Trend Analysis of Precipitation by MK Test in Kumaon Region of Uttarakhand (1901–2010)

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Abstract

Objective: To identify trend in annual precipitation time series using the M-K and Sen’s T-tests. Methods/Analysis: Climate change has disrupted the major climatic parameters at a global level. However, there is no equal change for all regions and have localized intensity especially in India. These changes should be identified nearby to manage the natural water resources. One of the most important climatic parameters is precipitation. As a starting point towards the apprehension of global climate change precipitation has been widely measured. The main objective of this study is to analyze the temporal variability of precipitation for the period 110 years, to enhance the hydrological status of the Uttarakhand districts of Kumaon region. The aim is to identify trend in annual precipitation time series using the M-K and Sen’s T tests. Sen’s estimator method has been used to estimate the extent of trend in precipitation. Before applying the M-K test for the trend in precipitation auto correlation effect is reduced. Finding: The analysis of M-K test shows non-significance increasing (positive) trend on annual basis. These areas experience a heavier rainfall for duration of shorter splash, which leads to very less scope for groundwater recharge and more runoff in these areas. Thus, these findings give a broad overview of the regional rainfall behavior in the study area. Applications/Improvements: The similar study can be carried out for other places as well with more locations for more diversity in the results attributing to the surroundings etc. to get a more clear and precise view about the trend in annual precipitation.

Keywords: Mann-Kendall Tests, Non-Parametric Tests and Auto Correlation, Precipitation, Sen’s Estimator Tests

1. Introduction

Climate change has begun to mark itself worldwide as scientific facts in the form of increased downpours and storms, rising in temperature, diminishing of glaciers and rise in sea level etc. US EPA studies identify the patterns of global temperature with the help of using data from 1901 to the present by National Oce1anic and Atmospheric Administration’s National Climatic Data Centre (NCDC). This report states that in the late 1970’s the average global warming was 0.35° to 0.51°F per decade and the global average surface temperature since 1901 has risen with an average rate of 0.13°F per decade.

The essential element of climate is temperature and precipitation and the changes in these can affect human health, plants, animals and ecosystems. A raise in temperature can result in heat wave incidents and leads to illness and death and also cause change in species of animals and plants. The rainfall trends increases can result in an increment in the floods frequency and a decrease could lead in instances of drought1. An increasing temperature trend causes more evaporation, which leads to increase in rainfall. It is found that the mean annual
temperature of India has raised at the rate of 0.05 °C/decade, which is due to rise of maximum temperature (0.07 °C/decade) and minimum temperature (0.02 °C/decade) from 1901 to 2003.

The trend and magnitude of temperature over the last century had increase over the Indian sub continent and is mostly constant with the worldwide. A rising trend of mean annual temperature from 1881-1997 at a rate of 0.57°C per 100 years. The changes in precipitation forms and its splashing timing can have widespread effect on the availability of water and can cause change in animal and plant species.

The average temperature is increasing in the Upper Ganga Canal Command area with level of non-significant trend. Increasing trend in rainfall was predicted in the Upper Ganga Canal Command Area and it was concluded that there may be an impact of climate change which is contributing to the prolonged and heavy rainfall that is rising with time.

The temperature in the high altitude regions of Uttarakhand found an increasing trend in average temperature in the region. The main objective of this study is to identify the monotonic trend of precipitation by using MK Test and Sen’s Slope estimator.

2. Study Area

Kumaon region covers an area of more than 35,000 sq. kms. and has Nainital as headquarter. The Kumon Region hassix districts namely Almora, Bageshwar, Champawat, Nainital, Pithoragarh, and Udham Singh Nagar with Nainital town as the administrative center of the region. The Kumaon region has a population density of 170 per sq. Km. The total population of the region is 3565383 which comprises of 1800795 male and 1764588 Female.

Towards the northern side lies the Tibet, on the eastern side is Nepal, Uttar Pradesh lies at the southern side and on western side laies the Garhwal region which is one of the part of Uttarakhand state. The people of the Kumaon region are called Kumaonis, who are well known for their martial skills and bravery. The most important towns of the Kumaon region are Haldwani, Nainital, Rudrapur, Almora, Pithoragarh, Mukteshwar and Ranikhet as shown in Figure 1.

The Kumaon region apart from the Himalayan mountains has two sub-mountain strips called the Terai and the Bhabhar. Rest of Kumaon, has a maze of mountains, except the Great Himalayas. The main rivers are the Sharda (Kali), the Pindari and Kailganga, are the tributary of Alaknanda.

3. Trend Analysis

The auto correlation effect from time series of precipitation and temperature is necessary to be removed in a trend analysis. In a non parametric test if the auto correlation is positive then it suggest a significant trend which is more than specified by the Significance level. The procedure of analysis methodology used for MK Test in the study area is shown in Figure 2.

Pre-whitening should be done in a time series. To reduce the effect of serial correlation pre-whitening technique should be applied on the non parametric test.

\[ pw X_j = X_j - CX_{i-1} \] (1)
Where \( x_j \) is the pre-whitened data to be used in the subsequent trend analysis and \( c \) is the lag-1 serial correlation coefficient as determined directly from the data using Equation 1.

### 3.1 M-K Test (Mann-Kendall)

Trend analysis test was frequently used in similar application and is a resourceful tool for analyzing the trends in hydrological and other associated variables\(^\text{12}\). Mann-Kendall (MK) test also known as Kendall’s \( r \)-statistic, which is extensively used to analyze arbitrariness against trend. It is a rank-based procedure, which is robust to the influence of extremes and good for use with skewed variables. The objective of the M-K test is to review statistically, if there is a monotonic upward or downward trend of the variable of interest over time\(^\text{14–15}\). A monotonic downward trend indicates that the variable is constantly decreases and upward trend indicates the increase with respect to time, but the trend may be or may not be linear. For a parametric linear regression analysis MK test may be applied which can be used to study if the slope of the predictable linear regression line is different from zero. The residuals from the fitted regression line are normally distributed as regression analysis requires. As M-K test is a non-parametric (distribution-free) analysis so this hypothesis is not required.

According to M-K test, the null hypothesis \( H_0 \) states that the discontinuous data \((x_1, \ldots, x_n)\) is a sample of \( n \) independent and identically distributed random variables. The alternative hypothesis \( H_1 \) is not similar for all \( k, j < n \) with \( k = j \) for the distributions of \( x_k \) and \( x_j \). The S (Test Statistics), having mean zero and equation (4) is used to calculate the variances using equations (2) and (3) and asymptotically normal.

\[
S = \sum_{k=1}^{n} \sum_{j=k+1}^{n} \text{sgn}(x_j - x_k) \quad (2)
\]

\[
\text{sgn} (x_j - x_k) = \begin{cases} +1 & \text{if } (x_j - x_k) > 0 \\ 0 & \text{if } (x_j - x_k) = 0 \\ -1 & \text{if } (x_j - x_k) < 0 \end{cases} \quad (3)
\]

\[
\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{t=1}^{n} t(t-1)(2t+5)}{18} \quad (4)
\]

\[
Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases} \quad (5)
\]

### 3.2 SEN’S Slope Estimator

Sen’s estimator is required to predict the magnitude of trend. By this method the true slope is estimated and linear trend is present. Here, the slope \( (T_i) \) of all data pairs is first computed as Sen\(^\text{15}\).

\[
T_i = \frac{x_j - x_k}{j-k} \quad \text{For } i = 1, 2, \ldots, N \quad (6)
\]

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

\[
Q_i = \begin{cases} T_{(N+1)/2} & \text{if } N \text{ is odd} \\ \frac{1}{2} \left( T_{N/2} + T_{(N+2)/2} \right) & \text{if } N \text{ is even} \end{cases} \quad (7)
\]

The Sen’s estimator is estimated as \( Q_i=T_{(N+1)/2} \) if \( N \) is odd and it is estimated as \( Q_i=[T_{N/2}+T_{(N+2)/2}]/2 \) if \( N \) is even. Lastly \( Q_i \) is estimated at 100 \((1-\alpha)\%\) confidence interval by a two sided test and then by the non-parametric test \( Q_o \), a exact slope can be derived in the time series with a positive value signifies an increasing or upward trend and a negative value signifies a decreasing or downward trend.

### 4. Results

Trend analysis of rainfall for the period of 1901-2010 (110 years) in Uttarakhand region has been done in the present study. Mann-Kendall and Sen’s Slope Estimator has been
used for the determination of the rainfall trend detection. Initially, value of Serial correlation coefficient after pre-whitening the rainfall series for 1901-2010 of all the four station are given in Table 1 with their latitude and longitude.

Rainfall Trend in Uttarakhand region is presented station wise (1901-2010) namely: Almora, Bageshwar, Champawat, Nanital, Pithoragarh, Udham Singh Nagar as shown in Table 2 and Table 3 and their graphical representation in Figure 3 and Figure 4.

Almora: In Almora station, on annual basis rainfall trend results shows the increasing trend with No significant level. On other hand, Seasonal basis the pre-monsoon series shows the increasing trend with 95% confidence of level and monsoon series shows the decreasing trend with 99% confidence of level. Post monsoon shows the decreasing trend and winter series shows increasing trend with level of non-significance. on monthly basis , the month of march and may shows the increasing trend with 90% level of confidence, month of July show decreasing trend with 90% level of confidence, the month of August shows the decreasing trend with 95% level of confidence.

Bageshwar: In Bageshwar station, on annual basis rainfall trend results shows the increasing trend with No significant level. On other hand, Seasonal basis the pre-monsoon series shows the increasing trend with 95% level of confidence and monsoon series shows the decreasing trend with 99% level of confidence of level. Post monsoon shows the increasing trend and winter series shows decreasing trend with level of non-significance. On monthly basis, the month of January and July shows the decreasing trend with 90% level of confidence, month of November show increasing trend with 90% level of confidence and month of August show decreasing trend with 99% level of confidence.

Champawat: In Champawat station, on annual basis rainfall trend results shows the increasing trend with No significant level. On other hand, Seasonal basis the pre-monsoon series shows the increasing trend with 95% level of confidence and monsoon series shows the decreasing trend with 99.9% confidence of level. Post monsoon shows and winter series shows the increasing trend with level of non-significance. On monthly basis, the month of July shows the decreasing trend with 95% level of confidence, August shows the decreasing trend with 99.9% level of confidence, month of May show increasing trend with 90% level of confidence and month of November show increasing trend with 99% level of confidence.

| S. No. | City       | Latitude | Longitude | Variance | Pre- Monsoon | Monsoon | Post-Monsoon |
|--------|------------|----------|-----------|----------|-------------|---------|--------------|
| 1      | Almora     | 29.59    | 79.65     | 47269.6  | 1370.63     | 64151.7 | 1605.12      |
|        |            |          |           | 228.06   | 242.08      | 2362.55 | -18.73       |
|        |            |          |           | 0        | 0.18        | 0.04    | -0.01        |
| 2      | Bageshwar  | 29.85    | 79.77     | 47269.6  | 1829.6      | 66176.0 | 2323.42      |
|        |            |          |           | 228.06   | 227.93      | 3533.05 | -16.91       |
|        |            |          |           | 0        | 0.12        | 0.05    | -0.01        |
| 3      | Champawat  | 29.33    | 80.10     | 47269.6  | 1179.84     | 80453.71| 2435.65      |
|        |            |          |           | 228.06   | 274.3       | 6306.91 | -42.31       |
|        |            |          |           | 0        | 0.23        | 0.08    | -0.02        |
| 4      | Nanital    | 29.38    | 79.45     | 47269.6  | 728.66      | 58708.32| 1473.22      |
|        |            |          |           | 228.06   | 169.83      | 2468.52 | -30.64       |
|        |            |          |           | 0        | 0.23        | 0.04    | -0.02        |
| 5      | Pithoragarh| 29.58    | 80.22     | 47269.6  | 3124.04     | 57928.05| 2700.2       |
|        |            |          |           | 228.06   | 264.15      | 2726.16 | -22.92       |
|        |            |          |           | 0        | 0.08        | 0.05    | -0.01        |
| 6      | Udham Singh Nagar | 28.98 | 79.40 | 47269.6 | 543.3      | 50771.15| 1317.4       |
|        |            |          |           | 228.06   | 98.07       | -1703.11| -28.07       |
|        |            |          |           | 0        | 0.18        | -0.03   | -0.02        |
### Table 2. Rainfall Trend in the Alomra, Bageshwar and Champawat Regions of Uttarakhand is presented station wise (1901–2010)

| Time series       | Almora          | Bhageshwar       | Champawat        |
|-------------------|-----------------|------------------|------------------|
|                   | Test Z | Signific. | Q     | Test Z | Signific. | Q     | Test Z | Signific. | Q     |
| JAN               | -1.10  | -0.065     | -1.70 | +      | -0.100  | -0.77 | -0.043 |
| FEB               | 0.27   | 0.019      | -0.26 | -0.020 | 0.54    | 0.028 |
| MAR               | 1.87   | +          | 0.080 | 0.98   | 0.054   | 1.26  | 0.050  |
| APR               | 0.44   | +          | 0.013 | -0.86  | -0.042  | 0.96  | 0.028  |
| MAY               | 1.81   | +          | 0.131 | 0.82   | 0.062   | 1.85  | +      | 0.134 |
| JUN               | -0.60  | -0.159     | -0.97 | -0.261 | -0.87   | -0.229|
| JUL               | -1.76  | +          | -0.680 | -1.78 | +      | -0.632 | -2.34 | +      | -0.943|
| AUG               | -2.57  | *          | -0.895 | -3.17 | **     | -1.082 | -3.57 | ***    | -1.300|
| SEP               | 0.34   | 0.100      | 0.022 | -0.053 | 0.15    | -0.052|
| OCT               | -0.29  | -0.015     | -0.40 | -0.025 | -0.38   | -0.029|
| NOV               | 2.07   | *          | 0.233 | 1.81   | +      | 0.024  | 2.74  | **     | 0.025 |
| DEC               | -0.25  | -0.006     | -0.67 | -0.018 | -0.36   | -0.005|
| Annual            | 0.96   | 0.637      | 0.96  | 0.637  | 0.96    | 0.637 |
| pre-monsoon (Mar-May) | 2.36   | *          | 0.230 | 0.75   | 0.081   | 2.45  | *      | 0.239 |
| monsoon (June-Sept) | -2.59   | **         | -1.966 | -3.25 | **     | -2.498 | -3.53 | ***    | -2.896|
| post-monsoon (oct-Nov) | -0.03   | -0.003     | 0.00  | 0.00   | 0.17    | 0.011 |
| Winter (Dec-Feb)  | 0.05   | 0.005      | -0.97 | -0.114 | 0.07    | 0.007 |

### Table 3. Rainfall Trend in the Nanital, Pithoragarh and Udham Singh Nagar Regions of Uttarakhand is presented station wise (1901–2010)

| Time series       | Nanital          | Pithoragarh      | Udham Singh Nagar |
|-------------------|------------------|------------------|-------------------|
|                   | Test Z | Signific. | Q     | Test Z | Signific. | Q     | Test Z | Signific. | Q     |
| JAN               | -1.00  | -0.045     | -1.46 | -0.108 | -1.15   | -0.050 |
| FEB               | 0.52   | 0.027      | -0.40 | -0.035 | 0.24    | 0.011 |
| MAR               | 1.45   | 0.056      | 0.58  | 0.039  | 1.08    | 0.035 |
| APR               | 0.74   | 0.018      | -0.81 | -0.052 | 0.14    | 0.003 |
| MAY               | 2.07   | *          | 0.112 | 0.80   | 0.076   | 1.65  | +      | 0.085 |
| JUN               | -0.50  | -0.116     | -0.89 | -0.199 | -0.20   | -0.030|
| JUL               | -1.68  | +          | -0.567 | -1.61 | -0.542 | -0.47  | -0.152 |
| AUG               | -2.39  | *          | -0.868 | -3.51 | ***    | -1.038 | -2.37 | *      | -0.768|
| SEP               | 0.10   | 0.028      | -0.26 | -0.050 | 1.13    | 0.303 |
| OCT               | -0.04  | -0.003     | -0.59 | -0.049 | -0.26   | -0.010|
| NOV               | 1.84   | +          | 0.015 | 0.99   | 0.013   | 0.48  | 0.004 |
| DEC               | 0.01   | 0.000      | -0.73 | -0.023 | -0.33   | -0.005|
| Annual            | 0.96   | 0.637      | 0.96  | 0.637  | 0.96    | 0.637 |
| pre-monsoon (Mar-May) | 2.83   | **         | 0.204 | 0.20   | 0.034   | 2.29  | *      | 0.154 |
| monsoon (June-Sept) | -2.51   | *          | -1.845 | -3.20 | **     | -2.236 | -1.17 | -0.799 |
| post-monsoon (oct-Nov) | 0.34    | 0.019      | -0.28 | -0.030 | -0.29   | -0.015|
| Winter (Dec-Feb)  | 0.10   | 0.009      | -0.90 | -0.144 | -0.36   | -0.025|
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Figure 3. Rainfall Trend Graph represented for Alomra, Bageshwar and Champawat stations (1901–2010).

Figure 4. Rainfall Trend Graph represented for Nanital, Pithoragarh and Udham Singh Nagar stations (1901–2010).
Nanital: In Nanital station, on annual basis rainfall trend results shows the increasing trend with No significant level. On other hand, Seasonal basis the pre-monsoon series shows the increasing trend with 99% level of confidence and monsoon series shows the decreasing trend with 95% confidence of level. Post monsoon shows and winter series shows the increasing trend with level of non-significance. On monthly basis, the month of July shows the increasing trend with 90% level of confidence, August shows the decreasing trend with 95% level of confidence, month of May show increasing trend with 95% level of confidence and month of November show increasing trend with 90% level of confidence.

Pithoragarh: In Pithoragarh station, on annual basis rainfall trend results shows the increasing trend with No significant level. On other hand, Seasonal basis the pre-monsoon series shows the increasing trend with level of non-significance and monsoon series shows the decreasing trend with 99% confidence of level. Post monsoon shows and winter series shows the decreasing trend with level of non-significance. On monthly basis, the month of August shows the decreasing trend with 99.9% level of confidence.

Udham Singh Nagar: In Udham Singh Nagar station, on annual basis rainfall trend results shows the increasing trend with No significant level. On other hand, Seasonal basis the pre-monsoon series shows the increasing trend with 95% level of confidence and monsoon series shows the decreasing trend with level of non-significance. Post monsoon shows and winter series shows the decreasing trend with level of non-significance. On monthly basis, the month of May shows the increasing trend with 90% level of confidence and August shows the decreasing trend with 95% level of confidence.

5. Conclusion

The study analyzed the rainfall data of 110-years from 1901 to 2010 to determine the trend of rainfall in the Kumaon regions of Uttrakhand. As this region is rapidly growing, any change in the rainfall trend pattern may have considerable impact on the people of this region. The Z value of MK Test revealed increasing trend in rainfall so it can be concluded that there may be an impact of climate change is present which is contributing to the prolonged and heavy rainfall that is rising with time. Similarly, Sen's Slope has also estimated increasing magnitude of slope for rainfall data. This study is to find out the annual trend for rainfall time series which is found to be increasing (positive) with level of non significance trend, pre-monsoon trend increasing with different level of confidence for different region, monsoon trend is decreasing with different level of confidence for different region while post-monsoon and winter trend are not constant they are in increasing trend for some region and in decreasing trend for with level of no significance.

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