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A comparative study of trends in rainfall over meteorological subdivisions of Uttar Pradesh

SUSHEEL KUMAR PATEL AND N SUBASH*

ICAR- Indian Institute of Farming Systems Research, Modipuram, Meerut, Uttar Pradesh, India

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ABSTRACT

In this study investigation of trends in rainfall over two subdivisions (East and West) of Uttar Pradesh was carried out. In both subdivisions decrease in rainfall during monsoon and increase in summer season has been observed. However in both the subdivisions during second three decades (1957-1986) increased in rainfall has been found during post monsoon. In West subdivision there was increase during second three (1957-1986) decades in monsoon season which decreased in current three decades (1987-2016). However in East subdivision continues decrease in rainfall has been noticed during monsoon season and during post monsoon decrease of 14 mm and 12 mm in rainfall was recorded, moreover in summer season increase of rainfall (4mm and 5mm) was noticed in East and West U P respectively. No seasonal significant trend in rainfall was noticed in both the subdivisions. As far as monthly analysis concern there was increase in rainfall (4-5mm) in the month of May and June. In East U P January, February, March, July, August, September, October, November and December months recorded decrease in rainfall and February and April remained constant. Similarly in West U P January, April, July, August, September, October and November recorded decrease in rainfall and February, March and April remained unchanged. This analysis provide an insight into the variability of rainfall pattern in both the subdivisions and useful for researchers and planners for their planning of construction of water holding structures in future.

Keywords: Monsoon; Meteorological subdivision; trends; coefficient of variation; standard deviation

INTRODUCTION

Water resource has become a prime concern for any development and planning including food production, flood control and effective water resource management. Precipitation is a key component of the hydrologic cycle and changes in its pattern would directly influence the water resources of a region, as it affects stream flows, soil moisture and groundwater reserves (Jain *et al.,* (2013). On average, 21.3 % days of a year is considered as rainy, while heavy and extreme rainfall in this region together occupies nearly 15% of the rainy days (Arati Paul (2017*)*. Trend analysis can help in better understanding of the changing pattern of the prominent climatic variables. Rainfall trends in response to climate change and probability analysis have been studied by various researchers (Singh and Kumar (2016), Jayawardene *et al.,* (2005); Kumar and Jain, (2010)) and they have emphasized that the knowledge of location specific rainfall variations is essential for proper water harvesting and water management practices. No direct relationship between increasing rainfall and increasing maximum temperature when monthly or seasonal pattern is concerned over meteorological subdivisions of India (Subash *et al.,* (2014). Decrease in annual average runoff and availability of water will project up to 10–30% (IPCC 2007). Detailed knowledge of the rainfall pattern helps in planning crop calendar and designing of different soil and water conservation structures/measures including water harvesting structures to meet out irrigation requirement during drought periods. The amount of rainfall received during the period and its distribution affects the crop growth and yield. The abnormalities in rainfall, i.e. excess or lack of rainfall often leads to flooding or droughts that exert severe impacts on human lives and economy of a region. For optimal management of water resources, rainfall characteristics of a specific area are necessary. The zoning of land based on homogeneous rainfall characteristics may give a better comprehension of rainfall distribution and intensity for a specific region. Results from previous statistical studies are indicative of decreasing trends in rainfall over certain parts of India (IMD, 2010). A similar decrease in the frequency of monsoon depressions over the Bay of Bengal was observed by Dash *et al.* (2004), while Pal and Al-Tabbaa (2009) found a decreasing trend in precipitation over Kerala during pre-monsoon season. Parthasarathy and Dhar (1974), Thapaliyal and Kulshrestha (1991), Rao and Kumar (1992), Rupakumar*et al.* (1992), Srivastava *et al.* (1992) and Parthasarathy *et al.* (1993), Kothyari and Singh (1996), Kripalani and Kulkarni (1996, 2001), Sinha Ray and Srivastava (2000), Sadhukhan *et al.* (2000), Patra *et al.* (2005), Kothawale*et al.* (2010), Kumar *et al.* (2010), Kumar and Jain (2010), Pal and Al-Tabbaa (2010a,b, 2011), Arora *et al.* (2010), Subash and Ram Mohan (2010) and Subash *et al.* (2011) studied the trends of annual and seasonal rainfall at various locations and at different scales over India. Most of the above attempts have been made in the past to determine trends in the rainfall over sub-divisions or based on weather station data. In this study, we have tried to analyse and compare the rainfall trends and its characteristics over two adjacent meteorological subdivisions of Uttar Pradesh using 90 years rainfall data (1927-2016).

*Corresponding Author Email : nsubashpdfsr@gmail.com

MATERIALS AND METHODS

STUDY AREA

Uttar Pradesh (U P), with a total area of 243,290 square kilometres, is India's fourth-largest state in terms of land area and it is situated on the Central Northeast of India and shares an international boundary with Nepal (Fig 01). U P has a humid subtropical climate and experiences four distinct seasons. The winter in January and February is followed by summer between March and May and the monsoon season between June and September. Summers are extreme with temperatures fluctuating between 0 °C and 50 °C with dry hot winds.

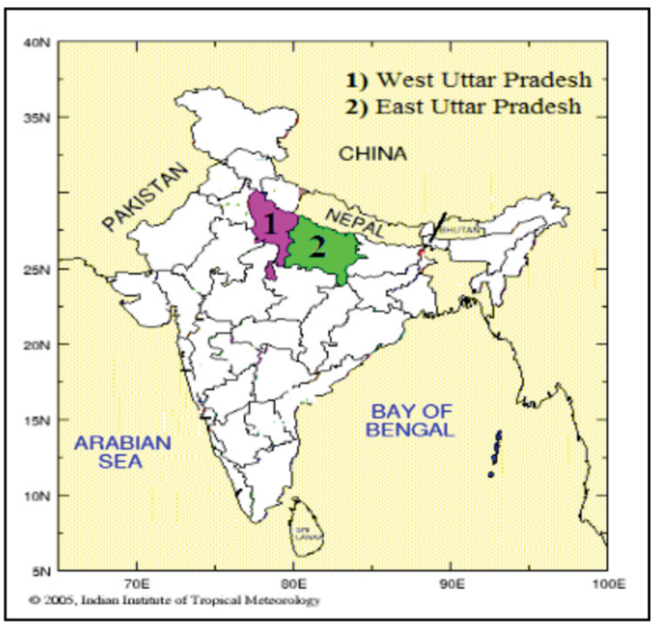


Fig. 1: Two meteorological subdivisions of U P.

DATA/METHODOLOGY

Based on the topography and climatologically prevailing conditions over the sub-continent, the India Meteorological Department has divided the country into 36 meteorological sub-divisions. The sub-divisional monthly time series of rainfall data were collected from the IITM (http://www.tropmet.res.in) during the period 1927–2016. There are 26 and 19 rain gauge stations, respectively in East U P and West U P sub-divisions. The homogeneity or stationarity of the monthly data series was tested by Swed and Eisenhart's test and the Mann–Kendall rank test (WMO 1966) and found that all the sub-divisions the number of run lie within the required limits of 5 % significance level (Parthasarathy *et al.* 1987). They have also tested the nature of the frequency distribution of the chi-square statistic with ten equal probability class intervals (Cochran, 1952). Mooley and Parthasarathy (1984), Parthasarathy *et al.* (1990, 1992, 1993, 1994), Pant and Rupa kumar (1997), Mooley *et al.* (1981) provided a more detailed discussion of the methodology adopted for quality, completeness and homogeneity of these data sets. The quality controls of data were also performed and more details are available in www.tropmet.res.in.

Trend Analysis

In the present study, trend analysis has been done by using non-parametric Man- Kendall test, which is being used for studying the spatial variation and temporal trends of hydro climatic series. A non-parametric test is taken into consideration over the parametric one since it can evade the problem roused by data skew (Smith, 2000). Man-Kendall test is preferred when various stations are tested in a single study (Hirsch *et al.,* (1991). Mann-Kendall test had been formulated by Mann (1945) as non-parametric test for trend detection and the test statistic distribution had been given by Kendall (1975) for testing non-linear trend and turning point.

Autocorrelation: Trend detection in a series is largely affected by the presence of a positive or negative autocorrelation (Hamed and Rao (1998), Serrano *et al.* (1999), Yue *et al.* (2003), Novotny and Stefan (2007). With a positive autocorrelation in the series, possibility for a series of being detected as having trend is more, which may not be always true. On the other hand, this is reverse for negative autocorrelation in a series, where a trend is not detected. The coefficient of autocorrelation

$$\rho_k = \frac{\sum_{t=1}^{n-k}(x_t-\bar{x}_t)(x_{t+k}-\bar{x}_{t+k})}{\left[\sum_{t=1}^{n-k}(x_t-\bar{x}_t)^2 \times \sum_{t=1}^{n-k}(x_{t+k}-\bar{x}_{t+k})^2\right]^{1/2}} \qquad (1)$$

where, $\bar{x}_t$ and *Var* (x_t) are considered as the sample mean and sample variance of the first $(n-k)$ terms respectively, and $(\bar{x}_{t+k})$ and *Var* (x_{t+k}) are the sample mean and sample variance of the last $(n-k)$ terms respectively. Further, the hypothesis of serial independence is tested by the lag-1 autocorrelation coefficient as $H0 : \rho 1 = 0$ against $H1 : |\rho 1| > 0$ using

$$t = |\rho 1|\sqrt{\frac{n-2}{1-\rho_1{}^2}} \qquad (2)$$

Where the *t* test statistic has a Student's *t*-distribution with $(n-2)$ degrees of freedom *(Cunderlik and Burn, 2004)*. If $|t| \geq t\alpha/2$, then the null hypothesis about serial independence is rejected at the significance level α.

Mann-Kendall Test: The Mann-Kendall statistic *S* is given as

$$S = \sum_{i-1}^{n-1}\sum_{j=i+1}^{n} sgn(x_j - x_i) \qquad (3)$$

The application of trend test is done to a time series x_i that is ranked from i = 1,2,………n-1 and x_j, which is ranked from j = i+1,2,……….n. Each of the data point x_i is taken as a reference point which is compared with the rest of the data points x_j so that,

$$sgn(x_j - x_i) = \begin{cases} +1, if\ (x_j - x_i) > 0 \\ 0, if (x_j - x_i) = 0 \\ -1, if\ (x_j - x_i) < 0 \end{cases} \qquad (4)$$

It has been documented that when n ≥ 8, the statistic S is approximately normally distributed with the mean.

$$E(S)=0 \qquad (5)$$

The variance statistic is given as

$$Var(s) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i)(i-1)(2i+5)}{18} \qquad (6)$$

Where t_i is considered as the number of ties up to sample i. The test statistics Z_c is computed as

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & \text{if } S > 0 \\ 0, & \text{if } S= \\ \frac{S+1}{\sqrt{Var(S)}}, & \text{if } S<0 \end{cases} \quad (7)$$

Z_c here follows a standard normal distribution. A positive (negative) value of Z signifies an upward (downward) trend. A significance level α is also utilized for testing either an upward or downward monotone trend (a two-tailed test). If Z_c appears greater than $Z_{\alpha/2}$ where α depicts the significance level, then the trend is considered as significant.

Modified Mann–Kendall test: Pre-whitening is being used for detecting a trend in a time series in the presence of autocorrelation (Cunderlik and Burn, (2004). Nonetheless, pre-whitening is stated to reduce the rate of detection of significant trend in the MK test (Yue *et al.*(2003). Thus, the Modified MK test (Rao *et al.* (2003) has been used for trend detection of an auto correlated series. In the present study, the auto correlation between ranks of the observations ρk has been estimated after subtracting an estimate of anon-parametric trend such as Sen's median slope from the data. Significant values of ρk have only been used for calculating the variance correction factor n/n_s^*, as the variance of S is underestimated for the positively auto correlated data:

$$\frac{n}{n_s^*} = 1 + \frac{2}{n(n-1)(n-2)} \times \sum_{k=1}^{n-1}(n-k)(n-k-1)(n-k-2)\rho k \quad (8)$$

Where n represents the actual number of observations, n_s^* is represented as an effective number of observations to account for the autocorrelation in the data and ϱk is considered as the autocorrelation function for the ranks of the observations. The corrected variance is then calculated as (Rao et al. (2003)

$$V^*(S) = V(S) \times \frac{n}{n_s^*} \quad (9)$$

Where *V (S)* is from Equation (6). The rest is same as in the MK test.

Sen's Slope Estimator Test: The magnitude of trend is predicted by the Sen's estimator. Here, the slope (T_i) of all data pairs is computed as (Sen, (1968)

$$-T_i = \frac{x_j - x_k}{j-k} \quad \text{for } i = 1,2,\ldots\ldots,N \quad (10)$$

Where x_j and x_k are considered as data values at time j and k (j>k) correspondingly. The median of these N values of T_i is represented as Sen's estimator of slope which is given as:

$$Q_i = \begin{cases} T_{\frac{N+1}{2}} & \text{N is odd} \\ \frac{1}{2}\left(T_{\frac{N}{2}} - T_{\frac{N+2}{2}}\right) & \text{N is even} \end{cases} \quad (11)$$

Sen's estimator is computed as Q_{med}=T(N+1)/2 if N appears odd, and it is considered as $Q_{med}=[T_{N/2}+T_{(N+2)/2}]/2$ if N appears even. At the end, Q_{med} is computed by a two sided test at 100 (1-α)% confidence interval and then a true slope can be obtained by the non-parametric test. Positive value of Q_i indicates an upward or increasing trend and a negative value of Q_i gives a downward or decreasing trend in the time series.

RESULTS AND DISCUSSION

Maximum annual rainfall of 1530 mm was received in East U P in 1936, whereas in 1979 received a minimum rainfall of 603mm as shown in Fig 02. However, in West UP maximum (1305mm) and minimum rainfall (507mm) was recorded during 1961 and 2014, respectively. The average annual rainfall of 90 years (1927-2016) in East U P and West UP was found 995 mm and 862 mm, respectively with a standard deviation (SD) of 199 mm and 176 mm, respectively. When we compare the average annual rainfall during first 30-year – F30 - (1927-1956) and last 30-year (L30) (1957-1986) period, there is

Table 1: Mean monthly rainfall over different meteorological subdivisions of Uttar Pradesh and its percent contribution to annual rainfall.

Months	East U P				West U P			
	1927 -2016	1927 -1956	1957 -1986	1987 -2016	1927 -2016	1927 -1956	1957 -1986	1987 -2016
January	17 (1.7)	21 (2.0)	18(1.8)	13(1.4)	18(2.1)	21(2.4)	18(2.0)	15(1.8)
February	16 (1.6)	21 (2.1)	11(1.1)	16(1.7)	20(2.3)	23 (2.6)	15(1.6)	21(2.6)
March	9 (0.9)	9 (0.9)	9(0.8)	8(0.9)	13(1.5)	11(1.3)	13(1.4)	13(1.7)
April	7 (0.7	7 (0.7)	7(0.7)	7(0.8)	7(.08)	5(0.6)	7(0.8)	7(0.9)
May	18 (1.8)	14 (1.4)	17(107)	22(2.04)	15(1.8)	9(1.1)	17(1.9)	20(2.4)
June	114 (11.4)	107 (10.5)	10 2(10.0)	119(13.2)	85(9.8)	84(9.4)	80(8.7)	89(11.0)
July	290 (29.1)	304 (29.8)	300(29.5)	261(28.8)	254(29.5)	267(29.7)	273(29.8)	233(28.9)
August	278 (27.9)	282 (27.6)	290(28.5)	241(26.6)	260(30.1)	287(32.0)	289(31.5)	236(29.3)
September	191 (19.2)	203(2 0.0)	199(19.5)	177(19.5)	147(17.1)	144(16.0)	153(16.6)	140(17.4)
October	44 (4.4)	50(4.9)	53(5.2)	33(3.7)	31(3.6)	33(3.6)	38(4.2)	20(2.5)
November	5 (0.5)	5(0.5)	5(0.5)	3(0.3)	4(0.4)	4(0.5)	5(0.5)	3(0.4)
December	7 (0.7)	8(0.8)	7(0.7)	6(0.6)	8(1.0)	9(1. 0)	9(1.0)	8(1.0)

11.0 and 10.4 % decrease in Eastern U P and Western U P. During the period F30, rainfall has been reduced to 907 mm which is 88 mm lesser as compared to average annual fall (995) of 90 years in East U P. However, during L30, there is decrease of 57 mm and 93 mm as compared to mean of 90 years (1927-2016) and F30, respectively.

It was found that in East U P highest monthly rainfall (mean of 90years) was recorded in month of July (290mm) which is 29.1% of average annual rainfall followed by August (278mm, 27.9%) as shown in Table 1. Whereas in West UP the highest rainfall was recorded in the month of August (260mm, 30.1%) followed by July (254mm, 29.7%) (Fig. 3). Minimum monthly rainfall was recorded in the month of November in both the sub divisions. Increase of 4-5 mm rainfall was recorded in the month of May and June in both the divisions. Moreover, in both the subdivisions increase in rainfall was observed during F30 as compared to F30 in the month of July. During 1998-2016, 10% and 8.26% decrease in rainfall was observed in the month of July as compared to 1927-2016 in East and West U P respectively.

However, in the month of May and June increase in rainfall is noticed. In East U P January, February, March, July, August, September, October, November and December months recorded decrease in rainfall and February and April

Table 2: Mean seasonal and annual rainfall (mm) over different meteorological subdivisions of Uttar Pradesh and its percent contribution to annual rainfall.

Seasons	East U P				West U P			
	1927 -2016	1927 -1956	1957 -1986	1987 -2016	1927 -2016	1927-1956	1957 -1986	1987 -2016
Winter	33(3.3)	27(2.6)	29(2.8)	29(3.2)	38(4.4)	31(3.5)	33(3.6)	36(4.4)
Summer	33(3.3)	33(3.3)	33(3.2)	37(4.1)	35(4.0)	39(4.3)	37(4.1)	40(5.0)
Monsoon	873(87.7)	896(87.9)	892(87.6)	799(88.1)	746(86.5)	782(87.0)	795(86.7)	698(8 6.7)
Post monsoon	56(5.6)	63(6.2)	65(6.4)	42(4.6)	43(5.0)	46(5.2)	52(5.6)	31(3.9)
Annual	995	1019	1018	907	862	898	917	805

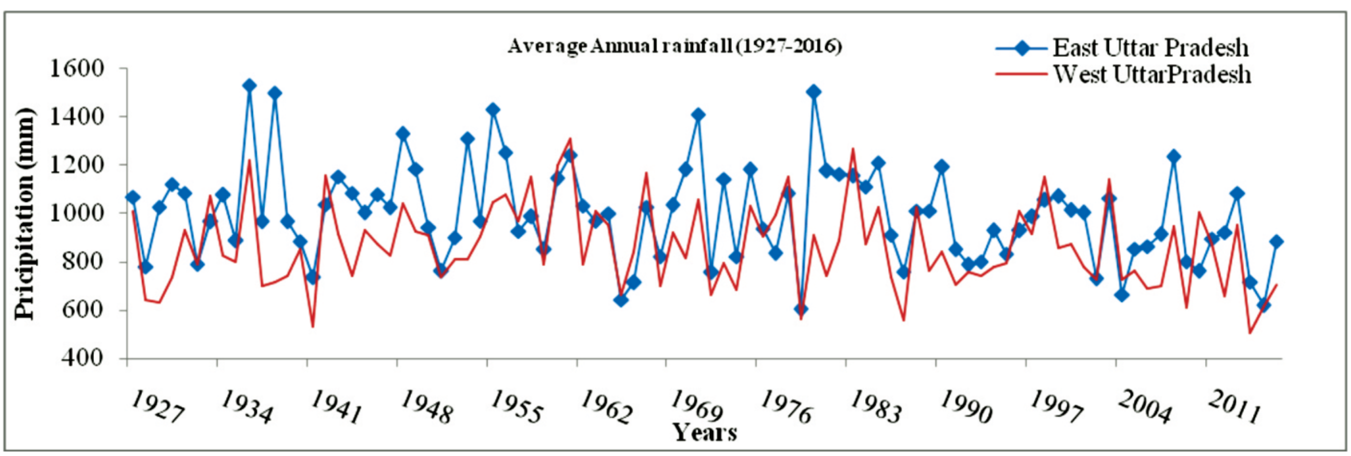
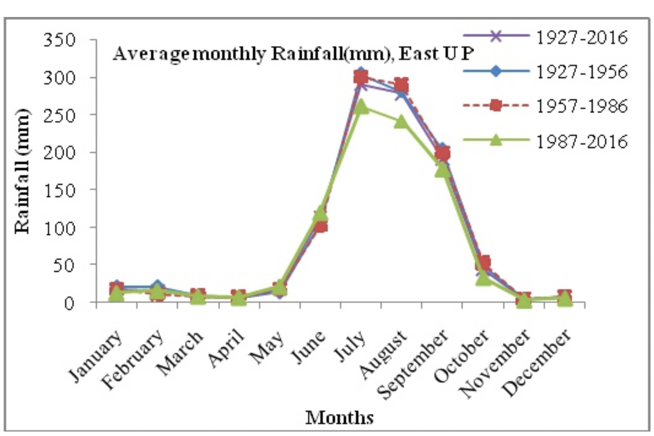


Fig. 2: Average annual rainfall (mm) in subdivisions of U P.



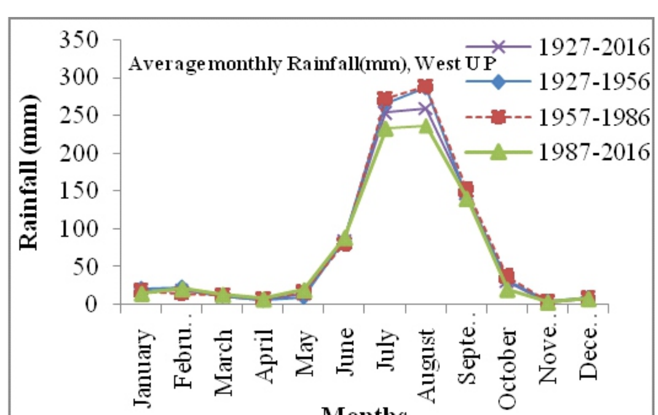
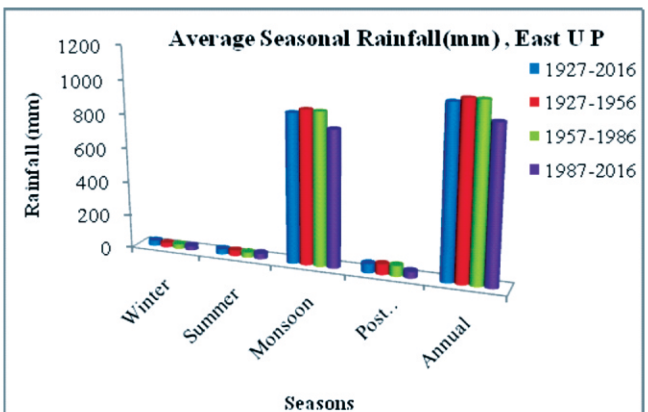


Fig. 3: Average monthly rainfall (mm) in East and West subdivisions of U P.

remained constant. Similarly in West U P January, April, August, July, September, October and November recorded decrease in rainfall and February, March and April remained unchanged.

Monsoon contributes large part (87%) of rainfall in U P, in last 90 years decrease of 54 mm and 48mm in rainfall (Fig. 4) was recorded during monsoon season in East & West U P respectively. 896 (87.9%) and 799(88.1%) rainfall was recorded during monsoon season in East U P during F30 and L30, which shows decrease in monsoon rainfall. However during post monsoon season decrease of 14 mm and 12 mm in rainfall was recorded, moreover in summer season increase of rainfall (4 mm and 5 mm) was noticed in East and West U P respectively. Decrease in rainfall in both the divisions was recorded during winter season.

As Fig. 4 shows during L30 there is maximum decrease in rainfall recorded during monsoon season in East subdivision of Utter Pradesh. Where as in West U P during 1957-1986 increase in rain fall (36 mm) was noticed, but during L30 the rainfall decreased (698 mm) with a decrease of 84 mm as compare to F30 (Table 2).



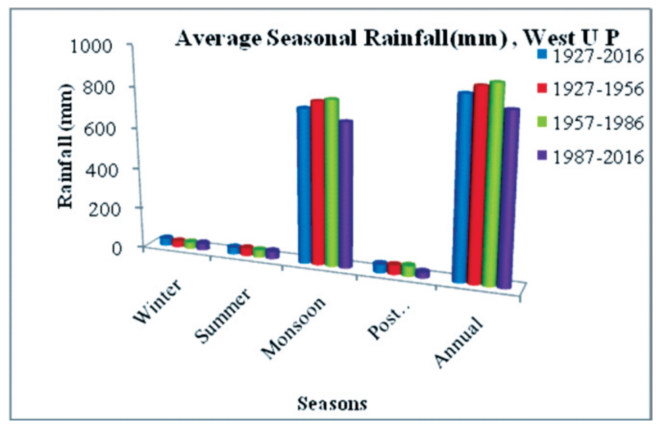
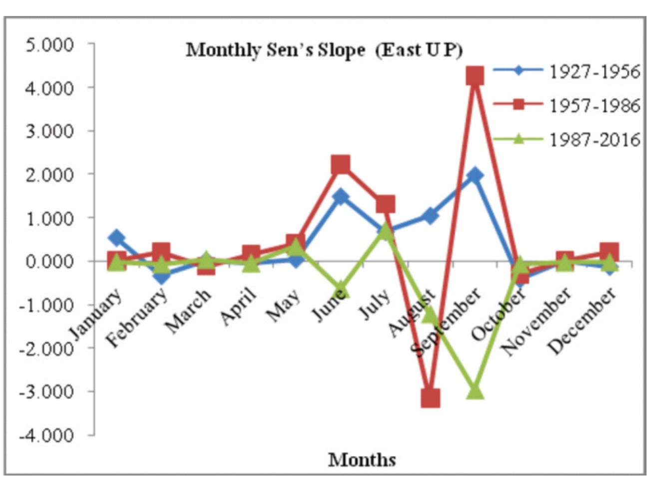


Fig. 4: Average seasonal rainfall (mm) in East and West subdivisions of U P.

No significant trend was found in rainfall during F30, however during L30 positive significance was noticed in the month of June at confidence level of 95%. Positive significance was observed in the month of April, December and September, during same time period in the month of August negative significance was noticed at confidence level of 90%. During L30 negative significance was observed in the month of September at conference level of 95 % in East subdivision of U P. Similarly in West subdivision of Uttar Pradesh a positive significance was noticed in the month of January and negative significance was observed in the month of November and December at a confidence level of 95% during F30. At confidence level of 90% positive significance was noticed in the month of June and negative significance was noticed in the month of August at confidence level of 95% during L30.

Seasonal trend analysis

No significance was observed in East subdivision of U P except time series 1957-1986, positive trend in monsoon season was noticed at conference level of 90% during same time series with a positive Sen's slope (4.630)(Fig.5). However in West U P no significant trend was observed in any season at conference level of 90% and 95%.



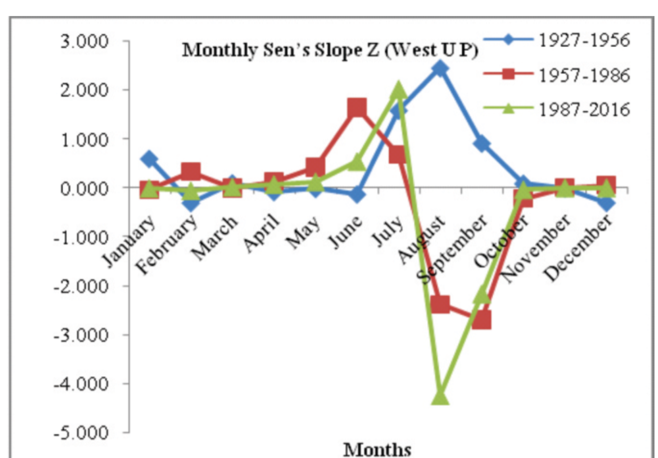


Fig. 5: Monthly Sen's slope in East and West subdivisions of U P.

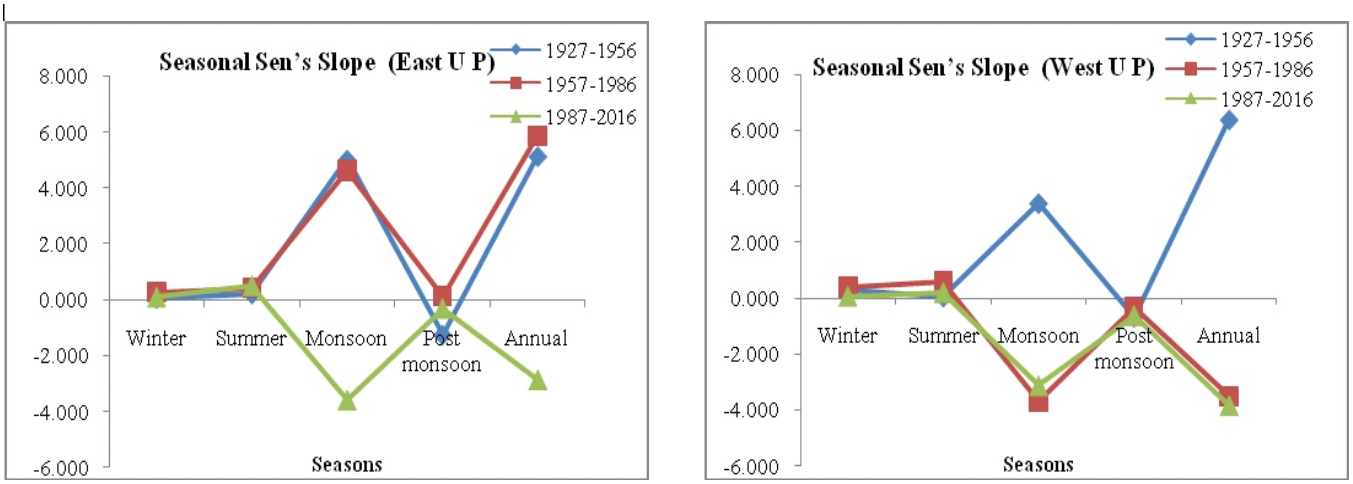


Fig. 6: Seasonal Sen's slope in East and West subdivisions of U P.

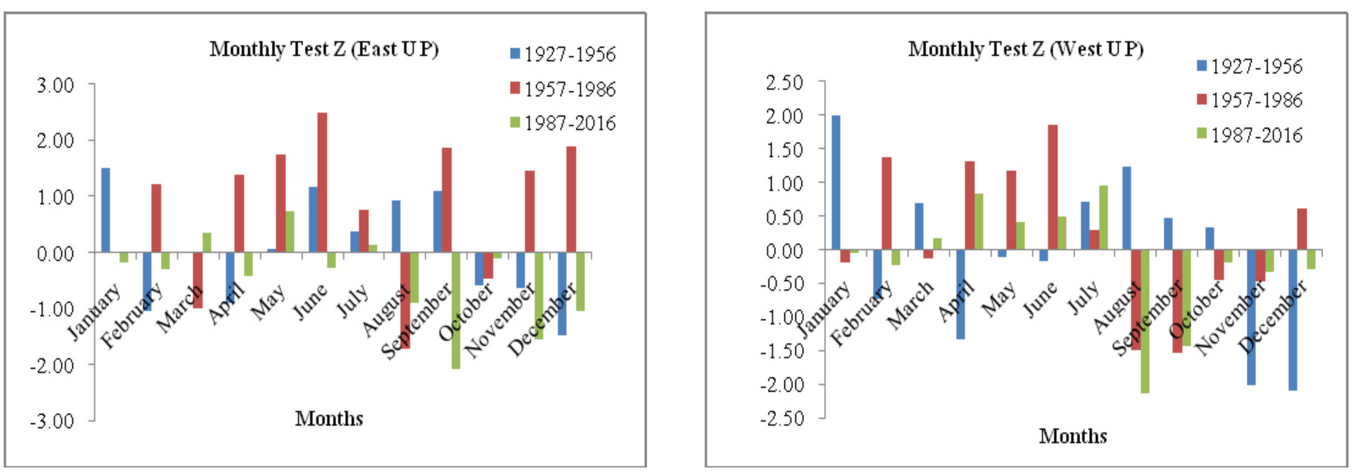


Fig. 7: Monthly Test Z in East and West subdivisions of U P.

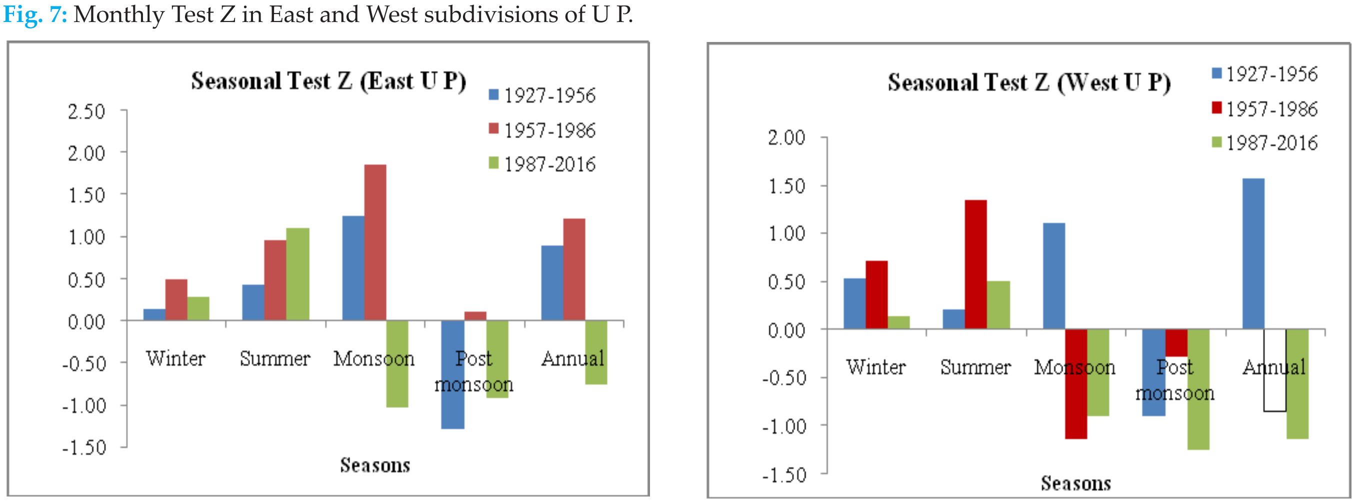


Fig. 8: Seasonal Test Z in East and West subdivisions of U P.

CONCLUSION

Analysing the data of last nine decades (1927-2016) it was observed that 11% and 10.35% decrease in current 30-year occurred as compared to first 30-year in East and West subdivision of U P respectively. In both the subdivisions in the month of May and June increase in rainfall is occurred which causes increase in rainfall during summer season. Keeping the same in mind, crop planning, alternate cropping systems, construction of water holding structures which reduce the uncertainty in agriculture sector and thereby reduce the risk in food security and livelihood of poor small and marginal farmers of the region.

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