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Trend Analysis of Annual and Seasonal Time Series over the Last 46 Years in Asan Watershed, Doon Valley Based on Gridded Data Set

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ABSTRACT

The study is carried out with changing long-term trend and variation in one of the significant climatic element. The daily gridded rainfall data of spatial resolution 0.25°x 0.25°, for the last 46 years *i.e.* 1970-2015, has been processed for the Asan watershed located in Doon Valley, Uttarakhand. The non-parametric Mann-Kendall (MK) test together with Sen's Slope Estimator has been used for the determination of trend and slope magnitude in the watershed respectively. The gridded statistics of annual and seasonal precipitation trends have been studied here to achieve the objective. It has been observed that the magnitude of precipitation in annual and monsoonal time series are increased for all grids except for grid 6 and 8 which show a decreasing trend. The Post Monsoon time series shows a decreasing trend in all grids except for grid 6 which show positive whereas both the summer and winter rainfall show increasing trend except for grid 6. The Coefficient of variability shows variation for annual and seasonal rainfall suggesting overall insignificant changes in the area.

Keywords: Statistical trend analysis, Mann-Kendall test, Sen's slope estimator, Rainfall variability, Watershed

INTRODUCTION

Food production, conservation and management of water resources are a prime and significant concern of any development and planning. Change in climatic conditions with time is responsible for the loss of freshwater availability. IPCC (2007), revealed that in the mid of 21st century, 10-30% of the water present in the earth will project up and also fall in annual average rainfall. Precipitation is important for the nourishment of vegetation and agriculture. Particularly in developing countries, the adverse effect of change in climate on small farmers is emphasized, as they are mostly dependent on natural and traditional methods of cultivating crops (UNDP, 2014). Also, it plays an important role in shaping hydrology and water quality. Rainfall together with temperature affects the variability of weather to a large extent to determine the crop cultivation in a different region of the world.

Climate change with reference to rainfall variability also discussed by various researchers *viz.,* Asfaw *et al*. (2018), Pandey *et al*. (2001), Gajbhiye *et al*. (2015; 2016), Longobardi *et al*. (2009), Hamilton *et al*. (2001), Birsan *et al*. (2005), Jhajharia *et al*. (2009, 2012, 2014 a, b), Kumar *et al*. (2010), Krishan *et al*. (2016; 2018), Xu *et al*. (2007), Modarres *et al*. (2007).

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For planning, management and development of water resources, trend detection of discharge, runoff and precipitation give necessary information regarding future possibilities (Hamilton *et al.,* 2001; Yue and Wang, 2004). For the studies related to climate change, the variability and trend analysis of rainfall is the most significant aspect. Disturbances in rainfall pattern, extreme precipitation events and drought condition affects the agricultural, hydrological and economic condition of the country.

The aim of this present study is to evaluate the variability of the rainfall for the past 46 years (1970-2015) obtained from Indian Meteorological Department portal to examine the spatial and temporal variability of the Asan watershed and the surroundings, located in Dehra Dun (Doon Valley) district, Uttarakhand. The watershed experienced severe changes in its climate since the last several decades. Urbanization and the increase in temperature affects weather and climate pattern of the valley. The change in climate directly affects the atmospheric conditions, water resources, and natural systems. As a result, observation, monitoring, and analysis of meteorological data are necessary.

The physiographical feature of the Doon valley is the sharp rise in the Himalayan range, locally known as the Mussoorie hill, which commences from nearly 1000m, at Rajpur and reaches about 2400m at Landour. Therefore, systematic observation of precipitation data is necessary for better food security as the distribution of rainfall affect the cropping pattern and its productivity (Kumar *et al.,* 2010). The climate of Doon Valley is generally temperate. It varies from tropical to cold depending upon the altitude of an area. The significant hindrance to the movement of the monsoon wind resulting in the heavy rainfall in the valley. About 85 percent of the total rainfall comes from the summer monsoon. The average annual rainfall in Dehradun is about 2200mm and in Rajpur and Mussoorie is even higher. The summer starts from March to June. The month of May is hottest with a mean temperature of 36.2^{o}Cat Dehradun and 24.8^{o}C at Mussoorie. In rainfall-runoff relationships, the rainfall is a significant component which influences flood/drought assessment and mitigation measures. The heavy rainfall is drained eastwards by the Song-Suswa river system is joined by large Himalayan streams such as Bindal, Rispana, Jakhan, etc., and westward by the Tons, Suarna, Sitala etc. Small seasonal streams from the Siwaliks, which meet the two main drainage channels, are dry during most of the year.

STUDY AREA

The Asan watershed is situated in latitude 30°14' 14'' N to 30°29' 54'' N and longitude 77° 39' 42'' E to 78° 05' 30'' E in Dehradun district, Uttarakhand State, India (Fig. 1). Asan watershed covers the estimated area of 712.34 Km^{2} and falls under 53F/11, 53F/15, 53F/16 and 53J/3 toposheets of Survey of India (scale-1: 50,000). Asan river forms one of the prominent watersheds *i.e.* Asan watershed in Doon valley at foothills of Siwalik range. Asan River is the tributary of Yamuna River flowing northwest of Doon valley and later joins the Yamuna River at Dhalipur. The Asan and the Yamuna are perennial rivers, and the origin point of the Asan River is from Chandrbani (spring water) in Dehradun district and joining Yamuna River at Vikasnagar. The Asan Barrage is located in the vicinity of rivers Asan and Yamuna. The watershed is characterized by a broad range of elevation ranging from 398m above MSL along the mainstream in the East and more than 2030m above MSL in the upper reaches of the watershed (Lesser Himalaya) which is located in NE direction of the watershed. Major landuse of the watershed includes agriculture, forest and settlements. The watershed comprises of a rural and urban population of approximately 0.455 million (Census data handbook, 2011). The calculated annual average rainfall over the watershed varies from 1274 mm to 1766.7mm.

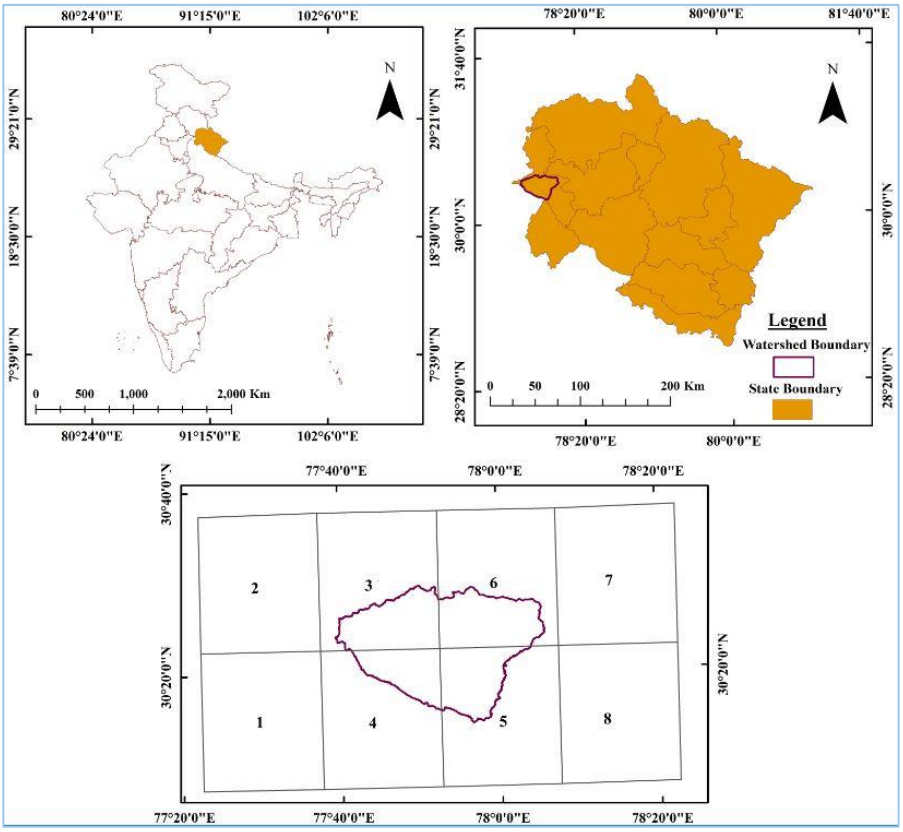

Fig. 1: Location map of the study area.

METHODOLOGY AND DATA USED

The daily gridded rainfall data of 0.25°x 0.25° spatial resolution for the last 46 years (1970-2015) for Asan watershed and its surrounding are obtained from Indian Meteorological Department (IMD) portal and to evaluate the spatial and temporal variability in the rainfall dataset. The four distinguished seasons of the study area are (1) winter (December-February), (2) summer (March-June), monsoon (July-September), and (4) post-monsoon (October-November). The monthly rainfall data is used to compute the annual and seasonal time series. In the present study, the statistical significance of trends is analyzed through Mann-Kendall (MK) test (Mann, 1945; Kendall, 1946) while the magnitude of changes in a time series is determined using a nonparametric method known as Sen's slope estimator (Sen, 1968). These non-parametric methods are widely used for analyzing the trends in several hydrological uses *viz.,* rainfall, temperature, pan evaporation, wind speed, etc. (Jhajharia *et al*. 2009, 2012, 2014 a, b).

Statistical test for trend detection methods:

The non-parametric trend detection is executed only for consistent data. Mann-Kendall (MK) test is used globally to analyze trends in meteorological variables (Gebremedhin *et al.,* 2016; Tabari *et al.*, 2015; Mekonnen and Woldeamlak, 2014). Mann-Kendall test is a non-parametric test, which is suitable for exceptionally distributed and missing data in hydrological time series. The test is used to detect a monotonic trend in time series of meteorological, environmental and climatic data. It is also useful to detect, whether the monotonic trend in the study area is statistically significant or not without specifying whether the trend is linear or non-linear (Yue *et al.,* 2002). Because of the presence of outliers in some dataset, this test is useful as it is statistically based on (+or-) signs, hence, the determination of trends is less affected by the outliers (Birsan *et al.,* 2005).

The MK test statistic represents by *'S'* of the series *'x'* is based on Mann (1945), Kendall (1975) and Yue *et al.* (2002) using the formula (eqn. 1):

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

where *'x_i'* and *'x_j'* are the time series which is ranked from i=1,2....n-2 and j=i+1,2….n respectively; where *'sgn'* is the signum function.

The associated variance with *'S'* is calculated from Mann, 1945 Modarres, R *et al.* 2009 (eqn. 2).

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^{m} tk(tk-1)(2tk+5)}{18} \qquad (2)$$

where *'m'* is the number of tied groups and *'tk'* is the number of data point's in-group *'k'.*

In the case where the sample size *n>10*, the test statistics *'Zc'* (eqn. 3) is calculated as follows:

$$Zc = \begin{cases} \frac{S-1}{\sqrt{V(S)}}, if\ S > 0 \\ 0 \quad if\ S = 0 \\ \frac{S+1}{\sqrt{V(S)}}, if\ S < 0 \end{cases} \qquad (3)$$

where *'Zc'* follows a normal distribution, a positive and negative *'Zc'* depict an upward and downwards trends for the period respectively. Trends are considered significant if *'Zc'* is greater than the standard normal deviate *'Z1- α/2'* for the desired value of '*α',* (α is the significance level which indicates the strength of trend). In the present study, the significance level of '*α ≤ 0*' is established for the evaluation of trends.

Magnitude of a trend:

Sen's slope test estimate both the slope and intercept. The magnitude of the trend is predicted by Theil (1950) and Sen (1968). For the present study, the Theil-Sen approach, the method used to express significant linear trends. To evaluate the true slope of an existing trend '*f(t)*', Sen's slope estimation method is used (eqn. 4), where the trend is supposed to be linear such as:

$$f(t)=Qt+B \qquad (4)$$

In general, the slope *'Q'* between any two values of a time series *'x'* (eqn. 5) can be estimated as:

$$Q=\frac{x_j - x_k}{j-k},\ k \neq j \qquad (5)$$

where, *'x_j'* and *'x_k'* are the data value in years *'j'* and *'k'*, j>k. For a time series 'x' having 'n' observation, there is a possible N=n (n-1)/2 values of 'Q' that can be calculated. According to Sen's method, the overall estimator of the slope is the median of these 'N' values of 'Q'. The overall slope estimator 'Q*' (eqn.6) is thus:

$$Q^* = \begin{cases} Q_{(N+1)/2} & if\ N\ is\ odd \\ \frac{Q_{N/2}+Q_{(N+2)/2}}{2} & if\ N\ is\ even \end{cases} \quad (6)$$

The method is valid for *'N'* as small as 10 unless there are many ties. A positive value of *'Q*'* indicates an upward or increasing trend, and a negative value gives a downward or decreasing trend in time series.

Coefficient of variation:

Coefficient of variation (CV) has been used to calculate the variability of the rainfall. A higher value of 'CV' is the indicator of larger variability and vice versa which is computed as (eqn. 7):

$$CV = \frac{\sigma}{\mu} \times 10 \quad (7)$$

where 'CV' is the coefficient of variation, 'σ' is a standard deviation and 'μ' is mean precipitation. According to Hare (2003), 'CV' is used to classify the degree of variability of rainfall events as less (CV<20), moderate (20<CV<30), and high (CV>30).

RESULT AND DISCUSSION

Statistical characteristics of annual and seasonal rainfall:

Rainfall is an important meteorological parameter which has a direct influence on agricultural production and other aspects such as water resources and water availability and it affects urban water supply and industrial, residential and agricultural water uses. In the present study, the mean, standard deviation, and coefficient of variation were analyzed for basic grid-based statistical parameters of annual and seasonal (monsoon, post-monsoon, summer, and winter) precipitation events for the period of 46 years (1970-2015) (Table-1). The annual rainfall data in the watershed for all grids varies from 1274.0 mm/year to 1766.9 mm/year with the weighted average rainfall of 1498.58 mm/year for all the grids. In case of monsoonal rainfall, the mean values range from 645.10 to 1075.9 mm/year within 8 grids, with the weighted average rainfall 854.75 mm/year for all grids. In post-monsoon rainfall, the values range from 23.8 to 37.9 mm/year within 8 grids, with the weighted average rainfall of 31.5 mm/year for all grids. In winter rainfall, the mean value ranges from 235.6 mm/year to 338.5 mm/year within 8 grids, with the weighted average of 291.98 mm/year for all the grids. In summer rainfall, the mean value ranges from 95.9 mm/year to 148.1 mm/year within 8 grids, with a weighted average from 115.8 mm/year for all the grids. These values indicate that the regions with greater rainfall have less variability than the regions with relatively lower rainfall. The observation of annual and seasonal rainfall records showed that the maximum rainfall was 2352.9mm in the year 2010 (wettest year) and minimum rainfall of 918.0mm in the year 1976 (driest year). The preliminary related statistics of mean annual and seasonal rainfall for all the grids shown in Table-2 and the grid-based representation of long term annual and seasonal rainfall trend are shown in Fig. 2(a-e).

Table-1: Statistics of grid-wise mean rainfall (mm) in the watershed.

Grid	Annual	Monsoon	Post-monsoon	Summer	Winter
1	1310.4	774.6	26.5	235.6	95.9
2	1504.8	910.4	29.5	280.0	106.6
3	1590.5	897.9	37.9	307.9	128.0
4	1766.9	1075.9	34.1	301.7	104.1
5	1627.7	987.2	28.9	279.9	96.0
6	1556.2	863.8	34.5	326.8	131.4
7	1358.2	645.1	37.2	338.5	148.1
8	1274.0	683.1	23.8	265.5	116.7

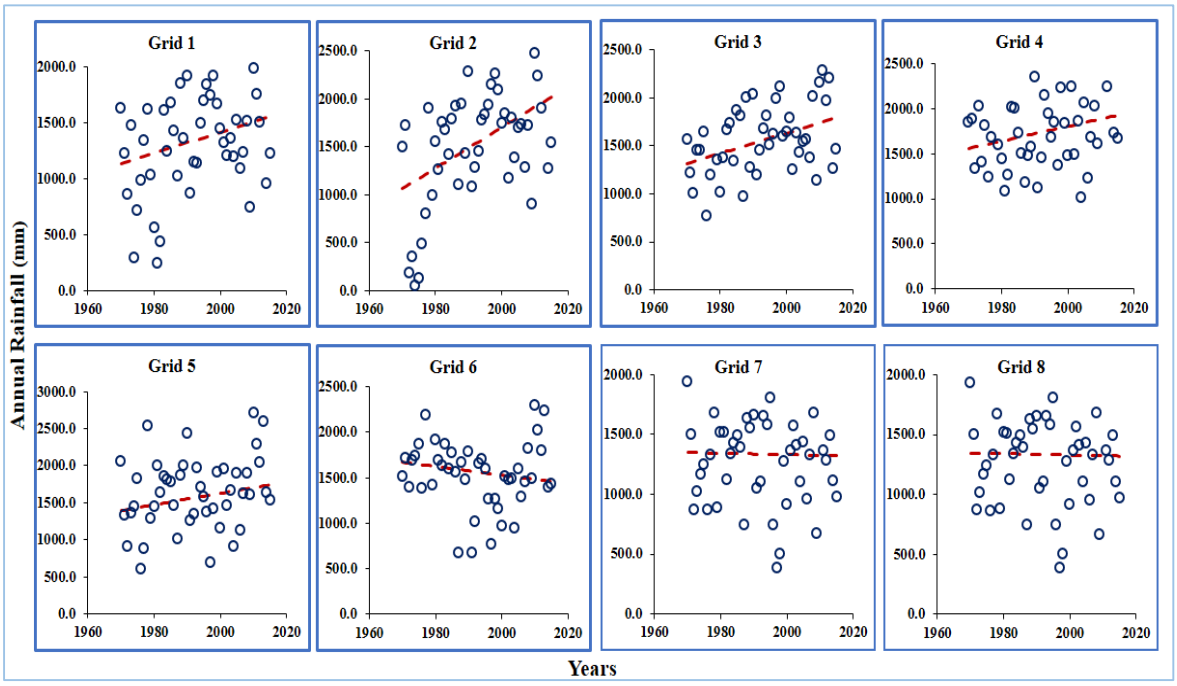

Fig. 2(a): Trend in Annual rainfall of each grid.

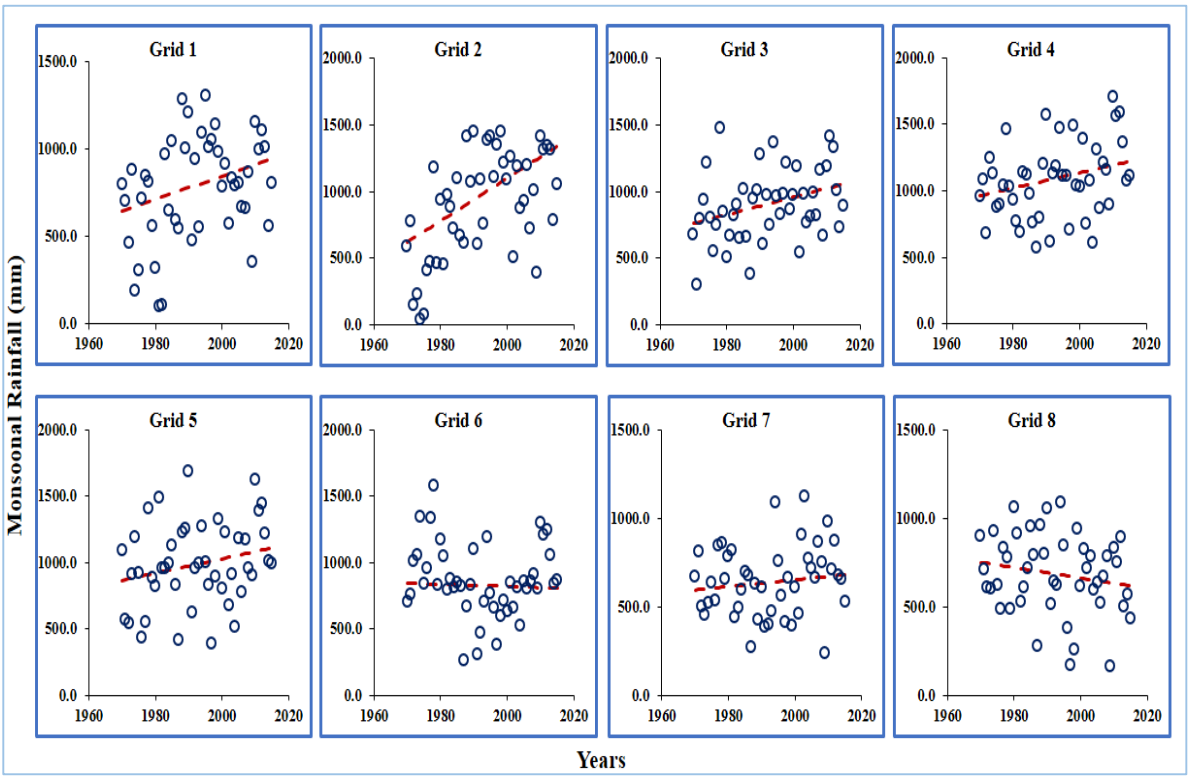

Fig. 2 (b): Trend in Monsoonal rainfall of each grid.

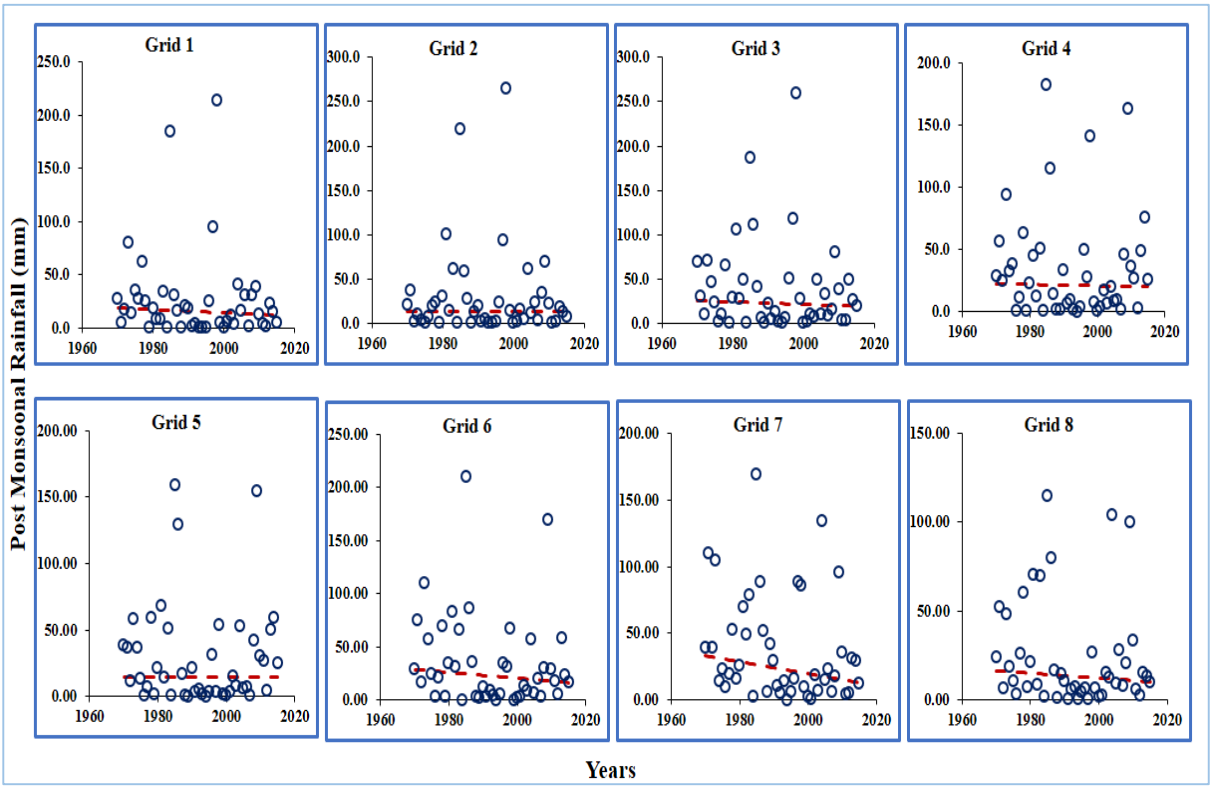

Fig. 2 (c): Trend in Post-Monsoonal rainfall of each grid.

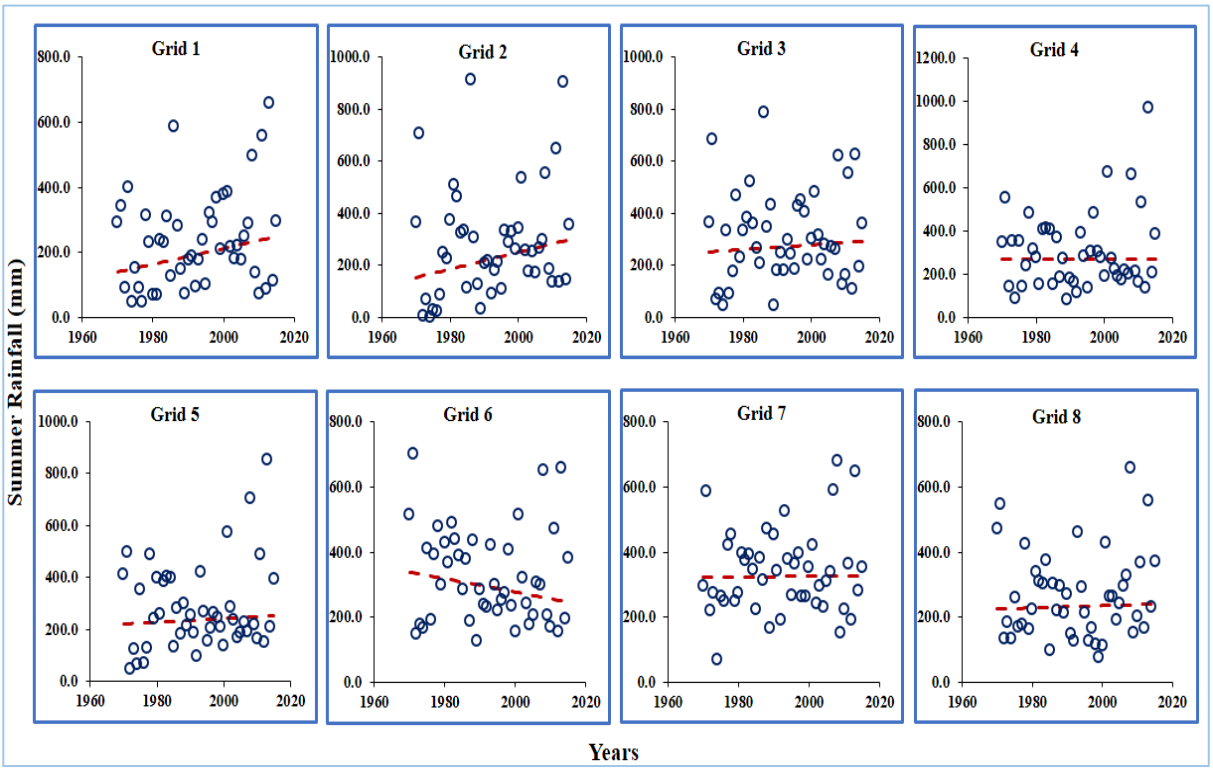

Fig. 2 (d): Trend in Summer rainfall of each grid.

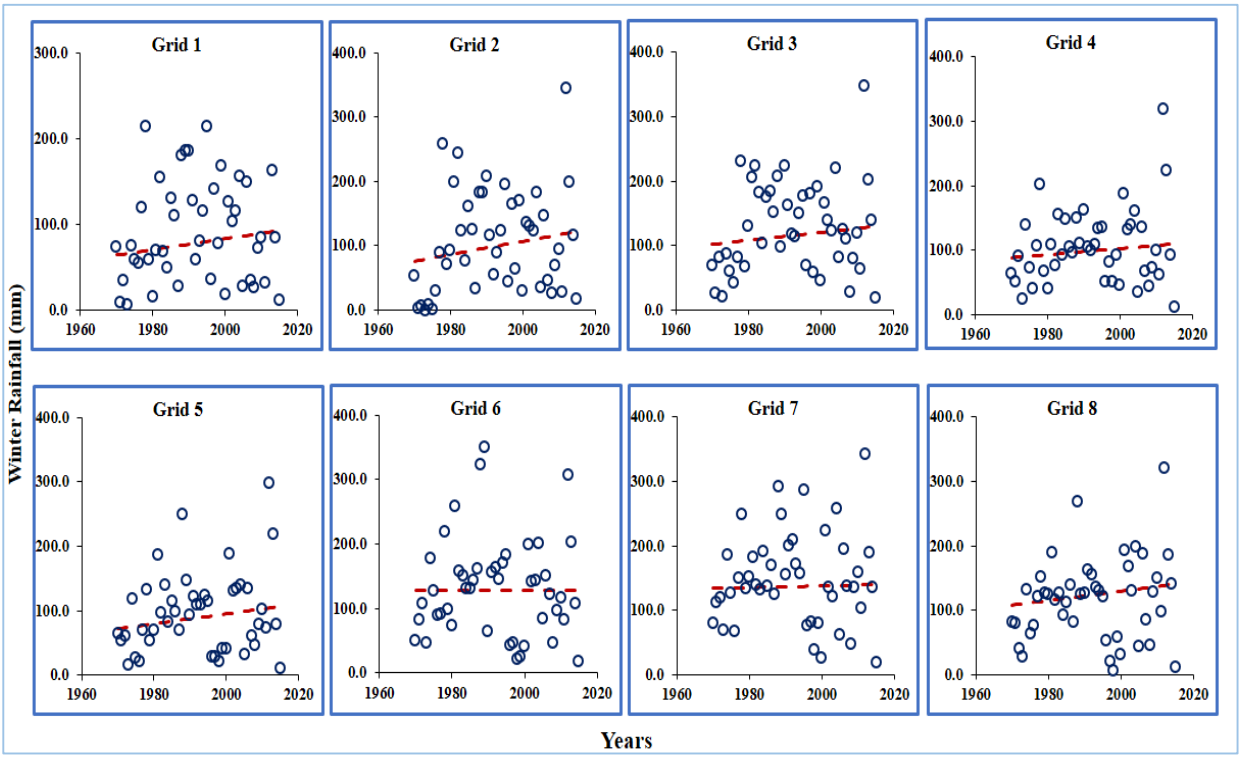

Fig. 2(e): Trend in Winter rainfall of each grid.

Trend Analysis:

Determination of the rainfall trend based on gridded data was done through Mann-Kendall and Sen's Slope estimator. The trend analysis is performed for the watershed by using average annual and seasonal rainfall data.

Seasonal and Annual rainfall trends:

For the period of 1970-2015, Table-2 shows *Zc*-statistics values of rainfall in a monthly time scale using the MK-test. The monsoonal season provides a maximum contribution to annual rainfall in the watershed, predominantly in the months of July, August, and September. The rainfall trends of annual and seasonal rainfall are shown in Fig. 2 (a-e). The significant increasing trends are identified using MK-test in the annual and seasonal rainfall data series, the *Zc*-statistics revealed that the increasing trends are found in annual and monsoonal rainfall except for grid 6 and 8 which show an insignificant decreasing trend. In the annual time series, grid 2 shows 1% significance level and grid 3 shows 5% while grids 1, 4 show 10%. In monsoonal time series, grid 2 shows 1% level of significance, grid 3 shows 5% significance level while grid 1 and 4 show 10% significance level. Grid 8 shows a decreasing trend for annual, monsoon and post-monsoon rainfall whereas increasing trend for summer and winter time series, which reflects the decadal variation of rainfall. In post-monsoon time series, all grids show insignificant decreasing trend series except for grid 7 which shows a significant decreasing trend, grid 5 of the same time series shows no trend, which may indicate depletion of water availability with time. The decreasing trend of post-monsoon rainfall indicates that the increasing trend in monsoonal rainfall would be led to decrease in the rainfall amount in the non-monsoon period due to which there would be a decrease in runoff from the area. In the seasonal time scale, the summer and wintertime series all grids show an insignificant increasing trend with grid 6 having a negative trend. The magnitude of positive trends showed that the number of positive trends is much more identified than the negative trends in rainfall series as shown in Fig. 3.

Table-2: Representation of *Zc*-statistics for the annual and seasonal rainfall.

Grid	Annual	Monsoonal	Post-Monsoonal	Summer	Winter
1	**1.86[c]**	**1.89[c]**	-0.89	1.48	0.91
2	**2.99[b]**	**3.39[b]**	-0.08	1.51	1.19
3	**2.10[a]**	**2.23[a]**	-0.71	0.38	1.55
4	**1.70[c]**	**1.76[c]**	-0.21	0.00	0.62
5	1.55	1.55	0.00	0.34	1.17
6	-1.04	-0.34	-1.04	-0.98	-0.02
7	0.89	0.83	**-1.72[c]**	0.13	0.19
8	-0.09	-1.2	-0.86	0.17	1.31

Number in bold indicate significant values. [c]Significant at the 10% level; [a]Significant at the 5% level [b]Significant at the 1% level

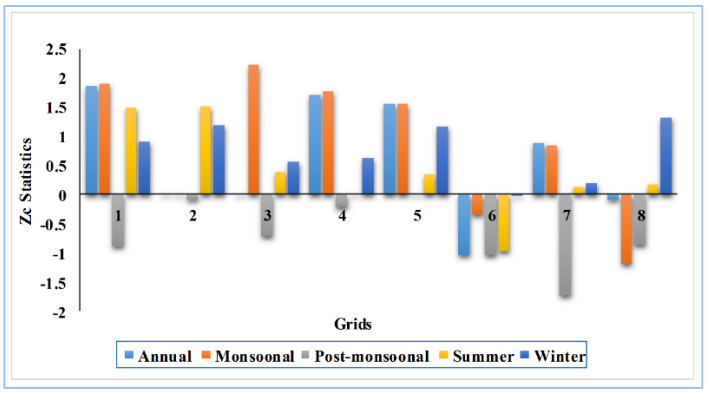

Fig. 3: *Zc*-Statistics for the annual and seasonal rainfall.

Table-3: Statistics of grid-wise Coefficient of Variance (CV) in percentage.

Grid	Mean Annual	Mean Monsoon	Mean Post-monsoon	Mean Summer	Mean Winter
1	33.50	39.55	158.79	61.16	68.18
2	39.64	43.90	174.47	74.98	73.22
3	23.94	29.46	132.78	55.42	53.93
4	25.17	26.16	124.68	57.49	54.85
5	29.30	31.53	129.36	58.38	63.97
6	25.82	31.17	124.58	43.78	58.08
7	26.69	30.26	105.27	37.50	47.95
8	28.30	32.62	123.14	49.23	54.32

Analysis of rainfall variability pattern:

The variability of annual and seasonal rainfall of the study area has been evaluated using the Coefficient of Variance (CV) for the time series of 1970 to 2015 (46 years). The coefficient of variation is a 'statistical measure of how the individual data points vary about the mean value'. The inter-annual variability of seasonal rainfall is greater than that of annual rainfall as given in Table-3. A greater value of 'CV' is the indicator of larger spatial variability, and vice versa. The 'CV' of mean annual and monsoonal rainfall for the study area ranges from 23.94% to 39.64% and 26.16% to 43.9% respectively. 'CV' for weighted mean annual rainfall

and monsoonal rainfall for all grids are 290.4% and 33.08% respectively. For post-monsoon rainfall time series, the 'CV' percentage ranges from 105.27% to 174.47% whereas the 'CV' of weighted mean rainfall of all grids is 134.13%. The 'CV' percentage for mean summer and winter rainfall ranges from 37.5% to 74.98% and 47.95% to 73.22% respectively while the value of weighted mean summer and winter rainfall for all grids are 54.74% and 59.31% respectively as shown in Table-3. The maximum annual and seasonal rainfall variability are shown in grid 2. The lesser value of 'CV' from each grid of annual and seasonal rainfall indicates the highest rainfall in that particular grid.

The variation in rainfall generally represents a normal characteristic of the dataset. However, from an agricultural point of view, it is essential to understand the seasonal variation for precise assessment of supplemental water requirements. Higher 'CV' indicates lower variability within the data series and vice-versa (Krishan, 2016). The maximum number of pixels is having a low value of 'CV' indicate that the inter-annual variability of monsoonal rainfall is greater than that of the annual rainfall. Overall, a high variation of rainfall is seen in the study area. The areas with higher inter-annual variability in rainfall are more susceptible to flood and droughts (Pandey and Ramasatri, 2001; Turkes, 1996). These values indicate that the regions with greater rainfall have less variability than the regions with relatively lower rainfall.

Magnitude of rainfall series:

Table-4: Sen's Slope value for the rainfall.

Grid	Annual	Monsoonal	Post-monsoonal	Summer	Winter
1	9.32	6.57	-0.145	2.42	0.63
2	21.3	16.1	-0.008	3.22	1.10
3	10.5	6.58	-0.141	0.89	0.62
4	8.2	5.76	-0.054	0.06	0.47
5	7.79	5.4	0.00	0.67	0.76
6	-4.74	-0.77	-0.27	-2.05	-0.02
7	4.38	1.92	-0.45	0.144	0.14
8	-0.60	-2.94	-0.13	0.32	0.73

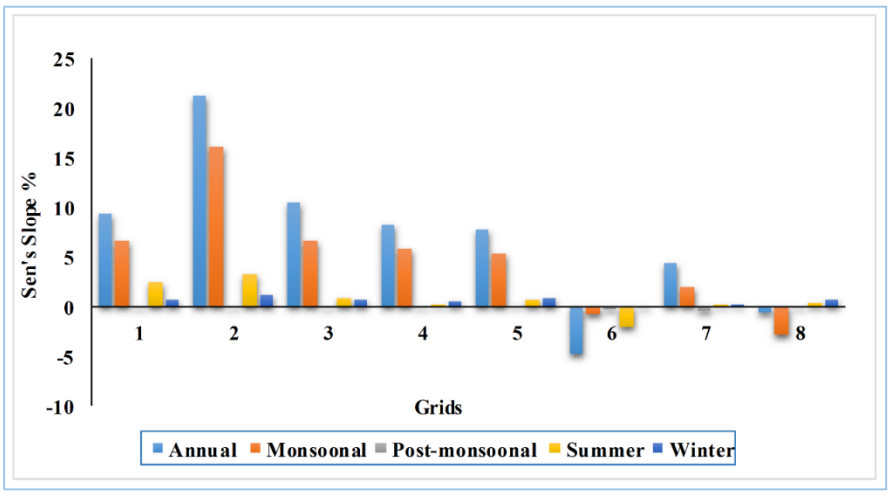

Fig. 4: Sens's Slope (%) for the annual and seasonal rainfall.

Table-4 shows the magnitude of annual and monsoonal rainfall series, the magnitude of trend ranges from -0.60 at grid 8 to 21.3 at grid 2 and -0.77 at grid 6 to 16.1 at grid 2 respectively. Grid 6 and 8 show the negative (decreasing) trend for both annual and monsoonal rainfall. For the post-monsoon time series, all values show a magnitude of a negative (decreasing) trend except grid 5 which shows no trend. For the summer and winter

season, all grids show positive (increasing) trend except for grid 6 of the Sen's estimator. The results are quite significant as the grids where MK trend analysis has shown a positive trend, the similar positive slope has been observed for Sen's slope and vice versa. As assumed rainfall trends show a large variation in magnitude and direction of trend from one grid to another (Fig. 4).

CONCLUSION

The present study examined the rainfall data for the last 46 years (1975-2015) of Asan watershed and surroundings in the Doon valley, Uttarakhand to determine the trend of precipitation. The study is carried out to estimate the rainfall trend using the MK-test and Sen's slope estimator. The analysis of annual and seasonal rainfall revealed significant, however, a varying trend in the different grids. The present study brings out some of the interesting and significant changes in the rainfall pattern in some of the grids. The monsoonal season provides a maximum contribution to annual rainfall in the watershed, predominantly in the months of July, August, and September. The *Zc*-statistics represents both positive and negative trend of rainfall in the area except for grid 6 which show an insignificant decreasing trend and slope for both the annual and seasonal rainfall. Similar information is also confirmed by Sen's slope estimator that indicates a periodic change in the magnitude of the slope and the rainfall. The Coefficient of variance (CV) suggested that the higher rainfall in particular grid is corresponds to lesser variability. The overall analysis indicates a long term increasing trend of annual rainfall in the watershed. Also, annual and seasonal rainfall indicating both the increasing and decreasing trend. The analysis also concluded that the number of decreasing trend increases after monsoonal season. From all the statistical conclusion, it is evident that some important changes in the trend of rainfall in span of the last 46 years. The scrutiny and findings related to rainfall data could be useful in managing water resources in the watershed. Dehradun is one of the important cities in the Himalayan region which suffered from urbanization and industrialization. Because of this, it is one of the vulnerable cities to urban climate change and that too mostly due to anthropogenic activities. The present research based on the analysis of rainfall data series duly supports the speculations that the variation in rainfall at the watershed is due to recent urbanization and industrialization processes. Expansion of land use land cover, construction and expansion of settlements, roads construction, mining activities etc. are some of the activities which influence the changing pattern of rainfall and furthermore, lead to change in the hydrological cycle and affect the agriculture productivity in Doon Valley.

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