

Trends of Climatic Variability in the Sub-Himalayan Region of Jammu Division

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Abstract

This study investigates long-term trends of climatic variability in the mountainous region of the Jammu division, located in the Sub-Himalayan zone of Jammu & Kashmir, India. The primary objectives are to assess the trends in temperature and precipitation over a 42-year period (1980–2022) across different seasons—pre-monsoon, monsoon, post-monsoon, and winter. A shape file of areas above 600 meters elevation was generated using SRTM DEM data, and data from nine meteorological stations were extracted from NASA POWER and IMD sources. A non-parametric statistical approach was employed using the Mann-Kendall trend test and Sen's Slope estimator to identify the direction and magnitude of climatic trends. Temperature averages and precipitation totals were seasonally aggregated, and results were spatially interpolated using Inverse Distance Weighting (IDW) in ArcMap 10.8. The results reveal a significant upward trend in temperature across most seasons, with the most pronounced warming occurring during the monsoon and post-monsoon periods. Precipitation trends exhibited regional and seasonal variability, with certain zones experiencing declining rainfall trends, particularly during the winter season. These findings highlight growing climatic instability in ecologically fragile mountainous regions, which has serious implications for agriculture, water security, and sustainable development in the Jammu division.

Key words: Climate variability, Temperature trends, Precipitation trends, Mann-Kendall test, Sen's slope, Mountain ecosystem

Climate and weather are two of the important parameters for any of the life support system on the planet earth to sustain in an efficient manner. Climate and weather are two of the commonly related terms ecosystem. The literal meaning of the term “weather” is the general condition of the atmosphere at a particular time and place with regards to temperature, moisture, precipitation and other related parameters, while on the other hand “climate” is defined as “the average weather condition of any area over a large period of time usually more than 30 years”. These both terms can be distinguished from the fact that “Climate is what you expect, Weather is what you get”. At the present time when the human kind is trying to colonize other planets like Mars, trying to colonize the south pole of moon but all these achievements of human kind are at the stake of globally changing climatic patterns. Climate change is the burning topic of this 21st century particularly in the last two decades of 20th century and the first two decades of 21st century. Soon after the Industrial Revolution more precisely after the world wars the situation of global climate began to deteriorate global warming is increased at an alarming rate, glaciers began to melt, erratic patterns are observed in different seasons over different parts of world [1]. Soon the global agencies started to tackle this ever-increasing problem of climatic change different conferences are being organized at the international level such as Stockholm conference and many more, different treaties are

signed between the member countries to resist this problem of climatic change at different scales. At present also the problem of climate change is very much serious as it encompasses one of the seventeen sustainable goals of the United Nation. Thirteenth goal of the sustainable development is about “Climate Action*” which clearly indicates how important this matter of climate is. This goal states that “Take urgent action to combat climate change and its impacts”. Climate is an important factor for all the activities taking place over the earth surface weather directly or indirectly [2]. Human with their selfish deeds from the ancient time more pronouncedly in the last four or five decades have changed the normal patterns of climate over the whole planet [3]. There is not a single place where one cannot find the impacts of climate change ranging from the small ecosystem to that of the global communities. In the Indian and particularly the Jammu and Kashmir's case this problem will be more in the near future. One can analyze the changing status of the climatic pattern of Jammu and Kashmir from the fact that before 2024 in the Kishtwar district of Jammu division there is inches of snowfall in the month of January every year but in 2024 till the mid-February there is no such snowfall there. Jammu and Kashmir is home to the mountainous ecosystem of different types, mountains ecosystem is more fragile ecosystem in this world, they are more pronounced to any micro level change in the surroundings. Hence any small

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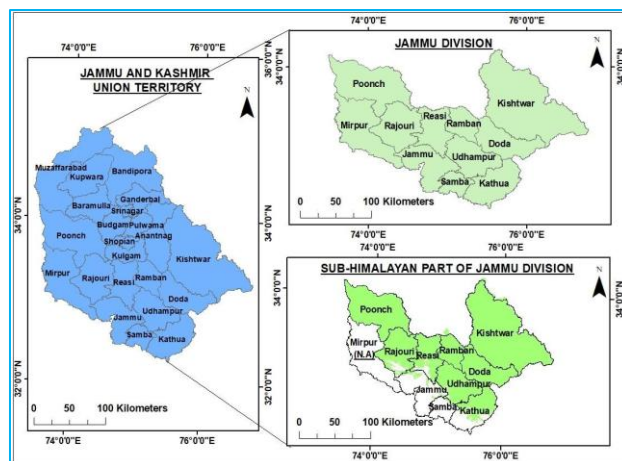
fluctuation in the mountain ecosystem can be disastrous many of times. It becomes very important to study the different elements of climate in the mountainous area as mountains are also the treasuries of resource no doubt that majority of the world's population resides in the low plains where there is abundant resource supply but on the other hand one should keep in mind the concept of lowland upland interaction that shows how important the mountains are to people living in the vicinity of plains [4-5]. In Jammu division there are also significant mountainous areas in the districts such as Kishtwar, Ramban, Poonch, Reasi and Rajouri. Here in this report thus as assessment is being made regarding the pattern of temperature and precipitation in the mountainous parts of Jammu division which is very important to know the status of the climatic change in the said area.

MATERIALS AND METHODS

Study area

Jammu and Kashmir is the northern most state of India in the north western Himalayas having locational extent between 32°58' and 36° 58' north latitude and 73°26' and 83°30' east longitude. This Union territory of Jammu and Kashmir is surrounded by Himachal Pradesh, Punjab in the south and Ladakh in the east. Jammu and Kashmir has 3.66%

(1,20,355 square kilometres) including PoK of Country's and is 12th largest among all the states and union territories of India.



Map 1 Study area

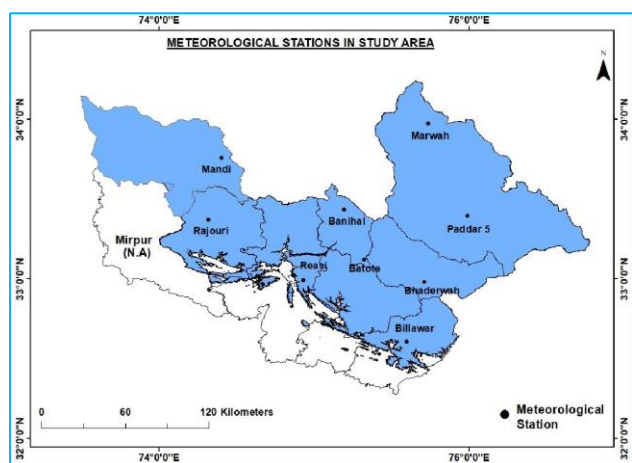
Meteorological stations

A total of 9 weather stations are selected here to access the trends of climatic parameters in our study area description of these stations is given below in the (Table 1).

Table 1 Latitudes and longitudes of all meteorological stations

S. No.	Station name	District	Latitude	Longitude
1	Rajouri	Rajouri	33.3716	74.3152
2	Katra	Reasi	32.9915	74.9318
3	Billawar	Kathua	32.606	75.597
4	Batote	Ramban	33.1216	75.3216
5	Bhaderwah	Doda	32.983	75.711
6	Mandi	Poonch	33.759	74.402
7	Banihal	Ramban	33.437	75.1939
8	Paddar 5	Kishtwar	33.398	75.99
9	Marwah	Kishtwar	33.975	75.736

Source: SKAUST-Jammu and Indian Meteorological Department (IMD)



Map 2 Meteorological stations in study area

As here in this report we have to access the temperature and precipitation of Jammu division in mountainous part so first of all a shape file of mountainous part of Jammu division is created then data is related to the said two elements of climate is collected all the nine meteorological stations selected for conducting this study, data collected is from year 1980 to 2022. As the data of temperature and precipitation collected for the meteorological stations comprises of all the months of the year and the annual value but for our study we need data for the four broad seasons as pre-monsoon season, monsoon season, post-

monsoon season and winter season. Data for these four seasons is calculated as:

For temperature data

For temperature average is calculated as:

- Pre-monsoon Season = (March value + April value + May value) / 3.
- Monsoon Season = (June value + July value + August value) / 3.
- Post-monsoon Season = (September value + October value + November value) / 3.
- Winter Season = (December value + January value + February value) / 3.

For Precipitation data

For precipitation only sum of the selected month is taken as:

- Pre-monsoon Season = (March value + April value + May value).
- Monsoon Season = (June value + July value + August value).
- Post-monsoon Season = (September value + October value + November value).
- Winter Season = (December value + January value + February value).

After the data of temperature and precipitation is obtained in the five selected fields of annual value, pre-monsoon value, monsoon value, post-monsoon value and winter value then to analyze the trend of these elements of

climate Mann- Kendall test and Sen’s slope are used for all the five selected fields.

Mann-Kendall test

The Mann-Kendall test is a non-parametric way to identify a trend in a series. This test is the result of the development of the non-parametric trend test first proposed by Mann (1945), this test was further studied by Kendall (1975) and improved by Hirsch et al (1982, 1984). The null hypothesis for these for these tests is that there is no trend in the series. The three alternative hypothesis are that there is a negative, non-null and positive trend. The Mann-Kendall tests are based on the calculation of Kendall’s tau measure of association between two samples. The computations assume that the observations are independent. The Mann-Kendall test consists of comparing each value of the time series with the others remaining, always in sequential order. The number of times that the remaining terms are greater than that under analysis is counted.

The Mann-Kendall statistic is given by:

$$S = \sum_{i=2}^n \sum_{j=1}^{i-1} \text{sign}(x_i - x_j)$$

Where n is the length of the data set, xi and xj are two generic sequential data values.

The function sign (xi – xj) assumes the following values:

$$\text{Sign}(x_i - x_j) = \begin{cases} +1, & \text{if } (x_i - x_j) > 0 \\ 0, & \text{if } (x_i - x_j) = 0 \\ -1, & \text{if } (x_i - x_j) < 0 \end{cases}$$

Under the hypothesis of independent and randomly distributed variables when n ≥ 8 the statistic S is approximately normally distributed with zero mean and the variance Var(S) as follows:

$$\text{Var}(S) = \frac{1}{18} [n(n - 1)(2n + 5)]$$

Where n is the length of the time series.

The standardized test statistic Z is given as:

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

The presence of a statistically significant trend is evaluated using the Z- value. This statistic is used to test null hypothesis such that no trend exists. A positive Z value indicates that an increasing trend in the time series, while on the other hand a negative Z-value indicates a decreasing trend.

Sen’s slope

Non-parametric method Sen’s slope was used by Sen in 1968 to estimate the magnitude of trends in the data time series. The slope of “n” values of can be estimated by the following equation:

$$\beta_i = \text{Median} \left[\frac{X_j - X_k}{j - k} \right] \quad (k < j)$$

In this equation Xj and Xk denote values data at time j and k, respectively and time j is after time k (k ≤ j). The median of “n” value of βi is the Sen’s slope estimator test.

A negative βi value represents a decreasing trend, a positive βi value represents an increasing trend over time.

If “n” is an even number then slope Sen’s estimator is computed by using the following equation:

$$\beta_{\text{med}} = \frac{1}{2} (\beta_{\lfloor \frac{n}{2} \rfloor} + \beta_{\lfloor \frac{n+2}{2} \rfloor})$$

If “n” is an odd number, then the estimated slope by using the Sen’s method can be computed as follows:

$$\beta_{\text{med}} = \beta_{\lfloor \frac{n+1}{2} \rfloor}$$

RESULTS AND DISCUSSION

As described earlier here in this report we are analysing the trends in the elements of climate particularly in terms of temperature and precipitation based on Mann-Kendall and Sen’s Slope. First temperature trends in selected five categories of annual values, pre-monsoon season value, monsoon season value, post-monsoon season value and winter season value are discussed then precipitation trends are discussed in the preceding heading.

Temperature trend using Mann-Kendall and Sen’s slope

After collecting data from the NASA POWER, values for all the selected five seasons of annual, pre-monsoon, monsoon, post-monsoon and winter season are calculated, here to calculate the values average temperature is calculated by the formula as shown in the methodology. After calculating values for the five said seasons then the Mann-Kendall test and Sen’s Slope values are calculated to find out the temperature trend as described below for all selected seasons.

Annual trend of temperature

Distribution of Mann-Kendall test Z-value and P-value along with the value of Sen’s Slope for the Annual temperature trend are given below in the (Table 2).

Table 2 Calculation of Mann-Kendall test and Sen’s slope trend for annual season temperature in all nine meteorological stations

S. No.	Station	MK (Z-value)	P-Value	Sen’s slope	Trend
1	Rajouri	0.62	0.52	0.005	Positive
2	Katra	1.13	0.25	0.01	Positive
3	Billawar	0.85	0.39	0.007	Positive
4	Batote	1.17	0.24	0.01	Positive
5	Mandi	0.57	0.56	0.006	Positive
6	Banihal	1.24	0.21	0.011	Positive
7	Paddar5	1.69	0.09	0.013	Positive
8	Bhaderwah	1.17	0.21	0.01	Positive
9	Marwah	1.26	0.2	0.01	Positive

source: data compiled by author in r-studio app

The data depicted in the (Table 1) revealed that the highest Z-value of Mann-Kendall test in terms of temperature related to season is found at Paddar 5 station while lowest at Mandi station of Poonch district of Jammu and Kashmir, which

highest P-value is found at Mandi station and lowest in Paddar 5 station. In terms of Sen’s Slope highest value is found at four stations namely Katra, Batote, Bhaderwah and Marwah all having value of 0.01 [6].

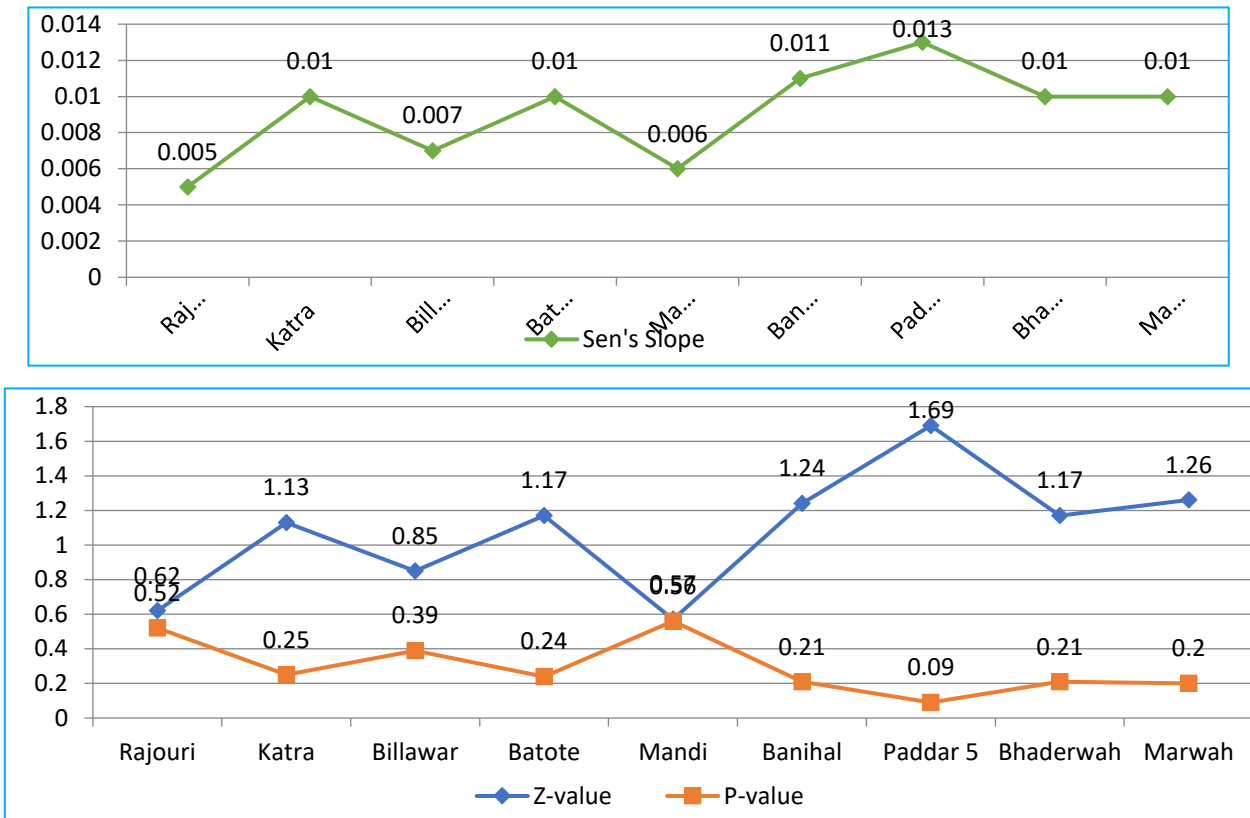
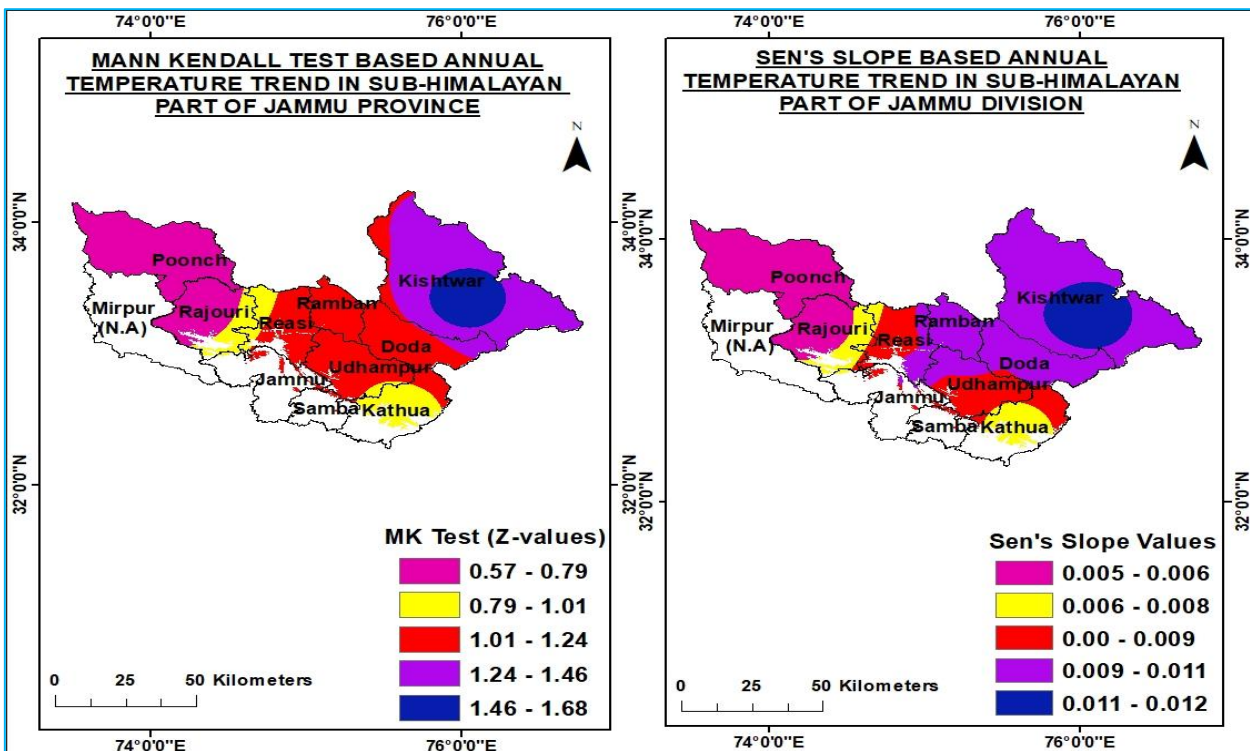


Fig 1 Annual temperature-based Sen's slope and Mann-Kendall test values for all meteorological stations



Map 3 Mann-Kendall Test and Sen's slope based annual temperature trend

In the Mann-Kendall test map there are five class intervals of Z-value, all the values are positive that clearly indicates that the trend in this case is positive. The lowest class interval is of 0.57 to 0.79 value that encompasses the north western part of Jammu division in the whole Poonch district and north western part of Rajouri district. In the next class interval of 0.79 to 1.01 small parts of Rajouri and Reasi district are present while it also encompasses the northern part of Kathua district. In the next class interval of 1.01 to 1.24 the majority area of Jammu division shows this trend in annual temperature

temporally from 1980 to 2022 areas of Reasi, Ramban, Udhampur and Doda majorly shows this trend while in the north western part of Kishtwar district trend of same class interval is observed. The next two class interval showing trend of 1.24 to 1.46 and 1.46 to 1.68 are primarily found in the Doda and Kishtwar district where in Doda district majorly shows trend in between 1.46 to 1.68 value while Kishtwar has major area showing trend between 1.46 to 1.68 Z-value [7-8].

In the annual temperature trend map of Sen's Slope value there are also five class interval all the values are positive that

indicates that the trend is positive. In the lowest class interval of 0.005 to 0.006 is found in the Poonch district along with the north western part of Rajouri district while the next interval of 0.006 to 0.008 trend value is observed in the middle part of Rajouri district and the northern part of Kathua district. Small eastern part of Rajouri district along with southern, western and eastern part of Udhampur district and eastern part of Kathua district shows trend in between 0 to 0.009. In terms of annual trend of temperature Sen's slope value majority mountainous

part of Jammu division shows a trend between 0.009 to 0.011 value as it encompasses area of Ramban, Reasi, Doda and Kishtwar district. Central part of Kishtwar district belongs to the highest-class interval of value between 0.011 to 0.012 [9].

Pre-monsoon season temperature trend

Distribution of Mann-Kendall test Z-value and P-value along with the value of Sen's Slope for the Pre- monsoon season temperature trend are given below in the (Table 3).

Table 3 Calculation of Mann-Kendall test and Sen's slope trend for pre-monsoon season temperature in all nine meteorological stations

S. No.	Station	MK (Z-value)	P-Value	Sen's Slope	Trend
1	Rajouri	1.08	0.27	0.022	Positive
2	Katra	1.47	0.14	0.028	Positive
3	Billawar	1.51	0.12	0.029	Positive
4	Batote	1.36	0.17	0.024	Positive
5	Mandi	1.06	0.28	0.022	Positive
6	Banihal	1.36	0.17	0.027	Positive
7	Paddar 5	2.22	0.02	0.032	Positive
8	Bhaderwah	1.36	0.17	0.024	Positive
9	Marwah	1.88	0.05	0.03	Positive

Source: Data compiled by Author in R-Studio app

From the (Table 3) it is clear that in terms of trend of temperature of Pre-monsoon highest trend z-value is found at Paddar 5 station while lowest is found at Mandi station with value of 1.06. In terms of P-value highest is found at Mandi station while lowest is found at Paddar 5 Station. In case of

Sen's Slope value all values are positive hence the trend at all the stations is positive in case of temperature trend of Pre-monsoon season highest Sen's Slope value is found at Marwah station at lowest at Rajouri and Mandi station both having trend value of 0.22 [10-12].

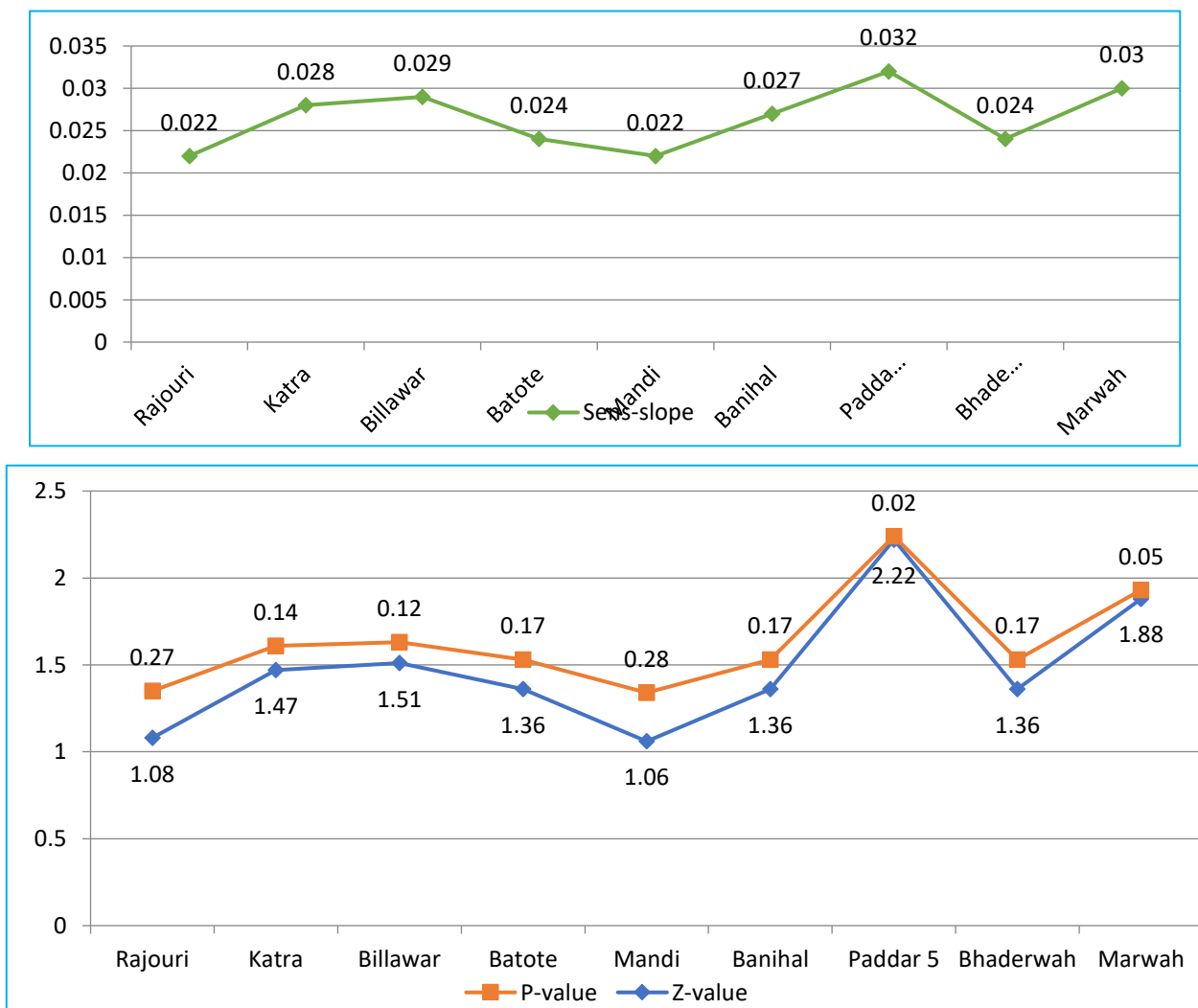
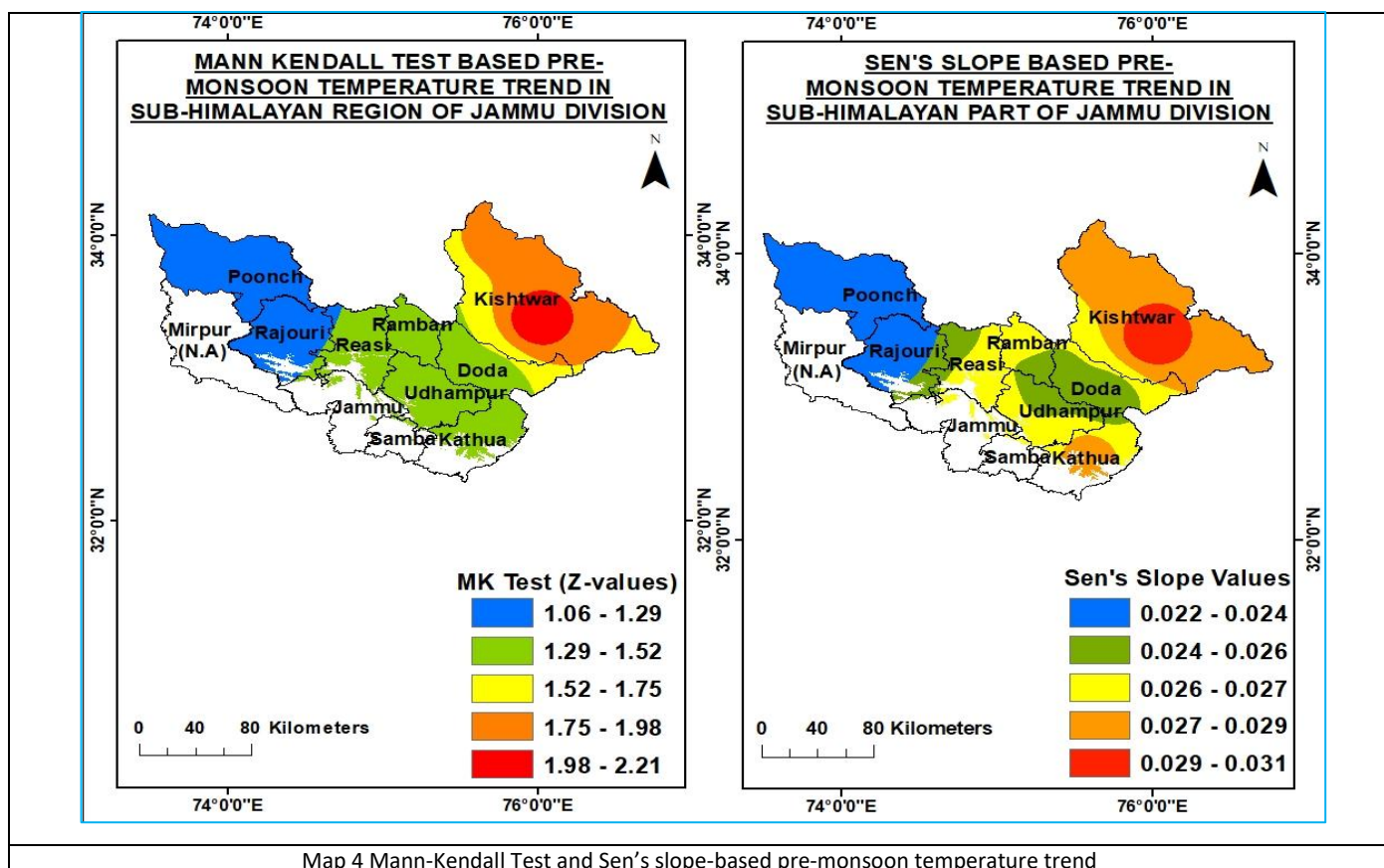


Fig 2 Pre-monsoon temperature-based Sen's Slope and Mann-Kendall test values for all meteorological stations



Map 4 Mann-Kendall Test and Sen's slope-based pre-monsoon temperature trend

In the Pre-monsoon temperature trend of Mann-Kendall Z-value there are five class interval all the class interval are positive which shows that the trend is positive in all areas. Whole Poonch district along with western part of Rajouri district belongs to the lowest class interval of 1.06 to 1.29. Majority part of mountainous area of Jammu division falls in the class interval of trend between 1.29 to 1.52 areas included are eastern part of Rajouri district, Reasi district, whole of Ramban district, northern and eastern part of Udhampur district and western part of Doda district. The remaining three class interval of Pre-monsoon temperature trend namely 1.52 to 1.75, 1.75 to 1.98 and 1.98 to 2.21 are found only in two districts of Doda and Kishtwar, eastern part of Doda district and south-eastern part of Kishtwar district shows trend in class interval of 1.52 to 1.75 while northern and middle portion of Kishtwar shows pre-monsoon trend in between 1.75 to 1.98. Temperature trend of highest-class interval is found in the central part of

Kishtwar. In the trend map of Pre-monsoon temperature using Sen's Slope there are also five class interval lowest trend value class interval is found in Poonch and western Rajouri district. Western part of Rajouri with value of 0.022 to 0.024 district and eastern part of Doda district along with northern Udhampur shows temperature trend in the class interval of 0.024 to 0.026. Majority of the area belongs to the trend interval of 0.026 to 0.027 areas included are Reasi district, southern Udhampur and eastern Kathua. Northern and Southern part of Kishtwar district along with northern Kathua belongs to the class interval of 0.027 to 0.029. Highest trend value is found in the central part of Kishtwar district [13-15].

Monsoon season temperature trend

Distribution of Mann-Kendall test Z-value and P-value along with the value of Sen's Slope for the Monsoon season temperature trend are given below in the (Table 4).

Table 4 Calculation of Mann-Kendall test and Sen's slope trend for monsoon season temperature in all nine meteorological stations

S. No.	Station	MK (Z-value)	P-Value	Sen's Slope	Trend
1	Rajouri	-1.79	0.07	-0.019	Negative
2	Katra	-1.85	0.06	-0.017	Negative
3	Billawar	-2.42	0.01	-0.023	Negative
4	Batote	-1.97	0.04	-0.016	Negative
5	Mandi	-1.61	0.1	-0.014	Negative
6	Banihal	-0.95	0.34	-0.007	Negative
7	Paddar 5	1.32	0.186	0.01	Positive
8	Bhaderwah	-1.97	0.04	-0.016	Negative
9	Marwah	0.48	0.62	0.002	Positive

Source: Data compiled by Author in R-Studio app

From the (Table 4) it is clear that in terms of Z-value of Mann-Kendall test highest value is found at Paddar 5 station while lowest is found at Billawar station. In terms of P-value highest value is found at Banihal station while lowest at Rajouri

station. In case of Sen's Slope here out of 9 stations 7 are showing negative trend highest value is found at Paddar 5 station. The majority of stations are undergoing a declining trend, with spatial variability in the magnitude [16-17].

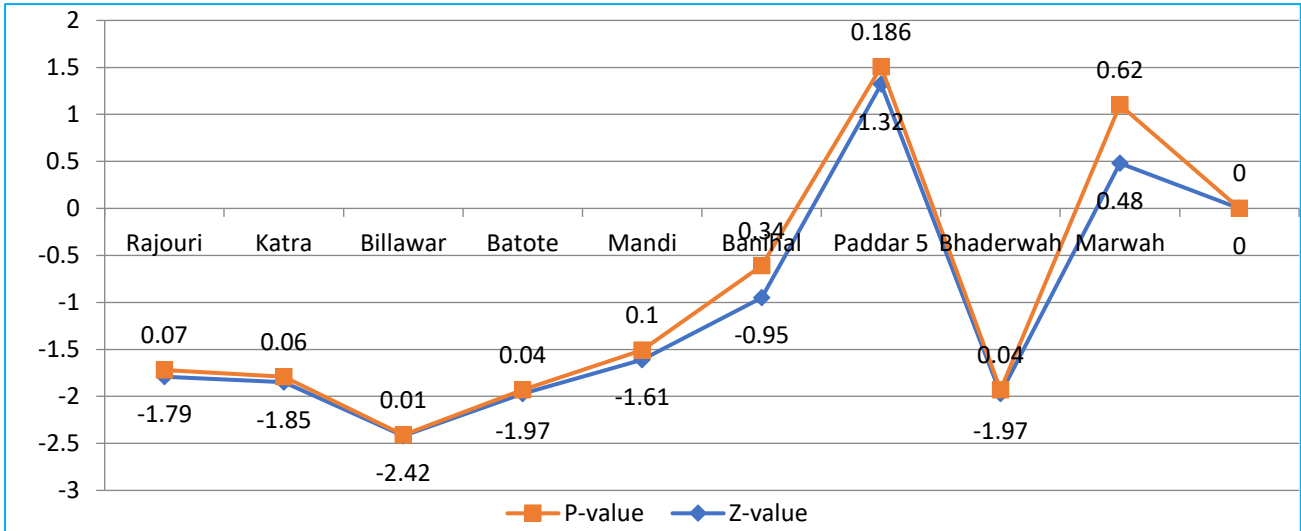
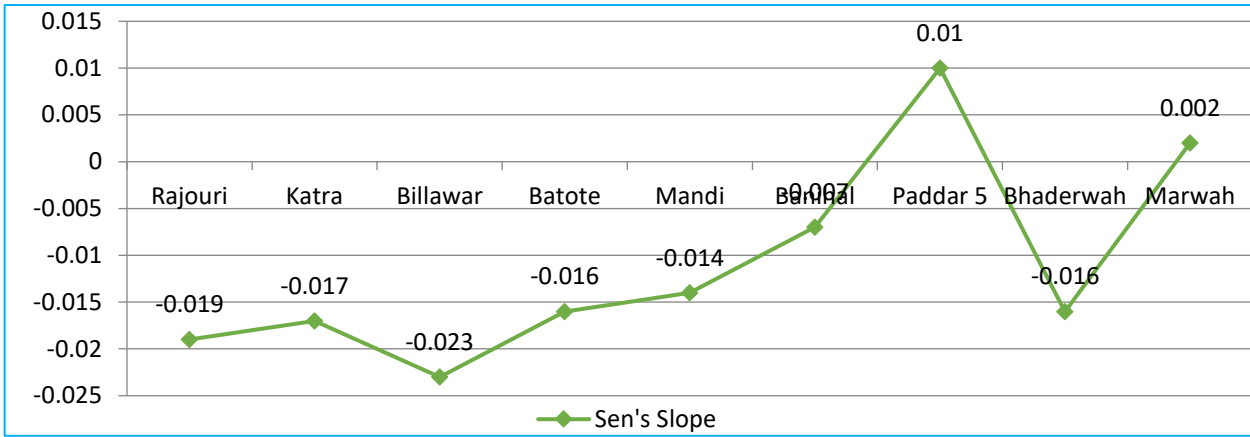
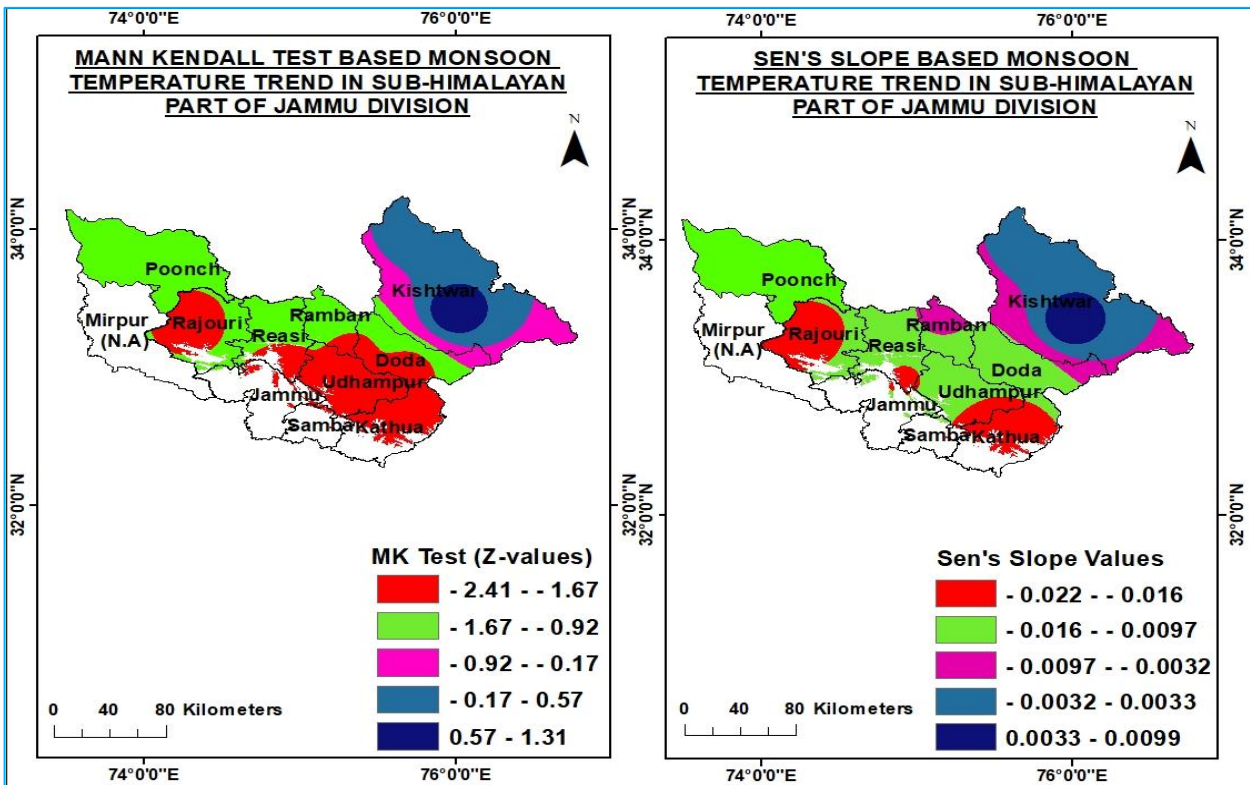


Fig 3 Monsoon temperature-based Sen's Slope and Mann-Kendall test values for all meteorological stations



Map 5 Mann-Kendall test and Sen's slope-based monsoon temperature trend

In the case of Monsoon temperature trend map out of all the 9-weather station under study only two Marwah and Paddar 5 shows positive trend while other with negative Z-value shows

negative trend. In the Mann Kendall test map of monsoon trend there are 5 class intervals, the lowest class interval having value between -2.41 to -1.67 is found in the western part of Rajouri

district southern part of Reasi district, northern part of Udampur and Kathua district and south-western part of Doda district. Poonch district, small part of Rajouri district, northern part of Ramban and Reasi district and northern part of Doda district belong to the class interval of -1.67 to -0.92 trend value. Extreme eastern and extreme southern part of Kishtwar district shown monsoon temperature trend in the class interval of -0.92 to -0.17 while northern part of Kishtwar along with south western part of Kishtwar district belong to the class interval of -0.17 to 0.57. Central part of Kishtwar district shows the highest monsoon trend having value between 0.57 to 1.31 [18].

In the Sen's Slope map of temperature trend of monsoon season there are also five classes. Western part of Rajouri district, northern part of Kathua district and small area of southern Reasi belongs to the lowest class interval of -0.022 to -0.016 while majority of the mountainous area of Jammu division lies in the class interval -0.016 to -0.0097 areas included are Poonch district eastern part of Rajouri district, Reasi district, Ramban district and major part of Doda district

Northern part of Ramban district and extreme western and southern part of Kishtwar district lies in the class interval of -0.0097 to -0.0032. Only eastern part of Doda and Kishtwar district belong to the trend of positive values, the highest class of 0.0033 to 0.0099 [19].

Post- monsoon season temperature trend

Distribution of Mann-Kendall test Z-value and P-value along with the value of Sen's Slope for the Post- monsoon season temperature trend are given below in the (Table 5). In terms of Z-value of Mann-Kendall test highest value is found Paddar 5 station with a value of 2.46 while lowest is found at Billawar station with value of 0.49. In case of P-value highest is found at Billawar station with value 0.61 and the lowest is found at Paddar station 0.01 value. In case of Sen's slope here all the stations show positive trend, highest value is found at Paddar 5 station having value of 0.021 while lowest Sen's slope value is found at Billawar station [20].

Table 5 Calculation of Mann-Kendall test and Sen's slope trend for post-monsoon season temperature in all nine meteorological stations

S. No.	Station	MK (Z-value)	P-Value	Sen's Slope	Trend
1	Rajouri	1.2	0.22	0.009	Positive
2	Katra	0.94	0.34	0.008	Positive
3	Billawar	0.49	0.61	0.002	Positive
4	Batote	1.43	0.15	0.011	Positive
5	Mandi	1.38	0.16	0.012	Positive
6	Banihal	1.78	0.07	0.015	Positive
7	Paddar 5	2.46	0.01	0.021	Positive
8	Bhaderwah	1.43	0.15	0.011	Positive
9	Marwah	1.9	0.05	0.016	Positive

Source: Data compiled by Author in R-Studio app

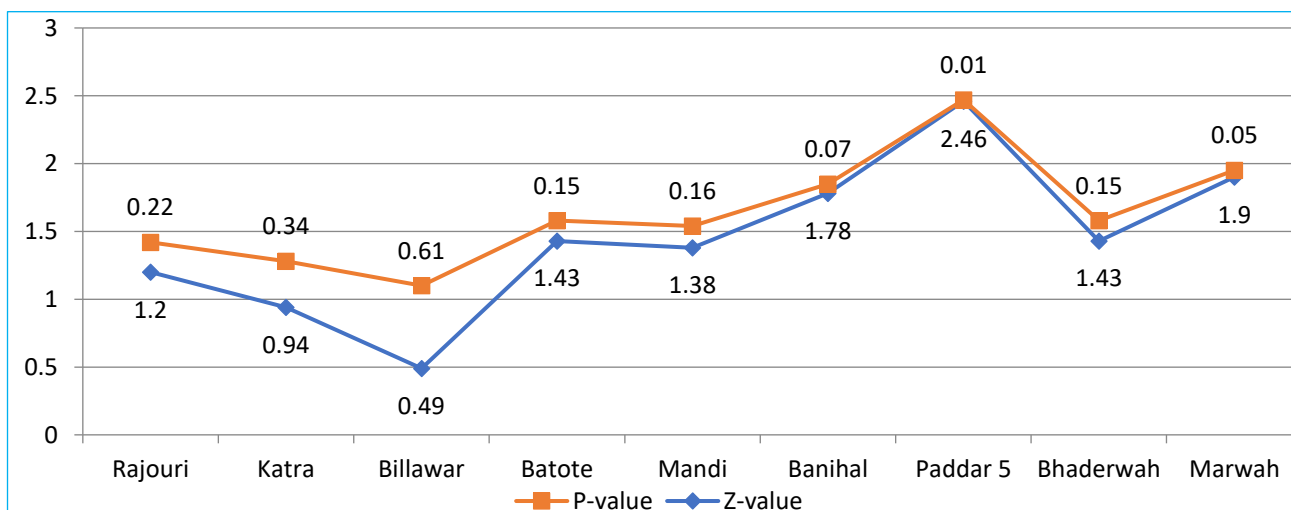
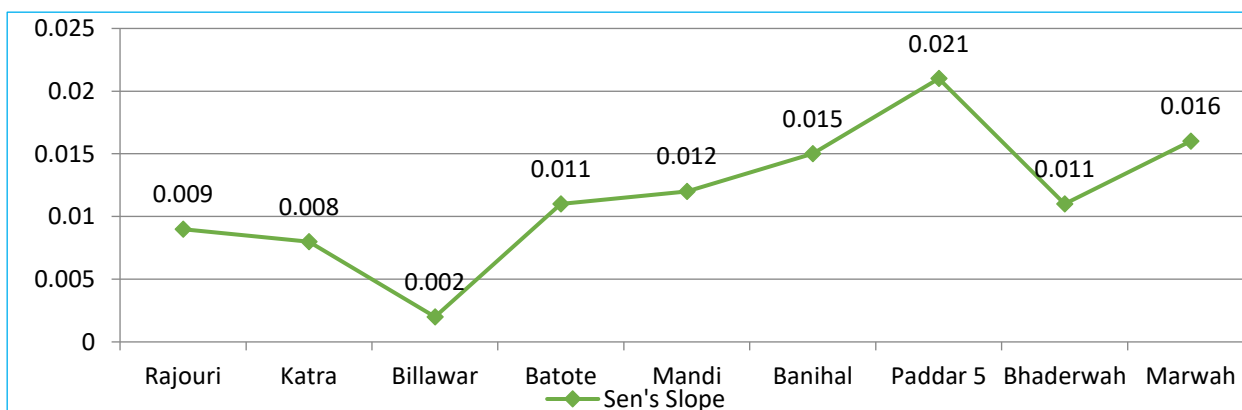
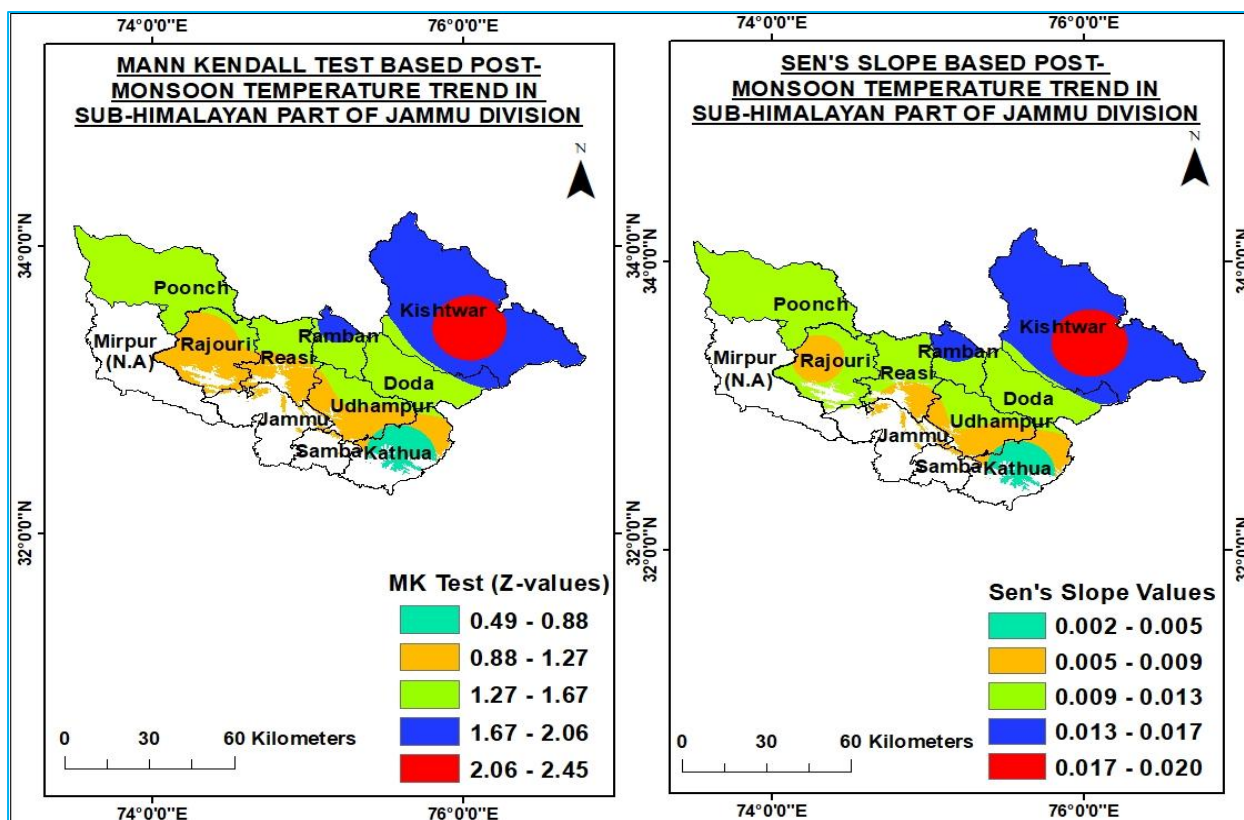


Fig 4 Post-monsoon temperature based Sen's Slope and Mann-Kendall test values for all meteorological stations



Map 6 Mann-Kendall Test and Sen's slope based post-monsoon temperature trend

In the post-monsoon temperature trend map based on Mann-Kendall test there are five class intervals the lowest class interval is having value between 0.49 to 0.88 only a small portion of area in the northern Kathua district shows this trend. District Rajouri, southern and western part of Reasi district, western and southern part of Udhampur belongs to the class interval of 0.88 to 1.27 trend value. Poonch district along with northern part of Reasi district, southern part of Ramban district and majority of Doda district belongs to the class interval of 1.27 to 1.67. Northern part of Ramban district and majority of Kishtwar district including western, southern and northern part shows trend value between 1.67 to 2.06. Central part of Kishtwar district around the Paddar 5 weather station shows highest trend among all the parts of study area having trend value between 2.06 to 2.45 [21].

In the Sen's slope bases trend map there are also five class intervals, the lowest class interval is having value of 0.002 to 0.0058 northern part of Kathua district shows temperature trend in this class interval. In the next class interval of 0.0058 to 0.009 western part of Rajouri and Reasi district and southern part of Udhampur district shows trend value in this class interval. Maximum mountainous part of Jammu division shown

trend value in the class interval of 0.009 to 0.013 areas showing this trend value are Poonch district, Reasi district, western, eastern and southern Ramban district, maximum of Udhampur district and western and eastern Doda. Kishtwar district shows the highest trend in terms of Sen's Slope in Post-monsoon season [22].

Winter season temperature trend

Distribution of Mann-Kendall test Z-value and P-value along with the value of Sen's Slope for the winter season temperature trend are given below in the (Table 6). The data depicted in the table revealed that in terms of Z-value of Mann-Kendall test highest value is found at Billawar station with value of 1.21 while lowest is found at Paddar 5 station with value of -0.04.

In case of P-value highest is found at Paddar 5 station with value 0.96 and the lowest is found at Billawar station 0.22 value. In case of Sen's slope here two stations show negative trend namely Paddar 5 and Marwah while all the remaining shows positive trend, highest value is found at Katra station having value of 0.016 while lowest Sen's slope value is found at Marwah station.

Table 6 Calculation of Mann-Kendall test and Sen's slope trend for winter season temperature in all nine meteorological stations

S. No.	Station	MK (Z-value)	P-Value	Sen's Slope	Trend
1	Rajouri	0.55	0.58	0.01	Positive
2	Katra	1.08	0.27	0.016	Positive
3	Billawar	1.21	0.22	0.013	Positive
4	Batote	0.61	0.53	0.01	Positive
5	Mandi	0.17	0.86	0.003	Positive
6	Banihal	0.29	0.76	0.007	Positive
7	Paddar 5	-0.04	0.96	-0.001	Negative
8	Bhaderwah	0.61	0.53	0.01	Positive
9	Marwah	-0.17	0.86	-0.003	Negative

Source: Data compiled by Author in R-Studio app

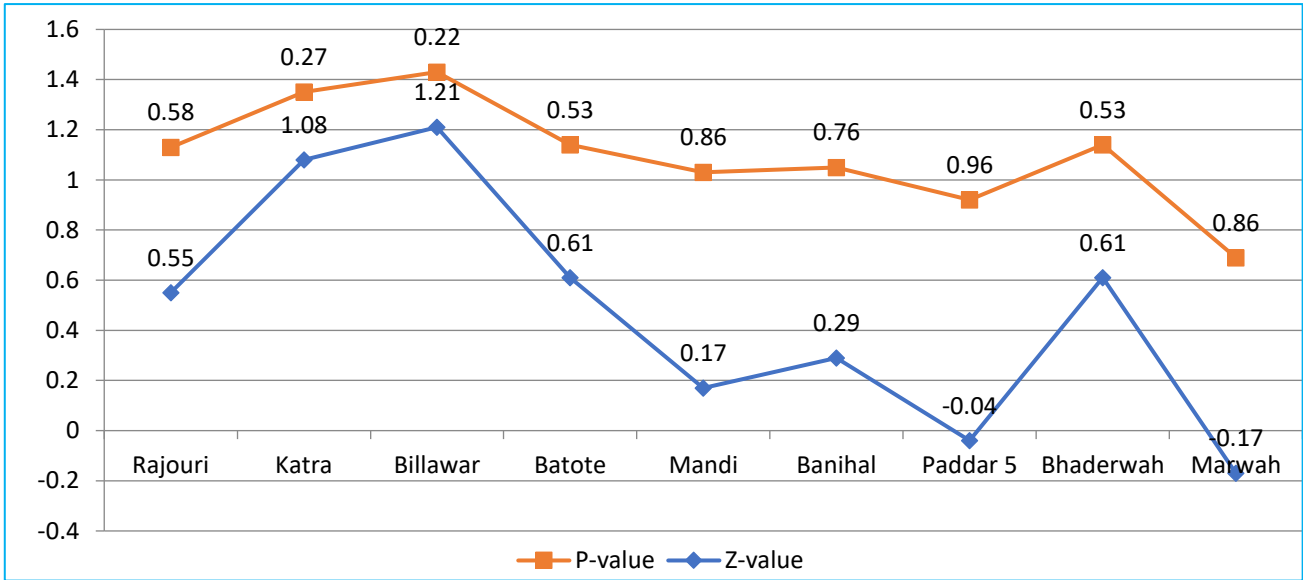
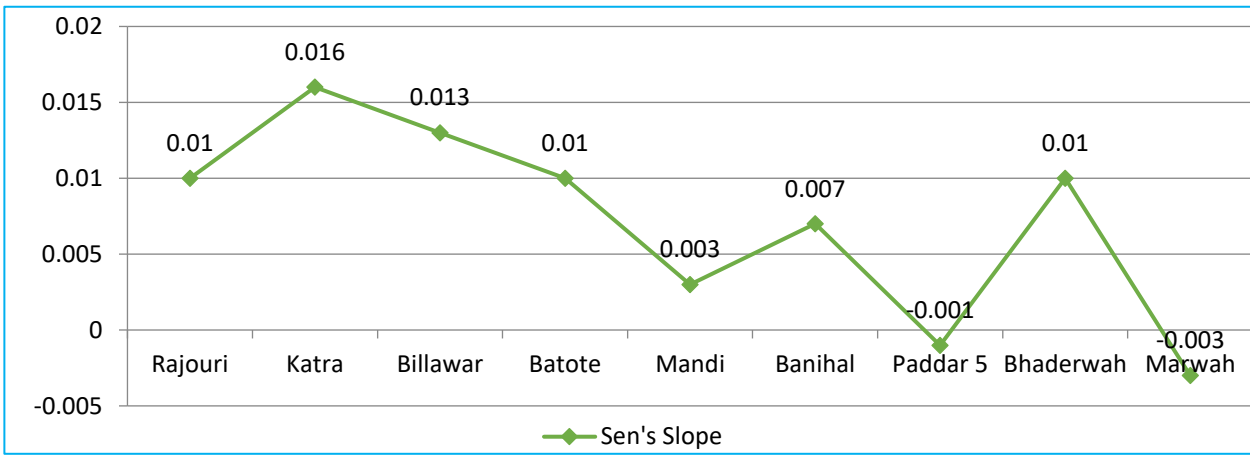
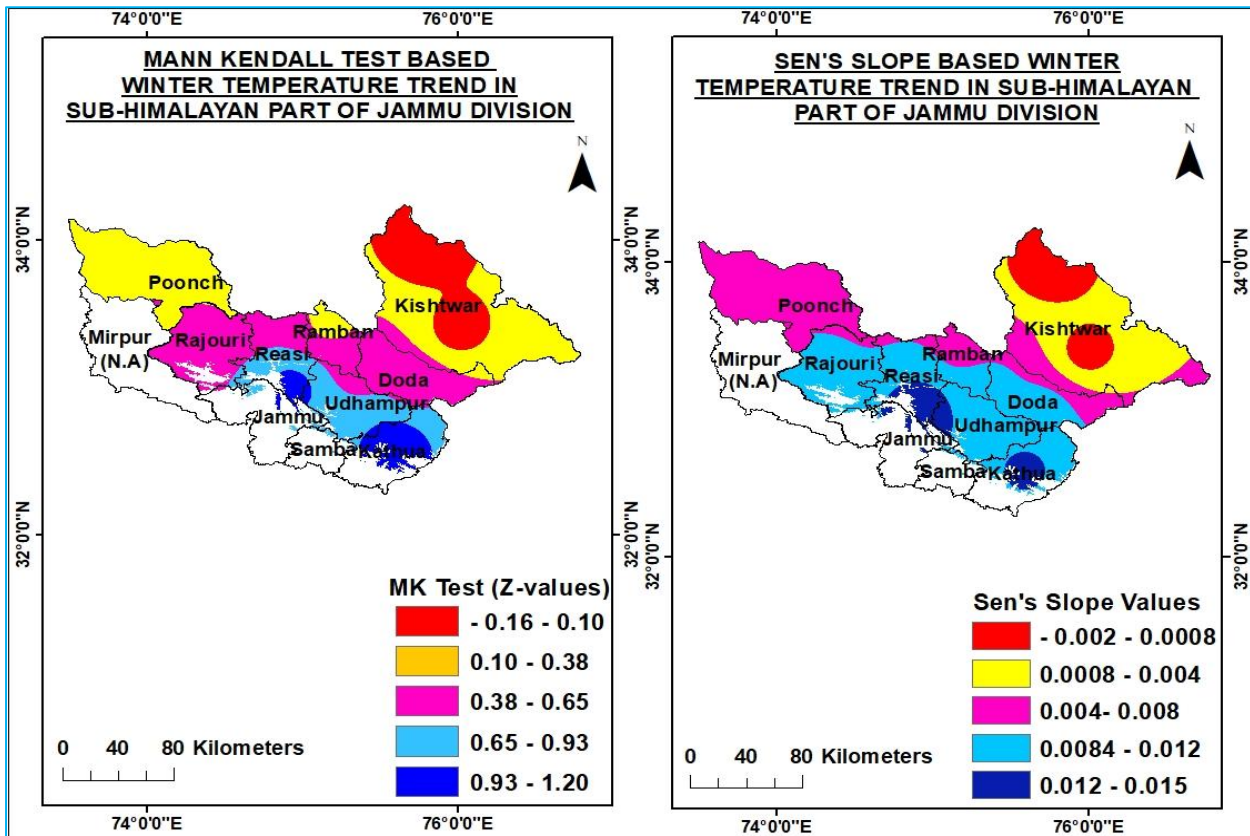


Fig 5 Winter temperature-based Sen's Slope and Mann-Kendall test values for all meteorological stations



Map 7 Mann-Kendall test and Sen's slope-based winter temperature trend

In the winter temperature trend map of Mann-Kendall test there are five class intervals the lowest class interval is having value of trend between -0.16 to 0.10 northern and central part of Kishtwar shows this trend. In the next class interval of 0.10 to 0.38 trend value eastern, southern and western part of Kishtwar along with northern Ramban and north western part of Poonch districts are present. Majority of the mountainous part of Jammu division shows winter trend in the class interval of 0.38 to 0.65 areas included are eastern and southern part of Poonch district, majority of Rajouri district, western and eastern part of Reasi district, northern and eastern part of Udhampur district, majority of Doda district. In the next class interval of Z-value of 0.65 to 0.93 southern mountainous parts of Jammu division shows trend in this class interval areas included are small portion of south east Rajouri district, southern part of Reasi district, western and south eastern part of Udhampur district in the highest-class interval of Z-value between 0.93 to 1.20 south western Reasi along with northern Kathua belong to this class interval [23].

In the Sen's slope map temperature map of winter season also there are five class intervals the lowest class interval is having value of Sen's slope between -0.002 to 0.0008 northern part of Kishtwar district along with small area near the Paddar area shows trend of Sen's slope in this class interval. Majority of the Kishtwar district including western, north western, south western, eastern area along with north eastern part of Poonch district belong to the class interval of 0.0008 to 0.004. In the next class interval of 0.004 to 0.008 north western Poonch, north eastern Rajouri, north eastern and north western Reasi

district, whole of northern Ramban district, northern and south eastern Doda are present all these area shows trend of Sen's slope in between 0.004 to 0.008. Majority of the area belongs to the class interval of 0.0084 to 0.012 area includes central and south western part of Rajouri district, southern part of Reasi district, north western, central and south eastern part of Udhampur district, eastern and northern part of Kathua district. In the highest-class interval of trend value between 0.012 to 0.015 south western part of Reasi district and small central part of Kathua district is present [24].

Precipitation trend using Mann-Kendall and Sen's slope

Again, in the case of precipitation like that of temperature after collecting data from the NASA POWER, values for all the selected five seasons of annual, pre-monsoon, monsoon, post-monsoon and winter season are calculated, here to calculate the values of precipitation same formula as shown in the methodology is used by adding the precipitation of the three months that are selected under these five broad divisions. After calculating values for the five said seasons then the Mann-Kendall test and Sen's Slope values are calculated to find out the temperature trend as described below for all selected seasons.

Annual trend of precipitation

Distribution of Mann-Kendall test Z-value and P-value along with the value of Sen's Slope for the Annual precipitation trend are given below in the (Table 7).

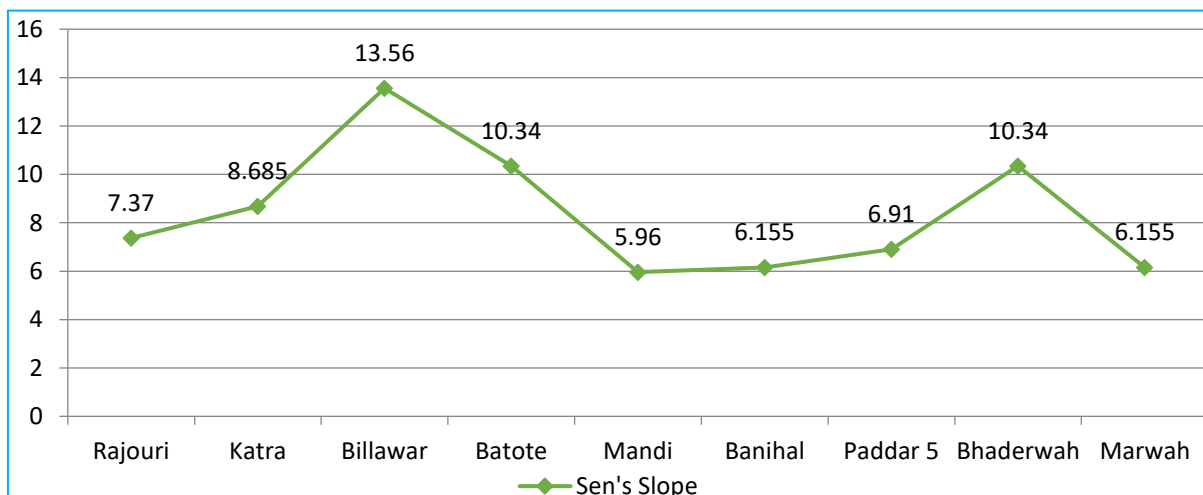
Table 7 Calculation of Mann-Kendall test and Sen's slope trend for annual season precipitation in all nine meteorological stations

S. No.	Station	MK (Z-value)	P-Value	Sen's Slope	Trend
1	Rajouri	1.49	0.13	7.37	Positive
2	Katra	2.09	0.03	8.685	Positive
3	Billawar	3.2	0.001	13.56	Positive
4	Batote	2.64	0.008	10.34	Positive
5	Mandi	1.33	0.18	5.96	Positive
6	Banihal	1.62	0.1	6.155	Positive
7	Paddar 5	2.18	0.02	6.91	Positive
8	Bhaderwah	2.64	0.008	10.34	Positive
9	Marwah	1.62	0.1	6.155	Positive

Source: Data compiled by Author in R-Studio app

From the (Table 7) highest trend value in terms of Z-value of Mann-Kendall test is found at Billawar weather station while least trend value is found at Mandi station in Poonch district. In terms of P-value highest is found at Mandi station

while least value is found at Billawar station. On the other hand, while analysing the Sen's slope trend all the stations have positive trend and highest value is found at Billawar station and least at Mandi station [25].



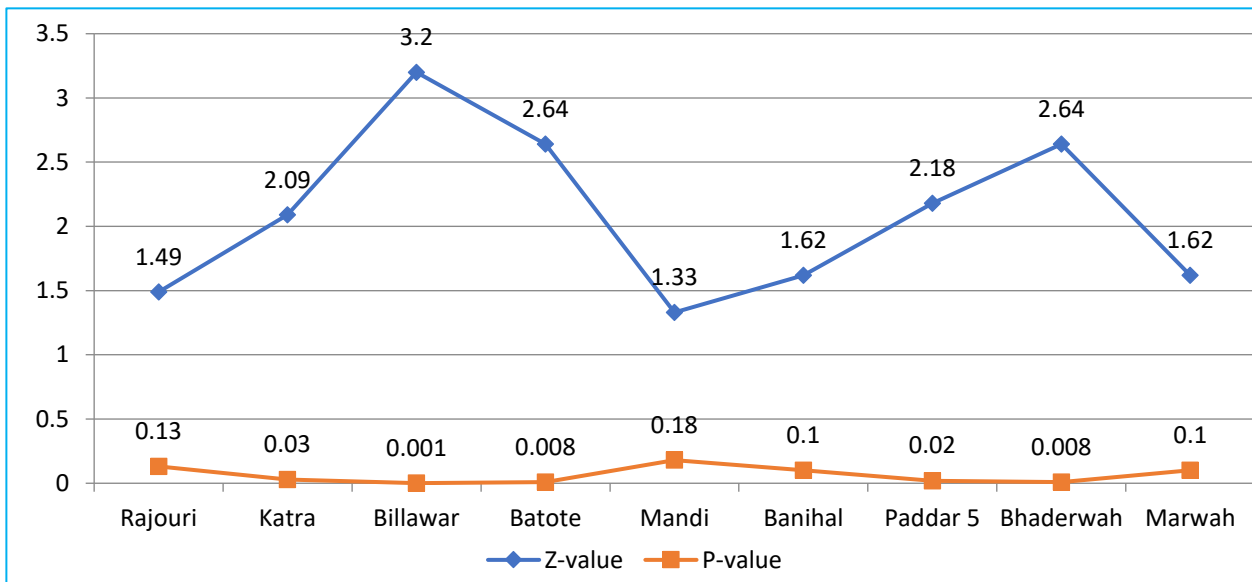
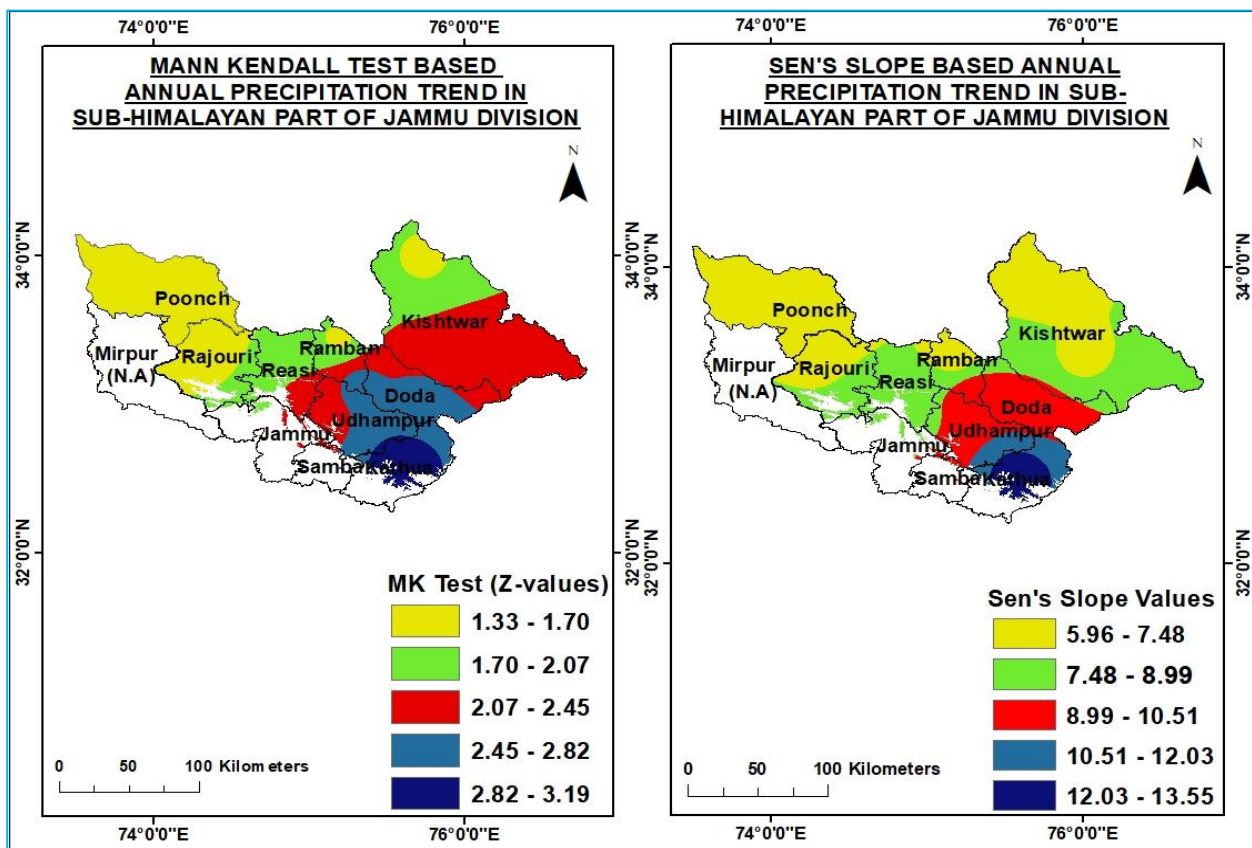


Fig 6 Annual precipitation-based Sen's Slope and Mann-Kendall test values for all meteorological stations



Map 8 Mann-Kendall test and Sen's slope based annual precipitation trend

In the Mann-Kendall test map of annual precipitation trend there are five class intervals of Z-value the lowest class interval is of value 1.33 to 1.70 this class intervals encompasses the north western part of Jammu division in the district of Poonch and Rajouri, this trend is also seen in the north eastern part of Kishtwar district, small portion of northern Ramban district also belongs to this class interval. North western and central part of Kishtwar district along with majority of Reasi district and northern part of Udhampur district belongs to the class interval of 1.70 to 2.07 Z-value. In the next class interval of 2.07 and 2.45 trend value majority of the mountainous area of Jammu division belongs to this class areas included are southern and south eastern part of Kishtwar district, majority of Doda district and small portion of Udhampur district. In the

next class interval of 2.45 to 2.82 trend value southern, eastern and western Udhampur is present. The highest-class interval of 2.82 to 3.19 is found at the northern part of Kathua district [26].

In the annual precipitation trend map of Sen's slope there are also five class intervals as the other maps the lowest class interval is having value between 5.96 to 7.48 areas included are northern and central Kishtwar, northern Ramban district, Poonch district and western part of Rajouri district. Next class interval is having value of Sen's slope between 7.48 to 8.99, majority of the area belongs to this class interval areas included are eastern Rajouri district central and southern Reasi district, eastern Udhampur district, north eastern Ramban district, south and south eastern Doda district and south eastern district. In the next class interval of 8.99 to 10.51 majority of Udhampur

district falls. In the highest-class interval of 12.03 to 13.55 trend value small portion of southern Udhampur district and northern part of Kathua district are present. The Mann–Kendall and Sen’s slope analyses reveal marked spatial variability in annual precipitation trends across Jammu division, with lower values concentrated in the northwestern districts and stronger positive trends in the southern and southeastern parts [27].

Pre-monsoon season precipitation trend

Distribution of Mann-Kendall test Z-value and P-value along with the value of Sen’s slope for the pre- monsoon season precipitation trend are given below in the (Table 8).

From the (Table 8) it is clear that majority of the weather stations shows negative trend in both Mann-Kendall test and

Sen’s slope value, 8 of 9 stations show negative value only Mandi station in the Poonch district shows positive trend. Highest trend value in terms of Z-value of Mann-Kendall test is found at Mandi weather station while least trend value is found at Billawar station. In terms of P-value highest is found at Rajouri station while least value is found at Batote station. On the other hand, while analysing the Sen’s slope trend majority stations have negative trend and highest value is found at Mandi station and least at Rajouri station.

Pre-monsoon precipitation shows a predominantly negative trend across stations, with Mandi (Poonch) as the only station exhibiting a positive trend, recording the highest Z-value and Sen’s slope, while Billawar and Rajouri show the lowest values [28-29].

Table 8 Calculation of Mann-Kendall test and Sen’s slope trend for pre-monsoon season precipitation in all nine meteorological stations

S. No.	Station	MK (Z-value)	P-Value	Sen’s Slope	Trend
1	Rajouri	-0.07	0.93	-9.473	Negative
2	Katra	-0.48	0.62	-0.754	Negative
3	Billawar	-0.66	0.5	-0.377	Negative
4	Batote	-0.62	0.52	-0.585	Negative
5	Mandi	0.16	0.87	0.22	Positive
6	Banihal	-0.15	0.87	-0.329	Negative
7	Paddar 5	-0.3	0.76	-0.319	Negative
8	Bhaderwah	-0.62	0.52	-0.585	Negative
9	Marwah	-0.15	0.87	-0.329	Negative

Source: Data compiled by Author in R-Studio app

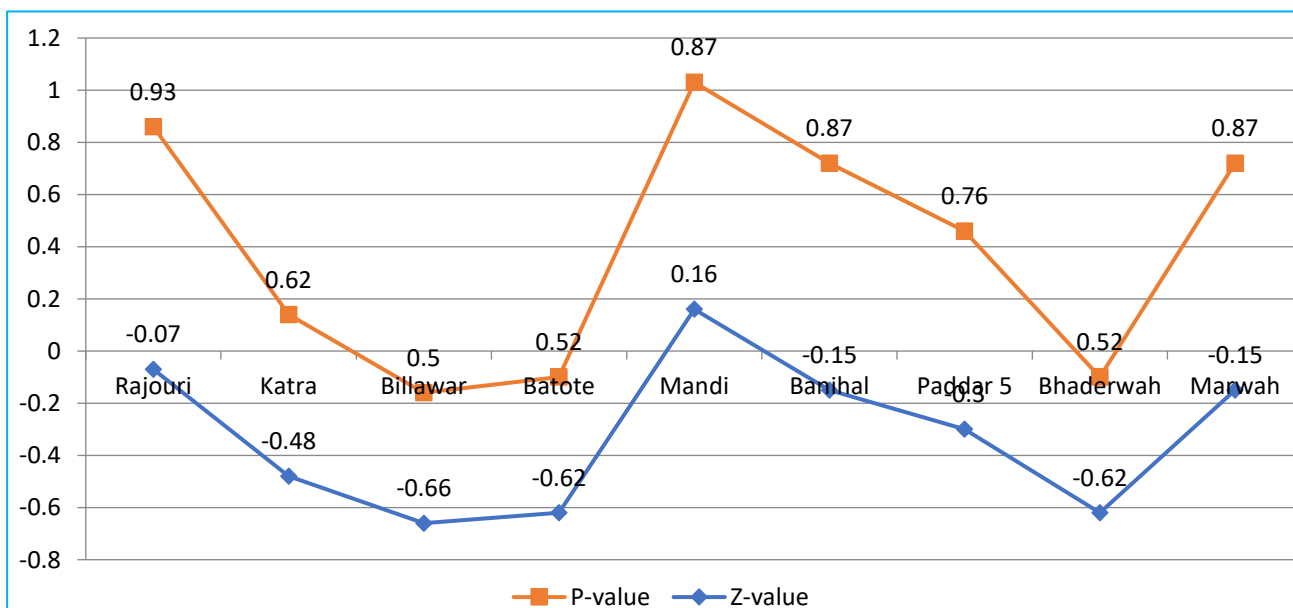
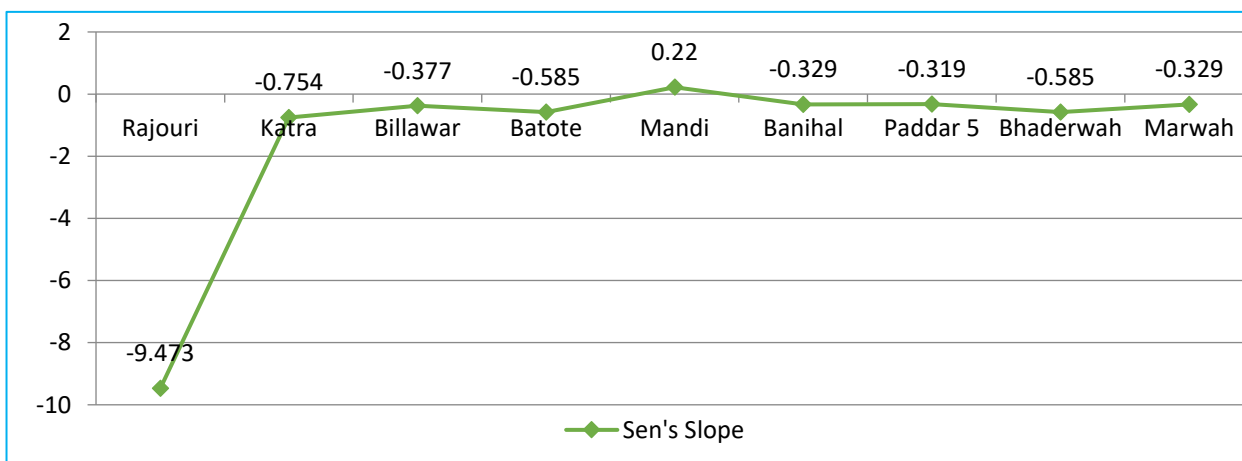
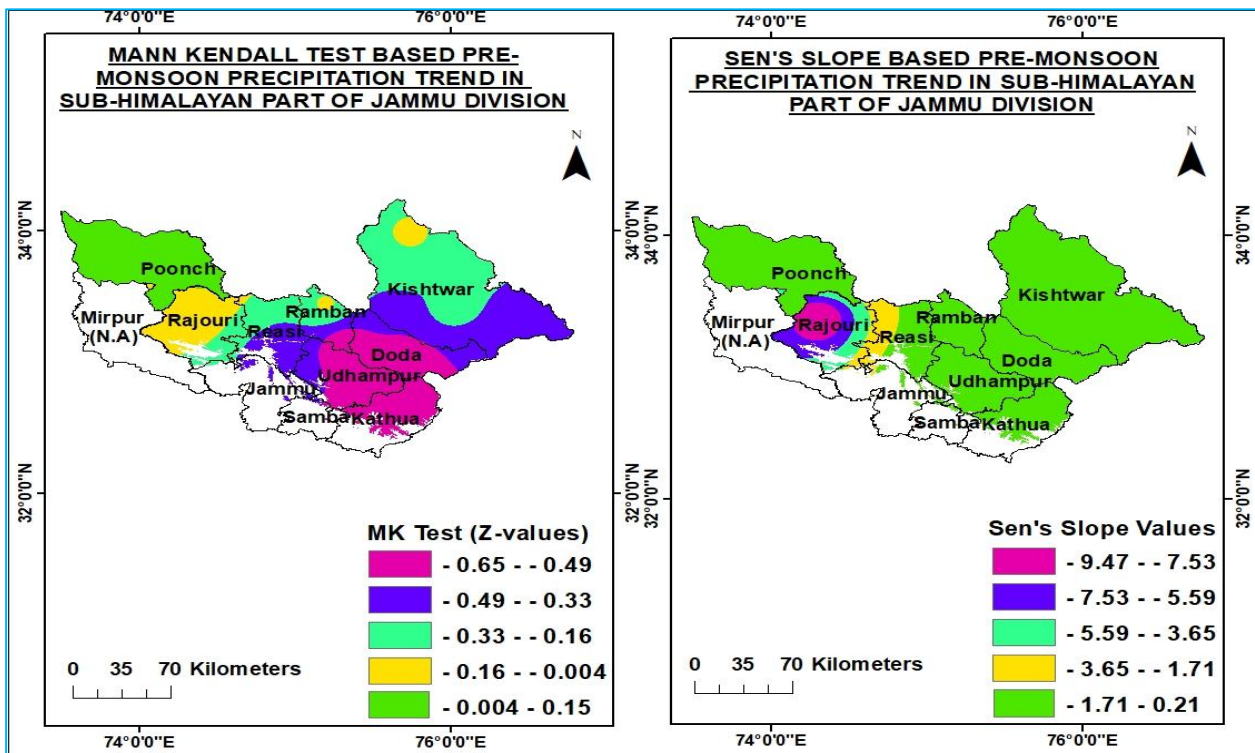


Fig 7 Pre-monsoon precipitation-based Sen’s Slope and Mann-Kendall test values for all meteorological stations



Map 9 Mann-Kendall test and Sen's slope-based pre-monsoon precipitation trend

In the pre-monsoon precipitation trend Mann-Kendall Z-value map there are five class intervals. The lowest class interval is having value of -0.65 to -0.49 this trend is present in the southern portion of Jammu division particularly in the northern Kathua district and southern Udhampur district. Next class interval is having Z-value between -0.49 to -0.33 this trend is analysed in the southern and south eastern part of Kishtwar district, southern and south eastern part of Doda district, northern and eastern Udhampur district and western part of Reasi district. In the next class interval of -0.33 to -0.16 northern, western and central Kishtwar district along with northern Ramban and eastern Reasi district are present. In the class interval having Z-value between -0.16 to -0.004 southern and western Rajouri district, southern and eastern Poonch district, small northern part of Ramban district and small portion of north eastern Kishtwar district are present. North western part of Poonch district belongs to the highest-class interval of -0.004 to 0.15 Z-value [30].

In the trend map of Pre-monsoon season precipitation using Sen's slope there are five class interval the lowest class

interval is having slope value in between -9.47 to -7.53 this trend is observed in the western Rajouri district no other area shows this much negative trend. In the next class interval of -7.53 to -5.59 western and southern portion of Rajouri district along with south western part of Poonch district belongs to this class. Next class interval is having value of -5.59 to -3.65 Z-value trend areas included are eastern and southern Rajouri district, southern and western part Poonch district. In the next class interval of -3.65 to -1.71 main areas are central Poonch district and north western, central and south western Reasi district. The highest-class interval is having value of -1.71 to 0.21 values majority of the area belongs to this class interval areas included are whole of Kishtwar, Doda, Udhampur and Ramban district, northern Kathua and western Reasi district.

Monsoon season precipitation trend

Distribution of Mann-Kendall test Z-value and P-value along with the value of Sen's slope for the monsoon season precipitation trend are given below in the (Table 9).

Table 9 Calculation of Mann-Kendall test and Sen's slope trend for monsoon season precipitation in all nine meteorological stations

S. No.	Station	MK (Z-value)	P-Value	Sen's Slope	Trend
1	Rajouri	1.82	0.06	3.164	Positive
2	Katra	2.41	0.01	5.51	Positive
3	Billawar	3.36	0.0007	9.66	Positive
4	Batote	2.91	0.003	6.02	Positive
5	Mandi	1.35	0.17	1.92	Positive
6	Banihal	2.26	0.02	2.498	Positive
7	Paddar 5	2.66	0.007	2.812	Positive
8	Bhaderwah	2.91	0.003	6.027	Positive
9	Marwah	2.26	0.02	2.498	Positive

Source: Data compiled by Author in R-Studio app

From the (Table 9) highest trend value in terms of Z-value of Mann-Kendall test is found at Billawar weather station while least trend value is found at Mandi station in Poonch district. In terms of P-value highest is found at Mandi station

while least value is found at Billawar station. On the other hand, while analysing the Sen's slope trend all the stations have positive trend and highest value is found at Billawar station and least at Mandi station [31].

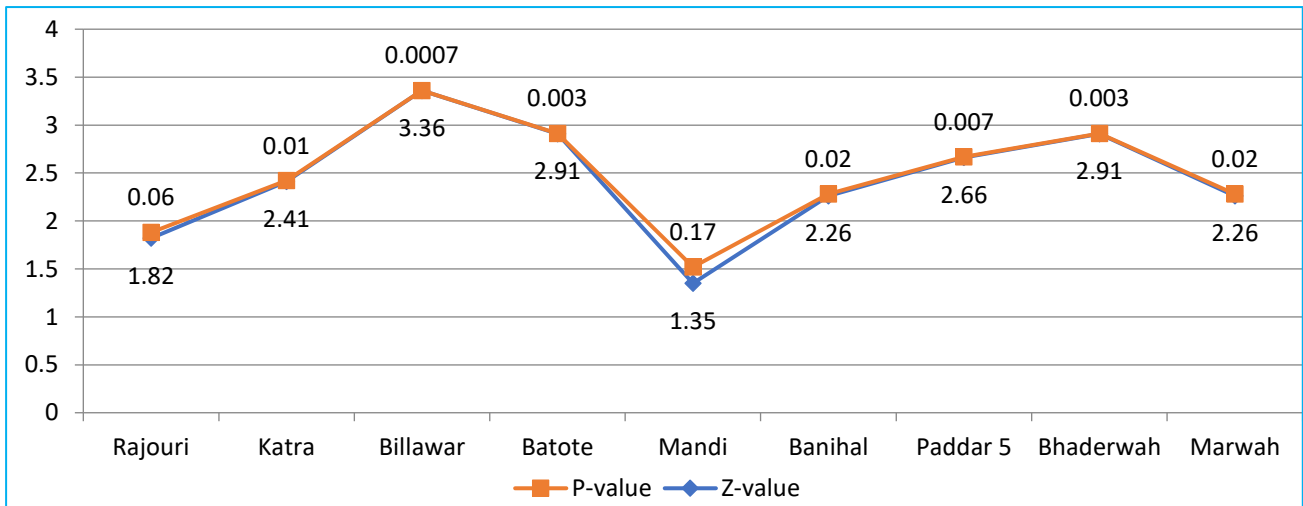
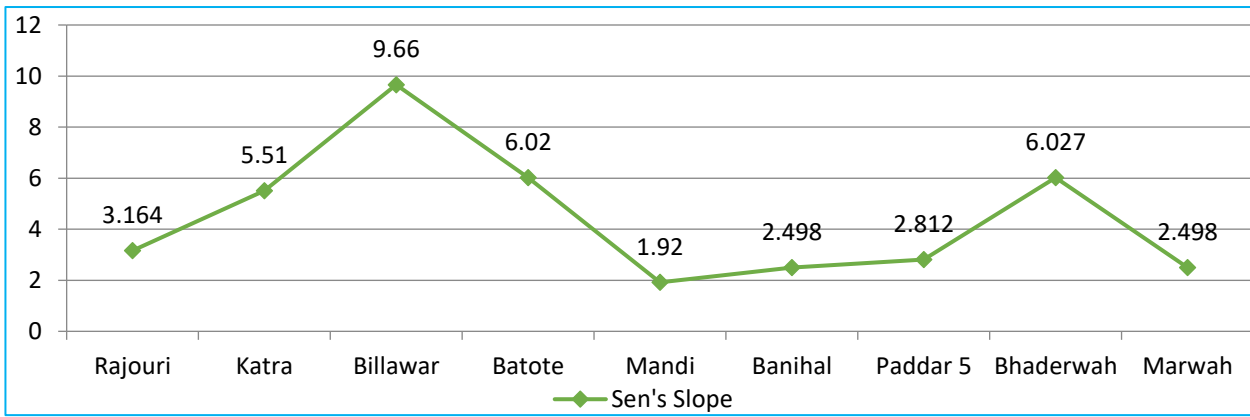
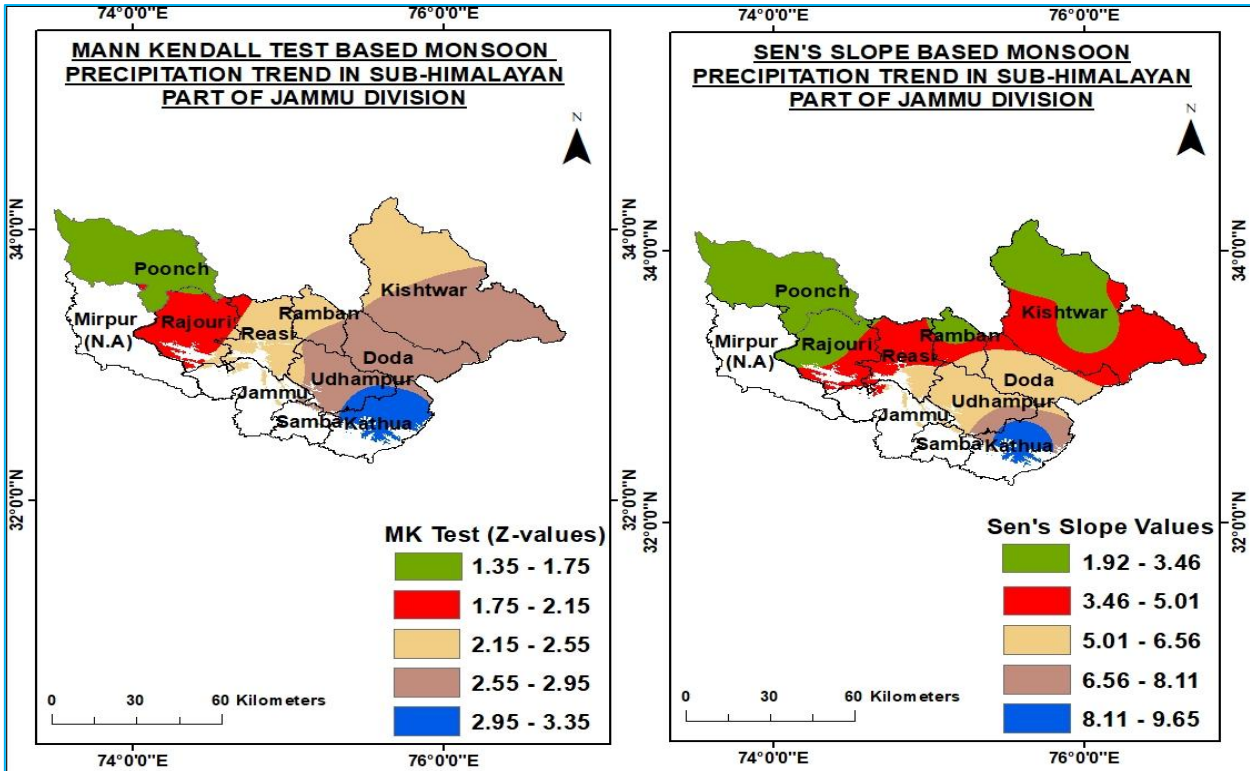


Fig 8 Monsoon precipitation-based Sen's Slope and Mann-Kendall test values for all meteorological stations



Map 9 Mann-Kendall test and Sen's slope-based monsoon precipitation trend

In the Mann-Kendall test map of monsoon season precipitation there are five class intervals, the lowest class interval is having Z-value between 1.35 to 1.75 area showing this trend is near the Mandi weather station in Poonch district. Western and south west part of Poonch district along with

majority of Rajouri district shows trend in between 1.75 to 2.15 Z-value. In the next class interval of value between 2.15 to 2.55, northern and western Kishtwar district along with northern and western Doda district and majority of Reasi district belong to this class interval. Majority of the area of mountainous part of

Jammu division shows monsoon precipitation trend in the class interval of 2.55 to 2.95 Z-value areas included are southern and eastern Kishtwar, majority of Doda district, southern and central Ramban district, majority of Udhampur district except the southern part. In the highest-class interval of Z-value between 2.95 to 3.35 northern Kathua district and small part of south eastern and south western Udhampur is present.

In the monsoon precipitation trend map of Sen's slope value there are five class intervals. In the extreme north eastern and north western part of mountainous area of Jammu division the trend value is of lowest class interval having value between 1.92 to 3.46 main areas are whole of Poonch district, western part of Rajouri district and northern part of Kishtwar district. In the next class interval having value between 3.46 to 5.01

southern and western part of Kishtwar district along with northern and western part of Doda district and western part of Reasi district belong to this class interval. Major part of Udhampur district, southern Reasi and Ramban district and south western part of Doda district belong to the class interval of 5.01 to 6.56 Z-value. The next two classes of value between 6.56 to 8.11 and 8.11 to 9.65 majorly south eastern part are present of Jammu division [32].

Post-monsoon season precipitation trend

Distribution of Mann-Kendall test Z-value and P-value along with the value of Sen's Slope for the post- monsoon season precipitation trend are given below in the (Table 10).

Table 10 Calculation of Mann-Kendall test and Sen's slope trend for post-monsoon season precipitation in all nine meteorological stations

S. No.	Station	MK (Z-value)	P-Value	Sen's Slope	Trend
1	Rajouri	1.46	0.14	1.056	Positive
2	Katra	1.14	0.25	1.004	Positive
3	Billawar	1.59	0.11	1.171	Positive
4	Batote	1.41	0.15	1.054	Positive
5	Mandi	1.71	0.08	1.272	Positive
6	Banihal	1.69	0.09	1.054	Positive
7	Paddar 5	1.28	0.2	0.791	Positive
8	Bhaderwah	1.41	0.15	1.054	Positive
9	Marwah	1.69	0.09	1.054	Positive

Source: Data compiled by Author in R-Studio app

From the (Table 10) highest trend value in terms of Z-value of Mann-Kendall test is found at Banihal and Marwah weather station while least trend value is found at Katra station. In terms of P-value highest is found at Katra station while least

value is found at Paddar 5 station. On the other hand, while analysing the Sen's slope trend all the stations have positive trend and highest value is found at Mandi station and least at Paddar 5 station [33].

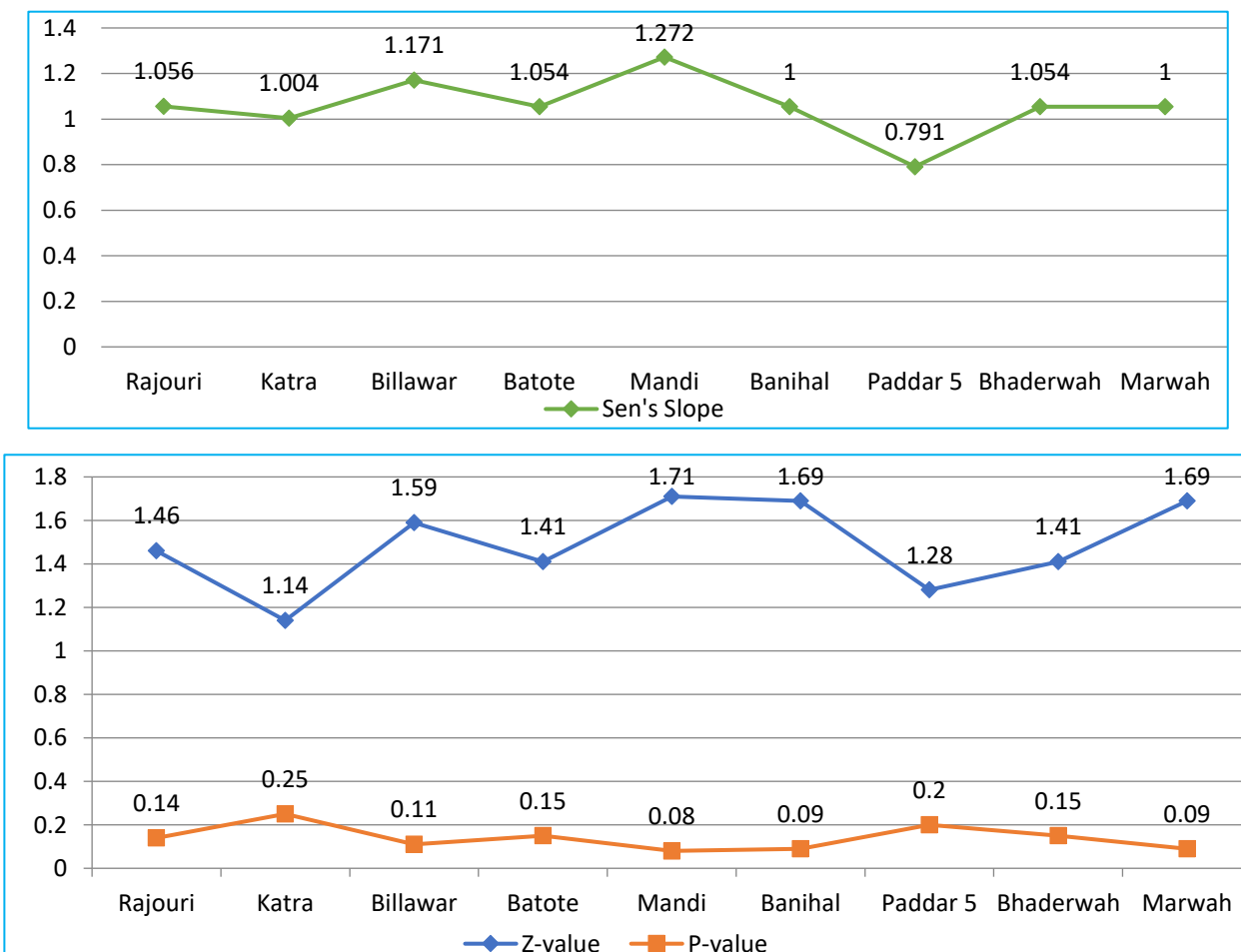
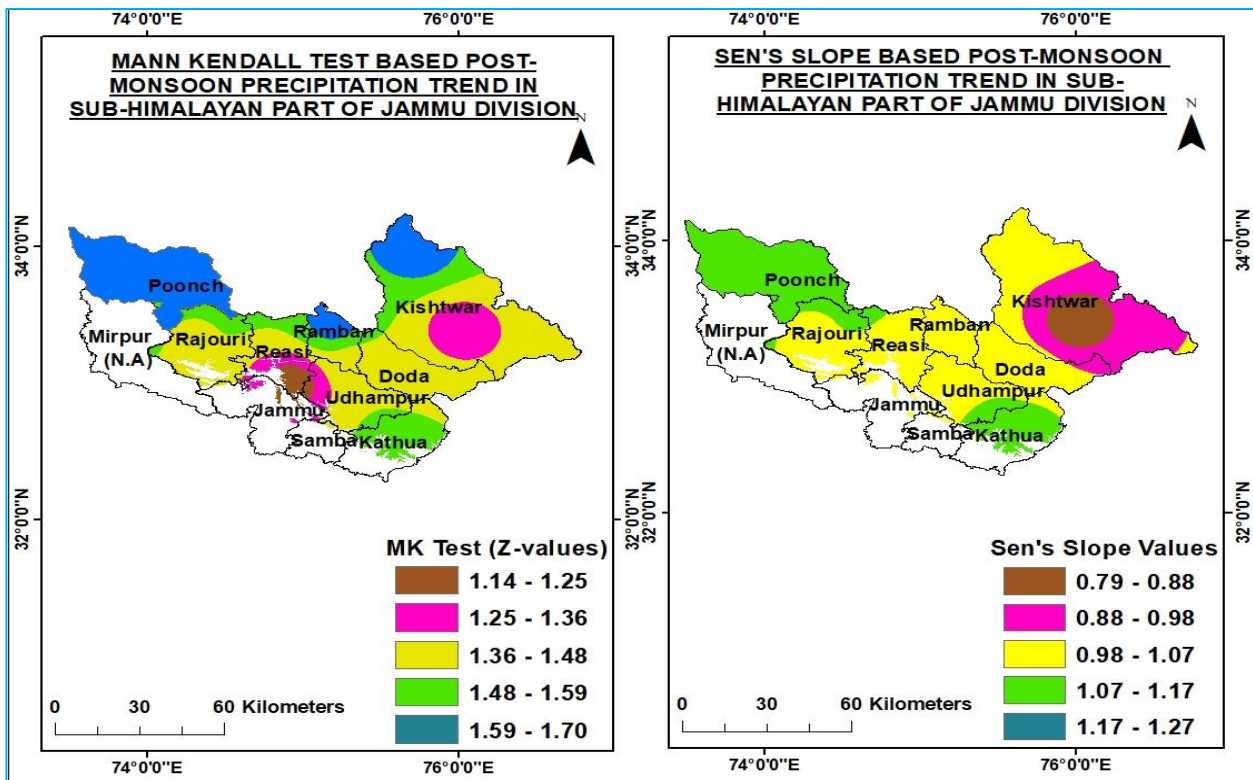


Fig 9 Post-monsoon precipitation based Sen's Slope and Mann-Kendall test values for all meteorological stations



Map 11 Mann-Kendall test and Sen's slope based post- monsoon precipitation trend

In the Mann-Kendall test map of Z-value in terms of post monsoon precipitation trend there are 5 class intervals the lowest class interval is having value between 1.14 to 1.25 areas showing this trend includes small portion of south western Reasi district and western Udhampur district. South eastern part of Rajouri district along with small portion of southern Reasi and western Udhampur belongs to the class interval of 1.25 to 1.36. In the next class interval of 1.36 to 1.58 Z-value majority of the mountainous area of Jammu division belongs to this class interval areas showing trend in this range includes central and western Rajouri district, southern Reasi and Ramban district, majority of Doda district and southern and south western part of Kishtwar district. In the next class interval of trend value between 1.48 to 1.59 value western and central part of Poonch district, northern part of Reasi, Doda and Ramban district and north western part of Kishtwar are present. Extreme north eastern and north western part of Jammu division belongs to the highest-class interval of 1.59 to 1.70 class interval areas showing trend in this range includes northern Kishtwar along with extreme northern Ramban district and north eastern Poonch district [34].

In the Sen's slope-based trend map of post monsoon season precipitation there are also five class intervals. The lowest class interval is having trend value between 0.79 to 0.88, this range of trend value is only found in the central Kishtwar district. Next class interval is also found in the near vicinity of this trend value in the central and eastern Kishtwar district having trend value between 0.88 to 0.98. Majority of the area belongs to the class interval of 0.98 to 1.07 area showing this trend are western, southern and eastern part of Rajouri district, whole of Reasi, Ramban and Udhampur district, majority of Doda district, eastern and northern and north eastern Kishtwar district. Western and southern part of Poonch district, northern part of Kathua district and north western part of Reasi district belong to the class interval of trend value 1.07 to 1.27. Extreme north eastern part of Poonch district belong to the highest-class interval of trend value 1.17 to 1.27 [35].

Winter season precipitation trend

Distribution of Mann-Kendall test Z-value and P-value along with the value of Sen's Slope for the winter season precipitation trend are given below in the (Table 11).

Table 11 Calculation of Mann-Kendall test and Sen's slope trend for winter season precipitation in all nine meteorological stations

S. No.	Station	MK (Z-value)	P-Value	Sen's Slope	Trend
1	Rajouri	1.01	0.3	1.171	Positive
2	Katra	1.03	0.3	1.146	Positive
3	Billawar	0.96	0.33	0.9	Positive
4	Batote	1.35	0.17	1.205	Positive
5	Mandi	1.57	0.11	2.028	Positive
6	Banihal	1.38	0.16	1.456	Positive
7	Paddar 5	1.43	0.15	1.201	Positive
8	Bhaderwah	1.35	0.17	1.205	Positive
9	Marwah	1.38	0.16	1.456	Positive

Source: Data compiled by Author in R-Studio app

The data depicted in (Table 11) revealed that the highest trend value in terms of Z-value of Mann-Kendall test is found

at Mandi weather station while least trend value is found at Billawar station. In terms of P-value highest is found at

Billawar station while least value is found at Mandi station. On the other hand, while analysing the Sen's slope trend all the

stations have positive trend and highest value is found at Mandi station and least at Billawar station [36].

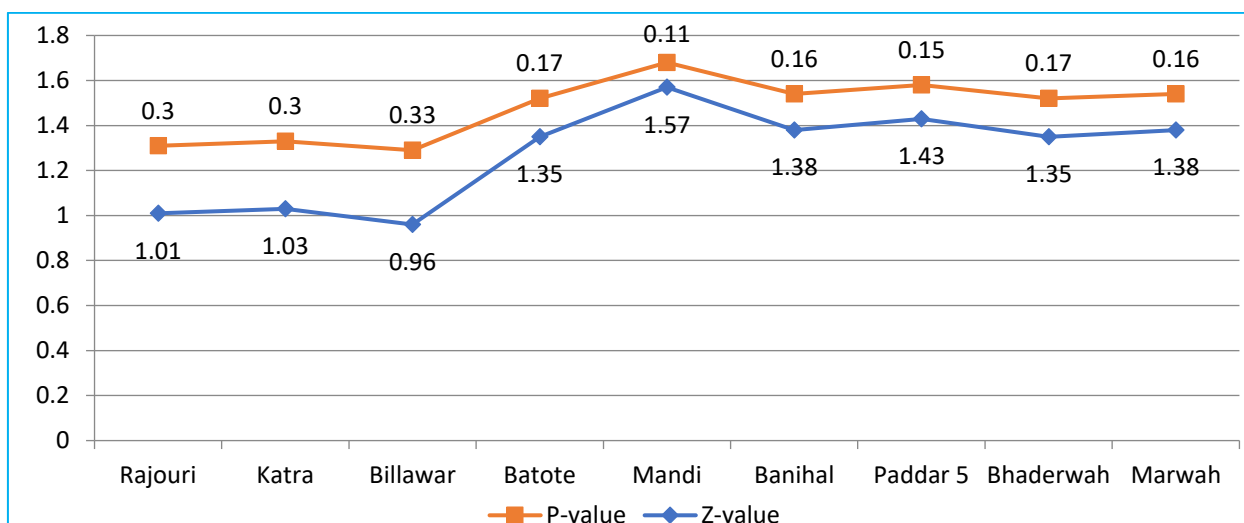
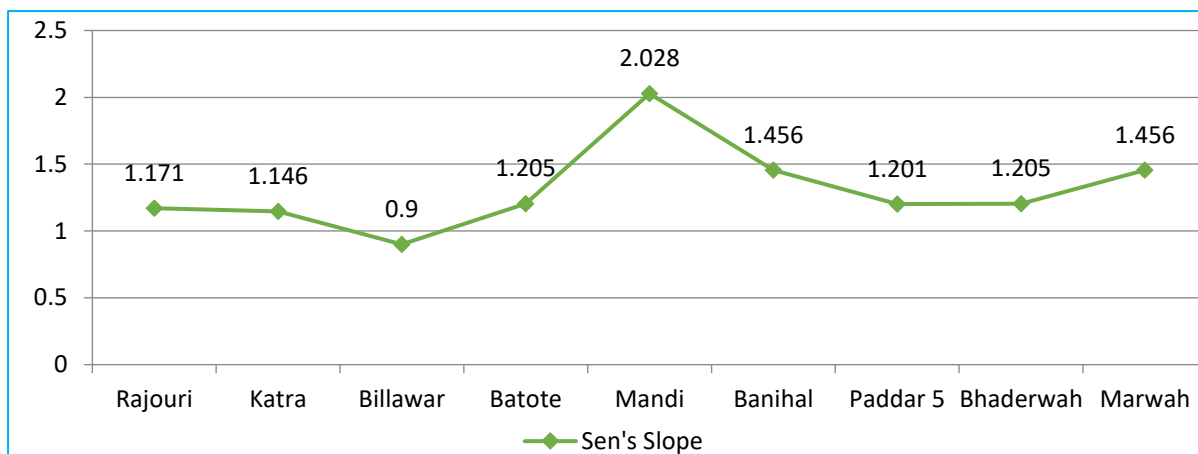
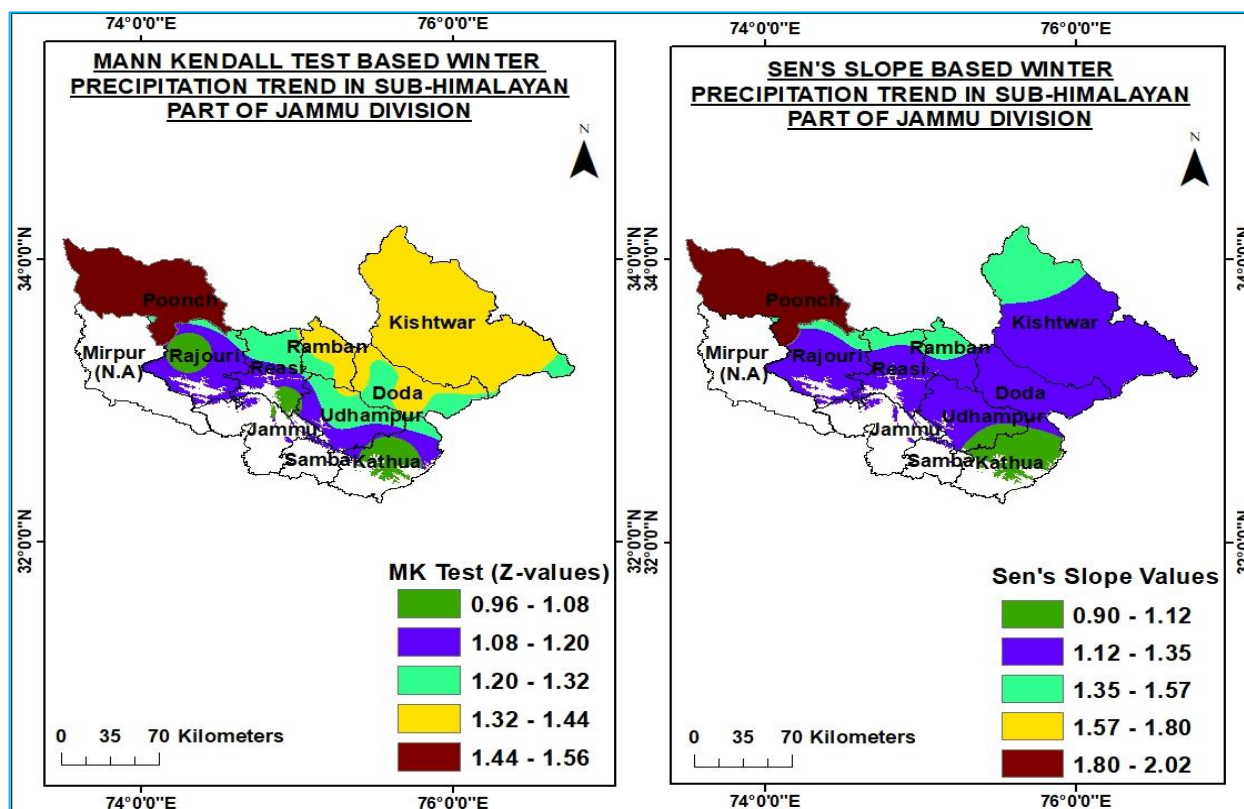


Fig 10 Winter precipitation-based Sen's Slope and Mann-Kendall test values for all meteorological stations



Map 12 Mann-Kendall Test and Sen's slope-based winter precipitation trend

In the case of winter precipitation trend map of Mann-Kendall Z-value there are five class intervals, the lowest class interval is having trend value between 0.96 to 1.08 this trend is shown only in small pockets in the western part of Rajouri district, western part of Udhampur district and central part of Kathua district. Next class interval is having value of trend value between 1.08 to 1.20 areas included are majority of Rajouri district, southern part of Reasi district and western part of Udhampur district along with northern part of Kathua district. Southern part of Poonch district, eastern and southern part of Reasi district, eastern part of Ramban district, central and southern part of Udhampur district and southern part of Doda district belongs to the class interval of 1.20 to 1.32. Majority of the area belongs to the class interval of 1.32 to 1.44 areas included are almost all of Kishtwar district except small part in southern area and north west part of Poonch district. Highest class interval is having trend value of 1.44 to 1.56 found only in the extreme north eastern part of Poonch district.

In the Sen's slope map of winter season trend there are also five class intervals the lowest class interval is having value between 0.90 to 1.12, this trend value can be observed in the south eastern part of mountainous area of Jammu division particularly in the north Kathua district. Majority of Jammu division mountainous area in terms of winter season precipitation shows Sen's slope trend in the class interval of 1.12 to 1.35 areas are western, southern and eastern part of Rajouri, Reasi and Ramban district, whole of Doda and Udhampur district and majority of Kishtwar district except the northern part. In the next class interval of trend value 1.35 to 1.57 value northern part of Kishtwar, Ramban and Reasi district are present. In the next class interval of 1.57 to 1.80 north

western part of Poonch district is present while the north western part of Poonch district shows trend in the highest-class interval of 1.80 to 2.02 [37-38].

CONCLUSION

This study comprehensively assessed the climatic variability in the mountainous regions of Jammu Division above 600 meters elevation, using long-term temperature and precipitation data from 1980 to 2022. The Mann-Kendall and Sen's Slope tests revealed statistically significant seasonal and annual trends—highlighting a general increase in temperature and variability in precipitation, particularly during the monsoon and winter seasons. Such changes reflect the broader impact of global climate change at the regional scale and underscore the vulnerability of the Sub-Himalayan ecosystem. As these mountainous areas are crucial for water resources, agriculture, and biodiversity, the observed trends may directly affect livelihood sustainability and ecological balance. These findings emphasize the need for micro-level climate monitoring, policy intervention, and adaptive strategies in mountainous districts like Rajouri, Kishtwar, and Doda, which are prone to ecological fragility and climate-induced disruptions.

Acknowledgement

First author hereby declare that Artificial Intelligence (ChatGpt) is used only to structure the abstract and the conclusion part. Author also expressed his gratitude to Miss Gurleen Kour (Research Scholar, Department of Geography, University of Jammu) for her guidance throughout the process.

LITERATURE CITED

- Woodward A. 2019. Climate change: Disruption, risk and opportunity. *Global Transitions* 1: 44-49.
- Santos FD, Ferreira PL, Pedersen JST. 2022. The climate change challenge: A review of the Barriers and solutions to deliver a Paris solution. *Climate* 10(5): 75. <https://doi.org/10.3390/cli10050075>
- Thornton PK, Ericksen PJ, Herrero M, Challinor AJ. 2014. Climate variability and vulnerability to climate change: a review. *Global Change Biology* 20(11): 3313-3328. <https://doi.org/10.1111/gcb.12581>
- Gadedjisso-Tossou A, Adjegan KI, Kablan AKM. 2021. Rainfall and temperature trend analysis by Mann-Kendall test and significance for rainfed cereal yields in Northern Togo. *Science* 3(1): 17. <https://doi.org/10.3390/sci3010017>
- Buytaert W, Celleri R, Willems P, De Bievre B, Wyseure G. 2006. Spatial and temporal rainfall variability in mountainous areas: A case study from the south Ecuadorian Andes. *Journal of Hydrology* 329 (3/4): 413-421. <https://doi.org/10.1016/j.jhydrol.2006.02.031>
- Dash S, Hunt J. 2007. Variability of climate change in India. *Current Science* 93(6): 782-788. Retrieved from: <https://www.researchgate.net/publication/228793182>
- Sarr B. 2012. Present and future climate change in the semi-arid region of West Africa: A crucial input for practical adaptation in agriculture. *Atmospheric Science Letters* 13(2): 108-112. <https://doi.org/10.1002/asl.368>
- Sahu K, Chandniha SK, Nema MK, Das GK, VLeekshmi H, Wadware P. 2023. Block level long-term rainfall variability using trend analysis in a state of central India. *Journal of Water and Climate Change* 15(1): 1-28.
- Mani T, Kottiswaran. 2016. Analysis of rainfall trend using Mann-Kendall test and the Sen's Slope estimator in Udumalpet of Tirupur district in Tamil Nadu. *Indian Journal of Agricultural Science and Research* 6(2): 131-138.
- Agarwal S, Suchithra AS, Singh SP. 2021. Analysis and interpretation of rainfall trend using Mann-Kendall's and Sen's slope method. *Indian Journal of Ecology* 48(2): 453-457.
- Bora SL, Bhuyan K, Hazarika PJ, Gogoi J, Goswami K. 2022. Analysis of rainfall trend using non-parametric methods and innovative trend analysis during 1901– 2020 in seven states of North East India. *Current Science* 122(7): 801.
- Seenu PZ, Jayakumar KV. 2021. Comparative study of innovative trend analysis technique with Mann-Kendall tests for extreme rainfall. *Arabian Journal of Geosciences* 14: 536.
- Dinpashoh Y, Mirabbasi R, Jhahharia D, Abianeh HZ, Mostafaiepour A. 2014 Effect of short term and long term persistence on identification of temporal trends. *Journal of Hydrologic Engineering* 19 (3): 617-625.
- Dharani C, Maragatham N, Geethalakshmi V, Ramanathan S, Kannan B. 2022. Rainfall variability analysis and trend assessment in Theni District of Tamil Nadu, India: An implication for crop planning. *Journal of Agrometeorology* 24(3): 305-308. <https://doi.org/10.54386/jam.v24i3.1797>
- Mehta D, Yadav SM. 2022. Temporal analysis of rainfall and drought characteristics over Jalore District of SW Rajasthan. *Water Practice and Technology* 17(1): 254-267. <https://doi.org/10.2166/wpt.2021.114>

16. Chandniha SK, Meshram SG, Adamowski JF, Meshram C. 2017. Trend analysis of precipitation in Jharkhand State, India, investigating precipitation variability in Jharkhand State. *Theoretical and Applied Climatology* 130: 261-274. <https://doi.org/10.1007/s00704-016-1875-x>
17. Goovaerts P. 2000. Geostatistical approaches for incorporating elevation into the spatial interpolation of rainfall. *Journal of Hydrology* 228(1/2): 113-129. [https://doi.org/10.1016/S0022-1694\(00\)00144-X](https://doi.org/10.1016/S0022-1694(00)00144-X)
18. Hamed KH, Rao AR. 1998 A modified Mann-Kendall trend test for autocorrelated data. *Journal of Hydrology* 204(1/4): 182-196. [https://doi.org/10.1016/S0022-1694\(97\)00125-X](https://doi.org/10.1016/S0022-1694(97)00125-X)
19. Chauhan A S, Singh S, Maurya RKS, Kisi O, Rani A, Danodia A. 2022. Spatio-temporal analysis of rainfall dynamics of 120 years (1901–2020) using innovative trend methodology: A case study of Haryana, India. *Sustainability* 14(9): 4888. <https://doi.org/10.3390/su14094888>
20. Kaur N, Yousuf A, Singh MJ. 2021. Long term rainfall variability and trend analysis in lower Shivaliks of Punjab. *India Mausam* 72(3): 571-582. <https://doi.org/10.54302/mausam.v72i3.1307>
21. Lacombe G, McCartney M. 2014. Uncovering consistencies in Indian rainfall trends observed over the last half century. *Climatic Change* 123(2): 287-299. <https://doi.org/10.1007/s10584-013-1036-5>
22. Hamilton JP, Whitelaw GS, Fenech A. 2001 Mean annual temperature and total annual rainfall trends at Canadian biosphere reserves. *Environmental Monitoring and Assessment* 67(1): 239-275. <https://doi.org/10.1023/A:1006490707949>
23. Bhat AA, Dhondiram PD, Gupta SK, Kanga S, Singh SK, Meraj G, Kumar P, Sajan B. 2025. Snow resources and climatic variability in Jammu and Kashmir, India. *Climate* 13(2): 28.
24. Pirasteh S, Samad A, Ahmad R, Thakural LN, Khan HH, Chauhan P, Khan A, Qamar MZ. 2025. Geospatial and AHP based identification of potential zones for groundwater recharge in Haridwar District of India. *Front. Environ. Science* 13: 1421918. doi: 10.3389/fenvs.2025.1421918
25. Kumar A, Attri PK. 2024. Analysis of pre-monsoon and post-monsoon seasonal rainfall trends by Mann-Kendall and Sen's slope estimator test in Himachal Pradesh, India. *Current World Environment* 19(2): 998-1010.
26. Madhusudhan MS, Ningaraju HJ, Shashank Patil MR. 2021. Analysis of rainfall trend series using Mann-Kendall and Sen's slope estimator statistical test in Mandya District, Karnataka. *International Research Journal of Engineering and Technology* 8(5): 3387-3393.
27. Kothawale DR, Revadekar JV, Rupakumar K. 2010. Recent trends in pre-monsoon daily temperature extremes over India. *Jr. Earth Syst. Science* 119(1): 51-65.
28. Patakamuri SK, Muthiah K, Sridhar V. 2020. Long-term homogeneity, trend, and change-point analysis of rainfall in the arid District of Ananthapuramu, Andhra Pradesh State, India. *Water* 12: 211.
29. Ahmad I, Tang D, Wang T, Wang M, Wagan B. 2015. Precipitation trends over time using Mann-Kendall and spearman's Rho tests in swat river basin, Pakistan. *Adv. Meteorology* 2015: 431860.
30. Vinay Kumar P, Venkateswara Naidu C. 2020. Is pre-monsoon rainfall activity over India increasing in the recent era of global warming? *Pure Appl. Geophysics* 177: 4423-4442.
31. Sathiyamoorthy V, Shukla BP, Pal PK. 2010. Increase in the pre-monsoon rainfall over the Indian summer monsoon region. *Atmospheric Science Letters* 11: 313-318.
32. Haldar S, Choudhury M, Choudhury S, Samanta P. 2023. Trend analysis of long-term meteorological data of a growing metropolitan city in the era of global climate change. *Total Environment Research Themes* 7: 100056.
33. Pal AB, Khare D, Mishra PK, Singh L. 2017. Trend analysis of rainfall, temperature and runoff data: a case study of Rangoon watershed in Nepal. *Int. Jr. Stud. Res. Technol. Management* 5: 21-38.
34. Sheikh MM, Manzoor N, Ashraf J, Adnan M, Collins D, Hameed S. 2015. Trends in extreme daily rainfall and temperature indices over south Asia. *International Journal of Climatology* 35: 1625-1637.
35. Saini R, Attada R. 2023. Analysis of Himalayan summer monsoon rainfall characteristics using Indian High-Resolution Regional Reanalysis. *International Journal of Climatology* 43(9): 1-22.
36. Naidu CV, Raju AD, Kumar PV, Satyanarayana GC. 2017. Perceptible changes in Indian summer monsoon rainfall in relation to Indian Monsoon Index. *Global and Planetary Change* 157: 8392.
37. Sharma S, Singh PK. 2017. Long term spatiotemporal variability in rainfall trends over the State of Jharkhand, India. *Climate* 5(1): 18. <https://doi.org/10.3390/cli5010018>
38. Hu ZZ, Yang S, Wu R. 2003. Long-term climate variations in China and global warming signals. *Journal of Geophysical Research* 108: 4614.