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A study on precipitation trends and drought climatology over Jammu & Kashmir, India: 1980-2020

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सार – 1980 से 2020 की अवधि के दौरान जम्मू और कश्मीर में वर्षा के रुझानों और सूखे की क्लाइमेटोलॉजी पर एक अध्ययन किया गया है। अलग-अलग महीनों में वर्षा के रुझानों का विश्लेषण मेकेन्डल परीक्षण, स्पीयरमैन रो परीक्षण, लीनियर रिग्रेशन विश्लेषण और परिवर्तनात्मकप्रवृत्तिविश्लेषण का उपयोग करके किया गया। मेकेन्डल परीक्षण के विश्लेषण से पता चला कि मॉनसून के बाद के मौसम (अक्टूबर और दिसंबर) के दौरान श्रीनगर, काजीगुंड और बडेरवाह के लिए क्रमशः -1.06, -1.24 और -1.03 मिमी/वर्ष के स्लोप वैल्यू के साथ वर्षा में महत्वपूर्ण कमी का रुझान (p<0.01) देखा गया। इसी तरह, मॉनसून से पहले के मौसम (मार्च-मई) के लिए बडेरवाह और काजीगुंड के लिए -1.59 और -1.58 मिमी/वर्ष के स्लोप वैल्यू के साथ वर्षा में महत्वपूर्ण कमी का रुझान (p<0.01) देखा गया। मार्च महीने में कुपवाड़ा के लिए -2.94 मिमी/वर्ष और मई महीने में बडेरवाह के लिए -1.73 मिमी/वर्ष के स्लोप वैल्यू के साथ वर्षा में महत्वपूर्ण कमी का रुझान (p<0.01) देखा गया। परिवर्तनात्मकप्रवृत्तिविश्लेषण के परिणामों से पता चला कि मार्च महीने में श्रीनगर, काजीगुंड, कुपवाड़ा और बडेरवाह के लिए क्रमशः -1.56, -3.16, -4.11 और -1.94 मिमी/वर्ष के स्लोप वैल्यू के साथ वर्षा में महत्वपूर्ण कमी का रुझान (p<0.01) देखा गया। सितंबर महीने में श्रीनगर और काजीगुंड के लिए क्रमशः 1.18 और 1.87 मिमी/वर्ष के स्लोप वैल्यू के साथ वर्षा में महत्वपूर्ण वृद्धि का रुझान (p<0.01) देखा गया। मौसमी विश्लेषण के परिणामों से पता चला कि मॉनसून के बाद के मौसम (अक्टूबर-दिसंबर) में श्रीनगर, काजीगुंड और कुपवाड़ा के लिए क्रमशः -0.95, -1.08 और -0.64 मिमी/वर्ष के स्लोप वैल्यू के साथ वर्षा में महत्वपूर्ण कमी का रुझान (p<0.01) देखा गया। वार्षिक वर्षा के रुझानों से अध्ययन किए गए सभी स्टेशनों के लिए महत्वपूर्ण कमी का रुझान देखा गया। कटरा में सबसे ज़्यादा वर्षा में कमी देखी गई, जिसका स्लोप वैल्यू -6.68 mm/year था। सभी स्टेशनों के लिए मौसम संबंधी सूखे की संभावना तय की गई और नतीजों से पता चला कि अध्ययनके कुल 40 सालों में से, श्रीनगर,काज़ीगुंड और कुपवाड़ा के लिए 6 वर्षमध्यम सूखे वाले वर्ष थे (1985, 1990, 1999, 2000, 2001 और 2002), जम्मू और कटरा के लिए 2 मध्यम सूखे वाले वर्ष (1987 और 2009) और बदेरवाह के लिए 2 मध्यम सूखे वाले वर्ष (1999 और 2001)। एक इनकंप्लीट गामा डिस्ट्रीब्यूशन मॉडल फिट करके, प्रत्येक मानक सप्ताह के लिए अलग-अलग संभावना स्तर (10-90%) पर वर्षा की मात्रा, जिसे पक्की वर्षा कहा जाता है, परिकलित की गई है। विश्लेषण के नतीजों से पता चला कि श्रीनगर, काज़ीगुंड, कुपवाड़ा और बदेरवाह स्टेशनों के लिए चौथे से 16वें मानक मौसम विज्ञान हफ़्ते के दौरान पश्चिमी विक्षोभ का सबसे ज़्यादा असर और 28वें से 37वें मानक मौसम विज्ञान हफ़्ते के दौरान मॉनसून का असर रहा। मॉनसून गतिविधि का असर खास है और जम्मू और कटरा स्टेशन पर 25वें से 40वें मानक मौसम विज्ञान हफ़्ते के दौरान सबसे ज़्यादा गतिविधि पाई गई।

ABSTRACT. A study has been conducted on precipitation trends and drought climatology over Jammu and Kashmir during the period 1980 to 2020. Trends of precipitation over different months were analyzed using Mekendal test, Spearman Rho's test, linear regression analysis and Innovative trend analysis. The analysis of Mekendal test showed decreasing significant precipitation trends ($p < 0.01$) during post monsoon season (October and December) with slope value -1.06, -1.24 and -1.03 mm/year for Srinagar, Qazigund and Baderwah respectively. Similar decreasing significant precipitation trends ($p < 0.01$) were observed for pre-monsoon season (March-May) with slope value -1.59 and -1.58 mm/year for Baderwah and Qazigund. Decreasing significant precipitation trends ($p < 0.01$) were observed for Kupwara in the month of March with slope value -2.94 mm/year and Baderwah in the month of May with slope value -1.73 mm/year. The results of Innovative trend analysis showed decreasing significant precipitation trends ($p < 0.01$) in the month of March for Srinagar, Qazigund, Kupwara and Baderwah with slope value -1.56, -3.16, -4.11 and -1.94 mm/year respectively. Increasing significant precipitation trends ($p < 0.01$) in the month of September for Srinagar and Qazigund with slope value 1.18 and 1.87 mm/year respectively. The seasonal analysis results showed decreasing significant precipitation trends ($p < 0.01$) in post-monsoon season (October-December) for Srinagar, Qazigund and Kupwara with slope value -0.95, -1.08 and -0.64 mm/year respectively. The annual precipitation trends showed decreasing significant trend for all the stations under consideration. The highest precipitation reduction was observed over Katra with slope value -6.68 mm/year. Probability of occurrence of Meteorological drought was determined for all the stations and results showed that out of total 40 years of study, 6 years were identified as moderate drought years for Srinagar, Qazigund and Kupwara (1985, 1990, 1999, 2000, 2001 and 2002), 2 moderate drought years for Jammu, and Katra (1987 and 2009) and 2 moderate drought years for Baderwah (1999 and 2001).By fitting an incomplete gamma distribution model, the amount of rainfall at various probability levels (10–90%) known as assured rainfall has been calculated for each standard week. The analysis results revealed the maximum impact of western disturbances during 4^{th} to 16^{th} standard Meteorological Week and impact of Monsoon during 28^{th} to 37^{th} standard Meteorological Week for stations Srinagar, Qazigund, Kupwara and Baderwah. The impact of Monsoon activity is notable and found maximum activity during 25^{th} to 40^{th} standard Meteorological Week over Jammu and Katra station.

Key words – Precipitation trends, Drought and monsoon.

1. Introduction

Jammu and Kashmir is the northernmost state of India, situated in the western Himalaya having an area of 42,241 sq. km. It is located between 32°17′ N and 37°05′ N latitude and 72°31′ E and 80°20′ E longitude with widely varying topography. With the exception of the far southwest, which is a low-lying plain area, it features a rugged topography with high mountains and numerous valleys. The Jammu region is made up of plains, foothills, and mountains covered with forest. The Jammu plains are an extension of the vast north Indian plains that rise from Punjab and continue to the Shivalik hills. The Shivalik hill is an outlying Himalayan mountain range that joins with the Pir Panjal range. The Kashmir valley is divided from the Jammu area by the Pir Panjal Mountain.

Studies on rainfall trends, rainfall variability and changes in different climatic parameters are necessary for these regions because, an average rainfall index for a vast country like India may not be an adequate indicator for various applications like agriculture, water and river basin management. Rainfall is the primary parameter in the hydrological cycle and varies greatly in amount, intensity and duration, both spatially and temporally, imparting a substantial influence on socioeconomic well-being. Many studies have been conducted across the world to understand the variability of rainfall at various scales (Guhathakurta and Rajeevan, 2008, Sahany *et al*., 2018). The analysis of rainfall trends is performed because it has a direct influence on agriculture, water resources management, and hydrology (Goswami *et al.,* 2006, Duhan *et al.*, 2000 and Haigh 2004). In the past several studies have been carried out to understand large spatial heterogeneity in the rainfall pattern at different temporal scales over the Indian region (Rajeevan *et al*., 2010; Deepesh *et al*., 2019, Taxak *et al*., 2014). Some previous studies in this context in India had identified rainfall coherent zones for applications like watershed (national and river basin level) management, flood and drought analysis, agricultural management, and improving regional forecast based on rainfall variability (Gadgil *et al*., 1993), and similarity in synoptic characteristics with the objective of identifying rainfall coherent zones to understand the processes/mechanisms that cause rainfall variability (Saikranthi *et al*., 2013).

The Indian Summer Monsoon (ISM) and Western Disturbances (WD) dominate atmospheric circulation patterns over Kashmir valley (Ray *et al*., 2015), although the impact of these weather systems has not been assessed. In contrast to the Greater Himalayan foothills, which get precipitation from WD, the Pirpanjal mountain range receives a significant contribution from both WD and ISM (Kumar and Acharya, 2016, Rashid *et al*., 2019). The climate of the northwestern Himalayas is mainly influenced by the WD from October to May (Dimri *et al*., 2015) and by ISM from July to September (Bhutiyani *et al*., 2010). The changing patterns of monsoonal rainfall over India (Naidu *et al*., 2009), decreased rainfall trends in Indian Himalayas (Basistha *et al.*, 2008), decreasing annual rainfall and rainy days in India (Kumar *et al.*, 2011) are some of obvious examples that can be seen throughout the world describing the impacts of climate change. Increased or decreased precipitation as well as changes in its spatiotemporal distribution would have an impact on runoff, soil moisture, and groundwater reserves as well as the frequency of droughts and floods (Lal, 2003, Kumar & Jain, 2011).

For planning suitable agricultural operations or activities, the idea of assessing probabilities with respect to a certain amount of rainfall is quite helpful. But in regions of uncertain precipitation, like Jammu and Kashmir, or in an arid/semiarid climate, one cannot fully depend on averages. The Markov chain model has been widely used to study the probabilities of rainfall occurrence (Kar, 2002; Singh *et al*., 2008).

The policy-makers frequently demand the rainfall trend at a high spatial resolution for the state to develop and execute policies for regions displaying declining rainfall patterns. In this context, the present study was carried to understand the spatio-temporal variability of rainfall and drought climatology over Jammu and Kashmir and to study long-term trends in observed rainfall from 1980 to 2020 using statistically robust approaches.

2. Data and methodology

2.1. *Study area and data collection*

In the present study we used daily precipitation data of 6 stations of J&K for the period 1980-2020 from India Meteorological Department. Locations of the stations are enlisted in Table 1.

TABLE 1

Latitude and Longitude of the stations

Location of station	Coordinates		Altitude AMSL (m)
	Latitude (°N)	Longitude (°E)	
Srinagar	34°03′	74°48′	1587
Qazigund	33°35′	75°09′	1690
Kupwara	34°01′	74°15′	1609
Jammu	32°55′	74°52′	367
Katra	32°58′	74°55′	1170
Bhaderwah	32°58′	75°43′	1688

2.2. *Statistical analysis*

Several statistical methods including both parametric and nonparametric, have been proposed to find trends in time series namely linear regression, Spearman's Rho test, Mann-Kendall test, and innovative trend analysis. In this work, precipitation patterns were analysed using the Mann-Kendall, Spearman's Rho and innovative trend analysis tests, and trend magnitude was determined using linear regression.

Mann–Kendall trend test: The Mann–Kendall test statistic S is calculated by using

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(xj - xi)$$

where n is the number of data points, xi and xj are the data values in time series i and j (j >i), respectively and sgn (xj - xi) is the sign function determined as:

$$sgn(xj - xi) = \begin{cases} 1\ if\ (xj - xi) > 0 \\ 0\ (xj - xi) = 0 \\ -1\ (xj - xi) < 0 \end{cases}$$

The positive (negative) value of S indicates an increasing (decreasing) trend. If n is larger than 10 and time series has approximately normal distribution, then the variance of the slope value becomes

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

where p is the number of tied groups; ti is the number of ties of extent i. The standard normal test statistics Z used for detecting a significant trend is expressed as:

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

Positive values of Zs indicate increasing trends while the negative Zs show decreasing trends.

Linear regression method: A linear regression method is one of methods which are used to estimate a slope. The slope indicates the mean temporal change of the studied variable. Positive values of the slope show increasing trends, while negative values of the slope indicate decreasing trends. A linear regression line has an equation of the form

$$y = a + bx$$

where x = the explanatory variable, y = the dependent variable, b = the slope of the line and a = the intercept.

Spearman's Rho test Spearman's Rho test is non-parametric method commonly used to verify the absence of trends. Its rank correlation coefficient D and the standardized rank correlation coefficient Z_d are expressed as follows:

$$D = 1 - \frac{6\sum_{i=1}^{n}(R(Xi) - i))^2}{n(n^2 - 1)}$$

$$Z_d = D\sqrt{\frac{n-2}{1-D^2}}$$

where R(Xi) is the rank of i^{th} observation Xj in the time series and n is the length of the time series. Positive values of Z_d indicate increasing trends while negative Z_d show decreasing trends.

Innovative trend analysis: The graphical innovative trend analysis (ITA) proposed by Şen (2012) was also utilized to detect time series trends. To determine the trend, a recorded time series is split into two equal parts and sorted separately in ascending or descending order. If the time series is trendless, all data points will fall on the 1:1 line. A monotonically growing or declining trend is indicated by all data points being above or below the 1:1 line, respectively. Unusual circumstances where data points fall below, above, or on the 1:1 line are classified as low, medium, and high values.

The Markov chain model has been used to study the probabilities of rainfall occurrence. The data were collected and processed on Excel sheets and Weather Cock Software according to the requirements to obtain critical results of the study area.

Markov chain probability model for dry and wet week analysis:

Weekly rainfall were extracted from daily rainfall data and used in a Markov chain probability model to analyze original, conditional, and consecutive dry and wet spells. In this process, weeks receiving 20 mm or more of rainfall are considered as wet and the remaining weeks as dry. Different formulae followed in this analysis are given below.

(i) Initial probability

$$P\ (d) = F\ (d) / N \quad (1)$$

$$P\ (w) = F\ (w) / N \quad (2)$$

where, P (d), F (d), P (w), F (w) and N stands for dry weeks probability, indicates dry week frequency, indicates wet weeks probability, indicates wet weeks frequency, and indicates total number of years respectively.

(ii) Conditional probability

$$P\ (dd) = F\ (dd) / F(d) \quad (3)$$

$$P\ (ww) = F\ (ww) / F\ (w) \quad (4)$$

$$P\ (wd) = 1 - P\ (dd) \quad (5)$$

$$P\ (dw) = 1 - P\ (ww) \quad (6)$$

where, P (dd) represents the probability for a dry week such that the previous dry week precede by dry week, P (ww) represents the probability for wet week preceded by wet week, F (ww) represents the Frequency of wet week preceded by wet week, P (wd) represents the probability for wet week preceded by a dry week, P (dw) represents the probability for dry week preceded by wet week.

(iii) Consecutive dry and wet week probabilities

$$P\ (2d) = P\ (dW1) \times P\ (ddW2) \quad (7)$$

$$P\ (3d) = P\ (dW1) \times P\ (ddW2) \times P\ (ddW3) \quad (8)$$

$$P\ (2w) = P\ (wW1) \times P\ (wwW2) \quad (9)$$

$$P\ (3w) = P\ (wW1) \times P\ (wwW2) \times P\ (wwW3) \quad (10)$$

where, P (2d) represents the probability of two consecutive dry weeks, P (dW1) represents probability 1st dry week, P (ddW2) represents the probability of the 2nd dry week preceded by dry week, P (3d) represents probability three consecutive dry weeks, P (2w) represents the probability of two consecutive dry weeks, P (wW1) indicates the probability of 1st wet week, P (wwW2) represents the probability of 2nd wet week preceded by wet week, P (3w) represents three consecutive wet weeks, and $P(wwW3)$ represents the probability of 3rd wet week preceded by wet week.

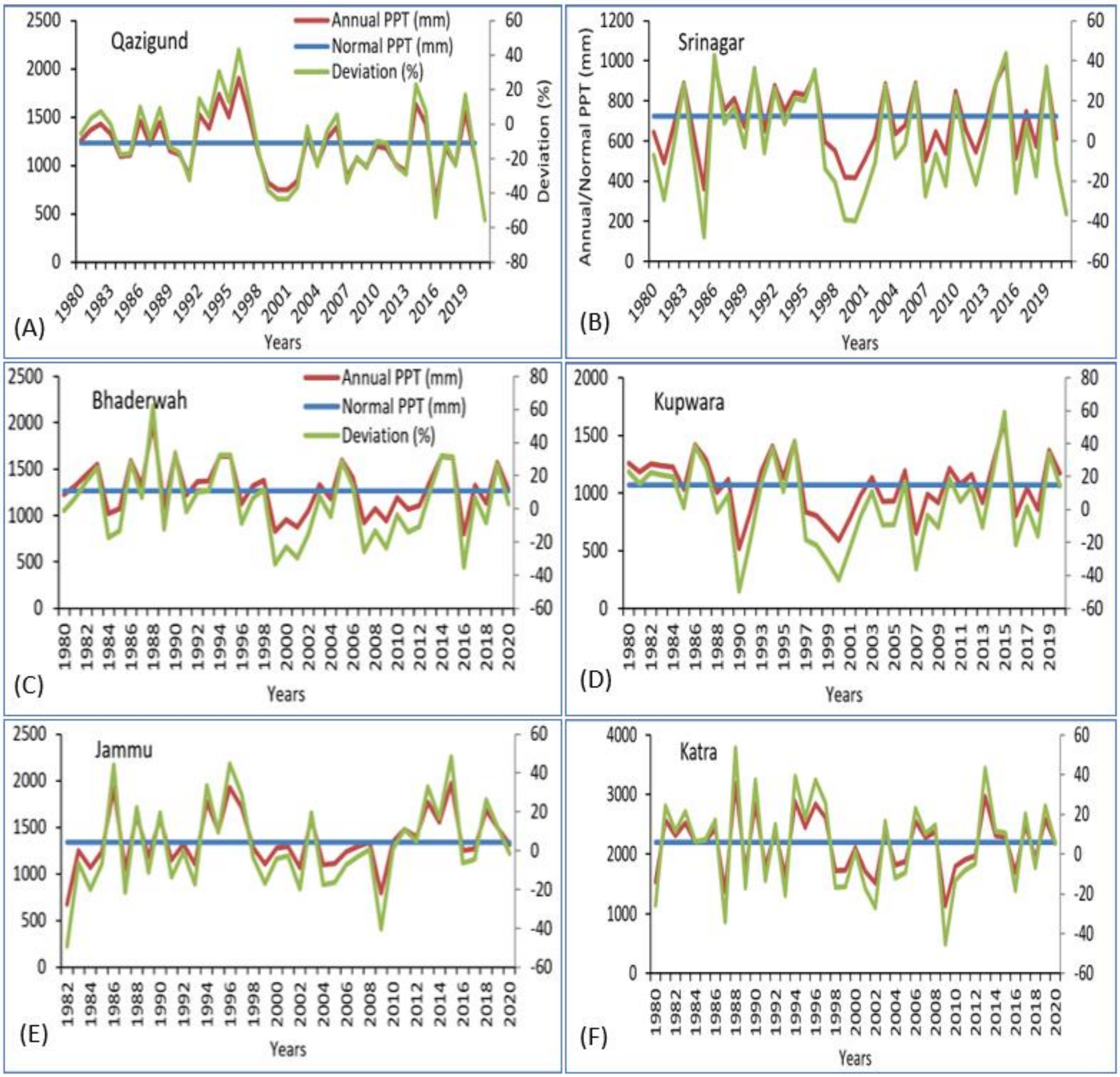
3. Results and discussion

The descriptive statistics of precipitation for each station during study period was carried out and results revealed highest standard deviation (SD 18.35) and mean (6.0) for Baderwah and least for Srinagar (SD 6.3 and mean 1.94) station (Table 2). The highest standard deviation for Baderwah is due to the fact that data values are more spread out of the mean thus exhibiting more variation. The area is influenced by both Western disturbances (WD) during winter and SW Monsoon during the Monsoon Period. Rest of the stations is either influenced by WD or SW Monsoon.

TABLE 2

Descriptive statistics of Precipitation over stations under study

Station Name	Annual Average Precipitation (mm)	Standard Deviation (mm)	Coefficient of variation (%)
Srinagar	722	6.30	32.1
Qazigund	1235	12.30	33.3
Kupwara	1069	8.00	26.6
Jammu	1338	13.10	35.1
Katra	2198	10.30	29.4
Bhaderwah	1262	18.35	30.9



Figs.1(a-f). Figures showing Annual Precipitation, Normal Precipitation and Deviation % of stations under study area

Trends of Precipitation over different months were analyzed using Mekendal test, Spearman's Rho test, linear regression analysis and Innovative trend analysis. The analysis of Mekendal test showed decreasing significant precipitation trends ($p<0.01$) for Srinagar in the month of October (slope value -2.098 mm/year), Qazigund in the month of May (-2.135) and Kupwara in the month of March and December (slope value -2.012 and -2.008 mm/year) respectively. Similar results were also observed in the month of March and December by Kupwara station for Spearman Rho and linear trend analysis. The seasonal analysis results showed increasing significant trends during winter (January and February) for Srinagar with slope value 2.030 and 1.960 for Mekendal and Spearman Rho test, while it showed decreasing significant trends during Pre-Monsoon season (March to May) for Qazigund (slope value -2.057) and Kupwara (-1.975) respectively. The Jammu Station showed decreasing significant trends in the month of January (slope value -2.734) and increasing significant trend in the month of September

TABLE 3

Precipitation trends for different months and seasons of stations using the Mann-Kendall, Spearman's rho and linear regression test

Months/ Seasons	Srinagar			Qazigund			Kupwara		
	ZD	Zs	Linear Trend	ZD	Zs	Linear Trend	ZD	Zs	Linear Trend
January	0.98	0.84	0.80	0.01	0.09	0.71	0.31	0.18	0.33
February	1.0	1.2	0.7	-0.6	-0.55	-0.59	1.18	1.36	1.39
March	-1.0	-0.98	-1.55	-1.29	-1.31	-2.7	**-2.3***	**-2.0***	**-2.9***
April	-0.04	-0.22	-0.25	-0.31	-0.35	-0.12	-1.29	-1.30	-1.19
May	-1.75	-1.8	-1.06	**-2.1***	**-1.9**	-1.9	-1.3	-1.4	-0.9
June	0.27	0.36	0.09	0.77	0.95	0.76	-0.12	-0.03	-0.02
July	0.27	0.24	0.09	-1.4	-1.6	-1.4	-1.04	-1.2	-0.94
August	-0.64	-0.86	-0.4	0.5	0.55	-0.24	-1.48	-1.78	-0.58
September	1.66	1.48	0.8	1.10	1.03	2.03	0.42	0.3	-0.08
October	**-2.1***	**-1.91***	**-0.88***	-1.1	-1.16	-0.95	-0.20	-0.40	-0.36
November	-0.17	-0.17	0.02	-0.38	-0.18	-0.40	0.28	0.21	0.21
December	-1.09	-1.15	**-2.33***	-1.16	-1.10	-2.36	**-1.9***	**-2.0***	**-2.5***
JF	**2.03***	**1.96***	0.77	0.12	0.09	0.06	1.63	1.64	0.86
MAM	-1.29	-1.34	-0.95	**-2.0***	**-2.1***	**-1.6***	**-1.9***	**-1.9***	-1.7
JJAS	0.39	0.42	0.14	1.02	0.81	0.27	-1.26	-1.30	-0.40
OND	**-2.0***	-1.8	**-1.06***	-1.51	-1.66	**-1.24***	-1.13	-1.23	-0.86
Annual	-1.26	-1.52	-0.32	-1.29	-1.55	-0.60	-1.75	**-2.03***	-0.62

(JF (January, February), MAM (March, April, May), JJAS (June, July, August & September),OND (October, November and December)

(3.913) for linear trend analysis. The decreasing significant trends were also observed by Katra in the month of July (-5.605) and Baderwah in the month of May (-1.989 mm/year) respectively. No significant results were observed for other months and seasons by Jammu, Katra and Baderwah.

The results of Innovative trend analysis showed highest reduction in Precipitation during the month of March for all the stations. The decline was highest in Kupwara (slope value -4.116) followed by Qazigund (-3.160). Similar declining trends were also observed for Jammu and Katra station with significantly decreasing trends with slope value -2.032 and -6.680 mm/year respectively. There is marginal rise in Precipitation trends during the month of September for Srinagar and Qazigund. The seasonal analysis showed significantly decreasing trends with p value < 0.001 for all the stations during Pre-Monsoon (March, April and May) and Post Monsoon (October, November and December) season. The annual Precipitation trend analysis also showed decreasing significant trends for all the stations. Bhutiyani *et al.* (2010) also studied precipitation trends in the northwest Himalayas and did not found any trends in precipitation during the winter season. Similar results were observed by Kumar and Jain (2010) and they found decreasing trends in monsoon and winter rainy days over all the stations. Decreasing trends in winter precipitation were also observed by Kumar and Jain, 2010; Dimri and Dash, 2012.

TABLE 4

Precipitation trends for different months and seasons of stations using the Mann-Kendall, Spearman's rho and linear regression test

Months/ Seasons	Srinagar			Qazigund			Kupwara		
	ZD	Zs	Linear Trend	ZD	Zs	Linear Trend	ZD	Zs	Linear Trend
January	**-3.22**	**-3.21**	**-2.73**	-0.23	-0.11	-0.17	-0.50	-0.37	0.09
February	0.27	0.31	0.34	-0.23	-0.47	-0.38	0.10	-0.06	0.35
March	-0.31	-0.60	-0.37	-0.74	-0.85	0.15	-1.52	-1.42	-1.91
April	-0.88	-0.87	0.60	-0.85	-0.96	-1.63	-0.09	-0.27	-1.13
May	-0.19	-0.26	-0.36	0.83	0.62	-0.48	**-1.98***	**-1.91**	-1.73
June	-0.61	-0.61	-0.88	1.29	1.20	**3.19***	1.40	1.25	1.37
July	1.06	1.03	1.65	-1.02	-0.91	**-5.60***	-0.85	-0.86	-1.04
August	-0.02	-0.21	-0.70	0.17	0.05	-0.57	-0.36	-0.44	0.05
September	**1.75**	**1.90**	**3.91***	-0.01	0.03	1.30	1.43	1.18	0.41
October	-0.65	-0.69	-0.06	-0.50	-0.58	-0.32	-1.19	-1.10	-0.9
November	0.24	0.05	0.10	0.16	0.25	-0.31	0.13	0.14	-0.36
December	0.53	0.55	-0.25	-0.58	-0.80	-2.09	-0.61	-0.77	-1.84
JF	-0.71	-0.85	-1.05	0.01	-0.08	-0.27	0.39	0.30	0.22
MAM	0.23	0.16	-0.01	-1.18	-1.22	-0.65	**-2.16***	**-2.00***	-1.59
JJAS	-1.07	-1.00	-0.21	-0.34	-0.41	-0.42	0.83	0.91	0.20
OND	1.37	1.34	1.19	-1.21	-1.16	-0.91	-1.18	-1.38	-1.03
Annual	-0.72	-0.66	-0.39	-0.55	-0.70	-0.57	-1.02	-1.22	-0.55

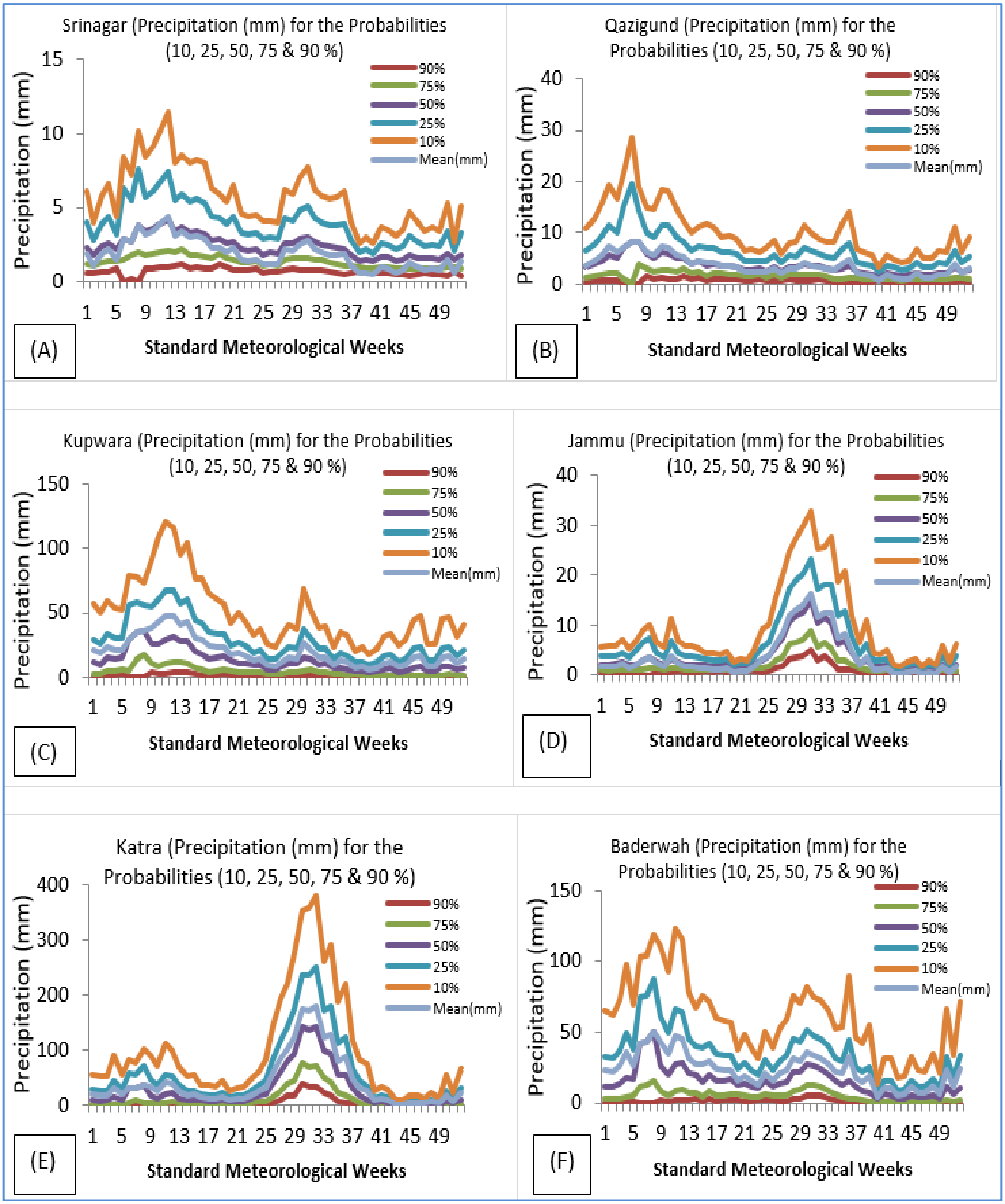
(JF (January, February), MAM (March, April, May), JJAS (June, July, August & September), OND (October, November and December)

TABLE 5

Precipitation trends for different months of stations using Innovative trend analysis

Months/ Seasons	Srinagar	Qazigund	Kupwara	Jammu	Katra	Baderwah
	Trend Slope					
January	**0.63***	-0.07	0.35	-0.15	**-0.91***	**-0.73***
February	**1.04***	-0.04	**1.95***	**-0.75***	**-0.64***	**1.05***
March	**-1.56***	**-3.16***	**-4.11***	**0.54***	-0.36	**-1.94***
April	**-0.28***	-0.30	**-1.03***	**-0.49***	**-1.66***	**-1.29***
May	**-0.94***	**-2.22***	**-0.81***	**-0.67***	0.09	**-1.67***
June	-0.06	0.18	-0.00	**1.72***	**3.37***	**1.12***
July	0.24	**-1.93***	**-0.68***	**-2.03***	**-6.68***	-0.55
August	**-0.40***	**-1.46***	**-1.02***	1.19	**-2.02***	-0.71
September	**1.18***	**1.87***	-0.02	0.03	0.19	-0.05
October	**-0.80***	**-1.02***	**-0.53***	**0.22***	**-0.16***	**-0.70***
November	-0.06	**-0.46***	**0.37***	**-0.28***	**-0.51***	**-0.73***
December	**-1.97***	**-1.76***	**-1.76***	**-0.87***	**-1.79***	**-1.53***
JF	**0.839***	-0.05	**1.15***	**-0.45***	**-0.78***	0.16
MAM	**-0.93***	**-1.89***	**-1.98***	-0.20	**-0.64***	**-1.63***
JJAS	**0.24***	-0.33	**-0.43***	0.23	**-1.28***	-0.05
OND	**-0.95***	**-1.08***	**-0.64***	**-0.31***	**-0.82***	**-0.98***
Annual	**-0.25***	**-0.86***	**-0.60***	-0.12	**-0.92***	**-0.64***

(JF (January, February), MAM (March, April, May), JJAS (June, July, August & September), OND (October, November and December)



Figs. 2 (a-f). Figures showing amount of rainfall at different probability levels (10-90%) of stations under study area

Meteorological drought was determined for all the stations (Figs. 1, A-F) and results showed that out of total 40 years of study, 6 years were identified as moderate drought years for Srinagar, Qazigund and Kupwara (1985, 1990, 1999, 2000, 2001 and 2002), 2 moderate drought years for Jammu, Katra (1987 and 2009) and for Baderwah (1999 and 2001). Above results are in agreement with Kundu and Singh, 2019 and Mallya *et al*., 2016 in which they found similar drought trends during the period 1999-2005.

The amount of rainfall at different probability levels (10-90%) called assured rainfall have been computed for each Meteorological standard week by fitting Incomplete Gamma Distribution model. The incomplete Gamma distribution probability analysis was based as suggested by Victor (2000). The incomplete gamma distribution used to model weekly or annual rainfall. For each station, the incomplete gamma distribution can be used to predict the probability of rainfall over a given week. For example, the distribution might indicate that there is a 50% chance of more than 5 mm of rainfall between the 5th to 13th and 25th to 37th Meteorological standard weeks.

The incomplete gamma distribution can also be used to model the standard deviation of annual rainfall. The standard deviation of annual rainfall varies between 6-18 mm (Table 2) for all the stations under study and each week from 5th to 13th and 25th to 37th Meteorological standard weeks received more than 5 mm of rainfall Figs. 2 (a-f).

The analysis results revealed the maximum impact of western disturbances during 4th to 16th standard Meteorological Week and impact of SW-Monsoon during 28th to 37th standard Meteorological Week for the stations Srinagar, Qazigund, Kupwara and Baderwah. The impact of Monsoon activity is prominent and found maximum activity during 25th to 40th standard Meteorological Weeks over Jammu and Katra station.

4. Conclusions

The following conclusions were drawn from the above study.

(*i*) The analysis of Mekendal test showed decreasing significant precipitation trends ($p < 0.01$) during post monsoon season (October and December) with slope value -1.06, -1.24 and -1.03 mm/year for Srinagar, Qazigund and Baderwah respectively. Similar decreasing significant precipitation trends ($p < 0.01$) were observed for pre Monsoon season (March-May) with slope value -1.59 and -1.58 mm/year for Baderwah and Qazigund. Decreasing significant precipitation trends ($p < 0.01$) were observed for Kupwara in the month of March with slope value -2.94 mm/year and Baderwah in the month of May with slope value -1.73 mm/year.

(*ii*) The results of Innovative trend analysis showed decreasing significant precipitation trends ($p < 0.01$) in the month of March for Srinagar, Qazigund, Kupwara and Baderwah with slope value -1.56, -3.16, -4.11 and -1.94 mm/year respectively. Increasing significant precipitation trends ($p<0.01$) in the month of September for Srinagar and Qazigund with slope value 1.18 and 1.87 mm/year respectively.

(*iii*) The seasonal analysis results showed decreasing significant precipitation trends ($p<0.01$) in post Monsoon season (October-December) for Srinagar, Qazigund and Kupwara with slope value -0.95, -1.08 and -0.64 mm/year respectively.

(*iv*) The annual precipitation trends showed decreasing significant trend for all the stations under consideration. The highest precipitation reduction was observed over Katra with slope value -6.68 mm/year.

(*v*) Probability of occurrence of Meteorological drought was determined for all the stations and results showed that out of total 40 years of study, 6 years were identified as moderate drought years for Srinagar, Qazigund and Kupwara (1985, 1990, 1999, 2000, 2001 and 2002), 2 moderate drought years for Jammu, and Katra (1987 and 2009) and 2 moderate drought years for Baderwah (1999 and 2001).

(*vi*) The analysis of amount of rainfall at different probability levels (10-90%) called assured rainfall revealed the maximum impact of western disturbances during 4th to 16th standard Meteorological Week and impact of Monsoon during 28th to 37th standard Meteorological Week for stations Srinagar, Qazigund, Kupwara and Baderwah. The impact of Monsoon activity is notable and found maximum activity during 25th to 40th standard Meteorological Week over Jammu and Katra station.

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