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A case study on the changing pattern of monsoon rainfall duration and its amount during the recent five decades in different agroclimatic zones of Punjab state of India

SARABJOT KAUR SANDHU and PRABHJYOT KAUR

Department of Climate Change and Agricultural Meteorology

Punjab Agricultural University, Ludhiana – 141 004, Punjab, India

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e mail : skchahal@pau.edu

सार — **वर्षा जलीय चक्र का एक महत्वपूर्ण हिस्सा है और इसके प्रतिरूप में कोई भी बदलाव जल संसाधनों को प्रभावित करता है। पंजाब में, जुलाई, अगस्त और सितंबर के चार महीनों के दौरान** 77 **दिनों की मॉनसून ऋतु में औसतन** 6 **मिमी/दिन की दर से वर्षा होती है। वर्तमान अध्ययन में गैर-प्राचलिक परीक्षणों यथा वर्णनात्मक आँकड़े, प्रवृत्ति विश्लेषण, मान केंडल परीक्षण और सेन का ढलान आदि का उपयोग करके राज्य के तीन हिस्सों के लिए मॉनसून वर्षा डेटा अर्थात राज्य के उत्तर पूर्वी क्षेत्र** (1984-2020), **मध्य मैदानी क्षेत्र** (1970-2020) **और दक्षिण पश्चिमी क्षेत्र** (1977-2020) **का विश्लेषण किया गया है। यद्यपि, मॉनसून ऋतु की अवधि पिछले दो दशकों में** 0.8 **दिन/वर्ष से बढ़ी है तथापि वर्षा में पिछले** 20 **वर्षों में से** 17 **वर्षों के दौरान वर्षा सामान्य से कम रही है। उत्तर पूर्वी क्षेत्र में वर्षा में गिरावट के कारण पाँच दशकों के लिए मॉनसून वर्षा विश्लेषण** 0.7 **मिमी/वर्ष की वर्षा की महत्वपूर्ण कमी दर्शाता है। सेन का ढलान मान** -4.77 (**बलोवाल**) **और** -0.60 (**बठिंडा**) **इस क्षेत्र में वर्षा की घटती प्रवृत्ति का संकेत देता है। कुल वर्षा में** ~70 **प्रतिशत योगदान देने वाले जुलाई-अगस्त के महीनों में** -0.04 **से** -2.50 **और** -0.24 **से** -3.14 **के बीच सेन के ढलान मानों के अनुसार हुई वर्षा में कमी की प्रवृत्ति राज्य में कृषि क्षेत्र के लिए अच्छे संकेत नहीं देती है।**

ABSTRACT. Rainfall is an important part of hydrological cycle and any alteration in its pattern influence water resources. In Punjab, the monsoon season of 77 days extending during three months July, August and September, receives rainfall at an average rate of 6 mm/day. In the present study, monsoon rainfall data for three parts of the state, *viz*., the north eastern region (1984-2020), Central plain region (1970-2020) and the south western region (1977-2020) of the state have been analyzed using non-parametric tests, *i.e*., descriptive statistics, trend analysis, Mann Kendall test and Sen's slope. Though, the duration of the monsoon season has increased over the last two decades at 0.8 day/year, the rate of rainfall has decreased as rainfall has been less than normal during 17 of the past 20 years. The monsoon rainfall analysis for the five decades indicates a significant decrease in rainfall at 0.7 mm/year which has mainly been due to a decline in rainfall in the north eastern region. The Sen's slope value of -4.77 (Ballowal) and -0.60 (Bathinda) indicate a decreasing trend of rainfall in the region. The decreasing trend in rainfall received during the July-August months with Sen's slope values ranging between -0.04 to -2.50 and -0.24 to -3.14, indicates that the months which contribute ~70 percent to total rainfall are not a good signal for the agriculture sector in the state.

Key words – Monsoon Rainfall, Mann Kendall test, Punjab, Sen's slope, Variability.

1. Introduction

Monsoon rainfall received during June to September months forms the backbone of rainfed cultivation of crops in India (Mishra *et al.*, 2012, Singh *et al.*, 2019). The irrigated cultivation of crops, especially in states like Punjab, which is primarily tube well irrigated, is also affected by the decline in monsoon rainfall, since it is directly linked to non-replenishment of ground water reservoirs (Kaur *et al.*, 2021). In a recent study by Maharana *et al*. (2021), the recent changes in rainfall pattern have led to a shift of the climate of Indo-gangetic plains (IGP) and northeast India towards a relatively arid regime while that of western India towards a relatively moist regime. The state of Punjab, which is a part of IGP, already has a semi-arid and subtropical climate with an annual rainfall varying from 250-350 mm in the southwestern parts to 900-1000 mm in sub mountainous northeastern parts (Prabhjyot Kaur *et al.*, 2016).

As the signals of climate change become more and more significant, changes in temperature and rainfall pattern and their extremes are being recognized and reported worldwide (Adger *et al.*, 2011; Yaduvanshi *et al.*, 2021). The latest report of the Intergovernmental Panel on Climate Change (IPCC 2021) has reported that the frequency and intensity of heavy precipitation events have increased since the 1950s in most land areas and the human-induced changes in the climate system have contributed to increases in droughts (agricultural and ecological) in some regions due to increased rates of evapotranspiration. The changes in rainfall patterns driven mainly by a rise in the global surface temperature @ 0.74 ± 0.18°C over the period of 1906-2005 (IPCC 2007) have declined the availability of fresh water during the middle of the 21st century.

Recent studies on the Indian summer monsoon have depicted a decreasing trend in rainfall during the second half of the 20th century in central India (Bollasina *et al.*, 2011; Mishra *et al.*, 2012). The monsoon current is established and strengthened by the warming of the Indian subcontinent which builds up a low pressure that helps strengthen the movement of moisture laden winds from the Indian Ocean (Bollasina, 2014). Since the middle of the 20th century, the greenhouse gas (GHG) induced warming of the Indian Ocean sea surface and the concomitant dampening of warming over the Indian subcontinent due to aerosols (Das *et al.*, 2015) and land-cover changes (Dimeyer *et al.*, 2010) has led to a weakening trend of the Indian monsoon (Singh *et al.*, 2019; Seth *et al.*, 2019). In a recent study by Katzenberger *et al.* (2021), using the four Shared Socioeconomic Pathways (SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5) models there is a linear dependence of the rainfall over the mean temperature. The study also revealed a high agreement between the results of four SSP models that if global warming is the major forcing for the monsoon dynamics, then the multi-model mean for four months of monsoon rainfall projects during 2015-2100 an increase of 0.33 mm d^{-1} and 5.3% per kelvin of the global warming. So the global warming induced due to GHG increase is a major determinant of changes in major rainfall systems of the world (Bushra *et al.*, 2020).

Simulation studies done using General Circulation Models (GCMs) indicate an increase in extreme daily rainfall events induced due to increasing atmospheric concentrations of GHGs at global level (Meehl *et al.*, 2000; Dubey *et al.*, 2012) coupled with a decrease in overall rainfall at the regional scale. To detect trends in hydrological and hydro meteorological time series data, different statistical test methods are used and they are broadly classified as parametric and non-parametric tests (Chen *et al.*, 2007). Though parametric tests are more powerful, they require independent and normally distributed data, which is rarely true for hydrological time series data. For non-parametric tests, data must be independent, but outliers are better tolerated. The Mann-Kendall (MK) trend test (Mann, 1945) and (Kendall, 1975) is one of the widely used non-parametric tests (Basistha *et al.*, 2009) to detect significant trends in hydrological time series (Longobardi and Villani, 2010). Since this MK test is a function of the ranks of the observations rather than their actual values, is not affected by the actual distribution of the data and is less sensitive to outliers.

The four month long monsoon season rainfall, contributes to 75-80 percent of total annual rainfall is a major reason for the 190 percent cropping intensity in the state. So the variability in monsoon season rainfall increases/decreases with long dry spells, during July when crops are at vegetative stage sudden extreme wet spells, especially during the mid-August time when the crops like rice are at flowering-pollination stage (Prabhjyot-Kaur *et al*., 2021a) or from the second week of September when rice and cotton crops are approaching towards harvesting stage do not augur good for crops in the state. In the present study, statistical trend/pattern analysis of the monsoon rainfall in the state and within different agroclimatic regions over the past five decades was done. Amongst the agroclimatic regions, the major monsoon season crops are maize, paddy and basmati rice in the north eastern part (Ballowal Saunkhri), paddy in the central region (Ludhiana), paddy and cotton in the south western region (Bathinda).

2. Data and methodology

2.1. *Study area*

Punjab state represents 1.5 % of the geographical area of India and lies in the northern part of the country with a latitude extent from 29° 33' to 32° 34' N and a longitude extent from 73° 53' to 76° 56' E. The mean annual rainfall in the state and different locations ranges from 250 to 1000 mm and more than 75 to 80 per cent of this rainfall is received under the influence of south west monsoon during the four months, June through September (Prabhjyot-Kaur *et al.*, 2021b). The 20 to 25 per cent of rainfall is received during the remaining eight months under the influence of western disturbances. The state is divided into six agro-climatic zones on the basis of physiography, rainfall and underground water quality and quantity. The Punjab state has total land area of 50,362 sq. kilometer with six agro climatic zones, *i.e.*, north eastern region (agro climatic zone I & II) having sub mountainous and undulating plain region (with 18.5% of available land area and rainfall >800-900 mm), central plain region (agro climatic zone III & IV-with 55 per cent of available land area and rainfall 500-800 mm) and south western region

Fig. 1. Representation of the three distinct study areas in Punjab

(agro climatic zone V-with 20% of available land area and rainfall <200mm). The sixth agro climatic zone comprises of flood plain region for four major rivers (Ghaggar, Sutlej, Beas and Ravi) with a land area of 7 per cent (Anonymous 2021). Accordingly the rainfall study was conducted (Fig. 1) for these three major land parts of the state viz. the north eastern region, Central plain region and the south western region of the state.

2.2. *Rainfall data used for study*

The monsoon rainfall (June-September) data for the recent five decades (1971-2020) and the data on onset and withdrawal of monsoon in the state for the recent two decades (2001-2020) was collected by the India Meteorological Department (IMD), Chandigarh. The rainfall data for three major regions of Punjab was collected from agrometeorological observatories situated at different research stations of Punjab Agricultural University (PAU), Ludhiana. The data for the north eastern part was collected from Regional Research Station, Ballowal Saunkhri for the time period of 1984-2020. For the Central plain region, data was collected from an agrometeorological observatory situated at PAU, Ludhiana for five decades, *i.e.*, 1970-2020. For the south western region, data was collected from regional research station, Bathinda, for the time period of 1977-2020.

2.3. *Statistical tools for analysis of rainfall data*

The preliminary analysis, *viz.*, a computation of maximum value, minimum value, mean, standard deviation, standard error, coefficient of skewness, coefficient of kurtosis and variance in the monsoon rainfall for each station was conducted. The time series trend analysis was done for the departure of the current rainfall from the normal. The statistical significance of the time series the trend was done by plotting trend lines and using Man-Kendall (MK) test, whereas the magnitude of the trend was determined by the non-parametric Sen's estimator method.

The Mann-Kendall (MK) test was employed to assess the trends in rainfall. It is a test, which has no prerequisite conditions for the data to be normally distributed. The MK test is a non-parametric test which is based on a null hypothesis (H_0) that there is no trend, the data are independent and randomly ordered while the alternative hypothesis (H_a) supposes that there is a trend (Koudahe *et al.*, 2018). The value of Z (absolute) is used to determine if there is a trend or not at the selected significance level. A positive/negative value of Z indicates an upward/downward trend. The true slope (rate of change per unit time) was predicted using the Sen's slope (SS) estimator (Sen 1968).

3. Results and discussions

This section begins with variability in onset, withdrawal and duration of monsoon in Punjab. The four subsequent results sections are structured around important parts like variability in monsoon rainfall in Punjab, trend analysis of monsoon rainfall, regionwise monsoon rainfall variability analysis and thelast but most important part is about implications of variability in monsoon rainfall.

3.1. *Variability in onset, withdrawal and duration of monsoon in Punjab*

The monsoon current enters the Kerala state of India on the 1st of June and these winds reach Punjab state on the 1st of July. In Punjab, monsoon withdrawal normally occurs on 15th September. The changes in the climate on the global and national level are influencing the onset and withdrawal of the monsoon. The variability of onset and withdrawal of monsoon current and the amount of rainfall in Punjab during the last 21 years are presented in Table 1 and Fig. 2. The onset of monsoon in Punjab was delayed for eleven years, *i.e.*, by up to 7 days during six years (2003, 2004, 2007, 2010, 2014 and 2016), by 8-14 days during two years (2006 and 2012) and more than 15 days during three years (2002, 2017 and 2019). There was early onset of monsoon for only nine years (2001, 2005, 2008, 2011, 2013, 2015, 2018, 2020 and 2021). Though the normal withdrawal of monsoon from Punjab should occur up to 15th September, there has been delayed withdrawal from Punjab during the past two decades. The very late withdrawal ($\geq$15 days) of the monsoon current from the

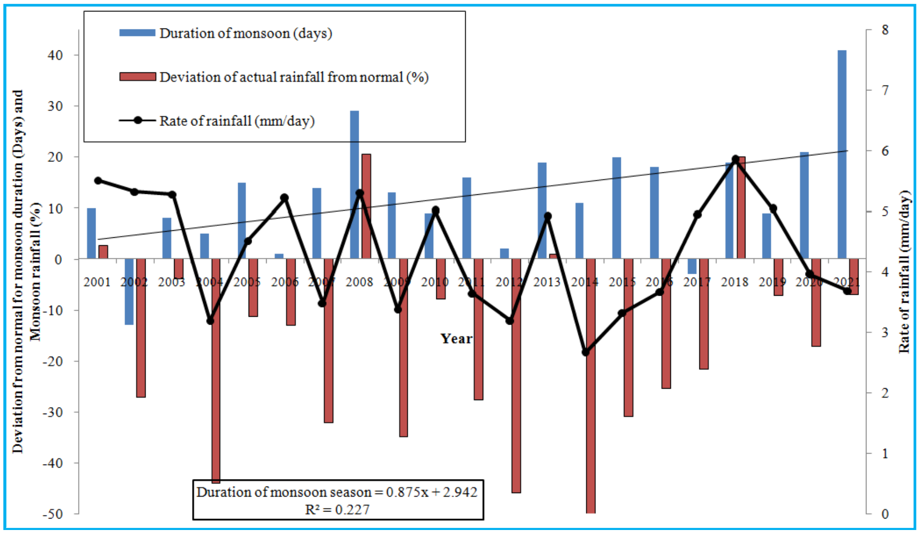

Fig. 2. Variability in duration of monsoon, rainfall/day and deviation of rainfall from normal in Punjab (2001 to 2021)

TABLE 1

Variability in onset, withdrawal and duration of monsoon current and the deviation in amount of monsoon rainfall in Punjab over the past two decades

Year	Onset date	Deviation from Normal (Days)	Withdrawal date	Deviation from Normal (Days)	Duration of monsoon season (Days)	Average rainfall (mm/day)	% Deviation of actual rainfall from normal
2001	24 June	**+7**	18 September	+3	87	5.51	+2.6
2002	19 July	-18	20 September	+5	64	5.32	-27.2
2003	5 July	-4	27 September	+12	85	5.28	-3.9
2004	8 July	-7	27 September	+12	82	3.19	-44.1
2005	29 June	+2	28 September	+13	92	4.51	-11.3
2006	10 July	-9	25 September	+10	78	5.21	-13.0
2007	4 July	-3	2 October	+17	91	3.48	-32.2
2008	16 June	+15	29 September	+14	**106**	5.31	**+20.3**
2009	1 July	0	28 September	+13	90	3.38	-36.0
2010	5 July	-4	28 September	+13	86	5.01	-8.0
2011	26 June	+5	26 September	+11	93	3.64	-7.0
2012	9 July	-8	25 September	+10	79	3.19	-47.0
2013	16 June	+15	19 September	+4	96	4.91	-2.0
2014	3 July	-2	28 September	+13	88	2.66	-50.0
2015	25 June	+6	29 September	+14	97	3.32	-31.0
2016	3 July	-2	5 October	+20	95	3.67	-29.0
2017	19 July	-18	30 September	+15	74	4.94	-21.0
2018	28 June	+3	1 October	+16	**96**	5.85	**+7.0**
2019	17 July	-16	10 October	+25	86	5.04	-7.0
2020	25 June	+6	30 September	+15	98	3.95	-17.1
2021	13 June	+18	08 October	+23	118	3.68	-7.0
Normal	**01 July**	-	**15 September**	-	**77**	**6.07**	**467 mm**

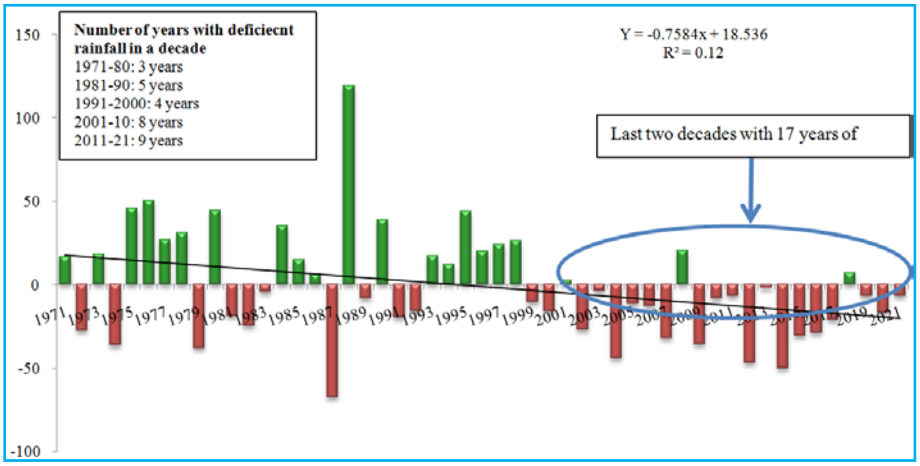

Fig. 3. Monsoon rainfall departure from normal rainfall over last five decades in Punjab (1971-2021)

state occurred in the month of October for seven years (2007, 2016, 2017, 2018, 2019, 2020 and 2021).

The normal duration of the monsoon in Punjab is 77 days (1 July to 15 September) which is increasing at0.8 day/year over the last two decades. During the last two decades, the duration of monsoon was reduced in only two years, *i.e.*, 2002 (13 days) and 2017 (03 days). But the monsoon rainfall was reduced by up to ~19% during nine years (2003, 2005, 2006, 2010, 2011, 2013, 2019, 2020 and 2021) and >20% during nine years (2002, 2004, 2007, 2009, 2012, 2014, 2015, 2016 and 2017). Interestingly, over the past 21 years, monsoon duration in Punjab was above normal for 19 years but above normal rainfall was received only during two years, *i.e.*, 2008 (+20.5% monsoon rainfall and duration of 106 days) and 2018 (+7% monsoon rainfall and duration of 96 days). The average rate of monsoon rainfall is 6 mm/day, during the past two decades it has been less than the normal rate but more than 5 mm/day for eight years, *i.e.*, 5.85 (2018), 5.51 (2001), 5.32 (2002), 5.31 (2008), 5.28 (2003), 5.21 (2006), 5.04 (2019) and 5.01 (2010).

3.2. *Variability in monsoon rainfall in Punjab*

The data on the amount of monsoon rainfall was analysed and the per cent departure from normal rainfall was calculated for the last five decades period (1971-2020) as presented in Fig. 3. The analysis indicates that during the five decades of study, 28 years (56%) received rainfall lower than normal monsoon rainfall in the state. But during the recent two decade (2001-2020), 17 years (80%) were deficient in the monsoon rainfall, though the duration of monsoon current was more than normal (77 days) in the state. So, in recent years the monsoon rainfall has declined in the state at a faster rate. These results are in concurrence with a study by Bushra *et al.* (2020), wherein they analysed rainfall trends in different parts of India using non-parametric techniques and revealed that rainfall during monsoon period in Punjab is showing a significant decreasing trend with z value>2.0.

3.3 *Region wise analysis of monsoon rainfall in Punjab*

The monsoon rainfall received during four months, (June to September) in North eastern (station Ballowal Saunkhri), Central (station Ludhiana) and South western (station Bathinda) parts of Punjab state is highly erratic and variable in time and space. The descriptive statistics of the monsoon rainfall in these three parts were calculated for the past decades. Over the past four decades (1984-2020), Ballowal Saunkhri, which falls under theSub mountain undulating zone, received the maximum amount of rainfall (1793.1 mm) during the monsoon season as compared to monsoon rainfall of the past five decades of Ludhiana (Central plain zone) and Bathinda (Western Zone) where it was 1241.9 and 866.4 mm respectively (Table 2). During the past few decades, Bathinda received minimum monsoon rainfall (106.2 mm) as compared to Ludhiana (164.4 mm) and Ballowal Saunkhri where it was 441.1 mm. As the table shows, the coefficient of skewness varied from 0.6 to 1.4, kurtosis varied between 0.2 to 3.0. For the time series data to be considered normally distributed, the coefficient of skewness and kurtosis must be equal to 0 and 3, respectively.

3.4. *Trend analysis of monsoon rainfall and rainy days*

The effect of climate change on precipitation was analyzed for the three regions of state by applying the Mann-Kendall (MK) test. The trend analysis of monsoon

TABLE 2

Descriptive statistics of the monsoon season monthly rainfall in Punjab

Parameter	June	July	August	September	Monsoon (J-S)
North eastern region (BallowalSaunkhri)					
Maximum	407.7	769.6	545.9	594.7	1793.1
Minimum	9.9	66.1	45.1	10.6	441.1
Mean	111.0	274.4	298.7	149.5	833.6
Median	85.2	238.2	299.0	105.5	818.3
Std. Deviation	86.5	148.0	113.0	122.6	270.2
Variance	7476.0	21911.2	12761.0	15038.8	73018.6
Std. Error	14.2	24.3	18.6	20.2	44.4
Kurtosis	2.9	2.3	-0.4	3.8	3.0
Skewness	1.5	1.3	0.1	1.8	1.4
Percent contribution to total rainfall	13.3	32.9	35.8	17.9	-
Central plain region (Ludhiana)					
Maximum	352.9	553.1	513.4	668.6	1241.9
Minimum	3.5	32.1	24.5	0.0	164.4
Mean	81.6	223.8	188.7	104.7	598.7
Median	50.3	199.7	157.8	63.2	580.5
Std. Deviation	74.5	131.3	112.7	125.8	236.6
Variance	5554.4	17228.1	12705.2	15818.9	55985.4
Std. Error	10.5	18.6	15.9	17.8	33.5
Kurtosis	4.1	-0.1	0.1	8.9	0.4
Skewness	2.0	0.7	0.8	2.7	0.7
Percent contribution to total rainfall	13.6	37.4	31.5	17.5	-
South western region (Bathinda)					
Maximum	426.8	504.9	408.1	532.1	866.4
Minimum	5.7	0.2	0	0	106.2
Mean	63.8	138.2	115.8	80.9	398.8
Median	36.8	122.2	87.6	57.3	414.4
Std. Deviation	73.0	98.8	98.9	97.0	174.5
Variance	5332.1	9768.4	9784.3	9418.0	30442.9
Std. Error	11.0	14.9	14.9	14.6	26.3
Kurtosis	13.8	3.9	1.0	10.4	0.2
Skewness	3.2	1.6	1.3	2.8	0.6
Percent contribution to total rainfall	16.0	34.6	29.0	20.2	-

rainfall and rainy days for the three regions was conducted by drawing trend lines along with regression equation [Figs. 4(a-c)]. The decadal variability in monsoon rainfall and rainy days was estimated by calculating z-statistics [Figs. 5(a-c)] and Sen's slope (Tables 3&4).

The rainfall as well as rainy days of monsoon season at Ballowal Saunkhri showed a declining trend [Fig. 4(a)]. Amongst the four months the decrease in rainfall was variable over the decades. The decline in rainfall during June month was witnessed during two decades (1984-90

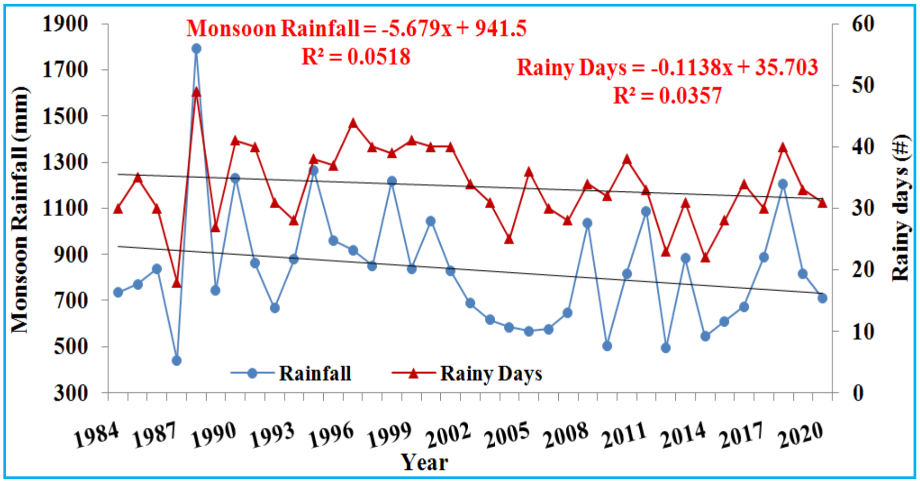

Fig. 4(a). Trend of monsoon rainfall and rainy days in north eastern region, Ballowal Saunkhri (1984-2020)

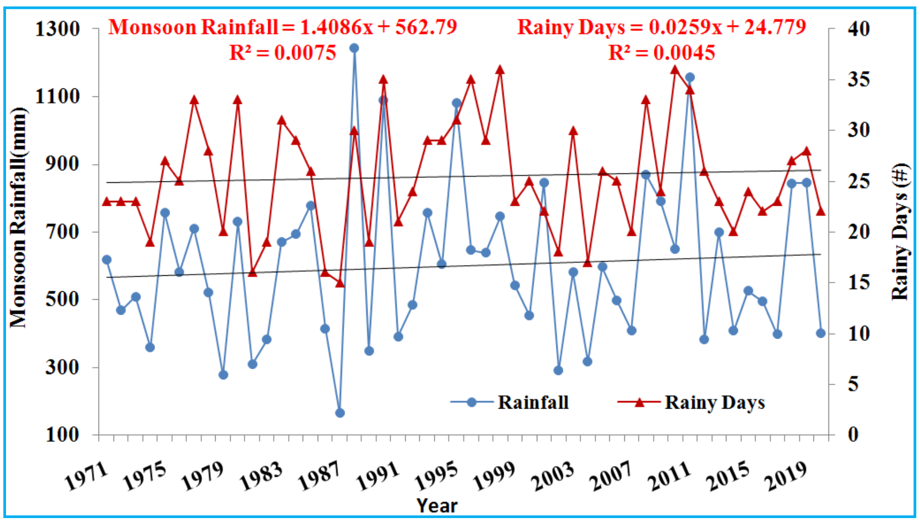

Fig. 4(b). Trend of monsoon rainfall and rainy days in central region, Ludhiana (1971-2020)

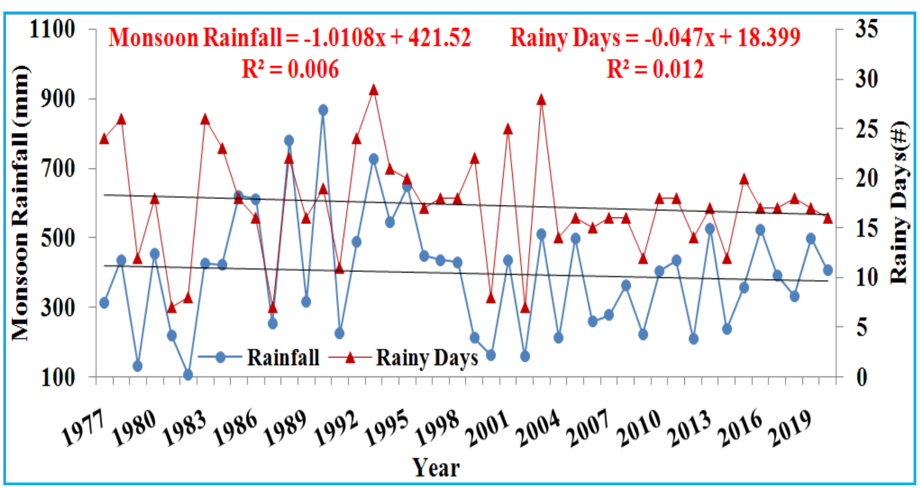

Fig. 4(c). Trend of monsoon rainfall and rainy days in south western region, Bathinda (1977-2020)

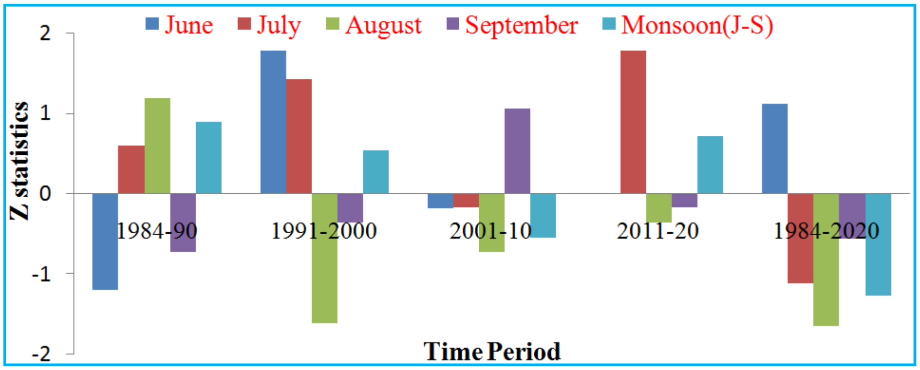

Fig. 5(a). Decadal variability in monsoon rainfall in north eastern region, Ballowal Saunkhri (1984-2020)

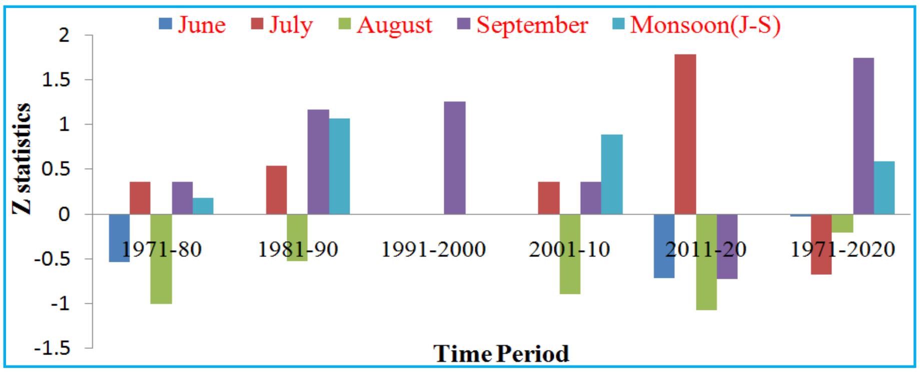

Fig. 5(b). Decadal variability in monsoon rainfall in central region, Ludhiana (1971-2020)

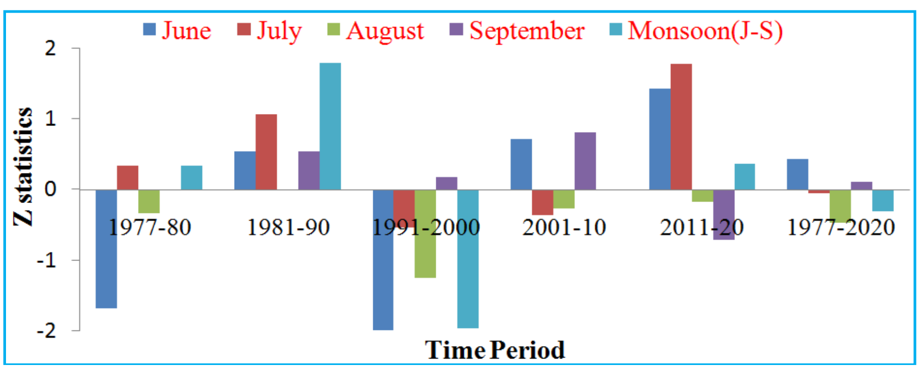

Fig. 5(c). Decadal variability in monsoon rainfall in south western region, Bathinda (1977-2020)

and 2001-10), July month during one decade (2001-10), August month during three decades (1991-2000, 2001-10 and 2011-20) decades and September month during three decades (1984-90, 1991-2000 and 2011-2020). Analysis of 36 years indicates increase in June month rainfall with Senslope value of 1.51. Whereas, July, August and September months showed decrease in rainfall with Sen slope values of 2.5,3.14 and 0.69, respectively. This has further led to decrease in entire monsoon rainfall with Sen's slope value of 4.77 at Ballowal Saunkhri (Table 3). The z-statistics analysis of monsoon rainfall and rainy days was conducted and presented in Figs. 5(a) and 6(a). This analysis showed significant decrease in August and overall monsoon rainfall during 36 years with values 1.65 and 1.27 respectively. In another study by Kaur *et al.* (2021) the trend analysis of rainfall in the lower Shivaliks of Punjab state in the same region during the last 29 years also revealed that rainfall depicted a decreasing trend.

Analysis of monsoon rainfall at Ludhiana showed increasing trend of rainfall and rainy days during the recent five decades [Fig. 4(b)]. Amongst the four months the decrease in rainfall/rainy days was variable over the decades [Figs. 5(b) and 6(b)]. The decline in rainfall

TABLE 3

Sen slope estimator for rainfall variability in different zones of Punjab

Months	Decades					1971-2020
	1971-80	1981-90	1991-2000	2001-10	2011-2020	
North eastern region (BallowalSaunkhri)						
June	--	-13.5	11.1	-2.9	0.1	1.51
July	--	40.8	25.4	-5.4	13.6	-2.50
August	--	18.4	-11.7	-5.1	-2.2	-3.14
September	--	-6.60	-2.03	17.5	-3.4	-0.69
Monsoon (J-S)	--	68.2	17.0	-13.5	24.0	-4.77
Central plain region (Ludhiana)						
June	5.4	2.28	0.02	1.15	-18.7	-0.01
July	9.6	8.4	1.45	20.5	19.38	-0.71
August	-7.9	-7.3	0.57	-11.9	-14.4	-0.25
September	0.69	22.7	6.7	2.73	-3.95	1.12
Monsoon (J-S)	6.5	61.8	6.8	23.7	-1.16	1.22
South western region (Bathinda)						
June	-15.9	1.91	-8.7	3.5	3.6	0.17
July	56.7	15.2	-7.9	-3.3	13.0	-0.04
August	-6.9	-1.84	-12.7	-4.0	-3.0	-0.24
September	-6.1	7.2	1.43	8.00	-6.6	0.03
Monsoon (J-S)	27.9	63.8	-40.5	2.12	9.8	-0.60

TABLE 4

Sen slope estimator for rainy days variability in different zones of Punjab

Month	Decades					1971-2020
	1971-80	1981-90	1991-2000	2001-10	2011-2020	
North eastern region (BallowalSaunkhri)						
June	--	-0.25	0.00	-0.40	0.00	0.00
July	--	0.50	0.44	0.00	0.50	0.00
August	--	0.50	0.00	0.00	0.14	-0.06
September	--	1.00	0.13	0.38	0.00	0.00
Monsoon (J-S)	--	1.20	0.60	-0.22	1.00	-0.17
Central plain region (Ludhiana)						
June	0.00	0.00	0.00	-0.20	-0.20	0.00
July	0.67	0.00	0.33	0.78	0.50	0.00
August	0.00	0.25	0.00	0.33	-0.50	0.00
September	0.00	0.28	0.00	0.29	-0.25	0.00
Monsoon (J-S)	0.83	0.57	1.00	1.00	-0.33	0.00
South western region (Bathinda)						
June	-1.83	0.22	-0.13	-0.22	0.00	0.00
July	0.00	0.00	-0.40	-0.40	0.29	-0.04
August	-0.25	0.00	-0.50	0.00	0.00	0.00
September	-0.67	0.25	0.11	0.00	-0.17	0.00
Monsoon (J-S)	-3.00	0.20	-1.00	0.00	0.00	-0.05

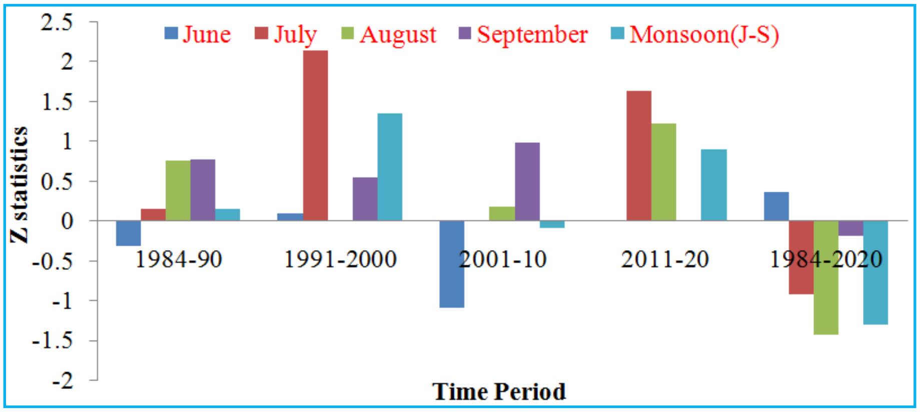

Fig. 6(a). Decadal variability in monsoon rainy days in north eastern region, Ballowal Saunkhri (1984-2020)

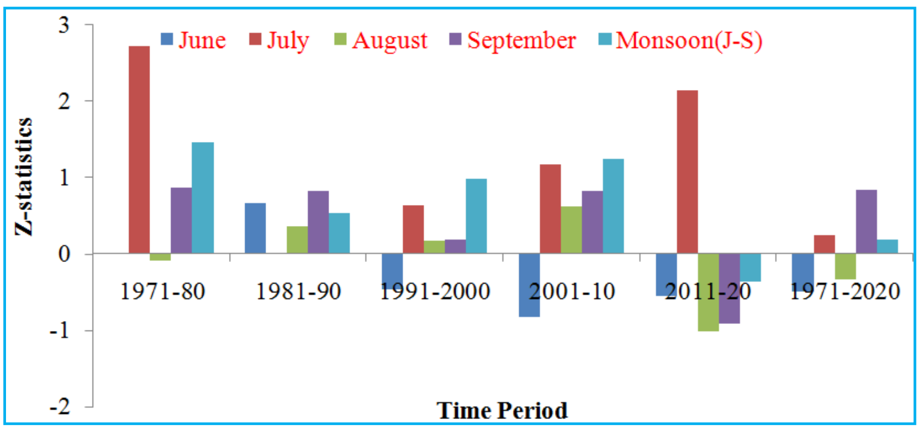

Fig. 6(b). Decadal variability in monsoon rainy days in central region, Ludhiana (1971-2020)

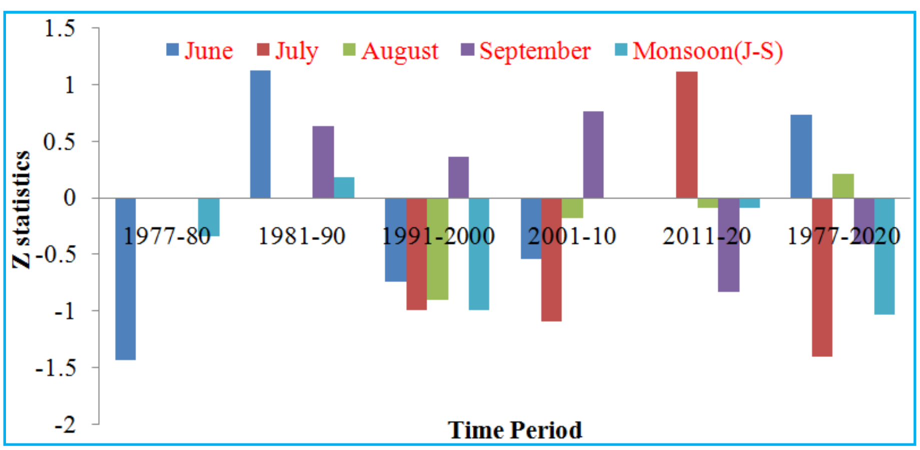

Fig. 6(c). Decadal variability in monsoon rainy days in south western region, Bathinda (1977-2020)

during June, August and September months was witnessed during 2011-20. At Ludhiana, over the recent five decades, the monsoon rainfall showed an overall increase in rainfall with Sen's slope value of 1.22 (Table 3) but rainy days exhibited no change during different months as well as entire monsoon period with Sen's slope value 0.00 (Table 4). The z-statistics analysis of last five decades monsoon rainfall indicate significant increase in September month rainfall with z-value of 1.74, whereas rainy days also showed increase though it was not significant [Figs. 5(b) and 6(b)]. The results of an earlier study by Hundal *et al.* (1997) for Ludhiana also depicted an increasing trend for both annual as well as *kharif* season rainfall over 30 years period.

The rainfall as well as rainy days of monsoon season at Bathinda showed a declining trend [Fig. 4(c)]. Amongst the four months the decrease in rainfall was variable over the decades. The decline in rainfall during June month was witnessed during two decades (1977-80 and 1991-2000), July month during two decades (1991-2000 and 2001-10), August month during five decades (1977-80, 1981-90, 1991-2000, 2001-10 and 2011-20) decades and September month during two decades (1977-80 and 2011-20). Analysis of 44 years indicates increase in June month rainfall with Sen's slope value of 0.17. Whereas, July and August months showed decrease in rainfall with Sen's slope values of 0.04 and 0.24. This further lead to decrease in entire monsoon rainfall and rainy days with Sen's slope value of 0.60 and 0.05, respectively. Over the five decades, there was a decrease in the monsoon season rainy days with Sen's slope values of -3.00 (1977-80) and -1.00 (1991-2000) as shown in Table 4. The z-value indicate decrease in monsoon rainfall and rainy days at Bathinda during last 44 years [Figs. 5(c) and 6(c)]. The z-value indicate significant decrease in monsoon rainfall during one decade 1991-2000 with z-value 1.97. The z-value indicates significant decrease in number of rainy days during last 44 years (1977-20). Similarly, Gill *et al.* (2010) also reported a decreasing trend in rainfall at Bathinda during 1984-2009.

3.5 *Implications of variability in monsoon rainfall*

The growth and production/productivity of crops gets adversely affected during the monsoon rainfall deficient years since the available water in the root zone of crops is replenished either by rainwater (Gupta *et al.* 2014) or by irrigation. On the other hand, if irrigation is applied, then the ground water resources get depleted. This condition holds true for crop production in Punjab wherein the farmers irrigate their crops (paddy) by tube well irrigation during deficient monsoon rainfall crop years. The studies on depleting water resources in the state have been documented in several earlier studies (Kaur and Vatta, 2015) and also in future prediction studies (Kaur *et al.*, 2021).

In the second grey scenario, the surplus rainwater received during the excessive monsoon rainfall years (such as 1975, 1977, 1980, 1985, 1988, 1990, 1993, 1995, 1998, 2001, 2008, 2009, 2011 and 2018) is not judiciously utilized by agricultural crops due to runoff losses or inundation of the crop field. So, the variability in monsoon rainfall is one of the major abiotic components which is highly responsible for determining water resources and crop productivity.

4. Conclusions

During the monsoon season, paddy is the main crop grown in the state. The area under paddy has increased from 0.6 Mha during 1970 (Singh *et al.*, 2006) to 3.01 Mha during 2018 (Anonymous 2019), *i.e.*, by>400 percent. To irrigate this water guzzling paddy crop, farmers of the state are dependent either on monsoon rainfall or on underground water. But over the last two decades, the duration of monsoon currents has increased from the normal of 77 days in Punjab, but the rate of monsoon rainfall is well below the average of 6 mm/day. Also, the distribution of the rainfall during the season is highly variable during the four months. The sudden and heavy shower of rainfall received in a short span of time is not only declining the water productivity of crops but also hampering the recharging of underground aquifers (Kaur and Vatta, 2015). In an ideal situation, the low intensity of rainfall is a booster for the growth of crops as well as for the recharging of the underground aquifer. But the declining trend of rainfall in the North eastern regions of the state lying in the foothills of Shivalik is redefining the average distribution of rainfall in the region. The abrupt changes in the monthly distribution of monsoon rainfall, *i.e.*, from 13, 33, 36, 18 percent during the months of June, July, August and September respectively (Table 2) is also not helping the situation as less rainfall during June and July causes a drain on the ground water resources. Later during the end of the season, heavy rainfall during September along with an extension in monsoon currents delay the maturity and hamper harvesting of the paddy crop. The cumulative effect of truant monsoon rainfall, very high cropping intensity and indiscriminate pumping out of underground water is pushing the water scarce state towards a water deficit desert.

Disclaimer : The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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