz., Patiala-ki-Rao (1982-2015), Ballawal Saunkhri (1987-2015) and Saleran (1984-2017) has been done in the present study using linear regression model, Mann Kendall test and Sen's slope. Further, the data for annual and seasonal rainfall and rainy days has also been analyzed on quinquennial basis, i.e., for the period of 1986-2000 and 2001-2015. The analysis of data showed that annual rainfall in the region ranged from 1000 to 1150 mm. The trend analysis of the data shows that the monthly rainfall is decreasing at Patiala-ki-Rao and Saleran, however, the trend was significant for May at Patiala-ki-Rao; and in March and November at Saleran. At Ballawal Saunkhri, the decreasing trend is observed from May to October, however, the trend is significant only in August. The decrease in annual and monsoon rainfall is about 13 to 17 mm and 12 to 13 mm per year respectively at three locations in lower *Shivaliks* of Punjab. The highest annual (1600-2000 mm) and monsoon (1500-1800 mm) rainfall during the entire study period was recorded in the year 1988 at three locations. The decadal analysis of the data shows below normal rainfall during April to October. The analysis of the rainfall and rainy days on monthly, annual and seasonal averages of 15 year basis showed that both rainfall and rainy days have decreased during the 2001-2015 as compared to 1986-2000 during all the seasons of the year.

Key words – Rainfall variability, Mann Kendall test, Sen's slope, Regression analysis, Lower *Shivaliks*.

1. Introduction

The developing countries are more prone to global warming issues like climatic variability than the developed countries (Stenseth *et al.*, 2002; Patz *et al.*, 2005). The agricultural sector is more vulnerable to the effects of climatic variations as compared to other sectors (Sanchez-Cohen *et al.*, 2013). As about 60% of agriculture

in India is rainfed, therefore rainfall can be considered as most important factor for crop planning in such areas. The probability of reduction in productivity increases with the erratic behaviour of rainfall in terms of frequency, intensity and distribution (Apatha, 2010). The scarcity in water availability due to delays in the onset of the rainy season, dry spells during the wet season and reduction in the length of the growing season results in crop failure.

The climate information can be very helpful in planning adaptation and mitigation measures to reduce vulnerability (Allan and Soden, 2008). The information on the rainfall behavior on annual, seasonal and decadal basis can be useful for the different agricultural operations, designing water harvesting structures, planning of sowing etc. A timely rainfall in the first months of summer season in rainfed regions is very important for successful crop growth (Rehman *et al.*, 2009). The lack of rain in the first month (May) of the *kharif* can delay sowing resulting in reduced crop yields. A detailed study of rainfall behaviour on annual, decadal and seasonal basis is very important for the better crop planning.

Trend analysis of rainfall is essential to study the impacts of climate change for water resources planning and management (Feizi *et al.*, 2015). Studies conducted so far suggested that the rainfall trends show a very diverse pattern at regional and national scales due to disproportion in natural resource (Sahu and Khare, 2015). Significant positive and negative trends in monthly rainfall were also observed by Becker *et al.*, (2006). Liang *et al.*, (2011) also studied temporal and spatial distribution of rainfall in northeast China from 1961 to 2008. Krishan *et al.*, (2018) also observed decreasing trend of annual and monsoon rainfall over the Eastern Ganga canal command area. A decreasing trend in rainfall in north-east India, central north-east India and west-central India has also been observed (Kumar *et al.*, 2010). Such climatic variations in frequency and intensity of precipitation will have unexpected consequences in terms of crop failures, droughts, high soil erosion rates and failures of soil conservation structures in many parts of the country. The lower Shivalik region of Punjab, commonly called Kandi region, constitute about 7.8% in the north eastern region of Punjab and lies in five districts namely Pathankot, Hoshiarpur, SBS Nagar, Rupnagar and SAS Nagar (Dogra, 2000; Yousuf *et al.*, 2017). The agriculture in this region is rainfed and behaviour of rainfall is changing due to climate change. The detection of current pattern of rainfall in changing scenario of climate, in terms of annual, seasonal and decadal basis certainly has great importance on the local, regional and national scales, due to the associated critical socioeconomic consequences (Kumar *et al.*, 2018). The annual, *kharif* and *rabi* rainfall has changed by -14.7, -12.9 and -1.9 mm per year, respectively at Ballowal Saunkhri (Prabhjyot-Kaur *et al.*, 2016). As the Kandi region of Punjab is highly dependent on rainfall, therefore, the trend analysis of this region needs to be done which would be helpful in adopting new technologies for agriculture. Therefore, this study has been done with the aim to characterize annual and seasonal rainfall, and to measure trends on both the spatial and the temporal scale for three locations in lower *Shivaliks* of Punjab.

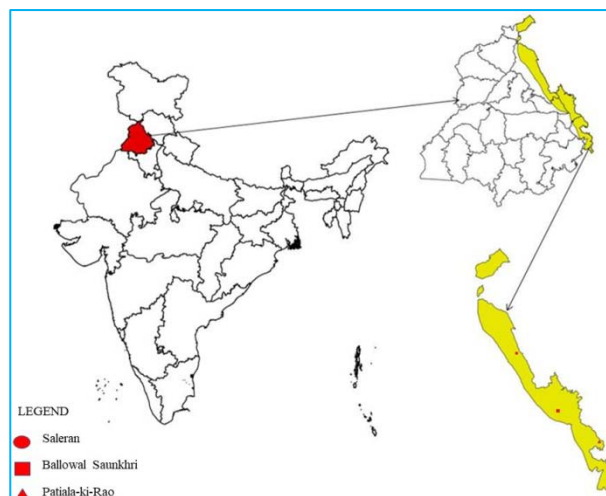


Fig. 1. Location of the different areas under study

2. Data and methodology

2.1. Study area

The study area comprises of three locations in three districts of Kandiregion, *i.e.*, Patiala-ki-Rao, SAS Nagar (30.4° N, 72.3° E); Saleran, Hoshiarpur (31.5° N, 75.9° E) and Ballowal Saunkhri, SBS Nagar (31.0° N, 76.3° E) which fall in the lower *Shivaliks* of Punjab (Fig. 1).

2.2. Weather data

The daily rainfall data for the three locations, *i.e.*, Patiala-ki-Rao (1982-2015), Saleran (1987-2015) and Ballowal Saunkhri (1984-2017) over lower *Shivaliks* of Punjab was obtained from ordinary rain gauge installed in Agrometeorological observatory. The normal values of rainfall used for comparison were derived by averaging of annual, monthly and seasonal sums for all the years, *i.e.*, 1982-2015 for Patiala-ki-Rao, 1987-2015 for Saleran and 1984-2017 for Ballowal Saunkhri. The data was further analysed on annual, seasonal and decadal basis. For seasonal trend analysis, the year was divided into four seasons, *i.e.*, Pre-monsoon (March-May), Monsoon (June-September), Post-monsoon (October-December) and Winter (January-February). The changes in weather parameters for *kharif* (May-October) and *Rabi* (November-April) cropping seasons were also analyzed.

2.3. Trend analysis

Trend analysis (using five yearly moving average) and statistical significance of trends of rainfall data was carried out using standard Mann-Kendall test statistics and linear regression analysis.

2.3.1. Mann-Kendall test

The trend analysis and estimation of Sen's slope are done using Kendall (1975) and Sen's (1968) method, respectively for the available rainfall data using XLSTAT software (Version 2019.2). Mann-Kendall test is a non-parametric test to find trends in time series which compares the relative magnitudes of data rather than data values themselves (Gilbert, 1987). The benefit of this test is that data need not to conform any particular distribution. In this test, each data value in the time series is compared with all subsequent values. Initially the Mann-Kendall statistics (S) is assumed to be zero, and if a data value in subsequent time period is higher than a data value in previous time period, S is incremented by 1, and *vice versa*. The net result of all such increments and decrements gives the final value of S. The Mann-Kendall statistics (S) is given as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{Sign}(X_j - X_i)$$

where,

$$\begin{aligned} \text{Sign}(X_j - X_i) &= 1 \text{ if } (X_j - X_i) > 0 \\ \text{Sign}(X_j - X_i) &= 0 \text{ if } (X_j - X_i) = 0 \\ \text{Sign}(X_j - X_i) &= -1 \text{ if } (X_j - X_i) < 0 \end{aligned}$$

Positive value of S indicates an increasing trend and a negative value indicates a decreasing trend. However, it is necessary to perform the statistical analysis for the significance of the trend. The test procedure using the normal - approximation test is described by Kendall (1975). This test assumes that there are not many tied values within the data set. The variance (S) is calculated by the following equation:

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{j=1}^p t_j(t_j-1)(2t_j+5)}{18}$$

where n , is the number of data points, p is the number of tied groups and t_j is the number of data points in the j^{th} group.

The normal Z- statistics is computed as:

$$Z = \frac{S-1}{\sqrt{\text{Var}(S)}} \text{ if } S > 0$$

$$Z = 0 \text{ if } S = 0$$

$$Z = \frac{S+1}{\sqrt{\text{Var}(S)}} \text{ if } S < 0$$

The trend said to be decreasing if Z is negative and the computed Z - statistics is greater than the z - value corresponding of the 5 % level of significance. The trend is said to be increasing if the Z is positive and the computed Z - statistics is greater than the z - value corresponding to the 5% level of significance. If the computed Z - statistics is less than the z - corresponding of the 5% level significance, there is no trend.

2.3.2. Sen's slope estimator

Simple liner regression is one of the most widely used model to detect the linear trend. However, this method requires the assumption of normality of residuals (McBean and Motiee, 2008). Viessman *et al.* (1989) reported that many hydrological variables exhibit a marked right skewness partly due to influence of natural phenomena and do not follow a normal distribution. Thus, the Sen (1968) slope estimator is found to be a powerful tool to develop the linear relationships. Sen's slope has the advantage over the regression slope in the sense that it is not much affected by gross data errors and outliers. The Sen's slope is estimated as the median of all pairwise slopes between each pair of points in the dataset (Sen, 1968). Each individual slope (m_{ij}) is estimated using the following equation:

$$m_{ij} = \frac{Y_j - Y_i}{(j - i)}$$

where, $I = 1$ to $n-1$, $j = 2$ to n , Y_j and Y_i are data values at time j and I ($j > i$), respectively. If there are n values of Y_j in the time series, there will be $N = n(n-1)/2$ slope estimates. The Sen's slope is the median slope of these N values of slopes. The Sen's slope is:

$$m = m_{\frac{n+1}{2}} \text{ if } n \text{ is odd}$$

$$m = \frac{1}{2} \left(m_{\frac{n}{2}} + m_{\frac{n+2}{2}} \right) \text{ if } n \text{ is even}$$

Positive Sen's slope indicates rising trend while negative Sen's indicates falling trend.

2.3.3. Linear regression analysis

Linear regression analysis is a parametric model and one of the most commonly used methods to detect a trend in a data series (Kaur and Kaur, 2019). This model

TABLE 1
Monthly and season wise variations in rainfall at different locations in lower Shivaliks of Punjab

Month/Season	Rainfall (mm)											
	Patiala-ki-Rao (1982-2015)				Saleran (1987-2015)				Ballowal Saunkhri (1984-2017)			
	Total (mm)	SD (mm)	CV (%)	Percent contribution to annual rainfall	Total (mm)	SD (mm)	CV (%)	Percent contribution to annual rainfall	Total (mm)	SD (mm)	CV (%)	Percent contribution to annual rainfall
January	35.5	31.7	89.3	3.5	36.2	32.1	88.8	3.1	36.4	32.6	89.6	3.5
February	35.7	33.7	94.2	3.5	53.0	46.5	87.7	4.6	41.0	34.4	83.9	3.9
March	30.6	39.6	129.4	3.0	36.4	40.6	111.8	3.2	32.8	30.1	91.7	3.1
April	18.7	23.3	124.3	1.9	20.6	23.6	114.7	1.8	20.7	17.4	83.9	2.0
May	30.1	40.6	134.9	3.0	34.5	42.4	123.0	3.0	32.1	28.3	88.2	3.1
June	127.3	110.0	86.4	12.7	107.2	92.1	85.9	9.3	107.9	88.5	82.0	10.3
July	280.6	128.0	45.6	27.9	349.1	177.2	50.8	30.3	273.7	154.1	56.3	26.0
August	267.4	122.4	45.8	26.6	313.8	153.3	48.9	27.3	296.5	113.3	38.2	28.2
September	155.8	105.9	68.0	15.5	157.0	166.8	106.2	13.6	152.5	118.2	77.5	14.5
October	-	-	-	-	16.9	25.8	153.4	1.5	25.3	47.1	186.6	2.4
November	6.9	18.2	263.2	0.7	7.3	20.2	276.3	0.6	5.9	12.1	204.5	0.6
December	18.5	28.3	153.4	1.8	19.7	23.0	116.7	1.7	26.1	40.0	153.0	2.5
Annual	1006.1	304.3	30.3	-	1150.9	351.9	30.6	-	1051.0	290.3	27.6	-
<i>Kharif</i>	860.4	275.6	32.0	85.5	978.0	331.2	33.9	85.0	888.0	275.3	31.0	84.5
<i>Rabi</i>	140.4	90.6	64.5	14.0	172.2	98.4	57.1	15.0	160.9	84.4	52.5	15.3
Pre-monsoon	78.6	67.1	85.4	7.8	91.5	63.2	69.0	7.9	85.7	43.9	51.3	8.2
Monsoon	831.2	278.5	33.5	82.6	927.2	341.1	36.8	80.6	830.7	276.5	33.3	79.0
Post-monsoon	25.2	39.7	157.6	2.5	43.1	42.3	98.3	3.7	57.3	64.8	113.1	5.5
Winter	71.2	51.1	71.8	7.1	89.2	54.7	61.4	7.7	77.4	40.1	51.8	7.4

develops a relationship between two variables (dependent and independent) by fitting a linear equation to the observed data. The data is first checked whether or not there is relationship between the variables of interest. This can be done by using the scatter plot. The linear regression model is generally described by the following equation:

$$Y = aX + b$$

Where, Y is the dependent variable, X is the independent variable, a is the slope of the line and b is the intercept constant. The F values (observed) were used to check the significance of coefficient of determination and were calculated using the formula as given below:

$$F = \frac{R^2}{1-R^2} \frac{n-p-1}{p}$$

where, R^2 is regression coefficient, n is number of observations, p is the number of independent variables whose value for linear regression is one. This calculated value of F was compared with tabulated value of $F_{(p, n-p-1)}$ at 1% level of significance to test the significance of the regression coefficient.

3. Results and discussion

3.1. Rainfall characteristics in lower Shivaliks of Punjab

The rainfall characteristics of Patiala-ki-Rao, Saleran and Ballowal Saunkhri are presented in Table 1. The average annual rainfall of Patiala-ki-Rao, Saleran and Ballowal Saunkhri is 1006, 1151 and 1051 mm respectively with the corresponding standard deviation as 304, 352 and 290 mm. The coefficient of variation of average annual rainfall at Patiala-ki-Rao, Saleran and

TABLE 2
Mann-Kendall test statistics in rainfall at different locations in lower *Shivaliks* of Punjab

Month/Season	Patiala-ki-Rao (1982-2015)		Saleran (1987-2015)		Ballawal Saunkhri (1984-2017)	
	Tau	Slope	Tau	Slope	Tau	Slope
January	-0.25*	-0.53	-0.40*	-1.12	-0.04	-0.07
February	-0.44*	-0.93	-0.44*	-0.93	-0.03	-0.05
March	-0.30*	-0.56	-0.27*	-1.22	0.03	0.09
April	-0.31*	-0.34	-0.21	-0.45	0.25	0.26
May	-0.52*	-1.61	-0.10	-0.62	-0.24	-0.54
June	-0.14	-0.71	-0.01	-0.04	0.43	2.70
July	-0.43*	-2.93	-0.30*	-4.40	-0.56*	-6.98
August	-0.31*	-2.83	-0.27*	-3.25	-0.43*	-4.13
September	-0.12	-0.66	-0.41*	-3.52	-0.51*	-3.46
October	-	-	0.47*	0.94	-0.01	-0.01
November	-0.39*	-0.33	-0.60*	-0.39	-0.43*	-0.30
December	-0.34*	-0.68	-0.33*	-0.45	-0.26*	-0.76
Annual	-0.43*	-14.57	-0.57*	-17.78	-0.45*	-12.89
<i>Kharif</i>	-0.36*	-9.53	-0.53*	-15.39	-0.49*	-12.63
<i>Rabi</i>	-0.38*	-4.75	-0.46*	-3.76	-0.16	-1.01
Winter	-0.39*	-1.92	-0.45*	-1.79	-0.002	0.0
Pre-monsoon	-0.49*	-3.34	-0.18	-1.11	0.03	0.06
Monsoon	-0.35*	-9.17	-0.52*	-14.63	-0.49*	-11.98
Post-monsoon	-0.43	-1.41	-0.15	-0.55	-0.35*	-1.73

*Significant at 5% level of significance

Ballawal Saunkhri are 30.3, 30.6 and 27.6 percent respectively. The contribution of monsoon rainfall to the annual rainfall was very high (approximately 80 percent) at all the three locations. The highest rainfall is recorded in July at Patiala-ki-Rao (281 mm) and Saleran (349 mm), however, at Ballawal Saunkhri, it is recorded in August (296 mm). The highest contribution to annual rainfall is in July at Patiala-ki-Rao and Saleran (27.9 and 30.3 percent respectively), while at Ballawal Saunkhri in August which contribute about 28 percent. June, August and September were the most rainfall contributing months at all locations and contributed respectively 12.7, 26.6 and 15.5 percent at Patiala-ki-Rao, 9.3, 27.3 and 13.6 percent at Saleran and 10.3, 28.2 and 14.5 percent at Ballawal Saunkhri. While, the contribution of other months is less than 5 percent at all three locations. Larger variations occurred in the rainfall during all other seasons except the monsoon which can be observed from least values of CV during monsoon as compared to other seasons. The contribution

of pre-monsoon, post-monsoon and winter months is less than 10 percent at all the locations.

3.2. Seasonal rainfall trends

3.2.1. Annual

The significantly decreasing trend has been observed for all the three locations using Mann Kendall test. The rate of decrease is 14.6, 17.8 and 12.9 mm/year respectively at Patiala-ki-Rao, Saleran and Ballawal Saunkhri (Table 2).

Using the linear regression model, the rate of change of average annual rainfall is defined by slope of regression line which is -17.9 mm/year, -16.8 mm/year and -13.98 mm/year for Patiala-ki-Rao, Saleran and Ballawal Saunkhri respectively. The declining trend of average annual rainfall was found to be significant at all

TABLE 3

Trend analysis in annual and seasonal rainfall using linear regression at different locations in lower *Shivaliks* of Punjab

Month/Season	Patiala-ki-Rao (1982-2015)		Saleran (1987-2015)		Ballawal Saunkhri (1984-2017)	
	Equation	R ²	Equation	R ²	Equation	R ²
January	$Y = -0.70X + 45.84$	0.21*	$Y = -0.86X + 50.54$	0.24*	$Y = -0.11X + 37.20$	0.01
February	$Y = -0.12X + 55.46$	0.33*	$Y = -0.95X + 69.53$	0.32*	$Y = -0.04X + 42.09$	0.002
March	$Y = -0.84X + 41.67$	0.17*	$Y = -1.16X + 55.24$	0.24*	$Y = 0.31X + 26.71$	0.05
April	$Y = -0.45X + 24.98$	0.13*	$Y = -0.42X + 27.67$	0.09	$Y = 0.25X + 16.30$	0.11
May	$Y = -1.89X + 62.45$	0.55*	$Y = -0.37X + 37.33$	0.03	$Y = -0.51X + 41.23$	0.11
June	$Y = 1.25X + 110.86$	0.05	$Y = -0.30X + 115.05$	0.003	$Y = 2.73X + 59.76$	0.41*
July	$Y = -3.41X + 348.13$	0.40*	$Y = -5.77X + 442.97$	0.29*	$Y = -7.27X + 407.24$	0.73*
August	$Y = -2.12X + 317.96$	0.09	$Y = -3.52X + 374.59$	0.16*	$Y = -4.29X + 374.28$	0.44*
September	$Y = -0.49X + 174.37$	0.01	$Y = -3.99X + 208.78$	0.41*	$Y = -3.63X + 220.37$	0.52*
October	-	-	$Y = 0.89X + 3.28$	0.44*	$Y = -0.09X + 27.71$	0.002
November	$Y = -0.56X + 18.38$	0.43*	$Y = -0.58X + 16.27$	0.32*	$Y = -0.36X + 12.78$	0.43*
December	$Y = -1.15X + 39.59$	0.40*	$Y = -0.80X + 31.38$	0.32*	$Y = -0.96X + 43.61$	0.25*
Annual	$Y = -11.49X + 24002$	0.30*	$Y = -16.05X + 33282$	0.39*	$Y = -13.98X + 29035$	0.57*
<i>Kharif</i>	$Y = -13.23X + 1183.9$	0.40*	$Y = -13.73X + 1190$	0.50*	$Y = -13.06X + 27036$	0.60*
<i>Rabi</i>	$Y = -5.43X + 259.86$	0.67*	$Y = -3.13X + 233$	0.39*	$Y = -0.80X + 178.5$	0.05
Winter	$Y = -1.81X + 120.07$	0.36*	$Y = -1.38X + 114.9$	0.32*	$Y = -0.15X + 379.5$	0.01
Pre-monsoon	$Y = -1.95X + 120.23$	0.19*	$Y = -1.15X + 110.71$	0.10	$Y = 0.05X - 7.4$	0.001
Monsoon	$Y = -13.57X + 1141.4$	0.42*	$Y = -13.79X + 1144.1$	0.50*	$Y = -12.46X + 25772$	0.58*
Post-monsoon	$y = -0.66x + 52.85$	0.11	$y = -0.49x + 50.96$	0.08	$Y = -1.42X + 2891.4$	0.24*

*Significant at 5% level of significance

the three locations (Table 3). The coefficient of determination (around 50%) explains the variability in rainfall with the passing years at all the locations.

3.2.2. *Kharif*

This is the one of the two main cropping seasons in lower *Shivaliks*. The sowing of the *kharif* crop is done with the onset of monsoon. The delay in onset of monsoon results in delayed sowing of crops. The amount and distribution of rainfall during the *kharif* season determines the performance of crops, growth, development and quality of the produce. It has been observed that rainfall is decreasing in the *kharif* season.

Using Mann Kendall test, it has been observed that *kharif* season rainfall at Patiala-ki-Rao, Saleran and Ballawal Saunkhri has been declining significantly at the rate of 9.5, 15.3 and 12.6 mm/year respectively (Table 2).

The trend is also negative and significant using linear regression analysis. This change is almost 13 mm/year at all the locations using the linear regression model and coefficient of determination explains 40 to 60 variability in the *kharif* season rainfall with the years (Table 3).

The rainfed regions are going to be affected more by decreasing rainfall as compared to irrigated regions. Therefore, farmers need to make some changes in the cropping pattern to cope with changing rainfall pattern like start growing less water requiring crops, such as pulse, millets etc.

3.2.3. *Rabi*

Rainfall is important during the sowing period of *rabi* crops mainly in the rainfed regions. This also saves pre sowing irrigation before the sowing of *rabi* crops. The sowing is usually done in the month of October or

TABLE 4

Monthly and seasonal rainfall features at at different locations in lower *Shivaliks* of Punjab

Month / Season	Patiala-ki-Rao (1982-2015)		Saleran (1987-2015)		Ballowal Saunkhri (1984-2017)	
	Highest	Lowest	Highest	Lowest	Highest	Lowest
January	113 (2004)	Nil (1984, 1986, 1991, 2007, 2009, 2011)	107 (2012)	Nil (2013, 2014)	118 (2004)	Nil (1986)
February	116.3 (1996)	Nil (1983, 2001, 2004, 2006-07, 2009-11)	139 (1998)	Nil (2014, 2015)	113 (2007)	Nil (2006)
March	174 (1995)	Nil (1983, 1084, 2004, 2006-12)	191.3 (2007)	Nil (1999, 2004, 2008, 2011, 2014-15)	144 (2015)	Nil (2002, 2004, 2008)
April	83.8 (1997)	Nil (1984, 1988-89, 1993, 1999, 2006-11, 2013, 2015)	76.4 (1998)	Nil (1990, 1999, 2000, 2013-15)	48 (1997)	Nil (1999, 2010)
May	171.2 (1983)	Nil (1984, 2006-08, 2012)	174 (1987)	Nil (1995, 1998, 2003, 2012, 2014)	115 (1999)	Nil (1995)
June	395.9 (2013)	Nil (2007, 2012)	482 (2008)	Nil (2014)	408 (2008)	10 (1995)
July	638 (1988)	77.2 (2004)	788.4 (1993)	50.7 (1987)	770 (1988)	66 (2002)
August	592.4 (2004)	115.2 (2014)	736.8 (2008)	26.5 (1993)	546 (1994)	45 (1993)
September	455.3 (1988)	Nil (1982)	914.3 (1988)	15.9 (1989)	595 (1988)	11 (2004)
October	-	-	97.3 (1998)	Nil (1988-89, 1993, 1995, 1999 to 2001, 2003, 2005, 2011-12)	229 (2004)	Nil (1988-89, 1993-94, 1999-2001, 2003, 2005, 2007, 2011)
November	81.1 (1997)	Nil (1982 to 1985, 1987, 1988, 1991, 1994, 1996, 1998 to 2002, 2005, 2006, 2008, 2009 and 2011-15)	102.5 (1997)	Nil (1987, 1988, 1994, 1996, 1999, 2001, 2002, 2004, 2005, 2008, 2013, 2015)	60 (1997)	Nil (1984, 1987-88, 1991, 1993-94, 1996, 1999, 2000, 2002, 2005, 2010-12, 2014)
December	106.9 (1990)	Nil (1982 to 1984, 1992-93, 1998, 1999, 2001, 2005-06, 2008-09, 2011, 2015)	74.3 (1990)	Nil (1993, 1996, 1998, 1999, 2002, 2005, 2008-09, 2013)	181 (1997)	Nil (1992-93, 1998-99, 2005, 2009)
Annual	1669 (1988)	570.4 (2009)	2007.4 (1988)	666.8 (2004)	2041.1 (1988)	624 (2012)
<i>Kharif</i>	1569.7 (1988)	432.1 (2014)	1858.6 (1988)	517.1 (2004)	1802.8 (1988)	500 (2012)
<i>Rabi</i>	342 (1989)	Nil (2006, 2008)	488.7 (1997)	Nil (2013)	421.9 (1997-98)	47.8 (2009-10)
Winter	160.8 (1996)	Nil (2007, 2009, 2011)	187.3 (1995)	Nil (2014)	163.4 (1996)	9.9 (2001)
Pre-monsoon	254 (1983)	Nil (1984, 2006-08)	243.4 (2001)	Nil (2015)	197 (2015)	28.7 (1984)
Monsoon	1549.8 (1988)	385.8 (1987)	1847.1 (1988)	412.5 (2004)	1793.1 (1988)	441.1 (1987)
Post-monsoon	159.8 (1997)	Nil (1982 to 1984, 1998-99, 2001, 2005, 2006, 2008-09, 2011, 2015)	183.5 (1997)	Nil (1999, 2005)	267.6 (1997)	Nil (1993, 1999)

November. It has been observed that rainfall during November is decreasing significantly which results in delayed sowing of *rabi* crops. The *rabi* season rainfall is decreasing significantly at Patiala-ki-Rao (4.7 mm/year) and Saleran (3.7 mm/year) (Table 2). Using linear regression, the change in *rabi* season rainfall is by

5.4 mm/year and 3.1 mm/year with coefficient of determination explaining 67 and 39 % variability at Patiala-ki-Rao and Saleran respectively (Table 3). But the decrease is not significant at Ballowal Saunkhri as observed by Mann Kendall test and linear regression model (Tables 2 & 3).

3.2.4. Pre-monsoon

The contribution of pre-monsoon rainfall to annual rainfall varies from 7.8% at Patiala-ki-Rao to 8.2% at Ballawal Saunkhri. More or less, the percent contribution is almost same at all the three locations. The results of Mann Kendall test show that decreasing trend in pre monsoon rainfall at Patiala-ki-Rao and Saleran whereas increasing trend at Ballawal Saunkhri. However, the trend is significant only at Patiala-ki-Rao, where rainfall is decreasing at the rate of 3.3 mm/year (Table 2). Similar results have been observed using linear regression model which shows rainfall is significantly decreasing at the rate of 1.9 mm/year at Patiala-ki-Rao (Table 3)

3.2.5. Monsoon

Monsoon season rainfall contributes maximum percentage to the annual rainfall. The percent contribution of monsoon rainfall to annual rainfall at Patiala-ki-Rao, Saleran and Ballawal Saunkhri is respectively 82.6, 80.6 and 79.0 (Table 1). The monsoon rainfall has shown the significantly decreasing trend at all the locations at the rate of 9.2, 14.6 and 11.9 respectively for Patiala-ki-Rao, Saleran and Ballawal Saunkhri (Table 2).

The linear trend analysis of monsoon season rainfall revealed significantly decreasing trend at the rate of 13.6 mm/year, 13.8 mm/year and 12.5 mm/year, respectively, at Patiala-ki-Rao, Saleran and Ballawal Saunkhri (Table 3).

Another interesting finding of the study is that the extreme rainfall events (more than 60 mm) during different months and seasons also occur which result in the runoff and soil erosion particularly in the high sloping regions as prevailing in lower *Shivaliks* (Table 4). Therefore, rain water can also be harvested during the extreme rainfall events which can be used for irrigation or other purposes in these regions during the dry spells.

3.2.6. Post-monsoon

The post-monsoon rainfall contributes least percentage to the annual rainfall. It varies from 2.5% at Patiala-ki-Rao to 5.5% at Ballawal Saunkhri (Table 1). Trend analysis using Mann Kendall test and linear regression shows the post-monsoon rainfall is decreasing at all three locations. However, the trend is significant only at Ballawal Saunkhri with rate of decrease 1.7 mm/year (using Mann Kendall test) and 1.4 mm/year (using linear regression model) (Tables 2 & 3).

3.2.7. Winter

The percent contribution of winter rainfall to annual rainfall is around 7% at all the locations (Table 1). The results of Mann Kendall tests show significantly decreasing trend at Patiala-ki-Rao (at the rate 1.9 mm/year) and Saleran (1.7 mm/year). Using linear regression model, the winter season rainfall is significantly decreasing at the rate of 1.8 mm/year and 1.4 mm/year, respectively, at Patiala-ki-Rao and Saleran. However, the decreasing trend at Ballawal Saunkhri was found to be non-significant using both Mann Kendall test and linear regression model.

3.2.8. Monthly

At Patiala-ki-Rao, the negative trend in rainfall is observed for all the months. The trend is significant for all the months except June and September. The highest and lowest decrease is observed for July (2.9 mm/year) and for April (0.3 mm/year), respectively. Similarly, at Saleran, the negative trend is observed for all the months except for October. The trend is significant for all the months except April, May and June. The highest and lowest decrease is observed for July (4.4 mm/year) and November (0.4 mm/year) respectively. At Ballawal Saunkhri, the negative trend is observed all the months except March, April and June. However, the trend is significant only for the month of July, August, September, November and December. The highest decrease has been observed for July (6.9mm / year) followed by August (4.1 mm/year).

Using linear regression, the trend analysis revealed that the monthly rainfall is significantly decreasing at the rate of 0.1 to 3.4 mm/year, 0.3 to 5.7 mm/year and 0.04 to 7.2 mm/year, respectively, at Patiala-ki-Rao, Saleran and Ballawal Saunkhri. The October month at Saleran, and April and June month at Ballawal Saunkhri have significantly increasing trends in rainfall. The rainfall during monsoon months is decreasing significantly during July (3.5mm/year) at Patiala-ki-Rao, during July to September (3.5 to 5.7 mm/year) at Saleran and (3.6 to 7.2mm/year) at Ballawal Saunkhri. While for month of June, rainfall is increasing (at Patiala-ki-Rao and Ballawal Saunkhri) and decreasing (at Saleran), but the trend is significant only at Ballawal Saunkhri.

3.3. Decadal variations in annual and seasonal rainfall at different locations in lower Shivaliks of Punjab

The decade wise percent deviation from normal rainfall on annual and seasonal basis at Patiala-ki-Rao, Saleran and Ballawal Saunkhri have been given in Fig. 2.

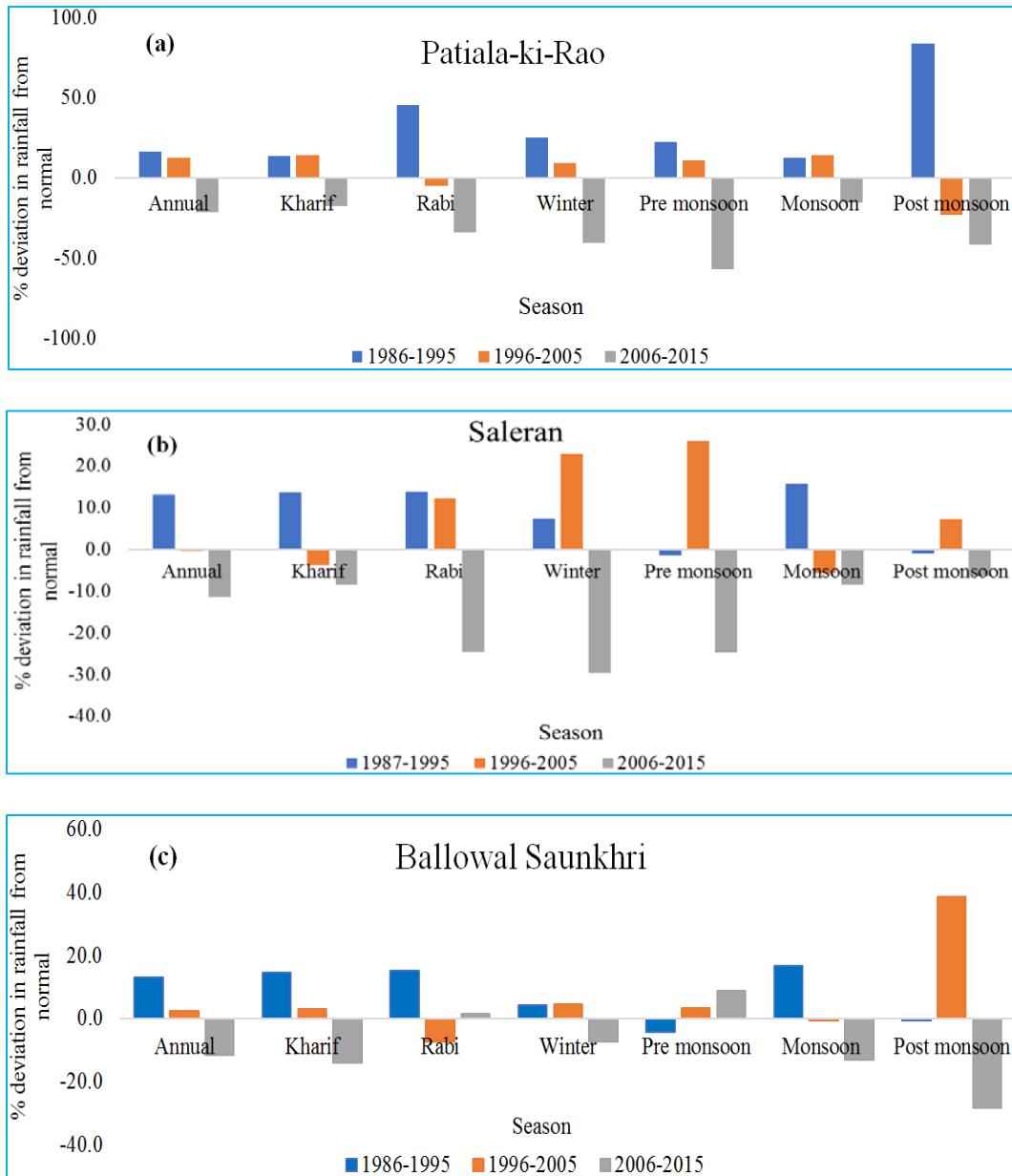


Fig. 2. Percent deviations in decadal rainfall on annual and seasonal basis at different locations in lower *Shivaliks* of Punjab

For Patiala-ki-Rao, the decade 1986-1995 had positive deviation in rainfall than the normal for all seasons, whereas decade 1996-2005 had also positive deviation in rainfall except seasons *rabi* and post monsoon. During the recent decade 2006-2015, the negative deviation for all the seasons has been observed [Fig. 2(a)].

Saleran has experienced above normal rainfall during the pre and post monsoon season of the decade

1986-1995. The annual rainfall, *kharif* and monsoon season during the decade 1996-2005 had below normal rainfall. All the seasons during decade 2006-2015 has below normal rainfall [Fig. 2(b)].

The data analysis for the Ballawal Saunkhri shows that pre and post monsoon season during the 1986-1995; *rabi* and monsoon during the 1996-2005; all seasons except *rabi* and pre monsoon during period 2006-2015 had below normal rainfall [Fig. 2(c)].

TABLE 5

Changes in annual and seasonal rainfall and rainy days during 15 year period at three locations in lower *Shivaliks* of Punjab

Seasons	Patiala-ki-Rao		Saleran		Ballawal Saunkhri		Lower <i>Shivaliks</i>	
	(1986-2000)	(2001-2015)	(1987-2000)	(2001-2015)	(1986-2000)	(2001-2015)	(1986-2000)	(2001-2015)
Rainfall (mm)								
Annual	1199.3	863.9	1313.2	999.4	1220.9	916.9	1244.5	926.7
<i>Kharif</i>	1013.6	764.1	1103.4	860.9	1042.3	755.1	1053.1	793.4
<i>Rabi</i>	184.5	102.5	206.5	140.2	179.0	153.0	190.0	131.9
Winter	86.0	53.4	108.0	71.6	82.3	73.2	92.1	66.1
Pre-monsoon	98.3	46.6	99.9	83.6	90.0	86.0	96.1	72.1
Monsoon	972.4	753.0	1053.3	809.5	978.1	701.1	1001.3	754.5
Post-monsoon	42.6	10.9	51.9	34.8	70.6	47.9	55.0	31.2
Rainy Days (#)								
Annual	54.1	43.1	57.2	45.8	55.3	46.8	55.5	45.2
<i>Kharif</i>	41.5	34.2	35.9	33.8	41.2	34.5	39.5	34.2
<i>Rabi</i>	12.9	8.5	14.5	12.3	13.8	12.3	13.7	11.0
Winter	5.7	4.3	7.1	5.6	6.5	5.8	6.4	5.2
Pre-monsoon	8.0	4.3	7.3	6.5	8.8	7.1	8.0	6.0
Monsoon	37.2	32.0	33.2	31.0	36.5	31.0	35.6	31.3
Post-monsoon	3.2	2.5	2.3	2.7	3.5	2.9	3.0	2.7

3.4. Monthly and seasonal rainfall extremes in rainfall amount at different locations in lower *Shivaliks* of Punjab

The extreme rainfall at Patiala-ki-Rao for different months and seasons over the past 34 years has been given in Table 4. Over the past three decades the highest rainfall was recorded during July (638 during 1988). During the monsoon season months, lowest rainfall over the past three decades was observed during June 2007 and 2012 (0 mm), July 2004 (77.2 mm), August 2014 (115.2 mm) and September 1982 (0.0 mm), whereas highest during June 2013 (395.9 mm), July 1988 (638 mm), August 1994 (592.4 mm) and September 1988 (455.3 mm). The overall highest and lowest rainfall during monsoon period has been recorded during the year 1988 (1549.8 mm) and 1987 (385.8 mm) at Patiala-ki-Rao, respectively.

The extreme rainfall at the Saleran for different months and seasons over the last 29 years have been given in Table 4. Over the past three decades, the highest rainfall was recorded during July (788.4 mm during 1993). During the monsoon season, lowest rainfall

over the past three decades was observed during June 2014 (0 mm), July 1987 (50.7 mm), August 1993 (26.5 mm) and September 1989 (15.9 mm), whereas highest during June 2008 (482 mm), July 1993 (788.4 mm), August 2008 (736.8 mm) and September 1988 (914.3 mm). The overall highest and lowest rainfall during monsoon period has been recorded during the year 1988 (1847.1 mm) and 2004 (412.5 mm) at Saleran, respectively.

The extreme rainfall at the Ballawal Saunkhri for different months and seasons over the last 34 years has been given in Table 4. Over the past three decades the highest rainfall was recorded during July (770 mm during 1988). During the monsoon season months, lowest rainfall over the past three decades was observed during June 1995 (10 mm), July 2002 (66 mm), August 1993 (45 mm) and September 2004 (11 mm), whereas highest during June 2008 (408 mm), July 1988 (770 mm), August 1994 (546 mm) and September 1988 (595 mm). The overall highest and lowest rainfall during monsoon period has been recorded during the year 1988 (1793.1 mm) and 1987 (441.1 mm) at Ballawal Saunkhri, respectively.

3.5. Changes in rainfall and rainy days at the three different locations in lower Shivaliks during the 15-year period

The annual and seasonal changes in rainfall and rainy days during the 15-year period for the three different locations in lower *Shivaliks* and the average of these locations have been given in Table 5. The data shows that the rainfall has decreased during the 2001 to 2015 as compared to the 1986 to 2000. Similarly, rainy days have also decreased at all the three locations in the lower *Shivaliks* Punjab. The overall view of the lower Shivalik shows that annual rainfall and rainy days during 2001-15 have reduced to 926.7 mm and 45 days, respectively, as compared to 1986-2000 (1244 mm rainfall and 55 rainy days). The data during the monsoon season shows decrease in rainfall and rainy days by 753.0 mm and 32 days, respectively, during 2001-15, as compared to 1986-2000 (1001 mm rainfall and 35 rainy days).

4. Conclusions

The present study shows the rainfall characteristics in lower Shivalik region of Punjab. The rainfall pattern of the region was analyzed using the Mann - Kendall analysis, Sen's slope estimator and simple linear regression method for the annual, *kharif*, *rabi*, pre-monsoon, monsoon, post-monsoon, winter and all the months of year. The study reveals that most of the rainfall is received during the monsoon season. The results of the tests show the erratic behavior and statistically significant decreasing trends in monthly and seasonal rainfall for all the locations under study. A significant decrease in annual (12 to 17 mm), *kharif* (9 to 15 mm), monsoon (9 to 14 mm) rainfall at all three locations has been observed so far, whereas *rabi* (3 to 5 mm) and winter (1 to 2 mm) season rainfall has decreased at Patiala-ki-Rao and Saleran except Ballawal Saunkhri. As the agriculture under the study areas is entirely dependent on rainfall, therefore, the declining trends coincide with the different crop growth phases/cultural operations which ultimately affect the crop production in these regions. Therefore, farmers need to adopt different strategies such as rain water harvesting, planting less water requiring and short duration crops/cultivars to cope with the reducing rainfall and to avoid the risks of crop failure.

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Disclaimer

The contents and views expressed in this research paper/article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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