MAUSAM, **73**, 1 (January 2022), 173-180

551.583 (540.15)

Long term monthly and inter-seasonal weather variability analysis for the lower *Shivalik foothills* of Punjab

NAVNEET KAUR, M. J. SINGH and SUKHJEET KAUR*

Regional Research Station-Punjab Agricultural University, Ballowal Saunkhri, SBS Nagar, Punjab – 144521, India

**Deptt. of CC&AM-Punjab Agricultural University, Ludhiana, Punjab – 141004, India*

(*Received 23 August 2020, Accepted 18 March 2021*)

e mail: navneetkaur@pau.edu

सार – इस शोध पत्र का उद्देश्य पंजाब के निचले शिवालिक तलहटी में मौसम के विभिन्न मानकों जैसे तापमान, वर्षा, वर्षा के दिनों, धूप के घंटों, वाष्पीकरण, सापेक्षिक आर्द्रता और तापमान के दीर्घकालिक रुझानों का अध्ययन करना है। निचले शिवालिक तलहटी का प्रतिनिधित्व करने वाले क्षेत्रीय अनुसंधान केंद्र बलोवाल सौंखरी के कृषि मौसम विज्ञान वेधशाला से लगभग 35 वर्षों के दैनिक मौसम डेटा का उपयोग खरीफ (मई-अक्टूबर), रबी (नवंबर-अप्रैल), शीत (जनवरी-फरवरी), मॉनसून पूर्व (मार्च-मई), मॉनसून (जून-सितंबर) और मॉनसूनोत्तर (अक्टूबर-दिसंबर) प्रवृत्ति विश्लेषण के लिए किया गया है। रैखीय समाश्रयण विधि का उपयोग प्रति वर्ष परिवर्तन के परिमाण और उसके निर्धारण के गुणांक का अनुमान लगाने के लिए किया गया है, जिसके सांख्यिकीय महत्व की जाँच F-परीक्षण द्वारा की गई । वार्षिक अधिकतम तापमान, सुबह और शाम की सापेक्षिक आर्द्रता में वृद्धि हुई है जबकि इस क्षेत्र में वर्षा, वाष्पीकरण, धूप के घंटे और पवन की गति में काफी कमी आई है। वार्षिक न्यूनतम तापमान और दैनिक तापमान की अवधि में कोई महत्वपूर्ण परिवर्तन नहीं देखा गया है। जनवरी, जून और दिसंबर को छोड़कर मासिक अधिकतम तापमान में उल्लेखनीय वृद्धि हुई, जबकि फरवरी, मार्च और अक्टूबर के लिए मासिक न्यूनतम तापमान में उल्लेखनीय वृद्धि हुई और जून में कमी आई। सर्दियों के मौसम को छोड़कर सभी मौसमों में अधिकतम तापमान में उल्लेखनीय वृद्धि हुई, जबकि खरीफ और मॉनसूनोत्तर ऋतु में केवल न्यूनतम तापमान में उल्लेखनीय वृद्धि हुई। इस क्षेत्र में वाष्पीकरण, धूप के घंटे और पवन की गति में भी कमी आई और सापेक्षिक आर्द्रता में काफी कमी आई। निचली शिवालिक तलहटी में खरीफ, मॉनसून और मॉनसून के बाद की वर्षा में उल्लेखनीय कमी देखी गई। चूंकि इस क्षेत्र में सुनिश्चित सिंचाई सुविधाओं का अभाव है, इसलिए वर्षा में कमी और अन्य मौसम प्राचलों में बदलाव का इस क्षेत्र की कृषि पर गहरा प्रभाव पड़ेगा, इसलिए जलवायु अनुकूल कृषि प्रौद्योगिकियों को विकसित करने की आवश्यकता है।

ABSTRACT. This paper aims to study the long-term trends in different weather parameters, *i.e.*, temperature, rainfall, rainy days, sunshine hours, evaporation, relative humidity and temperature over Lower Shivalik foothills of Punjab. The daily weather data of about 35 years from agrometeorological observatory of Regional Research Station Ballowal Saunkhri representing Lower Shivalik foothills had been used for trend analysis for *kharif* (May - October), *rabi* (November - April), winter (January - February), pre-monsoon (March - May), monsoon (June - September) and post monsoon (October - December) season. The linear regression method has been used to estimate the magnitude of change per year and its coefficient of determination, whose statistical significance was checked by the F test. The annual maximum temperature, morning and evening relative humidity has increased whereas rainfall, evaporation sunshine hours and wind speed has decreased significantly at this region. No significant change in annual minimum temperature and diurnal range has been observed. Monthly maximum temperature revealed significant increase except January, June and December, whereas, monthly minimum temperature increased significantly for February, March and October and decreased for June. Among different seasons, maximum temperature increased significantly for all seasons except winter season, whereas, minimum temperature increased significantly for *kharif* and post monsoon season only. The evaporation, sunshine hours and wind speed have also decreased and relative humidity decreased significantly at this region. Significant reduction in *kharif,* monsoon and post monsoon rainfall has been observed at Lower Shivalik foothills. As the region lacks assured irrigation facilities so decreasing rainfall and change in the other weather parameters will have profound effects on the agriculture in this region so there is need to develop climate resilient agricultural technologies.

Key words – Climate change, Weather variability, Trend analysis.

1. Introduction

The weather at global scale is being affected due to rapidly rising concentration of greenhouse gases in atmosphere as compared to preindustrial period due to the human interferences (Dlugokencky *et al.*, 2015). The radiative forcing due to these gases causes warming which results in more weather variability and extreme weather

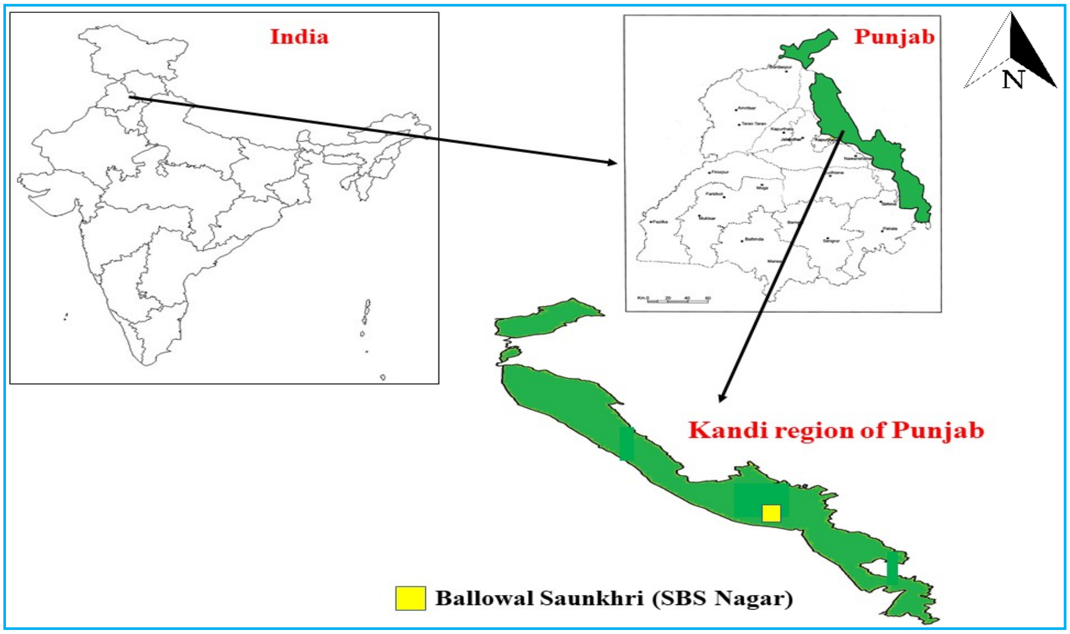

Fig. 1. Location of study area in lower *Shivalik foothills* of Punjab

event. The climate projections keeping in mind different scenarios have been made at global and regional scales. Several studies on climate projections indicate increase in recurrence and severity of heat/cold waves, drought/floods during throughout this century which will affect humans, animals, plants etc significantly (IPCC, 2014). The changing climate can be quantified by thorough long-term studies by analysing weather data such as rainfall, temperature etc. As agriculture is most vulnerable sector to the climate change, many studies focus on evaluation relation between climate change and crop production. To study the climate change effects on crop production, climate variability analysis is also needed. Besides the direct impact of changes in weather parameters on the crop production, it also affects the water availability and runoff directly (Liu and Allan, 2013). The indirect effect on crop production includes by its effect on evapotranspiration. One of the best ways of understanding how climate may change in future is to examine how it has changed in the past based upon long-term observational records. The impact of climate change on agriculture varies region-wise, *i.e.*, in rainfed and irrigated area depending on the availability of water. The rainfed areas are more prone to climate effects than irrigated due to dependence of their agriculture entirely on rainfall. Keeping this in mind, an effort has been made to investigate the trends of different weather parameters for Lower *Shivalik foothills* of Punjab. The Lower *Shivalik foothills* cover approximately 10.0% in the North Eastern Region of Punjab and parts of five districts, *i.e.*, Pathankot, Hoshiarpur, SBS Nagar, Rupnagar and SAS Nagar constitute this region. The agriculture in this region is mostly dependent on rainfall, the trend of which along with other weather parameters has been changing. The analysis of recent changes in weather parameters on annual, seasonal and decadal basis is of great value for detection of their impacts on ecosystem. Some studies on weather variability have been done in the region (Prabhjyot-Kaur *et al.*, 2016 and Kaur and Kaur, 2015) which observed change in the annual, -*kharif* and *rabi* rainfall and increase in maximum temperature in Lower *Shivalik foothills*. As this region is highly dependent on rainfall, therefore, the analysis of recent trends for this region will be helpful in adopting new technologies for agriculture, forestry, animals etc. Therefore, this study has been done with the aim to analyse annual, monthly and seasonal changes in weather parameters (maximum and minimum temperature, rainfall, evaporation, relative humidity, sunshine hours, wind speed) and their trends for Lower *Shivalik foothills* of Punjab.

2. Data and methodology

The daily meteorological data (1984-2019) for the different weather parameters was recorded at the agrometeorological observatory of the Regional Research station, Ballowal Saunkhri which represents the *kandi* region of Punjab. Climate variability analysis of the *kandi* region of Punjab state was carried out by analysing daily historical data of different meteorological parameters (maximum temperature, minimum temperature, rainfall, rainy days, sunshine hours, wind speed, relative humidity) for about 35 years on annual, monthly and seasonal basis (Ballowal Saunkhri : 31° 60' N, 76° 23' E, 296m) (Fig. 1). The annual data was divided in to different seasons, *i.e.*, *kharif* (May-October), *rabi* (November-April), winter (January-February), pre-monsoon (March-May), monsoon (June-September) and post monsoon (October-December). The annual, monthly and seasonal data was analyzed using the linear regression method by checking the coefficient of determination for its significance using the *F* test at 1 and 5% level of significance.

3. Results and discussion

3.1. *Monthly and seasonal variability trends*

The results from the regression analysis indicate that different weather parameters have positive as well as negative trends during different time period of the year. These results have been shown as:

3.1.1. *Maximum temperature*

The temperature of a given region varies depending on the latitude, longitude, altitude, season etc. of a region and these natural variations in the atmosphere are necessary for keeping the earth warm. But human interferences induced greenhouse gases emission have resulted in increasing temperature, the rate of change of which can be known by trend analysis. The slope and regression equations for annual, monthly and seasonal maximum, minimum and diurnal temperature have been shown in Table 1. The normal annual, monthly, *kharif*, *rabi*, winter, pre-monsoon, monsoon and post-monsoon maximum temperature of Lower *Shivalik foothills* is 30.0, 19.1 to 38.6, 34.4, 24.3, 20.9, 33.8, 34.1 and 26.7 °C, respectively. The results of this study indicate that maximum temperature has increased significantly at this region over the last 35 years (Table 1). The annual maximum temperature in Lower *Shivalik foothills* has increased significantly by 0.03 °C per year which means that a rise of about 1 °C has already occurred in the annual temperature over last 35 years. Whereas, Prabhjyot-Kaur *et al.* (2013) observed the significant increase in minimum temperature and no-significant changes in maximum temperature over six locations of Punjab under study.

The analysis of data on monthly basis shows that the maximum temperature has increasing monthly trend except January and June. The increasing trend in maximum temperature is significant for all the months except December. The maximum temperature during these months has increased significantly by 0.02 to 0.05 °C per year (0.7 to 1.75 °C over 35 years). The lowest increase has been observed for December (0.02 °C per year), while the highest increase for the March, April and October (0.05 °C per year). The analysis shows a decreasing trend for January and June month but this change is significant only for January month (0.04 °C per year which corresponds to 1.4 °C over last 35 years). The higher temperature affects the growth, water and nutrient uptake, pollen development, grain formation by affecting water requirement. The variations in average growing-season temperatures of ±2 °C in the main wheat growing areas can cause decline in grain yield by 50% which can be attributed to increased leaf senescence due to higher temperatures >34 °C (Asseng *et al*., 2011). Due to projections of increasing heat events. The global food security could also be under threat due to projections of increasing average temperatures and the frequency of heat events.

The seasonal analysis of maximum temperature shows significant increase in annual, *kharif*, *rabi*, pre monsoon, monsoon and post monsoon maximum temperature by 0.03, 0.04, 0.03, 0.05, 0.02 and 0.03 °C per year, respectively; and 1.05, 1.4, 1.05, 1.75, 0.7 and 1.05 °C, respectively, over the 35 years period as shown by slope of regression equations and coefficient of determination (Table 1). The winter season has shown decreasing trend in maximum temperature which is not significant in this region. Kothyari and Singh (1996) also observed increase in the annual maximum temperature over the Ganga basin. Kingra *et al*. (2018) observed the large fluctuations *i.e*., no significant variability trend in maximum temperature and rainfall patterns while significant increase in minimum temperature during rice growing period under different decades in North-East, Central and South-west regions.

3.1.2. *Minimum temperature*

The minimum temperature affects yield of crops by affecting respiration rate of plants. The normal minimum temperature at Ballowal Saunkhri ranges between 5.3 to 25.1 °C for different months. The analysis of the minimum temperature over the 35 years period suggests that annual minimum temperature has increased at Lower *Shivalik foothills* of Punjab, but this change is not significant. The analysis on monthly basis shows increasing trends for different months of year except January and June. The increasing trends are significant only for the months February (0.03 °C per year), March (0.03 °C per year) and October (0.05 °C per year), whereas decreasing trends are significant for only June month (0.02 °C per year). It means significant increase in minimum temperature for March and October months over past three and half decades is 1.05 to 1.75 °C, while significant decrease is 0.7 °C for June.

The all seasons show increasing trends, but the increase is significant only for *kharif* (0.01 °C per year)and post monsoon (0.02 °C per year) seasons (Table 1). It means that *kharif* and post monsoon season minimum temperature has increased about 0.35 and 0.7 °C

TABLE 1

Trend analysis of temperature for different time period of the year (1984-2019)

Month/Season	Maximum temperature (1984-2019)			Minimum temperature (1984-2019)			Diurnal temperature (1984-2019)		
	Normal	Equation	R^2	Normal	Equation	R^2	Normal	Equation	R^2
January	19.1	Y = -0.04X+ 19.8	0.23*	5.3	Y = -0.002X + 5.4	0.001	13.8	Y = -0.04X + 14.5	0.14**
February	22.8	Y = 0.03X + 22.4	0.16**	8.2	Y = 0.03X + 7.6	0.14**	14.6	Y = -0.002X + 14.7	0.001
March	28.1	Y = 0.05X + 27.0	0.17**	12.5	Y = 0.03X + 11.8	0.12**	15.6	Y = 0.02X + 15.2	0.03
April	34.7	Y = 0.05X + 33.9	0.12**	17.7	Y = 0.02X + 17.2	0.05	17.1	Y = 0.02X + 16.7	0.04
May	38.6	Y = 0.04X + 37.8	0.22*	22.2	Y = 0.02X + 21.8	0.07	16.4	Y = 0.02X + 15.9	0.04
June	37.7	Y = -0.02 + 38.0	0.03	24.9	Y = -0.02X + 25.3	0.14**	12.8	Y = 0.005X + 12.8	0.005
July	33.6	Y = 0.03X + 33.1	0.19*	25.1	Y = 0.01X + 24.9	0.07	8.5	Y = 0.02X + 8.2	0.106
August	32.8	Y = 0.04X + 31.9	0.33*	24.5	Y = 0.01X + 24.3	0.10	8.3	Y = 0.03X + 7.7	0.23*
September	32.6	Y = 0.04X + 31.9	0.26*	22.1	Y = 0.01X + 21.8	0.09	10.5	Y = 0.03X + 10.1	0.08
October	31.4	Y = 0.05X + 30.5	0.41*	16.2	Y = 0.05X + 15.3	0.32*	15.3	Y = 0.006X + 15.2	0.005
November	27.0	Y = 0.02X + 26.6	0.12**	10.6	Y = 0.02X + 10.2	0.09	16.5	Y = 0.005X + 16.4	0.003
December	21.6	Y = 0.02X + 21.4	0.04	6.4	Y = 0.004X + 6.3	0.006	15.2	Y = 0.01X + 15.1	0.01
Annual	30.0	Y = 0.03X + 29.5	0. 31*	16.3	Y = 0.01X + 16.0	0.10	13.7	Y = 0.01X + 13.5	0.05
Kharif	34.4	Y = 0.04X - 46.5	0.53*	22.5	Y = 0.01X + 22.2	0.16**	12.0	Y = 0.02X + 11.6	0.15**
Rabi	24.2	Y = 0.03X + 24.9	0.18*	10.1	Y = 0.02X + 9.7	0.07	15.4	Y = 0.003X + 15.4	0.001
Winter	20.9	Y = -0.004X + 21	0.01	6.7	Y = 0.01X + 6.4	0.04	14.2	Y = -0.02X + 14.6	0.08
Pre-monsoon	33.8	Y = 0.05X + 32.9	0.24*	17.5	Y = 0.01X + 6.4	0.04	16.3	Y = 0.02X + 15.9	0.06
Monsoon	34.1	Y = 0.02X + 33.7	0.18*	24.1	Y = 0.002X + 24.1	0.01	10.0	Y = 0.02X + 9.6	0.16**
Post monsoon	26.7	Y = 0.03X + 26.2	0.20*	11.0	Y = 0.02X + 10.6	0.16**	15.6	Y = 0.01X + 15.6	0.01

*Significant at 1% level of significance
** Significant at 5% level of significance

over past 35 years. Bhutiyani *et al*. (2007) showed increasing trend in minimum temperature over the northwestern Himalayan region during the 20th century**.** The significant increasing trends in maximum temperature were observed during month of February and March in North eastern regions, in March in Central region but decreasing trend in month of January in Central and south-west regions during temporal analysis (40 years) while increase in maximum temperature in all regions were observed during spatial analysis (Kingra *et al*., 2018). The average minimum temperature didn't show any significantly increasing trend (Sharma *et al.*, 2017).

3.1.3. *Diurnal temperature*

The normal diurnal temperature at Ballowal Saunkhri ranges from 8.3 to 17.1 °C. The increase in annual diurnal temperature range is non-significant. The diurnal range has decreased for January and February but it is significant only for January (0.04 °C per year), *i.e*., 1.4 °C over 35 years. For all other months increase in diurnal range has been observed but it is significant only for August month (0.03 °C per year).

Among different seasons, the diurnal range has decreased for winter season only, but this change was non-significant. An increase in diurnal range has been observed for all other seasons but significant only for *kharif* (0.02 °C per year) and monsoon season (0.02 °C per year). The change in *kharif* and monsoon diurnal temperature over the 35 year period is 0.7 °C (Table 1). Bhutiyani *et al*. (2007) showed increasing trend in diurnal temperature over the northwestern Himalayan region during the 20th century.

3.1.4. *Rainfall*

The rainfall variability analysis becomes very important as the amount and distribution of rainfall is very important for determining yield of crops. The rainfall variability trends were worked out by analyzing daily rainfall data on monthly, annual and seasonal basis (Table 2). The annual normal rainfall for the *kandi* region is 1064.9mm. The trend analysis of annual rainfall shows significant decrease at the rate of about 8mm per year. The normal rainfall during different months at Ballowal Saunkhri ranges from 6.6 to 299.7 mm being lowest for November & highest for August. The rainfall patterns showed the decreasing trends over the years (Sharma *et al*., 2017).

The analysis on monthly basis revealed a decrease in rainfall for May, July, August and November but it was significant for July (5.45 mm per year), August (3.02 mm per year) and November (1.61 mm per year).

TABLE 2

Trend analysis of rainfall, rainy days, evaporation and sunshine hours for different time period of the year (1984-2019)

Month/ Season	Rainfall (1984-2019)			Rainy days (1984-2019)			Evaporation (1984-2019)			Sunshine hours (1986-2019)		
	Normal	Equation	R^2	Normal	Equation	R^2	Normal	Equation	R^2	Normal	Equation	R^2
Jan	35.8	Y = 0.27X + 31.4	0.03	3	Y = 0.03X + 1.9	0.08	43.9	Y = -0.56X + 53.8	0.47*	5.8	Y = -0.07X + 7.2	0.59*
Feb	44.1	Y = 0.27X + 31.4	0.03	4	Y = 0.006X + 3.3	0.002	71.4	Y = -0.76X + 85.0	0.54*	7.2	Y = -0.04X + 7.9	0.36*
Mar	32.0	Y = 0.51X + 24.2	0.13**	3	Y = -0.02X + 3.3	0.04	128.1	Y = -1.20X + 149.7	0.42*	8.2	Y = 0.01X + 7.9	0.05
Apr	22.9	Y = 0.32X + 15.6	0.11**	2	Y = 0.03X + 1.5	0.14**	213.7	Y = -2.10X + 252.2	0.50*	9.4	Y = -0.03X + 9.97	0.30*
May	31.8	Y = -0.41X + 40.4	0.06	3	Y = -0.04X + 3.6	0.09	283.8	Y = -2.80X + 332.8	0.52*	10.0	Y = -0.03X + 10.5	0.40*
Jun	110.1	Y = 2.26X + 68.1	0.23*	6	Y = 0.03X + 4.9	0.09	237.8	Y = -3.12X + 294.7	0.47*	8.7	Y = -0.06X + 9.7	0.54*
Jul	274.5	Y = -5.45X +377.7	0.38*	11	Y = -0.08X + 12.9	0.20*	138.7	Y = -1.12X + 159.4	0.21*	6.0	Y = -0.02X + 6.5	0.17**
Aug	299.7	Y = -3.02X +352.3	0.22*	11	Y = -0.07X + 12.7	0.15**	112.6	Y = -0.96X + 129.9	0.27*	6.2	Y = -0.06X + 7.2	0.40*
Sep	156.3	Y = -1.61X +186.9	0.07	6	Y = -0.02X + 5.9	0.02	105.0	Y = -0.59X + 115.6	0.20*	7.6	Y = -0.03X + 8.1	0.19*
Oct	24.5	Y = -0.44X + 33.2	0.03	1	Y = -0.02X + 1.4	0.04	102.2	Y = -0.7974X +116.11	0.34*	8.7	Y = -0.05X + 9.6	0.43*
Nov	6.6	Y = -0.26X + 11.1	0.15**	1	Y = -0.01X + 1.0	0.07	68.4	Y = -0.38X + 75.0	0.22*	8.0	Y = -0.05X + 9.1	0.45*
Dec	26.6	Y = -0.67X + 38.5	0.10	1	Y = -0.03X + 1.6	0.05	47.0	Y = -0.30X + 52.3	0.28*	6.5	Y = -0.03X + 7.0	0.18**
Annual	1064.9	Y = -8.55X +1221.1	0.21*	51	Y = -0.18X + 54.3	0.10	1552.6	Y = -14.70X + 1816.5	0.55*	7.7	Y = -0.04X + 8.4	0.74*
Kharif	896.9	Y = -8.67X + 1058.6	0.26*	38	Y = -0.19X + 41.5	0.15**	980.0	Y = -9.39X + 1148.3	0.48*	7.9	Y = -0.04X + 8.7	0.74*
Rabi	165.9	Y = -0.20X + 169.3	0.002	13	Y = -0.04X + 13.7	0.02	568.9	Y = -4.78X + 651.49	0.51*	6.4	Y = -0.03X + 8.2	0.45*
Winter	80.0	Y = 0.25X + 73.0	0.01	6	Y = 0.035X + 5.3	0.04	115.3	Y = -1.32X + 138.83	0.58*	6.6	Y = -0.06X + 7.7	0.69*
Pre-monsoon	86.6	Y = 0.38X + 80.2	0.02	8	Y = -0.03X + 8.5	0.02	625.6	Y = -6.10X + 734.7	0.60*	9.2	Y = -0.02X + 9.5	0.31*
Monsoon	840.7	Y = -7.82X + 985.0	0.22*	34	Y = -0.14X + 36.5	0.10	594.0	Y = -5.79X + 699.48	0.41*	7.1	Y = -0.04X + 7.9	0.67*
Post monsoon	57.7	Y = -1.37X + 82.8	0.13**	3	Y = -0.05X + 4.0	0.10	217.6	Y = -1.48X + 243.49	0.34*	7.8	Y = -0.04X + 8.6	0.48*

*Significant at 1% level of significance
** Significant at 5% level of significance

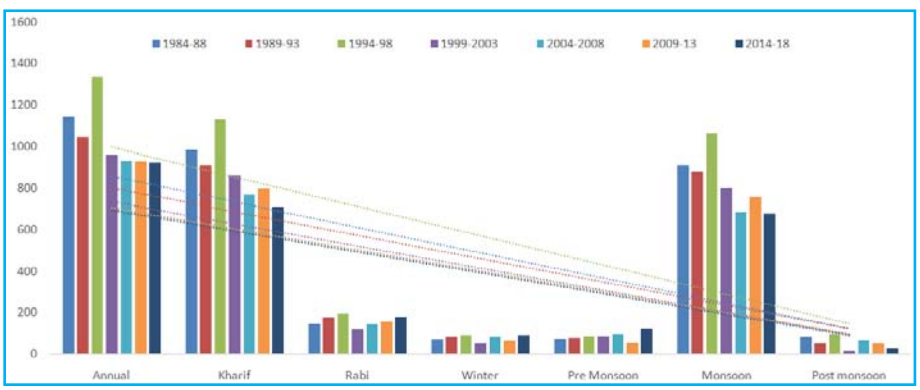

Fig. 2. Pentad wise changes in rainfall for the lower *Shivalik* region of Punjab

The perusal of data shows that rainfall increased for January to April and June month. But this increase in rainfall was significant during the months March, April and June and it was 0.51, 0.32 and 2.26 mm per year, respectively.

The trend analysis for different seasons shows that *kharif*, *rabi*, monsoon and post monsoon rainfall has decreased, whereas increased for winter and pre monsoon seasons. But this change is significant only for *kharif*, monsoon and post monsoon, *i.e.*, rainfall has reduced significantly by 8.8, 7.8 and 1.4 mm per year respectively for these seasons at this region (Table 2). It means that change of 303, 273 and 47 mm has occurred over 35 years period. Kumar *et al*., (1992) observed a decreasing trend (ranged between –6% and –8% of the normal per 100 years) in the monsoon rainfall over the Northeast peninsula, Northeast India and Northwest peninsula. Krishnakumar *et al.* (2011) revealed significant decrease in SW monsoon rainfall and an increase in post-monsoon season over Kerala. Yadav *et al*. (2014) have indicated an increasing trend of annual rainfall in Almora, Bageshwar, Nainital, Pauri Gharwal, Pithoragarh, Udhamsingh Nagar and Uttarkashi; and a decreasing trend of annual rainfall for Chamoli, Champawat, Rudraprayag and Tehri Garhwal district of Uttarakhand state, India in a study conducted from year 1971 to 2011. Kingra *et al.* (2017)

reported that the decreasing rainfall during *kharif* and *rabi* seasons from north-east to south-west regions of Punjab. Similar trends were also reported by Kaur *et al*. (2019). The analysis of pentad-wise shifts in rainfall for the Lower *Shivalik foothills* shows that for the different seasons, rainfall has decreased linearly (Fig. 2).

3.1.5. *Rainy days*

The slope and regression coefficients of the equations obtained by regressing the three yearly moving averages against time for monthly, annual and seasonal rainy days at different locations in Lower *Shivalik foothills* of Punjab are shown in Table 2. The Lower *Shivalik foothills* has annual 51 normal rainy days which have shown a non-significant but decreasing trend. The normal rainy days during different months at Ballowal Saunkhri ranges from 3 to 11 days during different months of the year. In general, the rainy days showed a decreasing trend during different months in the Lower *Shivalik foothills* of Punjab except January, February and April for which increasing trend in rainy days observed. , but the trend was significant only for July (0.08 days per year, *i.e*., 2.8 days over 35 years) and August (0.07 day per year, *i.e*., 2.45 days over 35 years). The significantly increasing trend in rainy days for the April month shows an increase of 1.05 days over past 35 years (0.03 days per year).

Among different seasons of the year, rainy days were found to be decreasing except winter season but the change in rainy days is significant only for the *kharif* season (0.19 day per year, *i.e*., 6.65 days over 35 years). Kothyari and Singh (1996) also found decreasing trend in monsoon rainy days in the Ganga basin.

3.1.6. *Pan evaporation*

Evaporation is a crucial parameter of hydrological cycle. The rate of change of evaporation plays a very important role for scheduling irrigation, runoff estimation etc (Ghuman *et al*., 2020). The normal pan evaporation at Ballowal Saunkhri ranges from 43.9 to 283.8 mm. For the Ballowal Saunkhri, the slope and regression coefficients of the equations obtained by regressing the three yearly moving averages against time for monthly, annual and seasonal pan evaporation is shown in Table 2. In general, the pan evaporation revealed a decreasing trend. The annual evaporation showed significantly decreasing evaporation at rate of 14.7 mm per year during past 35 years.

The analysis of the data revealed that the significant reduction in monthly pan evaporation by0.30 to 3.1 mm per year during different months of the year. The highest reduction was noticed for June (3.1 mm per year) and lowest for December (0.30 mm per year).

The change observed in *kharif*, *rabi*, winter, pre-monsoon, monsoon and post monsoon pan evaporation per year is 9.4, 4.8, 1.3, 6.1, 5.8 and 1.5 mm per year respectively and the corresponding change occurred during these seasons over 35 years is around 329, 168, 45.5, 213.5, 203, 52.5 mm. The reduction in evaporation may be attributed to the reduced sunshine hours, wind speed and increasing relative humidity at this region. Fu *et al*. (2009) also reported decreasing evaporation at different locations.

3.1.7. *Sunshine hour*

The sunshine hours are important parameters for determining the evaporation rate. These also affect the photosynthesis process which affects the yield of different crops. The slope and regression coefficients of the equations obtained by regressing the three-yearly moving averages against time for monthly and seasonal sunshine hours at different locations in Punjab are shown in Table 2. The annual sunshine hours at this region are 7.7 hours which are decreasing significantly at rate of 0.04 hours per year.

The normal monthly sunshine hours at Ballowal Saunkhri ranges from 5.8 to 10 hours being lowest in January and highest for May. In general, the monthly sunshine hours at Ballowal Saunkhri have also revealed a significant decreasing trend by 0.01 to 0.07 hours per year. This decrease corresponds to 0.35 to 2.45 hours over 35 years period. This decrease is lowest for month of March and highest for the January.

The change in *kharif*, *rabi*, winter, pre monsoon, monsoon and post monsoon sunshine hours over the 35 years period is 0.04, 0.03, 0.06, 0.02, 0.04 and 0.04 hours per year respectively, corresponding to a change of 1.4, 1.05, 2.1, 0.7, 1.4 and 1.4 hours over the 35 years, respectively.

3.1.8. *Morning relative humidity*

The normal morning relative humidity at Ballowal Saunkhri is 78% which has been increasing at rate of 0.33 percent per year corresponding to change of 11.5 percent over 35 years period. The mean monthly morning relative humidity in this region ranges between 51 to 91 percent being lowest for May and highest for January followed by August, September, December and July. The analysis of long term data indicates that morning relative humidity for all the months has been increasing significantly. The rate of change of relative humidity is 0.18 (August) to 0.44 (June) percent per year. It means the morning relative humidity has changed by 6.3 to 15.4 percent during last35 years.

TABLE 3

Trend analysis of relative humidity and wind speed for different time period of the year (1984-2019)

Month/Season	Morning Relative humidity (1983-2019)			Evening Relative humidity (1983-2019)			Wind speed (1984-2019)		
	Normal	Equation	R^2	Normal	Equation	R^2	Normal	Equation	R^2
January	91	Y = 0.32X + 85.1	0.35*	56	Y = 0.49X + 47.0	0.55*	2.8	Y = -0.05X + 3.6	0.26*
February	85	Y = 0.37X + 77.9	0.39*	48	Y = 0.35X + 41.5	0.55*	3.6	Y = -0.04X + 4.36	0.21*
March	74	Y = 0.34X + 68.0	0.36*	42	Y = 0.29X + 36.1	0.36*	4.3	Y = -0.07X + 5.46	0.34*
April	56	Y = 0.42X + 47.3	0.36*	30	Y = 0.37X + 22.6	0.41*	4.8	Y = -0.07X + 152.7	0.46*
May	51	Y = 0.32X + 44.7	0.46*	30	Y = 0.25X + 25.2	0.29*	5.1	Y = -0.06X + 6.1	0.35*
June	63	Y = 0.44X + 54.8	0.40*	44	Y = 0.43X + 35.2	0.39*	4.4	Y = -0.07X + 5.7	0.47*
July	85	Y = 0.28X + 79.2	0.26*	70	Y = 0.26X + 64.5	0.24*	3.1	Y = -0.06X + 4.1	0.42*
August	90	Y = 0.18X + 86.9	0.28*	75	Y = 0.11X + 72.9	0.16**	2.3	Y = -0.04X + 3.1	0.42*
September	89	Y = 0.27X + 83.9	0.36*	66	Y = 0.23X + 61.7	0.38*	2.2	Y = -0.04X + 2.9	0.37*
October	82	Y = 0.40X + 74.2	0.41*	47	Y = 0.25X + 42.5	0.26*	2.5	Y = -0.06X + 3.6	0.47*
November	84	Y = 0.35X + 77.1	0.30*	43	Y = 0.23X + 38.4	0.34*	2.6	Y = -0.05X + 3.4	0.35*
December	89	Y = 0.28X + 84.3	0.29*	51	Y = 0.19X + 46.9	0.19*	2.5	Y = -0.04X + 3.2	0.29*
Annual	78	Y = 0.33X + 72.0	0.46*	50	Y = 0.29X + 44.6	0.69*	3.3	Y = -0.06X + 4.3	0.42*
Kharif	77	Y = 0.32X + 70.6	0.47*	55	Y = 0.25X + 50.4	0.50*	3.3	Y = -0.06X + 4.3	0.44*
Rabi	80	Y = 0.36X + 72.9	0.42*	45	Y = 0.29X + 38.9	0.65*	3.4	Y = -0.05X + 4.2	0.29*
Winter	88	Y = 0.34X + 82.0	0.38*	52	Y = 0.43X + 44.8	0.70*	3.2	Y = -0.05X + 3.9	0.23*
Pre-monsoon	60	Y = 0.36X + 53.8	0.49*	34	Y = 0.30X + 28.3	0.46*	4.7	Y= -0.06X + 5.8	0.36*
Monsoon	82	Y = 0.29X + 76.6	0.40*	64	Y = 0.26X + 59.1	0.43*	3.0	Y = -0.06X + 3.9	0.44*
Post monsoon	85	Y = 0.34X + 78.7	0.34*	47	Y = 0.22X + 42.9	0.34*	2.5	Y = -0.05X + 3.4	0.39*

*Significant at 1% level of significance
** Significant at 5% level of significance

The *kharif*, *rabi*, winter, pre monsoon, monsoon, post monsoon season morning relative humidity has increased by 0.32, 0.36, 0.34, 0.36, 0.29 and 0.34 percent per year with corresponding increase of 11.2, 12.6, 11.9, 12.6, 10.2 and 11.9 percent over 35 years. Dai (2006) also found increasing humidity trends.

3.1.9. *Evening relative humidity*

The results of long term analysis of annual, monthly and seasonal evening relative humidity at Lower *Shivalik foothills* have been given in Table 3. The normal annual evening relative humidity at Ballowal Saunkhri is 50% which has been increasing at rate of 0.29 percent per year corresponding to change of 10.15 percent over 35 years period. The mean monthly evening relative humidity in this region ranges between 30 to 75 percent being lowest for April and May, whereas highest for August. The analysis of long-term data indicates that evening relative humidity for all the months has been increasing significantly at rate of -0.11 (August) to 0.49 (January) percent per year. It means the evening relative humidity has increased by 3.85 to 17.15 percent during last 35 years.

The analysis of *kharif*, *rabi*, winter, pre monsoon, monsoon, post monsoon season evening relative humidity has increased significantly by 0.25, 0.29, 0.43, 0.30, 0.26 and 0.22 percent per year with corresponding increase of 8.75, 10.15, 15.05, 10.5, 9.1 and 7.7 percent over 35 years.

3.1.10. *Wind speed*

The wind speed is very important parameter determining the evaporation rate. The annual wind speed at the Lower *Shivalik foothills* is 3.3 km/hr which has been found to decrease 0.06 km/hr per year, *i.e*., 2.1 km/hr since past 35 years. The normal wind speed at Ballowal Saunkhri ranges from 2.2 (September) to 5.1 (May) km/hr during different months of the year. The slope and regression coefficients of the equations obtained by regressing the three yearly moving averages against time for monthly, annual and seasonal wind speed at different locations in Punjab are shown in Table 3. In general, a decreasing trend in wind speed throughout the year has been observed in the Lower *Shivalik foothills* of Punjab state. The perusal of the data revealed that the monthly wind speed has reduced at rate of 0.04 to 0.07 km/hr/day. The lowest reduction has been observed for February, August, September and December, whereas highest for the March, April and June. The seasonal wind speed has also reduced significantly at the study region. The reduction in *kharif*, pre monsoon and monsoon wind speed is 0.06 km/hr/day, whereas the reduction in *rabi*, winter and post monsoon wind speed is 0.05 km/hr/day.

4. Conclusions

The analysis of meteorological data of the region indicated that maximum temperature has shown increase in most of the months, whereas the increase in minimum temperature is significant only for February, March and October. The analysis of rainfall data reveals an annual, seasonal and monthly decrease in most of months/seasons in Lower *Shivalik foothills* of Punjab. The increasing trend in relative humidity coupled with decreasing trend in wind speed, pan evaporation and sunshine hours suggested an increase in the prevalence of cloudy and humid weather conditions in the state. The significantly decreasing diurnal temperature range for January and increasing for August as result of significant decrease and increase in maximum temperature during these months respectively and stable minimum temperature has been observed. There are some definite indicators of climate change in the region and these needs to be correlated with crop productivity, water availability and use.

Acknowledgement

The authors are highly thankful to the India Meteorological Department, Pune for providing all the facilities and Met observers for recording the weather data. 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.

References

Asseng, S. Foster, I. and Turner, N. C., 2011, "The impact of temperature variability on wheat yields", *Global Change Biology*, **17**, 2, 997-1012.

Bhutiyani, M. R. Kale, V. S. and Pawar, N. J., 2007, "Long-term trends in maximum, minimum and mean annual air temperatures across the Northwestern Himalaya during the twentieth century", *Climatic Change*, **85**, 159-177.

Dai, A., 2006, "Recent Climatology, Variability and Trends in Global Surface Humidity", *Journal of Climatology*, **19**, 15, 3589-3606.

Dlugokencky, E. J. Hall, B. D. Montzka, S. A. Dutton, G. Muhle, J. and Elkins, J. W., 2015, "Global climate, atmospheric chemical composition-Long-lived greenhouse gases", [*In* State of the Climate in 2014 Blunden, J., Arndt, D. S., Eds]., *Bull. Amer. Meteorol. Soc*., **96**, 39-42.

Fu, G. Charles, S. P. and Yu, J., 2009, "A critical overview of pan evaporation trends over the last 50 years", *Climatic Change*, **97**, 93. https://doi.org/10.1007/s10584-009-9579.

Ghumman, A. R. Ghazaw, Y. M. Alodah, A. Rauf, A. U. Shafiquzzaman, M. and Haider, H., 2020, "Identification of Parameters of Evaporation Equations Using an Optimization Technique Based on Pan Evaporation", *Water*,**12**, 228. doi : 10.3390/w12010228.

IPCC, 2014, "Summary for Policymakers. *In*: Climate Change : Impacts, Adaptation and Vulnerability Part A : Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change" (Field, C. B., Barros, V. R., Dokken, D. J., Mach, K. J., Mastrandrea, M. D., Bilir, T. E., Chatterjee, M., Ebi, K. L., Estrada, Y. O., Genova, R. C., Girma, B., Kissel, E. S., Levy, A. N., MacCracken, S., Mastrandrea, P. R. and White, L. L. (eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014, 1-32.

Kaur, H. and Kaur, Prabhjyot, 2015, "Temperature features in different agroclimatic zones of Punjab", *Agricultural Research Journal*, **52**, 4, 32-35.

Kaur, Prabhjyot, Sandhu, Sandhu, S., Singh, S. and Gill, K. K., 2013, "Climate Change - Punjab Scenario", School of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana, p16.

Kaur, S., Kingra, P. K., Setia, R. and Singh, S. P., 2019, "Comparative analysis of rice productivity of three agroclimatic zones of Punjab", *Agricultural Research Journal*, **56**, 1, 49-55.

Kingra, P. K., Setia, R., Kaur, J., Singh, S., Singh, S. P., Kukal, S. S. and Pateriya, B., 2018, "Assessing the impact of climate variations on wheat yield in northwest India using GIS", *Spatial Information Research*. doi : https://doi.org/10.1007/s41324-018-0174-2.

Kingra, P. K., Setia, R., Singh, S., Kaur, J., Kaur, S., Singh, S. P., Kukal, S. S. and Pateriya, B., 2017, "Climatic variablilty and its characterization over Punjab, India", *Journal of Agrometeorology*, **19**, 3, 246-250.

Kothyari, U. C. and Singh, V. P., 1996, "Rainfall and temperature trends in India", *Hydrology Process*, **10**, 357-372.

Krishnakumar, S. K., Patwardhan, A. Kulkarni, K. Kamala, K. Rao, K. and Jones, R., 2011, "Simulated projections for summer monsoon climate over India by a high-resolution regional climate model (PRECIS)", *Current Science*,**101**, 312-325.

Kumar, R. Pant, K. Parthasarathy, G. B. B. and Sontakke, N. A., 1992, "Spatial and sub-seasonal patterns of the longterm trends of Indian summer monsoon rainfall", *International Journal of Climatology*, **12**, 257-268.

Liu, C. and Allan, R. P., 2013, "Observed and simulated precipitation responses in wet and dry regions", *Environmental Research Letters*, **30**, 8, 1850-2100. doi : 10.1088/1748-9326/8/3/034002.

Prabhjyot, Kaur, Sandhu, S. S. Singh, H. Kaur, N. Singh, S. and Kaur, A., 2016, "Climatic features and their variability in Punjab", 14th Biennial Workshop on All India Coordinated Research Project on Agrometeorology, 1-78, PAU, Ludhiana.

Sharma, V., Kumar, V., Sharma, S., Sharma, R. K., Khokhar, A. and Singh, M. J., 2017, "Climatic Variability Analysis at Ballowal Saunkhri in Submontane Punjab (India)", *Climate Change and Environment Sustainability*, **5**, 1, 83-91.

Yadav, R. Tripathi, S. K., Pranuthi, G. and Dubey, S. K., 2014, "Trend analysis by Mann-Kendall test for precipitation and temperature for thirteen districts of Uttarakhand", *Journal of Agrometeorology*, **16**, 2, p164.