Assessment of long-term climatic variability of Uttarakhand
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ABSTRACT

A trend analysis was performed for historic (1901–2002) climatic variables (Rainfall, Maximum Temperature, and Minimum Temperature) of Uttarakhand State located in Northern India. In the serially independent climatic variables, the Mann-Kendall test (MK test) was applied to the original sample data. However, in the serially correlated series, prewhitening is utilized before employing the MK test. The results of this study indicated a declining trend of rainfall in the monsoon season for seven out of thirteen districts of Uttarakhand state. However, an increasing trend was observed in Haridwar and Udham Singh Nagar districts for summer season rainfall. For maximum and minimum temperature, a few districts exhibited a declining trend in the monsoon season whereas many districts exhibited an increasing trend in the winter and summer seasons. Mountain dominated areas (as Uttarakhand states) are specific ecosystems, distinguished by their diversity, sensitivity and intricacy. Thus, the variability of rainfall and temperature has a severe and rapid impact on mountainous ecosystems. Nevertheless, mountains have significant impacts on hydrology, which may further threaten populations living in the mountain areas as well as in adjacent, lowland regions.

Keywords: Trend Analysis; Mann-Kendall Test; Climate Change; Uttarakhand State

1. Introduction

Changing behavior of the hydrological cycle directly affects the availability and quantity of fresh water, which is a major environmental concern of the 21st century[1,2]. As reported by the Intergovernmental Panel on Climate Change (IPCC), the Indian sub-continent will be adversely affected by enhanced variability of climate, rising temperature, and substantial reduction of summer rainfall in some parts, and water stress by 2020[3]. Detection of trends in long-term series of climatic data is of paramount importance and is of practical significance. Studies of change are also of importance because of our need to understand the impact that man is having on the “natural” world[4]. From the statistical point of view, the variability of the climatic parameters can be identified by the presence of statistical evidence of persistence, cycles, trend, and other non-random components.

There are two different approaches to analyzing trends and are classified as parametric method and nonparametric method. Parametric testing procedures are widely used in classical statistics. In parametric testing, it is necessary to assume an underlying distribution for the data (often the normal distribution) and to make assumptions that data observations are independent of one another. For many climatic and hydrological series, these assumptions are not appropriate. Firstly, hydrological series rarely have a normal distribution. Secondly, there is often temporal
dependence in hydrological series. If parametric techniques are to be used, it may be necessary to (a) transform data so that its distribution is nearly normal and (b) restrict analyses to annual series, for which independence assumptions are acceptable, rather than using the more detailed monthly, daily or hourly flow series. In non-parametric and distribution-free methods, fewer assumptions about the data need to be made. With such methods, it is not necessary to assume a distribution. However, many of these methods still rely on assumptions of independence. The most popular nonparametric test for detecting a trend in the time series is Mann-Kendall (MK) test[5,6]. Owing to these facts this study aims at analyzing the persistence and trend of rainfall and minimum and maximum temperature of Uttarakhand State, India. This study could serve as a baseline for the preparation of a sustainable water resources development and management plan for the Uttarakhand State.

2. Materials and methods

2.1 Study area

The Uttarakhand state (Figure 1) (28°43' N to 31°27' N and 77°02' E to 81°02' E; 51,125 km²) is a mountain-dominated state (approximately 90% covered by mountains). The state shares its boundaries with the other Indian states Himachal Pradesh in the northwest and Uttar Pradesh in the South, and with Nepal and China in the southeast and northeast respectively[7]. This Himalayan region has transformed considerably in the recent past, owing to the growth of population (about 10 million) and the resultant increased demand for natural resources in the region. The cultivated land, forests, pastures, and rangelands have deteriorated and depleted steadily and significantly leading to their conversion into degraded and non-productive lands. These rapid land use changes have not only disrupted the fragile ecological equilibrium in the mountains through indiscriminate deforestation, degradation of land resources, and disruption of the hydrological cycle but also have significant and irreversible adverse impacts on the rural economy, and society, livelihood, and life quality of mountain communities.

2.2 Methodology

The methodology used for the evaluation of trends in hydrological variables for the Uttarakhand state is carried out using the Mann-Kendall non-parametric trend test[5,6]. The following steps involved in this study: (i) test the serially correlated or serial-correlated effects of observed climatic data; (ii) if positive serial correlation (persistence) is present in the climatic data, it is removed by pre-whitening; (iii) applying the Mann-Kendall test; (iv) applying Theisel-sen test to get the slope; (v) applying Sen’s median estimator to get the relative change.

2.2.1 Persistence

Persistence is also referred to as autocorrelation or serial correlation. As per WMO[8], persistence is a “tendency for successive values of the series to “remember” their antecedent values, and to be influenced by them.” The approach proposed by WMO[8] and Matalas[9] is widely used in studies related to long-term climatic variations. Several research studies carried out by Rodhe and Virji[10]; Granger[11]; Ogallo[12]; Anyadike[13]; Drosdowsky[14]; Nicholson and Palao[15]; Türkes et al.[16] used the approach proposed by WMO[8] and Matalas[9]. Persistence is
evident in long series of climatic observations characterized by a positive serial correlation. Significant negative $r$ is very likely to be indicative of high-frequency oscillations, whereas significant positive $r$ is likely to be indicative of low-frequency fluctuations and persistence in climatic series. To test the persistence in the climatological time series, the normalized anomaly of the time series is used. A normalized series is obtained as follows:

$$ X_t = \frac{(x_t - \bar{x})}{\sigma} $$

(1)

Where $X_t$ is the normalized anomaly of the series, $x_t$ is the observed time series, $\bar{x}$ and $\sigma$ is the long-term mean and standard deviation of annual/seasonal time series. All serial correlation coefficients of normalized climatic series are computed for lags $L = 0$ to $m$, where $m$ is the maximum lag (i.e. $m = n/3$); $n$ is the length of the series. The serial correlation coefficient was computed from equation 2.

$$ r_L = \frac{\sum_{t=1}^{n-L} (X_t - \bar{X}_t) \cdot (X_{t+L} - \bar{X}_{t+L})}{\sqrt{\sum_{t=1}^{n-L} (X_t - \bar{X}_t)^2 \cdot \sum_{t=1}^{n-L} (X_{t+L} - \bar{X}_{t+L})^2}}^{1/2} $$

(2)

To test the significance of serial correlation, equation 3 is used.

$$ r_k = \frac{-1 \pm t_g \frac{(n-k-1)^{1/2}}{n-k}}{n-k} $$

(3)

Where $t_g = 1.645, 4.965, 2.326$ are at 90, 95, and 99 percent confidence intervals, respectively. The “null” hypothesis of the randomness of climatic series against the serial correlation is rejected for the large value of $r_1$. If $r_1$ does not significantly differ from zero, then the series is regarded to be free from persistence. In this case, the appropriate null continuum is termed “white noise”. However, in the study, serial correlation coefficients up to lag-3 were assessed.

### 2.2.2 Original Mann-Kendall

The MK test also called Kendall’s tau test due to Mann and Kendall, is the rank-based nonparametric test for assessing the significance of a trend and has been widely used in hydrological trend detection studies. It is based on the test statics $S$ defined as below:

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

(4)

Where, $x_1, x_2, \ldots, x_n$ represent $n$ data points where $x_j$ represents the data point at time $j$.

A very high positive value of $S$ is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend.

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

(5)

It has been documented that when $n \geq 10$, the statistic $S$ is approximately normally distributed with the mean

$$ E(S) = 0 $$

And its variance is

$$ \text{VAR}(S) = \frac{n(n-1)(2n+5) - \sum_{t=1}^{m} (t(t-1)(2t+5))}{10} $$

(6)

where $n$ is the number of data points, $m$ is the number of tied groups (a tied group is a set of sample data having the same value), and $t_i$ is the number of data points in the $i^{th}$ group.

The standardized test statistic $Z$ is computed as follows:

$$ Z = \frac{\frac{S}{\sqrt{\text{VAR}(S)}}}{\text{if } S > 0} $$

$$ 0 \text{ if } S = 0 $$

$$ \frac{S+1}{\sqrt{\text{VAR}(S)}} \text{ if } S < 0 $$

(7)

The null hypothesis, $H_0$, meaning that no significant trend is present, is accepted if the test statistic $Z$ is not statistically significant, i.e. $-Z_{0.02} < Z < Z_{0.02}$, where $Z_{0.02}$ is the standard normal deviate. In this study, three different significance levels i.e., 1%, 5%, and 10% were considered.

### 2.2.3 Mann-Kendall test with pre-whitening

Several approaches have been suggested for removing the serial correlation from a data set prior to applying the test. The pre-whitening approach is
most common which involves computation of serial correlation and removing the correlation if the calculated serial correlation is significant at a 5% significance level as suggested by Burn and Hag Elnur [18].

The MK test with the prewriting procedure suggested by Yue et al. [19] is applied in the following manner to detect a significant trend in a serially correlated time series.

1. The slope (β) of a trend in sample data is estimated using the approach proposed by Theil [20] and Sen [21].

The original sample data $X_t$ was unitized by dividing each of their values with the sample mean $E(X_t)$ prior to conducting the trend analysis [19]. By this treatment, the mean of each data set is equal to one and the properties of the original sample data remain unchanged. If the slope is almost equal to zero, then it is not necessary to continue to conduct trend analysis. If it differs from zero, then it is assumed to be linear, and the sample data are de-trended by:

$$X'_t = X_t - T_t = X_t - \beta t$$

(8)

2. The lag-1 serial correlation coefficient ($r_1$) of the de-trended series $X_t$ is computed using Equation (6.8). If $r_1$ is not significantly different from zero, the sample data are considered to be serially independent and the MK test is directly applied to the original sample data. Otherwise, it is considered to be serially correlated and AR (1) is removed from the $X'_t$ by

$$Y'_t = X'_t - r_1 X'_{t-1}$$

(9)

This pre-whitening procedure after de-trending the series is referred to as the trend-free pre-whitening (TFPW) procedure. The residual series after applying the TFPW procedure should be an independent series.

3. The identified trend ($T_t$) and the residual $Y'_t$ are combined as:

$$Y_t = Y'_t + T_t$$

(10)

The blended series ($Y'_t$) just includes a trend and a noise and is no longer influenced by serial correlation. Then the MK test is applied to the blended series to assess the significance of the trend.

### 2.2.4 Slope

Slope of the lines fit to the time series of climatic data provides a picture of changes that have occurred at any location over an extended period. The slope of the data set can be estimated using the Thiel-Sen Approach. This equation is used instead of a linear regression because it limits the influence that the outliers have on the slope [22].

$$\beta = \text{Median} \left[ \frac{X_i - X_j}{i - j} \right] \quad \text{For all } i < j$$

(11)

where $X_i$ and $X_j$ are data values at times $j$ and $i (i > j)$, respectively.

### 2.2.5 Relative change

To compute the relative change of different climatic parameters, the following equation was used.

$$RC = \frac{n \beta}{|\bar{x}|} \times 100$$

(12)

Where, $n$ is the length of trend period (years), $\beta$ is the magnitude of the trend slope of the time series which is determined by Sen’s median estimator, and $|\bar{x}|$ is the absolute average value of the time series.

### 2.3 Data requirements

To study the climatic variability, district level Monthly Rainfall (1901 to 2002) and Monthly Maximum and Minimum Temperature (1901 to 2002) were considered for 13 districts of Uttarakhand state. These data were collected from India Water Portal website (http://www.indiawaterportal.org/).

### 3. Result and discussion

The present study was conducted to analyze the variability of rainfall, maximum temperature and minimum temperature for Uttarakhand state on seasonal and annual time step. For seasonal analysis, the year was classified into water year (three seasons, each of 4 months duration). Season 1 corresponds to the monsoon season (June–September), season 2 corresponds to the winter season (October–January)
and season 3 corresponds to the winter season (February–May). A non-parametric test (Man-Kendall test) was used in this study. The climatic variables were tested for persistence. In case of station exhibiting significant persistence, pre-whitening test is carried out prior to trend analysis to eliminate the effect of serial correlation. Trend analysis was carried out at 1, 5 and 10% significance level.

3.1 Rainfall

The trend was analyzed for a period of (1901–2002). In season 1 for Almora (Table 1) it can be observed that there is a decreasing trend in rainfall. The sen slope for monsoon season was -1.51 while the relative change was found to be -15.87. In season 2 there was no significant trend was found. The sen slope was -0.13 and relative change was -18.26. In season 3 no significant trend was found. The sen slope was 0.15 and relative change was 16.62 in yearly there was no significant trend was found. The sen slope was -1.93 and relative change was -14.94.

### Table 1. Serial correlation analysis and trend analysis for rainfall for Almora District

| Season | \( r_1 \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|-----------|-----|-------|-----------|-----------|-----------------|
| Season 1 | -0.1358 | -1.8221 | -10 | -1.5157 | 1058.185 | -15.8735 |
| Season 2 | 0.2078 | -0.8715 | 0 | -0.1385 | 56.981 | -18.2685 |
| Season 3 | 0.0545 | 1.1942 | 0 | 0.1552 | 81.741 | 16.6272 |
| Yearly | -0.1238 | -1.517 | 0 | -1.9395 | 1414.692 | -14.9449 |

The trend was analyzed for a period of (1901–2002). In season 1 for Bageshwar (Table 2), it can be observed that there is a decreasing trend in rainfall. The sen slope for monsoon season was -15.15 while the relative change was found to be -15.87. In season 2 there was no significant trend was found the sen slope was -0.13 and relative change was -18.26. In season 3 no significant trend was found the sen slope was 0.15 and relative change was 16.62 in yearly there was no significant trend was found. The sen slope was -1.93 and relative change was -14.94.

### Table 2. Serial correlation analysis and trend analysis for rainfall for Bageshwar District

| Season | \( r_1 \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|-----------|-----|-------|-----------|-----------|-----------------|
| Season 1 | -0.1228 | -1.8221 | -10 | -1.5157 | 1058.185 | -15.8735 |
| Season 2 | 0.2044 | -0.8715 | 0 | -0.1385 | 56.981 | -18.2685 |
| Season 3 | 0.0222 | 1.1942 | 0 | 0.1552 | 81.741 | 16.6272 |
| Yearly | -0.1297 | -1.517 | 0 | -1.9395 | 1414.692 | -14.9449 |

The trend was analyzed for a period of (1901–2002). In season 1 for Chamoli (Table 3) it can be observed that there is a decreasing trend in rainfall. The sen slope for monsoon season was -2.155 while the relative change was found to be -15.87. In season 2 there was no significant trend was found the sen slope was -0.20 and relative change was -18.26. In season 3 no significant trend was found the sen slope was 0.13 and relative change was 16.62 in yearly there was no significant trend was found the sen slope was -1.35 and relative change was -14.94.

### Table 3. Serial correlation analysis and trend analysis for rainfall for Chamoli District

| Season | \( r_1 \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|-----------|-----|-------|-----------|-----------|-----------------|
| Season 1 | -0.1612 | -1.8456 | -10 | -2.150 | -18.4267 | -15.8735 |
| Season 2 | 0.2397 | -1.0416 | 0 | -0.2067 | 84.171 | -18.2685 |
| Season 3 | -0.0432 | 0.6719 | 0 | 0.1381 | 140.2314 | 16.6272 |
| Yearly | -0.1342 | -1.3937 | 0 | -1.3550 | -12.0807 | -14.9449 |

The trend was analyzed for a period of (1901–2002). In season 1 for Champawat (Table 4) it can be observed that there is a decreasing trend in rainfall. The sen slope for monsoon season was -3.08 while the relative change was found to be -21.84. In season 2 there was no significant trend was found the sen slope was -0.10 and relative change was -13.67. In season 3 no significant trend was found the sen slope was 0.13 and relative change was 15.32 in yearly there is a decreasing trend was
The trend was analyzed for a period of (1901–2002). In season 1 for Dehradun, it can be observed that there is a decreasing trend in rainfall. The sen slope for monsoon season was -1.56 while the relative change was found to be -16.97. In season 2 there was no significant trend was found the sen slope was -0.09 and relative change was -14.63 In season 3 no significant trend was found the sen slope was 0.15 and relative change was 20.67 in yearly there is a decreasing trend was found the sen slope was -1.51 and relative change was -14.24.

The trend was analyzed for a period of (1901–2002). In season 1 for Garhwal, it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was -0.78 while the relative change was found to be -9.30. In season 2 there was no significant trend was found the sen slope was -0.12 and relative change was -19.40 In season 3 no significant trend was found the sen slope was 0.16 and relative change was 20.42 in yearly no significant trend was found the sen slope was -0.75 and relative change was -5.93.

The trend was analyzed for a period of (1901–2002). In season 1 for Hardwar, it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was 0.23 while the relative change was found to be 3.39. In season 2 there was no significant trend was found the sen slope was -0.07 and relative change was -13.38 In season 3 there was increasing trend found the sen slope was 0.17 and relative change was 26.76 in yearly there is decreasing trend was found the sen slope was -0.38 and relative change was 3.90.

The trend was analyzed for a period of (1901–2002). In season 1 for Nainital, it can be observed that there was decreasing trend in rainfall. The sen slope for monsoon season was -1.56 while the relative change was found to be -16.97. In season 2 there was no significant trend was found the sen slope was -0.09 and relative change was -14.63 In season 3 there was increasing trend found the sen slope was 0.15 and relative change was 20.67 in yearly there was decreasing trend was found the sen slope was -1.51 and relative change was -14.24.

The trend was analyzed for a period of (1901–2002). In season 1 for Pithodagar, it can be observed that there was decreasing trend in rainfall. The sen slope for monsoon season was -1.67 while the relative change was found to be -17.56. In season 2 there was no significant trend was found the sen slope was -0.17 and relative change was -17.60.

| Table 5. Serial correlation analysis and trend analysis for rainfall for Dehradun District |
|---------------------------------------------------------------|
| **Season** | **r** | **ZMK** | **Trend** | **Sen slope** | **Intercept** | **Relative change** |
|----------------|--------|--------|------------|---------------|---------------|-------------------|
| Season 1      | -0.121 | -1.7517| -10        | -1.5681       | 1017.601      | -16.975           |
| Season 2      | 0.2077 | -0.76  | 0          | -0.0964       | 47.9003       | -14.633           |
| Season 3      | 0.0688 | 1.4876 | 0          | 0.154         | 64.1587       | 20.6739           |
| Yearly        | -0.1193| -1.6813| -10        | -1.5155       | 1167.304      | -14.2409          |

| Table 6. Serial correlation analysis and trend analysis for rainfall for Garhwal District |
|---------------------------------------------------------------|
| **Season** | **r** | **ZMK** | **Trend** | **Sen slope** | **Intercept** | **Relative change** |
|----------------|--------|--------|------------|---------------|---------------|-------------------|
| Season 1      | -0.1874| -1.0182| 0          | -0.7839       | 1050.722      | -9.3044           |
| Season 2      | 0.1952 | -0.9771| 0          | -0.1234       | 48.8094       | -19.4052          |
| Season 3      | 0.0618 | 1.5111 | 0          | 0.1664        | 72.1954       | 20.4264           |
| Yearly        | -0.1549| -0.6837| 0          | -0.7544       | 1320.415      | -5.933            |
was -16.32. In season 3 there was increasing trend found the sen slope was 0.14 and relative change was 8.45 in yearly there was decreasing trend was found the sen slope was -1.91 and relative change was -15.09.

| Season | \( r_1 \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|--------|-----|-------|-----------|-----------|-----------------|
| Season 1 | -0.2018 | 0.355 | 0 | 0.2369 | 853.2654 | 3.3954 |
| Season 2 | 0.1444 | -0.7512 | 0 | -0.0707 | 54.3734 | -13.3885 |
| Season 3 | 0.1038 | 1.9571 | 10 | 0.173 | 57.1172 | 26.7639 |
| Yearly | -0.0035 | 0.5252 | 0 | 0.3813 | 949.9835 | 3.9017 |

Table 7. Serial correlation analysis and trend analysis for rainfall for Haridwar District

| Season | \( r_1 \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|--------|-----|-------|-----------|-----------|-----------------|
| Season 1 | -0.121 | -1.7517 | -10 | -1.5681 | 1017.601 | -16.975 |
| Season 2 | 0.2077 | -0.76 | 0 | -0.0964 | 47.9003 | -14.6333 |
| Season 3 | 0.0688 | 1.4876 | 0 | 0.154 | 64.1587 | 20.6739 |
| Yearly | -0.1193 | -1.6813 | -10 | -1.5155 | 1167.304 | -14.2409 |

Table 8. Serial correlation analysis and trend analysis for rainfall for Nainital District

| Season | \( r_1 \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|--------|-----|-------|-----------|-----------|-----------------|
| Season 1 | -0.1089 | -1.5023 | 0 | -1.1605 | 926.194 | -13.3603 |
| Season 2 | 0.2323 | -0.7952 | 0 | -0.1774 | 79.2775 | -16.3269 |
| Season 3 | -0.059 | 0.6426 | 0 | 0.1451 | 158.3344 | 8.4525 |
| Yearly | -0.1338 | -2.1273 | -5 | -1.9153 | 1339.953 | -15.0913 |

Table 9. Serial correlation analysis and trend analysis for rainfall for Pithodagar District

The trend was analyzed for a period of (1901–2002). In season 1 for Rudrapryag (Table 10) it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was -1.16 while the relative change was found to be -13.36. In season 2 there was no significant trend was found the sen slope was -0.17 and relative change was -18.84. In season 3 no significant trend found the sen slope was 0.14 and relative change was 9.94 in yearly there was no significant trend was found the sen slope was -1.05 and relative change was -9.55.

| Season | \( r_1 \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|--------|-----|-------|-----------|-----------|-----------------|
| Season 1 | -0.0931 | -1.9747 | -5 | -1.6767 | 1057.788 | -17.567 |
| Season 2 | 0.2457 | -0.7952 | 0 | -0.1774 | 79.2775 | -16.3269 |
| Season 3 | -0.1059 | 0.6426 | 0 | 0.1451 | 158.3344 | 8.4525 |
| Yearly | -0.1124 | -2.1273 | -5 | -1.9153 | 1339.953 | -15.0913 |

Table 10. Serial correlation analysis and trend analysis for rainfall for Rudraprayag District

The trend was analyzed for a period of (1901–2002). In season 1 for Tiharigarwal (Table 11) it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was -0.076 while the relative change was found to be -9.04. In season 2 there was no significant trend was found the sen slope was -0.13 and relative change was -19.43. In season 3 no significant trend found the sen slope was 0.18 and relative change was 15.95 in yearly there was no significant trend was found the sen slope was -0.57 and relative change was -12.52. In season 3 there was increasing trend found the sen slope was 0.16 and relative change was 24.97 in yearly there was no significant trend was found the sen slope was -0.86 and relative change was 10.70.

| Season | \( r_1 \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|--------|-----|-------|-----------|-----------|-----------------|
| Season 1 | -1.038 | -1.5023 | 0 | -1.1605 | 926.194 | -13.3603 |
| Season 2 | 0.2323 | -0.9771 | 0 | -0.17 | 72.2283 | -18.8451 |
| Season 3 | -0.059 | 0.8245 | 0 | 0.1407 | 133.0556 | 9.9485 |
| Yearly | -0.1338 | -1.206 | 0 | -1.0516 | 1161.76 | -9.5537 |

Table 11. Serial correlation analysis and trend analysis for rainfall for Tiharigarwal District

The trend was analyzed for a period of (1901–2002). In season 1 for Utham Singh Nager (Table 12) it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was -1.03 while the relative change was found to be -11.89. In season 2 there was no significant trend was found the sen slope was -0.07 and relative change was -12.52. In season 3 there was increasing trend found the sen slope was 0.16 and relative change was 24.97 in yearly there was no significant trend was found the sen slope was -0.86 and relative change was 10.70.

| Season | \( r_1 \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|--------|-----|-------|-----------|-----------|-----------------|
| Season 1 | -1.038 | -1.5023 | 0 | -1.1605 | 926.194 | -13.3603 |
| Season 2 | 0.2323 | -0.9771 | 0 | -0.171 | 72.2283 | -18.8451 |
| Season 3 | -0.059 | 0.8245 | 0 | 0.1407 | 133.0556 | 9.9485 |
| Yearly | -0.1338 | -1.206 | 0 | -1.0516 | 1161.76 | -9.5537 |
The trend was analyzed for a period of (1901–2002). In season 1 for Uttarkashi (Table 13) it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was -0.88 while the relative change was found to be -11.26. In season 2 there was no significant trend found the sen slope was -0.14 and relative change was -17.32. In season 3 no significant trend found the sen slope was 0.19 and relative change was 14.89 in yearly there was no significant trend was found the sen slope was -0.67 and relative change was -15.51.

### 3.2 Maximum temperature

The trend was analyzed for a period of (1901–2002). In season 1 for Almora (Table 14) it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was -0.0026 while the relative change was found to be -0.79. In season 2 there was no significant trend found the sen slope was -0.0042 and relative change was 1.71. In season 3 there was increasing trend found the sen slope was 0.0063 and relative change was 2.06 in yearly there was no significant trend was found the sen slope was -0.0012 and relative change was -0.40.

The trend was analyzed for a period of (1901–2002). In season 1 for Bageshwar (Table 15) it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was -0.0021 while the relative change was found to be -0.706. In season 2 there was increasing trend was found the sen slope was 0.0052 and relative change was 2.39. In season 3 there was increasing trend found the sen slope was 0.0068 and relative change was 2.51 in yearly there was no significant trend was found the sen slope was 0.0017 and relative change was 0.64.

The trend was analyzed for a period of (1901–2002). In season 1 for Chamoli (Table 16) it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was -0.0018 while the relative change was found to be -0.71. In season 2 there was increasing trend was

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### Table 11. Serial correlation analysis and trend analysis for rainfall for Thrigarwal District

| Season | $r_i$ | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|-------|-----|-------|-----------|-----------|-----------------|
| Season 1 | -0.1591 | -1.0299 | 0 | -0.7629 | 890.4837 | -9.0429 |
| Season 2 | 0.1944 | -1.0123 | 0 | -0.1389 | 60.9164 | -19.4369 |
| Season 3 | 0.0213 | 1.206 | 0 | 0.1834 | 103.7123 | 15.9538 |
| Yearly | -0.1635 | -0.76 | 0 | -0.5724 | 1045.566 | -5.6473 |

### Table 12. Serial correlation analysis and trend analysis for rainfall for Udham Singh Nager District

| Season | $r_i$ | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|-------|-----|-------|-----------|-----------|-----------------|
| Season 1 | -0.1369 | -1.2999 | 0 | -1.0352 | 943.3654 | -11.8998 |
| Season 2 | 0.2211 | -0.6719 | 0 | -0.078 | 42.1054 | -12.5243 |
| Season 3 | 0.074 | 1.7165 | 10 | 0.1631 | 56.1379 | 24.9779 |
| Yearly | -0.1327 | -1.1238 | 0 | -0.8677 | -8.6984 | 10.7058 |

### Table 13. Serial correlation analysis and trend analysis for rainfall for Uttarkashi District

| Season | $r_i$ | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|-------|-----|-------|-----------|-----------|-----------------|
| Season 1 | -0.0742 | -1.2294 | 0 | -0.8856 | 820.6787 | -11.2603 |
| Season 2 | 0.2117 | -1.1238 | 0 | -0.1442 | 72.5596 | -17.3201 |
| Season 3 | -0.0684 | 1.1297 | 0 | 0.1954 | 114.7676 | 14.8911 |
| Yearly | -0.1097 | -0.8362 | 0 | -0.6799 | 1035.254 | -15.5107 |

### Table 14. Serial correlation analysis and trend analysis for maximum temperature for Almora District

| Season | $r_i$ | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|-------|-----|-------|-----------|-----------|-----------------|
| Season 1 | 0.2052 | 0.5229 | 0 | -0.0026 | 26.8665 | -0.7912 |
| Season 2 | 0.3664 | 1.517 | 0 | 0.0042 | 15.4856 | 1.717 |
| Season 3 | 0.0895 | 1.8251 | 10 | 0.0063 | 30.8373 | 2.0601 |
| Yearly | 0.3271 | 0.6367 | 0 | 0.0012 | 20.0432 | 0.4075 |

### Table 15. Serial correlation analysis and trend analysis for maximum temperature for Bageshwar District

| Season | $r_i$ | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|-------|-----|-------|-----------|-----------|-----------------|
| Season 1 | 0.1523 | 0.6776 | 0 | -0.0027 | 28.3456 | -0.7912 |
| Season 2 | 0.3694 | 1.8251 | 0 | 0.0042 | 16.4856 | 1.717 |
| Season 3 | 0.0895 | 1.8251 | 10 | 0.0063 | 30.8373 | 2.0601 |
| Yearly | 0.3271 | 0.6367 | 0 | 0.0012 | 20.0432 | 0.4075 |

### Table 16. Serial correlation analysis and trend analysis for maximum temperature for Chamoli District

| Season | $r_i$ | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|-------|-----|-------|-----------|-----------|-----------------|
| Season 1 | -0.1369 | -1.2999 | 0 | -1.0352 | 943.3654 | -11.8998 |
| Season 2 | 0.2211 | -0.6719 | 0 | -0.078 | 42.1054 | -12.5243 |
| Season 3 | 0.074 | 1.7165 | 10 | 0.1631 | 56.1379 | 24.9779 |
| Yearly | -0.1327 | -1.1238 | 0 | -0.8677 | -8.6984 | 10.7058 |
found the sen slope was 0.0059 and relative change was 3.34. In season 3 there was increasing trend found the sen slope was 0.0075 and relative change was 3.38 in yearly there was no significant trend was found the sen slope was 0.0013 and relative change was 0.59.

| Season | $r_1$   | ZMK   | Trend | Sen slope | Intercept | Relative change |
|--------|---------|-------|-------|-----------|-----------|-----------------|
| Season 1 | 0.2322 | -1.2764 | 0 | -0.0021 | 23.1663 | -0.706 |
| Season 2 | 0.3694 | 1.8339 | 10 | 0.0052 | 13.4495 | 2.39 |
| Season 3 | 0.0957 | 2.0099 | 5 | 0.0068 | 26.9239 | 2.5152 |
| Yearly  | 0.3484 | 0.983 | 0 | 0.0017 | 17.082 | 0.6495 |

The trend was analyzed for a period of (1901−2002). In season 1 for Dehradun (Table 18) it can be observed that there was decreasing trend in rainfall. The sen slope for monsoon season was -0.0042 while the relative change was found to be -1.22. In season 2 no significant trend was found the sen slope was 0.0032 and relative change was 1.27. In season 3 there was increasing trend found the sen slope was 0.0083 and relative change was 2.69 in yearly there was no significant trend was found the sen slope was 0.0013 and relative change was 0.42.

| Season | $r_1$   | ZMK   | Trend | Sen slope | Intercept | Relative change |
|--------|---------|-------|-------|-----------|-----------|-----------------|
| Season 1 | 0.2074 | -1.1825 | 0 | -0.0018 | 19.518 | -0.7141 |
| Season 2 | 0.3546 | 1.9982 | 5 | 0.0059 | 10.7106 | 3.3418 |
| Season 3 | 0.0991 | 2.3799 | 5 | 0.0075 | 21.9611 | 3.3861 |
| Yearly  | 0.3264 | 0.8597 | 0 | 0.0013 | 12.7265 | 0.5915 |

The trend was analyzed for a period of (1901−2002). In season 1 for Garwal (Table 19) it can be observed that there was decreasing trend in rainfall. The sen slope for monsoon season was -0.0034 while the relative change was found to be -0.99. In season 2 no significant trend was found the sen slope was 0.0042 and relative change was 1.67. In season 3 there was increasing trend found the sen slope was 0.0069 and relative change was 2.22 in yearly there was no significant trend was found the sen slope was 0.0011 and relative change was 0.36.

The trend was analyzed for a period of (1901−2002). In season 1 for Hardwar (Table 20)
it can be observed that there was decreasing trend in rainfall. The sen slope for monsoon season was -0.0056 while the relative change was found to be -1.62. In season 2 no significant trend was found the sen slope was 0.0038 and relative change was 1.49. In season 3 there was increasing trend found the sen slope was 0.0079 and relative change was 2.50 in yearly there was no significant trend was found the sen slope was 0.0016 and relative change was 0.52.

Table 19. Serial correlation analysis and trend analysis for maximum temperature for Garwal District

| Season | r₁ | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|----|-----|-------|-----------|-----------|-----------------|
| Season 1 | 0.1612 | -2.0686 | -5 | -0.0034 | 28.7206 | -0.9954 |
| Season 2 | 0.3711 | 1.6285 | 0 | 0.0042 | 15.473 | 1.6771 |
| Season 3 | 0.0903 | 1.9865 | 5 | 0.0069 | 30.9591 | 2.2253 |
| Yearly | 0.3069 | 0.8539 | 0 | 0.0011 | 20.8239 | 0.367 |

Table 20. Serial correlation analysis and trend analysis for maximum temperature for Haridwar District

| Season | r₁ | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|----|-----|-------|-----------|-----------|-----------------|
| Season 1 | 0.129 | -2.8286 | -1 | -0.0056 | 35.2652 | -1.62 |
| Season 2 | 0.3605 | 1.6226 | 0 | 0.0038 | 16.1702 | 1.4902 |
| Season 3 | 0.1031 | 2.4559 | 1 | 0.0079 | 31.2375 | 2.5099 |
| Yearly | 0.267 | 0.7893 | 0 | 0.0016 | 22.4635 | 0.5239 |

The trend was analyzed for a period of (1901–2002). In season 1 for Nainital (Table 21) it can be observed that there was decreasing trend in rainfall. The sen slope for monsoon season was -0.0031 while the relative change was found to be -0.91. In season 2 there was increasing trend was found the sen slope was 0.0042 and relative change was 1.64. In season 3 there was increasing trend found the sen slope was 0.0064 and relative change was 2.00 in yearly there was no significant trend was found the sen slope was 0.0011 and relative change was 0.35.

Table 21. Serial correlation analysis and trend analysis for maximum temperature for Nainital District

| Season | r₁ | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|----|-----|-------|-----------|-----------|-----------------|
| Season 1 | 0.1766 | -1.8045 | -10 | -0.0031 | 28.6573 | -0.9132 |
| Season 2 | 0.3674 | 1.7693 | 10 | 0.0042 | 16.1001 | 1.6413 |
| Season 3 | 0.0868 | 1.875 | 10 | 0.0064 | 32.2123 | 2.0029 |
| Yearly | 0.313 | 0.7424 | 0 | 0.0011 | 21.2796 | 0.3545 |

The trend was analyzed for a period of (1901–2002). In season 1 for Pithodagar (Table 22) it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was -0.0014 while the relative change was found to be -0.52. In season 2 there was increasing trend found the sen slope was 0.0065 and relative change was 3.60. In season 3 there was increasing trend found the sen slope was 0.0073 and relative change was 1.17 in yearly there was no significant trend was found the sen slope was 0.0026 and relative change was 0.35.

Table 22. Serial correlation analysis and trend analysis for maximum temperature Pithodagar District

| Season | r₁ | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|----|-----|-------|-----------|-----------|-----------------|
| Season 1 | 0.2491 | -0.7834 | 0 | -0.0014 | 19.7754 | -0.5268 |
| Season 2 | 0.3548 | 2.186 | 5 | 0.0065 | 11.3044 | 3.6092 |
| Season 3 | 0.0961 | 2.3884 | 1 | 0.0073 | 22.8328 | 3.2587 |
| Yearly | 0.3473 | 1.5698 | 0 | 0.0026 | 14.441 | 1.1776 |

The trend was analyzed for a period of (1901–2002). In season 1 for Rudraprayag (Table 23) it can be observed that there was no significant trend in rainfall. The sen slope for monsoon sea-son was -0.003 while the relative change was found to be -0.92.

Table 23. Serial correlation analysis and trend analysis for maximum temperature Rudraprayag District

| Season | r₁ | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|----|-----|-------|-----------|-----------|-----------------|
| Season 1 | 0.4291 | -0.7834 | 0 | -0.0014 | 19.7754 | -0.5268 |
| Season 2 | 0.3548 | 2.186 | 5 | 0.0065 | 11.3044 | 3.6092 |
| Season 3 | 0.0961 | 2.3884 | 1 | 0.0073 | 22.8328 | 3.2587 |
| Yearly | 0.3473 | 1.5698 | 0 | 0.0026 | 14.441 | 1.1776 |
found the sen slope was 0.0015 and relative change was 0.51.

The trend was analyzed for a period of (1901-2002). In season 1 for Tiharigarwal (Table 24) it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was -0.003 while the relative change was found to be -0.92. In season 2 there was no significant trend found as the sen slope was 0.0041 and relative change was 1.76. In season 3 there was an increasing trend found as the sen slope was 0.0075 and relative change was 2.57. In yearly there was no significant trend found as the sen slope was 0.0015 and relative change was 0.51.

Table 23. Serial correlation analysis and trend analysis for maximum temperature Rudraprayag District

| Season   | $r_1$   | ZMK  | Trend | Sen slope | Intercept | Relative change |
|----------|---------|------|-------|-----------|-----------|-----------------|
| Season 1 | 0.1979  | -1.5874 | 0     | -0.003    | 26.307    | -0.9237         |
| Season 2 | 0.3577  | 1.5639 | 0     | 0.0041    | 14.8321   | 1.7658          |
| Season 3 | 0.0908  | 2.2388 | 5     | 0.0075    | 28.953    | 2.5773          |
| Yearly   | 0.3223  | 0.9125 | 0     | 0.0015    | 19.2476   | 0.5198          |

Table 24. Serial correlation analysis and trend analysis for maximum temperature Tiharigarwal District

| Season   | $r_1$   | ZMK  | Trend | Sen slope | Intercept | Relative change |
|----------|---------|------|-------|-----------|-----------|-----------------|
| Season 1 | 0.1979  | -1.5874 | 0     | -0.003    | 26.307    | -0.9237         |
| Season 2 | 0.3577  | 1.5639 | 0     | 0.0041    | 14.8321   | 1.7658          |
| Season 3 | 0.0908  | 2.2388 | 5     | 0.0075    | 28.953    | 2.5773          |
| Yearly   | 0.3223  | 0.9125 | 0     | 0.0015    | 19.2476   | 0.5198          |

Table 25. Serial correlation analysis and trend analysis for maximum temperature for Udham Singh Nager District

| Season   | $r_1$   | ZMK  | Trend | Sen slope | Intercept | Relative change |
|----------|---------|------|-------|-----------|-----------|-----------------|
| Season 1 | 0.137   | -2.6467 | -1     | -0.0044   | 35.0165   | -1.282          |
| Season 2 | 0.3628  | 1.8926 | 10    | 0.0044    | 16.2194   | 1.6833          |
| Season 3 | 0.0547  | 1.605  | 0     | 0.0054    | 33.9421   | 1.605           |
| Yearly   | 0.3222  | 1.3527 | 0     | 0.0024    | 20.1978   | 0.7978          |

The trend was analyzed for a period of (1901-2002). In season 1 for Uttarkashi (Table 26) it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was -0.0044 while the relative change was found to be 1.28. In season 2 there was an increasing trend found as the sen slope was 0.0044 and relative change was 1.68. In season 3 there was no significant trend found as the sen slope was 0.0054 and relative change was 1.60. In yearly there was no significant trend found as the sen slope was 0.0024 and relative change was 0.79.

Table 26. Serial correlation analysis and trend analysis for maximum temperature for Uttarkashi District

| Season   | $r_1$   | ZMK  | Trend | Sen slope | Intercept | Relative change |
|----------|---------|------|-------|-----------|-----------|-----------------|
| Season 1 | 0.2542  | -1.2236 | 0     | -0.0021   | 19.4942   | -0.8181         |
| Season 2 | 0.3628  | 1.7869 | 10    | 0.0044    | 10.7135   | 2.5375          |
| Season 3 | 0.099   | 2.2799 | 5     | 0.0083    | 21.4659   | 3.8485          |
| Yearly   | 0.301   | 1.3527 | 0     | 0.0024    | 14.8805   | 1.1209          |

3.3 Minimum temperature

The trend was analyzed for a period of (1901-2002). In season 1 for Almora (Table 27) it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was -0.0013 while the relative change was found to be -
In season 2 there was increasing trend was found the sen slope was 0.0054 and relative change was 8.63. In season 3 there was increasing trend found the sen slope was 0.0048 and relative change was 4.84. In yearly there was no significant trend was found the sen slope was 0.002 and relative change was 1.81.

The trend was analyzed for a period of (1901–2002). In season 1 for Bageshwar (Table 28) it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was -0.0016 while the relative change was found to be -0.76. In season 2 there was increasing trend was found the sen slope was 0.0054 and relative change was 8.63. In season 3 there was no significant trend found the sen slope was 0.0065 and relative change was 4.85. In season 3 there was increasing trend found the sen slope was 0.0065 and relative change was 4.85. In yearly there was no significant trend was found the sen slope was 0.002 and relative change was 1.81.

### Table 27. Serial correlation analysis and trend analysis for minimum temperature for Almora District

| Season | \( r_1 \) | ZMK  | Trend | Sen slope | Intercept | Relative change |
|--------|---------|------|-------|-----------|-----------|-----------------|
| Season 1 | 1.1209 | -1.2999 | 0 | -0.0013 | 11.2492 | -0.7638 |
| Season 2 | 0.4073 | 1.7576 | 10 | 0.0054 | 3.4453 | 8.6325 |
| Season 3 | 0.1299 | 1.8163 | 10 | 0.0048 | 8.3498 | 4.8429 |
| Yearly  | 0.4367 | 0.7247 | 0 | 0.002 | 5.6039 | 1.8134 |

### Table 28. Serial correlation analysis and trend analysis for minimum temperature for Bageshwar District

| Season | \( r_1 \) | ZMK  | Trend | Sen slope | Intercept | Relative change |
|--------|---------|------|-------|-----------|-----------|-----------------|
| Season 1 | 0.3674 | -1.0006 | 0 | -0.0016 | 13.4094 | -0.7657 |
| Season 2 | 0.264 | 1.4642 | 0 | -0.0016 | 5.76 | 4.8558 |
| Season 3 | 0.1431 | 1.96 | 10 | 0.0065 | 13.2449 | 4.8426 |
| Yearly  | 0.4447 | 1.1825 | 0 | 0.0021 | 7.6289 | 1.5205 |

### Table 29. Serial correlation analysis and trend analysis for minimum temperature for Chamoli District

| Season | \( r_1 \) | ZMK  | Trend | Sen slope | Intercept | Relative change |
|--------|---------|------|-------|-----------|-----------|-----------------|
| Season 1 | 0.3569 | -0.9125 | 0 | -0.0013 | 11.2492 | -0.7638 |
| Season 2 | 0.3985 | 1.963 | 10 | 0.0054 | 3.4453 | 8.6325 |
| Season 3 | 0.1555 | 1.5287 | 0 | 0.0048 | 8.3498 | 4.8429 |
| Yearly  | 0.4947 | 1.159 | 0 | 0.002 | 5.6039 | 1.8134 |

The trend was analyzed for a period of (1901–2002). In season 1 for Champawat (Table 30) it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was -0.0036 while the relative change was found to be -1.47. In season 2 there was increasing trend was found the sen slope was 0.0037 and relative change was 3.56. In season 3 there was increasing trend found the sen slope was 0.0077 and relative change was 8.89. In yearly there was no significant trend was found the sen slope was 0.0016 and relative change was 0.94.

The trend was analyzed for a period of (1901–2002). In season 1 for Dehradun (Table 31) it can be observed that there was decreasing trend in rainfall. The sen slope for monsoon season was -0.002 while the relative change was found to be -0.78. In season 2 there was increasing trend was found the sen slope was 0.0047 and relative change was 3.98. In season 3 there was increasing trend found the sen slope was 0.006 and relative change was 3.51 in yearly there was no significant trend was found the sen slope was 0.0017 and relative change was 0.97.

The trend was analyzed for a period of (1901–2002). In season 1 for Garwal (Table 32) it can be observed that there was decreasing trend in rainfall. The sen slope for monsoon season was -0.0036 while the relative change was found to be -1.47. In season 2 there was increasing trend was found the sen slope was 0.0037 and relative change was 3.56. In season 3 there was increasing trend found the sen slope was 0.0077 and relative change was 8.89 in yearly there was no significant trend was found the sen slope was 0.0016 and relative change was 0.94.
rainfall. The sen slope for monsoon season was -0.0026 while the relative change was found to be 1.053. In season 2 there was increasing trend was found the sen slope was 0.004 and relative change was 3.73 in season 3 there was increasing trend found the sen slope was 0.0063 and relative change was 3.98 in yearly there was no significant trend was found the sen slope was 0.0013 and relative change was 0.75.

**Table 30.** Serial correlation analysis and trend analysis for minimum temperature for Champawat District

| Season | \( r_1 \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|----------|-----|-------|-----------|-----------|-----------------|
| Season 1 | 0.3335 | -1.1414 | 0 | -0.002 | 16.8885 | -0.7819 |
| Season 2 | 0.3957 | 1.9043 | 10 | 0.0047 | 6.8631 | 3.9885 |
| Season 3 | 0.1261 | 1.7957 | 10 | 0.006 | 16.915 | 3.5128 |
| Yearly | 0.4185 | 1.0651 | 0 | 0.0017 | 10.4251 | 0.9711 |

**Table 31.** Serial correlation analysis and trend analysis for minimum temperature for Dehradun District

| Season | \( r_1 \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|----------|-----|-------|-----------|-----------|-----------------|
| Season 1 | 0.2082 | -2.1332 | -5 | -0.0036 | 19.7902 | -1.4755 |
| Season 2 | 0.3263 | 1.6813 | 10 | 0.0037 | 6.724 | 3.5687 |
| Season 3 | 0.1364 | 2.3268 | 1 | 0.0077 | 15.501 | 4.8975 |
| Yearly | 0.3399 | 0.9125 | 0 | 0.0016 | 11.1407 | 0.9486 |

The trend was analyzed for a period of (1901–2002). In season 1 for Hardwar (Table 33) it can be observed that there was decreasing trend in rainfall. The sen slope for monsoon season was -0.0055 while the relative change was found to be -2.20. In season 2 there was increasing trend was found the sen slope was 0.0038 and relative change was 3.51, in season 3 there was increasing trend found the sen slope was 0.0076 and relative change was 4.63 in yearly there was no significant trend was found the sen slope was 0.0016 and relative change was 0.91.

The trend was analyzed for a period of (1901–2002). In season 1 for Nainital (Table 34) it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was -0.0008 while the relative change was found to be -0.48. In season 2 there was increasing trend was found the sen slope was 0.0058 and relative change was 9.85. In season 3 there was no significant trend found the sen slope was 0.0052 and relative change was 5.36 in yearly there was no significant trend was found the sen slope was 0.0022 and relative change was 2.044.

**Table 32.** Serial correlation analysis and trend analysis for minimum temperature for Garhwal District

| Season | \( r_1 \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|----------|-----|-------|-----------|-----------|-----------------|
| Season 1 | 0.2759 | -1.7576 | -10 | -0.0026 | 17.8706 | -1.053 |
| Season 2 | 0.3929 | 1.7693 | 10 | 0.004 | 6.2136 | 3.7351 |
| Season 3 | 0.1262 | 1.9865 | 5 | 0.0063 | 15.8154 | 3.9833 |
| Yearly | 0.3831 | 0.7394 | 0 | 0.0013 | 10.4616 | 0.7524 |

**Table 33.** Serial correlation analysis and trend analysis for minimum temperature for Haridwar District

| Season | \( r_1 \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|----------|-----|-------|-----------|-----------|-----------------|
| Season 1 | 0.1487 | -3.0662 | -1 | -0.0055 | 25.5878 | -2.2058 |
| Season 2 | 0.3479 | 1.7517 | 10 | 0.0038 | 6.8057 | 3.5119 |
| Season 3 | 0.1214 | 2.3034 | 5 | 0.0076 | 16.2155 | 4.6353 |
| Yearly | 0.2852 | 1.0534 | 0 | 0.0016 | 12.4939 | 0.9109 |
The trend was analyzed for a period of (1901–2002). In season 1 for Rudraprayag (Table 36) it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was -0.0016 while the relative change was found to be -0.91. In season 2 there was increasing trend was found the sen slope was 0.005 and relative change was 7.28. In season 3 there was increasing trend found the sen slope was 0.0069 and relative change was 6.50 in yearly there was no significant trend was found the sen slope was 0.0025 and relative change was 2.14.

The trend was analyzed for a period of (1901–2002). In season 1 for Tiharigarwal (Table 37) it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was -0.0024 while the relative change was found to be -1.05. In season 2 there was increasing trend was found the sen slope was 0.004 and relative change was 4.18. In season 3 there was increasing trend found the sen slope was 0.0069 and relative change was 4.75 in yearly there was no significant trend was found the sen slope was 0.0014 and relative change was 0.91.

The trend was analyzed for a period of (1901–2002). In season 1 for Utham Singh Nager (Table 38) it can be observed that there was decreasing trend in rainfall. The sen slope for monsoon season was -0.0032 while the relative change was found to be -1.26. In season 2 there was increasing trend was found the sen slope was 0.0045 and relative change was 3.91. In season 3 there was increasing trend found the sen slope was 0.006 and relative change was 3.49 in yearly there was no significant trend was found the sen slope was 0.0015 and relative change was 0.81.

The trend was analyzed for a period of (1901–2002). In season 1 for Uttarkashi (Table 39) it can be observed that there was no significant trend in rainfall. The sen slope for monsoon season was -0.0016 while the relative change was found to be -0.94. In season 2 there was increasing trend was found the sen slope was 0.0046 and relative change was 7.94. In season 3 there was increasing trend found the sen slope was 0.0054 and relative change was 5.61 in yearly there was no significant trend was found the sen slope was 0.0019 and relative change was 0.81.

### Table 34. Serial correlation analysis and trend analysis for minimum temperature for Nainital District

| Season | \( r_i \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|---------|-----|-------|-----------|-----------|-----------------|
| Season 1 | 0.2954 | -1.6167 | 0 | -0.0025 | 17.9395 | -1.0119 |
| Season 2 | 0.4123 | 1.8221 | 10 | 0.0044 | 6.514 | 3.7608 |
| Season 3 | 0.0966 | 1.5258 | 0 | 0.0053 | 17.5028 | 3.0192 |
| Yearly | 0.4111 | 0.6837 | 0 | 0.0013 | 10.5588 | 0.7121 |

### Table 35. Serial correlation analysis and trend analysis for minimum temperature for Pithodagar District

| Season | \( r_i \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|---------|-----|-------|-----------|-----------|-----------------|
| Season 1 | 0.3825 | -0.4431 | 0 | -0.0008 | 10.7559 | -0.4804 |
| Season 2 | 0.386 | 2.0921 | 5 | 0.0058 | 3.3051 | 9.8564 |
| Season 3 | 0.1541 | 1.6402 | 0 | 0.0052 | 8.0658 | 5.3635 |
| Yearly | 0.479 | 1.3057 | 0 | 0.0022 | 5.6357 | 2.0442 |

### Table 36. Serial correlation analysis and trend analysis for minimum temperature for Rudraprayag District

| Season | \( r_i \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|---------|-----|-------|-----------|-----------|-----------------|
| Season 1 | 0.2993 | -1.0416 | 0 | -0.0016 | 12.6194 | -0.9128 |
| Season 2 | 0.3859 | 1.9982 | 5 | 0.005 | 3.896 | 7.2844 |
| Season 3 | 0.1488 | 2.3855 | 1 | 0.0069 | 10.4692 | 6.5066 |
| Yearly | 0.4122 | 1.3233 | 0 | 0.0025 | 6.6802 | 2.1487 |

### Table 37. Serial correlation analysis and trend analysis for minimum temperature for Tiharigarwal District

| Season | \( r_i \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|---------|-----|-------|-----------|-----------|-----------------|
| Season 1 | 0.2516 | -1.4466 | 0 | -0.0024 | 17.3722 | -1.055 |
| Season 2 | 0.3615 | 1.6754 | 10 | 0.004 | 5.9132 | 4.1847 |
| Season 3 | 0.1382 | 2.1508 | 5 | 0.0069 | 14.3856 | 4.7506 |
| Yearly | 0.1382 | 0.8539 | 0 | 0.0014 | 9.4437 | 0.9131 |

### Table 38. Serial correlation analysis and trend analysis for minimum temperature for Utham Singh Nager

| Season | \( r_i \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|---------|-----|-------|-----------|-----------|-----------------|
| Season 1 | 0.2516 | -1.4466 | 0 | -0.0024 | 17.3722 | -1.055 |
| Season 2 | 0.3615 | 1.6754 | 10 | 0.004 | 5.9132 | 4.1847 |
| Season 3 | 0.1382 | 2.1508 | 5 | 0.0069 | 14.3856 | 4.7506 |
| Yearly | 0.1382 | 0.8539 | 0 | 0.0014 | 9.4437 | 0.9131 |

### Table 39. Serial correlation analysis and trend analysis for minimum temperature for Uttarkashi

| Season | \( r_i \) | ZMK | Trend | Sen slope | Intercept | Relative change |
|--------|---------|-----|-------|-----------|-----------|-----------------|
| Season 1 | 0.2516 | -1.4466 | 0 | -0.0024 | 17.3722 | -1.055 |
| Season 2 | 0.3615 | 1.6754 | 10 | 0.004 | 5.9132 | 4.1847 |
| Season 3 | 0.1382 | 2.1508 | 5 | 0.0069 | 14.3856 | 4.7506 |
trend was found the sen slope was 0.0022 and relative change was 2.01.

| Season    | $r_1$ | ZMK  | Trend | Sen slope | Intercept | relative change |
|-----------|-------|------|-------|-----------|-----------|-----------------|
| Season 1  | 0.2545| -1.963| -10   | -0.0032   | 19.1573   | -1.263          |
| Season 2  | 0.4097| 2.051 | 5     | 0.0045    | 6.5669    | 3.9117          |
| Season 3  | 0.12  | 1.8574| 10    | 0.006     | 17.0131   | 3.4959          |
| Yearly    | 0.3883| 0.801 | 0     | 0.0015    | 11.0223   | 0.8199          |

Table 38. Serial correlation analysis and trend analysis for minimum temperature for Udhamsingh Nager

| Season    | $r_1$ | ZMK  | Trend | Sen slope | Intercept | relative change |
|-----------|-------|------|-------|-----------|-----------|-----------------|
| Season 1  | 0.3022| -0.9419| 0     | -0.0016   | 12.2031   | -0.9433         |
| Season 2  | 0.358 | 1.828 | 10    | 0.0046    | 3.4203    | 7.9417          |
| Season 3  | 0.157 | 1.6872| 10    | 0.0054    | 7.9486    | 5.6152          |
| Yearly    | 0.456 | 1.2999| 0     | 0.0022    | 5.8631    | 2.0111          |

Table 39. Serial correlation analysis and trend analysis for minimum temperature for Uttarkashi District

4. Conclusions

In this study, trend analyses of rainfall, maximum temperature and minimum temperature were carried out for the Uttarakhand state. The study inferred that in Season I (monsoon season) seven out of thirteen districts have exhibited a declining trend in rainfall. In Season II (winter season) no significant trend was found. An increasing trend was observed in rainfall in Season III (summer season) for Haridwar and Uddham Singh Nagar districts. The yearly analysis of rainfall exhibited a decreasing trend in five districts of Uttarakhand. A decreasing trend was observed in Season I for maximum temperature in five districts of Uttrakhand state. An increasing trend of maximum temperature was exhibited by eight districts in winter season. In summer season, the entire state (except for Uddham Singh Nagar district) showed an increasing trend for maximum temperature. However, the yearly analysis did not show any trend for maximum temperature. For minimum temperature, in season I, a decreasing trend was observed for four districts. An increasing trend was observed in eight districts in season II. Except for Bageshwar district, entire state has exhibited an increasing trend of minimum temperature in Season III. However, the yearly analysis did not exhibit any trend for minimum temperature.

Conflict of interest

The authors declared no conflict of interest.

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