Summer Internship Report On

# SPATIAL AND TEMPORAL RAINFALL TRENDS IN UTTARAKHAND-CENTRAL HIMALAYAS


Submitted

By

**PRITI**

**(M.Sc Geology)**

**Enrolment No. – GA113197**

**Pt. LMS Gov. P.G. COLLEGE, Rishikesh- 249201**

SURPERVISED

BY

Dr. L.N. Thakural

Scientist 'C'

National Institute of Hydrology

Roorkee

# *ACKNOWLEDGEMENT*

Firstly, I thank almighty God for helping me one way or the other and providing strength to me. This project would not have been possible without the kind support and help of many individuals and organization. I would like to extend my sincere thanks to all of them.

I take this opportunity to express my profound gratitude indebtedness to my research supervisor Dr. L.N. Thakural, Scientist, National Institute of Hydrology (NIH), Roorkee for his invaluable guidance, enthusiastic encouragement and useful critiques throughout the course of my research project. The help, guidance and suggestions given by him from time to time enabled me to complete my project successfully.

I would like to express my sincere gratitude to Director, NIH, Roorkee who allowed me to carry out my summer internship at his renowned institution.

I would also like to thank Prof. D.C. Nainwal, Head of Geology Department and Principal, Govt. P.G. College, Rishikesh and Prof. Pankaj Pant for providing facilities of the department.

Finally, I thank my parents and my dear friends for their support and encouragement throughout my studies.

PRITI

Date: 16 Aug, 2016

Place: Rishikesh

# *DECLARATION*

I hereby declare that the work presented in this report entitled "SPATIAL AND TEMPORAL RAINFALL TRENDS IN UTTARAKHAND-CENTRAL HIMALAYAS" is an authentic work of my own done under the guidance of **Dr. L. N. Thakural**, Scientist 'C', National Institute of Hydrology, Roorkee.

(PRITI)

Date: 16 Aug, 2016

Place: Roorkee

# *CERTIFICATE*

It is certified that **Miss. PRITI**, Enrolment No. GA-133197, a student of M.Sc II[nd] year (Geology), Govt. P.G. College, Rishikesh, completed the internship project from June 02, 2016 to July 22, 2016 at **National Institute of Hydrology**, Roorkee under my supervision and this report is based on her own work.

Thakural

**(Dr. L.N. Thakural)**

(Scientist 'C')

National Institute of Hydrology

Roorkee-247667 (India)

Date: 16 August, 2016

Place: Roorkee

# *CONTENTS*

1. Introduction
2. Study Area
   2.1 Geography
   2.2 Physiography
   2.3 Geology
   2.4 Geomorphology
   2.5 Climatology
3. Data Used
4. Methodology
   4.1 Trend Analysis
      4.1.1 Linear Regression Model
      4.1.2 Mann-Kendall Test
      4.1.3 Sen's Slope Estimator Test
5. Results and Discussion
6. Conclusions
7. Bibliography

# ABSTRACT

*Rainfall being one of the most important parameter of climate change controls the availability of water in a region. Evaluation of the trend of rainfall at global, regional and basin scales are necessary for proper planning, development and management of water resources. This study aims to determine trends in the annual and seasonal rainfall in Uttarakhand state covering a part of Central Himalayas. Daily based Gridded rainfall data of 0.25×0.25° resolution (Indian Meteorological Department) was analysed to study long term spatial and temporal trends of rainfall on annual and seasonal scales in Uttarakhand state located in Northern India during period of 112 years (1901–2012). In this study, both parametric (linear regression method) and non-parametric (Mann–Kendall test and Sen's slope estimator) have been used to analyse trends in the rainfall and their magnitudes for Uttarakhand state. The gridded data of 13 districts namely Almora, Bageshwar, Champawat, Chamoli, Dehradun, Haridwar, Nainital, Pauri Garhwal, Pithoragarh, Rudra Prayag, Tehri Garhwal, Udham Singh Nagar and Uttarkashi have been considered for spatial and temporal trends.*

*For the analysis of data the year has been divided into four principal seasons namely pre-monsoon, monsoon, post-monsoon and winter.*

- **Key words:** Climate change, rainfall trend, Linear regression test, Mann–Kendall test, Sen's slope estimator test.

# 1. INTRODUCTION

Earth is passing through the crisis of climate change due to the global warming conditions. The emission of greenhouse gases by various anthropogenic activities are resulting in the increase of temperature at a considerable rates thus changing the climate. The climate change have become a very serious problem for our planet since last few decades. It is affecting the planet adversely and causing very critic effects on the natural processes taking place on the earth. Such mainly encountered processes are changes in temperature, changes in precipitation rates, wind energy and direction, rise in sea level etc. all caused by global warming of the planet. Potential climate change and its impacts on hydrological systems pose a threat to water resources throughout the world.

**Climate change** - Climate change is a change in the statistical distribution of weather patterns when that change lasts for an extended period of time (i.e., decades to millions of years). The climatic variability of an area is referred to the long term change in rainfall, temperature, humidity, evaporation, wind speed and other meteorological parameters.

The earth's climate is naturally variable on all time scales. However, its long term state and average temperature are regulated by the balance between incoming and outgoing energy, which determines the Earth's Energy Balance. Any factor that causes a sustained change to the amount of incoming energy or the amount of outgoing energy can lead to climate change. As these factors are external to the climate system, they are referred to as "climate forcers" invoking the idea that they force or push the climate towards a new long-term state either warmer or cooler depending on the cause of change.

Factors that cause climate change can be divided into two broad categories – those related to natural processes and those related to human activity. The natural causes entails variations in the Sun's energy reaching earth, changes in reflectivity of earth's atmosphere and surface, changes in the greenhouse effect, which affects the amount of heat retained by earth's atmosphere, eruption of volcanic gases into upper atmosphere etc. The human causes of climate change includes activities like burning of fossil fuels, conversion of land for forestry and agriculture, deforestation, industrialization etc. most of the

human activities are contributing to greenhouse effect by increasing the amount of greenhouse gases into the atmosphere.

According to the Intergovernmental Panel on Climate Change (IPCC), future climate is likely to affect agriculture, increase the risk of hunger and water scarcity, and lead to more rapid melting of glaciers. Freshwater availability in many river basins in India is likely to decrease due to climate change.

Climate change is defined by various parameters. Here we are considering one of the most important parameter of climate change, rainfall. Rainfall is one of the key climatic variables that affect both the spatial and temporal patterns of water availability. Variability of the climate is leading to the greater changes in rainfall amounts in different regions of the world. In some regions the rainfall amount has increased so much that it leads to disasters like floods while in others it has decreased so much that those regions are subjected to drought leading to water crises. Quantification of climate change is necessary in order to detect the change that has already occurred and this will be further helpful to make predictions or forecast for future. This will also lead to better preparedness for natural disasters.

During the tragic Uttarakhand disaster, one of the most discussed but the most elusive topics has been rainfall. Uttarakhand is experiencing extreme weather conditions since past few years and hence attracted the interest of various scientists and researchers to get more deep knowledge about the changing climate by considering the most active parameter of climate variability, rainfall.

Past studies have shown that the Himalayas are highly effected by the climate change. In the analysis of trends of rainfall in the Indian Himalayas, observed that rainfall has decreased in the Indian Himalayas during last century as a sudden shift, rather than gradual trend.

## *Objective of the study:*

The main objective of the study are:-

1) Creation of the database for the Uttarakhand.
2) Long-term spatial and temporal variations of rainfall over Uttarakhand region.

# 2. STUDY AREA

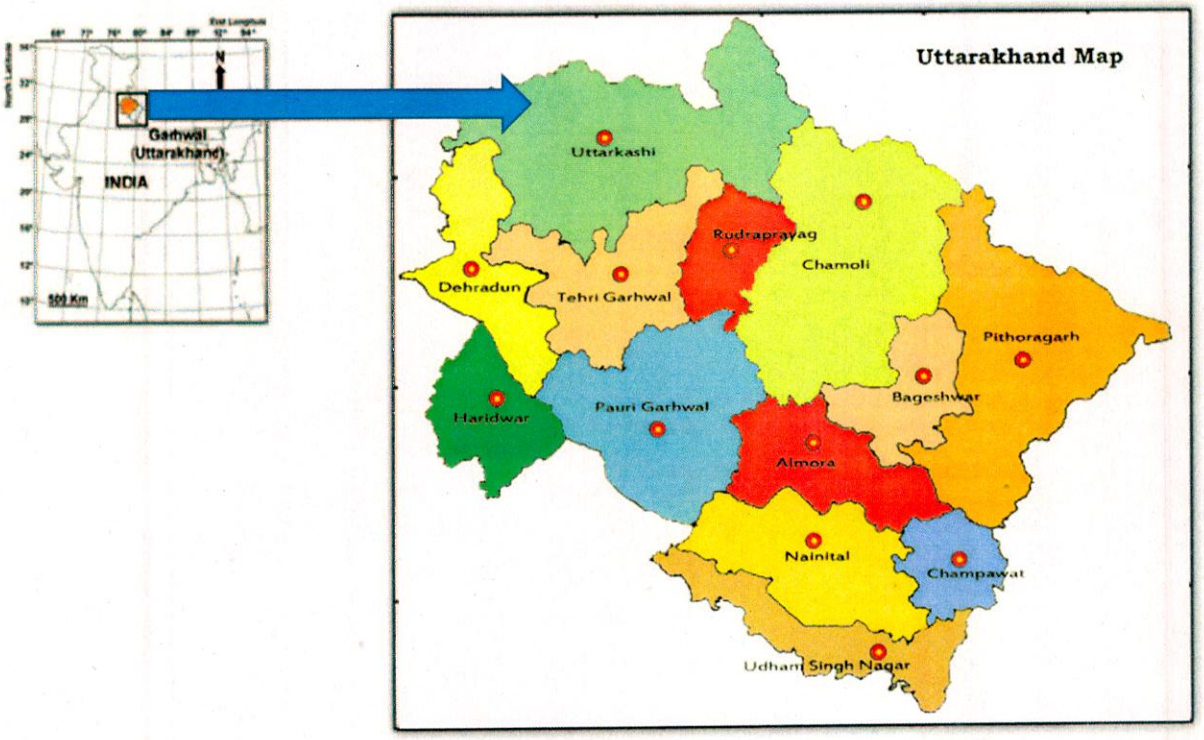



**Fig. Location of Uttarakhand in India**

The study area, Uttarakhand is an Indian state situated at the northern extremity of the country, falling in Central Himalayas. The State has 2 Divisions i.e. Garhwal and Kumaun. It has 13 districts and Dehradun is the capital city. Uttarakhand consists of 13 districts i.e., Almora Bageshwar, Chamoli, Champawat, Dehradun, Haridwar, Nainital, Pauri Garhwal, Pithoragarh, Rudra Prayag, Tehri Garhwal, Udham Singh Nagar and Uttarkashi.

## 2.1 GEOGRAPHY

Uttarakhand is surrounded by states of Himachal Pradesh from the west, Uttar Pradesh from South and South-west, Nepal from east and China particularly Tibet from north and north-eastern sides. The state is situated between 28°43' and 31°25' Northern latitudes and 77°45' and 81°03' Eastern longitudes. It covers the area of 53,483 $km^2$ (20,650 sq. mi). Two of the most important river of Uttarakhand are Ganga originating at Gangotri glacier and the Yamuna

which originates at Yamunotri glacier and are fed by myriad lakes, glacial melts and streams in the region. The unique Himalayan ecosystem plays host to a large number of animal, plants and rare herbs.

Uttarakhand lies at the southern slope of the Himalayan range and is largely a hilly state. The climate and vegetation vary greatly with elevation, from glaciers at the highest elevations to subtropical forests at the lower elevations.

The state has a temprate climate except in the plain areas where the climate is tropical with temperatures ranging from sub-zero to 43°C. The average annual rainfall of the state is 1,229mm.

## 2.2. PHYSIOGRAPHY

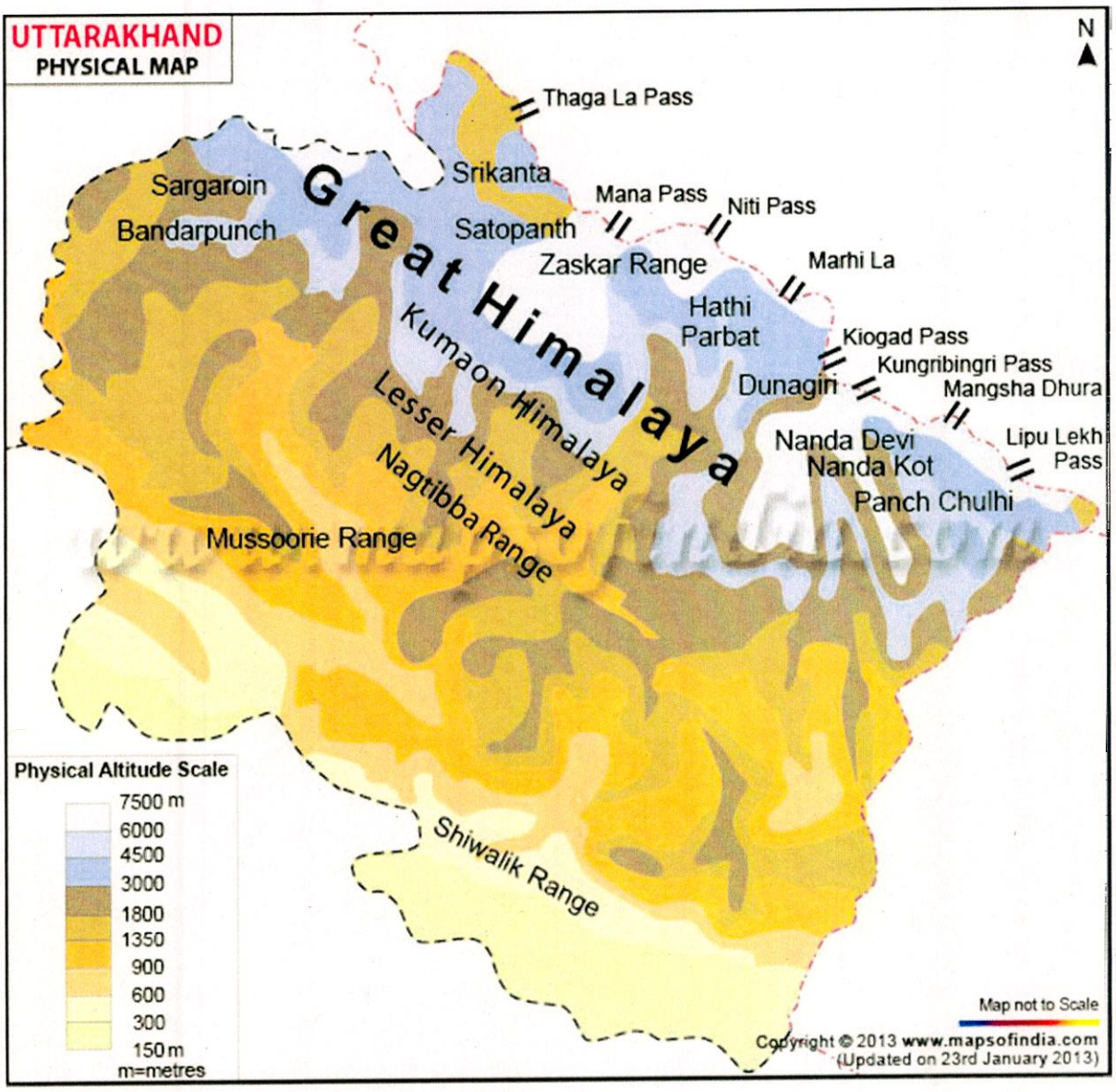


**Fig. Physical map of Uttarakhand**

Physiographically, the state is divided mainly into four units, i.e. the plain area in the foothills with an average height of 175-600m is **Terai** (finer alluvium deposit) and **Bhabar** (deposits of pebbles) region. The second zone comprises of of area with average elevation of 600m – 1200m and is known as **Shivaliks**. The third zone is known as **Lesser Himalayas** covering area with average elevation of 1200 – 3000m. The average elevation of fourth zone is 300 - 7500m and is known as **Great Himalayas**. Most of the northern parts of the state are part of Greater Himalaya ranges, covered by the high Himalayan peaks and glaciers, while the lower foothills are covered by forests.

The state is characterized by the number of huge mountain peaks, ridges, plains that are fragmented by major faults, thrusts and lineaments and Nappes. There is a huge elevation range in the state varying from 250 - 7817 meters above mean sea level. Broadly, the altitude increases from Shivalik Himalayan region (south) to Great Himalayan region. Similarly, the climate of the region changes from warm tropical in Shivalik to warm temprate-extremely cold glacial region in Greater Himalaya (Singh and Mal, 2012).

## 2.3 GEOLOGY

The State is rich in mineral deposits like limestone, marble, rock phosphate, dolomite, magnesite, copper, gypsum, etc. The State is completely affixed by the complex geological setting. In this area, a large variety of rocks are developed in the central crystalline complex of the Greater Himalayas and the Lesser Himalayas, as well as the sub-Himalayas. The area is very sensitive towards mass wasting process.

## 2.4 GEOMORPHOLOGY

The geomorphology of the State is completely defined by the Himalayas, being completely land locked. The State has a wide range of geomorphic features like cliffs, rocky slopes, waterfalls, major and minor ridges, river valleys, highly dissected denudation hills, moderate and low dissected

denudation hills, river terraces, and various fluvial geomorphic features like point bar, meandering scars, and natural levees.

## 2.5 CLIMATOLOGY

With regard to importance in local climatology rainfall analysis, the study area occupies a key location. It is located where Himalayan range changes in north-west direction to south-eastern direction (Khacher, 1997). The climate in the northern part of Uttarakhand is typically Himalayan. This mountain range itself exerts an appreciable extent of influence on monsoon and rainfall patterns. The eastern flanks of the Himalayan ranges are subject to heavy rainfall while the western section is relatively dry.

Uttarakhand is characterized by two types of climate, sharply differentiated in the plains and the mountainous regions. The climatic condition of the plain region is very similar to plains. The hilly region has cold winters with snowfall for quite a long time, good rainfall in the monsoon, and mild summers. This climate attracts tourists for simply scenic beauty, adventure or even looking for a spiritual environment.

### Rainfall

The State is bestowed with a relatively high average annual rainfall of 1229mm. • Source: Meteorological Department

Normally rain starts in the State in late April and continues up to September. However, the intensity of rainfall increases during the months of June to September. Higher rainfall occurring during first week of July. Rain continues through August until the first week of September.

Unlike, remote eastern and Western Himalayan areas the Uttarakhand receives rainfall from two sources i.e.:

1) Western disturbances coming from Mediterranean Sea leading to winter precipitation.
2) Summer precipitation is caused by south-west monsoon.

It is imperative to mention that most of the rainfall in Uttarakhand occurs principally through south-west monsoon winds only. The eastern Himalayan rainfall is caused by western disturbances in winters (Palazzi et al., 2013). Thus,

the study area is characterized by complex air circulation, topography and rainfall patterns. Thus, the understanding of its physical causes becomes complicated.

## Temperature

Based on the topography of the area and its geographical location, the temperature varies throughout the region. The average temperature in the State varies from -1.7° C to 42° C. Summers are extremely hot with temperatures going above the 40°C mark and with a lot of humidity. Winters can be very cold with temperatures going below 5°C. The lowest temperature recorded is -5 to -7°C and highest is between 40 to 45°C.

# 3. DATA USED

The data used in this study was obtained from the Indian Meteorological Department (IMD). A homogeneous daily based gridded rainfall data at a high resolution of 0.25°*0.25° for a long-term period of 112 years from 1901 to 2012 is used to determine a long term spatial and temporal trends in rainfall data series in Uttarakhand region.

The dataset obtained from IMD included the rainfall data for whole country (India). The data for Uttarakhand region was extracted from it with the help of fortran.exe programme for this study and was then managed in MS-excel and grid-wise daily rainfall data was arranged for the period of 112 years (1901-2012). The gridded data was then managed in such a form that we get the total monthly rainfall values for every year. This data was distributed on different excel sheets for all different 13 districts.

Finally, the year was divided into 4 seasons namely, Pre-monsoon (March, April, May), Monsoon (June, July, August, September), Post-monsoon (October, November) and Winter (December, January, February) to get the seasonal values of rainfall and also the annual values for each station. At last the mean for every season and the annual values were determined and the deviation from mean values were calculated for seasonal and the annual scales. Thereafter, data was used to carry out the Mann-Kendall test and the Sen's slope test.

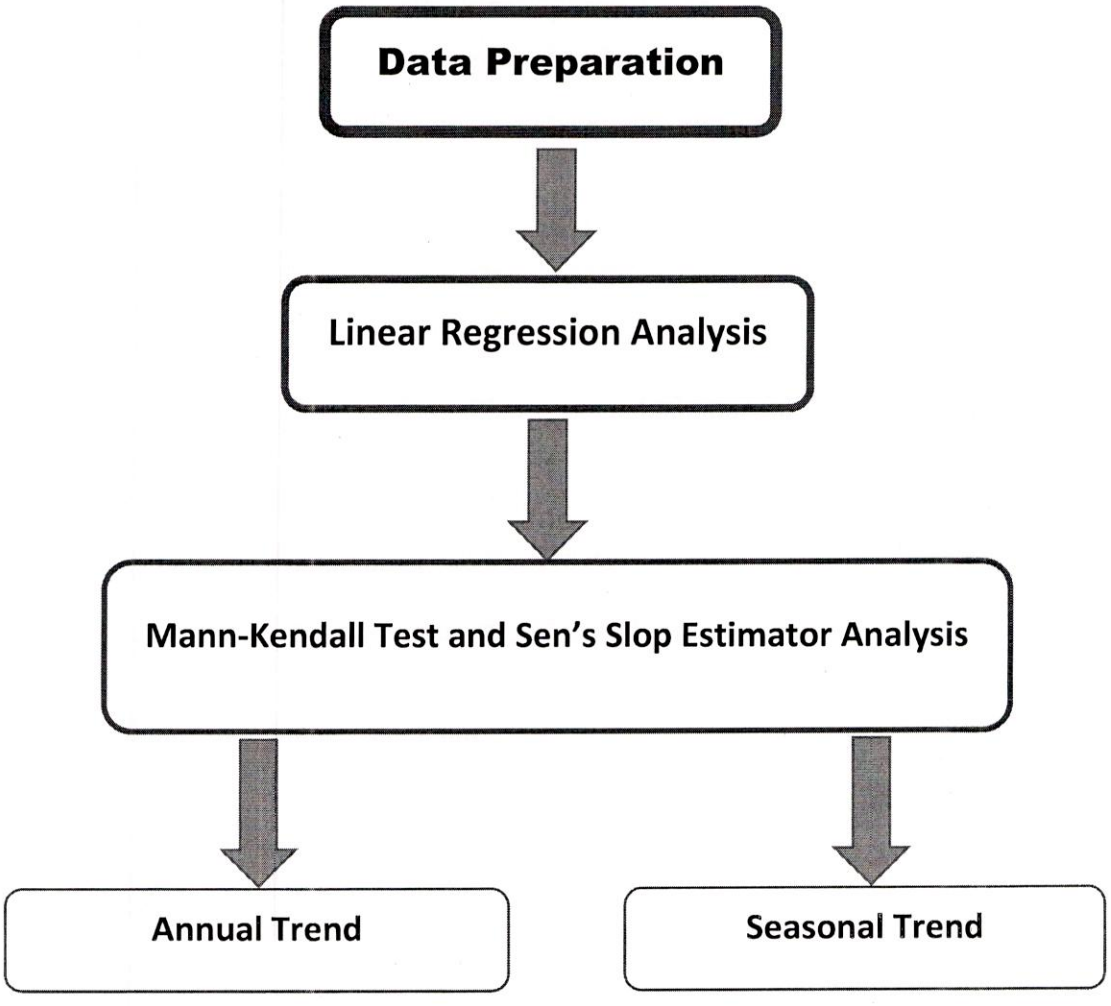
# 4. METHODOLOGY

The computed data series comprising of seasonal and annual rainfall for all the districts prepared in MS-Excel were used to analyse the trends of rainfall in the given region of Uttarakhand.

## 4.1 TREND ANALYSIS

The statistical analysis is used to determine the measure of central tendency (mean) for the rainfall data of Uttarakhand. For identifying the trend in the rainfall data, the statistical analysis of linear regression method (parametric method) and Mann-Kendall test and Sen's slope estimator test (non-parametric method) were used in the present study.

The procedure of the analysis being applied in the study:-



### 4.1.1 Linear Regression Model

The simple linear regression model was used to determine trends in rainfall variables. Linear regression is one of the simplest method to calculate the trend of data in time series.

Regression model is a parametric method. One of the most useful parametric models to detect the trend is "simple linear regression model". The methods of linear regression requires the assumptions of normality of residuals, constant variance and true linearity of relationship. The model for y can be described by an equation of the form

$$y = mx + c$$

where,

$x$ = time (year)

$m$ = slope coefficient

$c$ = least square estimate of the intercept

Here, $x$ is the explanatory variable and y is the dependent variable. The slope line is $m$, and $c$ is the intercept (value of y when $x = 0$). The slope regression describes the trend whether positive or negative. In this study independent variable, $y$ is rainfall and explanatory variable x is year.

If the slope is significantly different from zero statistically, it is entirely reasonable to interpret that there is a real change occurring over time. The sign of the slope defines the direction of the trend of the variable, increasing if the sign is positive and decreasing if the sign is negative.

In this study, Microsoft Excel was used to calculate the trend lines and statistical values of linear regression analysis. The value of R,square ($R^2$), or the square of the correlation coefficient from the regression analysis is used to show how strong the correlation and relationship between the variable X and Y.

### 4.1.2 Mann-kendall Test

Mann-Kendall test is statistical test widely used for the analysis of trend in climatologic and hydrologic time series. There are two advantages of using this

test. First, it is a non-parametric test and does not require the data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series.

The Mann-Kendall statistic *S* is given as

$$S=\sum_{k=1}^{n-1}\sum_{j=k+1}^{n}\operatorname{sgn}(x_j-x_k) \tag{1}$$

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

$$\operatorname{sgn}(x_j-x_i)=\begin{cases}+1 & if \quad (x_j-x_i)>0\\ 0 & if \quad (x_j-x_i)=0\\ -1 & if \quad (x_j-x_i)<0\end{cases} \tag{2}$$

For $n$ > 8, $S$ follows approximately normal distribution with mean i.e.

$E(S) = 0,$ (3)

The variance statistics is given by,

$$Var(S)=\frac{1}{18}\left[N(N-1)(2N+5)-\sum_{i=1}^{m}t_i(t_i-1)(2t_i+5)\right] \tag{4}$$

Where, $t_i$ is considered as the number of ties up to sample $i$.

The test statistics $Z_{mk}$ (Mann-Kendall Co-efficient) is computed as,

$$Z_{MK}=\begin{cases}\dfrac{S-1}{\sqrt{Var(S)}} & if \quad S>0\\ 0 & if \quad S=0\\ \dfrac{S+1}{\sqrt{Var(S)}} & if \quad S<0\end{cases} \tag{5}$$

$Z_{mk}$ here follows a standard normal distribution. A positive and negative value of $Z_{mk}$ indicates an upward trend and downward trend respectively. A significance level $a$ is also utilised for testing either an upward monotone trend (a two-tailed test). If $Z_{mk}$ appears greater than $Z_{a/2}$ where $a$ depicts the significance level, then the trend is considered as significant. Generally, $Z_{mk}$

values are 1.645, 1.960 and 2.576 for significance level of 10%, 5% and 1% respectively. But for greater length of data, $Z_{mk}$ /sqrt(n) is also used as Mann-kendall statistic to determine the trend, where n is the number of data values. In this analysis, the null hypothesis was tested at 95% confidence level.

### 4.1.3 Sen's Slope Estimator Test

Sen's slope estimator test is better than the linear regression test to analyse trend. It is used to estimate the true slope of an existing trend (as change per year). Therefore, it is the most powerful method for a linear trend.

The slope $T_i$ of all data pairs can be computed by,

$$T_i = \frac{x_j - x_k}{j - k}, \qquad (6)$$

Where, $x_j$ and $x_k$ are considered as data values at time $j$ and $k$ $(j > k)$ correspondingly.

The median of N values of $T_i$ is represented as Sen's estimator of slope is given by,

$$Q_i = \begin{cases} T_{\frac{N+1}{2}} & if\ N\ is\ odd \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & if\ N\ is\ even \end{cases} \qquad (7)$$

After calculating $Q_i$, for testing the significance, $Q_{median}$ is computed by a two sided test at 100 $(1 - a)$% confidence interval and then a true slope can be obtained by non-parametric test. Like Mann-Kendall test, positive and negative values of $Q_i$ represents an upward and downward trend respectively.

# 5. RESULTS AND DISCUSSION

The results shows the values of Z-statistics carried out by Mann-Kendall test and the Sen's slope values carried out by Sen's slope estimator test for seasonal and annual scales for given stations(districts) for the period of 112 years (1901-2012). The negative values indicates the decreasing trend of rainfall whereas the positive values indicates the increasing trend of rainfall in the region. The bold values indicate statistical significance of the results at 95% confidence level as per the Mann-Kendall test. The given Sen's slope values indicates the changes in rainfall amount in mm/year for given seasonal and annual sessions.

**District-wise results:-**

## 1) For Almora district

**Table 1: Mann-Kendall Statistics and Sen's slope values for seasonal and annual rainfall for Almora district**

| Session | Z-Statistic | Sen's Slope | Trend acc. To Sen's Slope | Result |
|---|---|---|---|---|
| Pre-Monsoon | **2.56** | **0.498** | ↑ | Significant |
| Monsoon | 1.42 | 1.643 | ↑ | Non-significant |
| Post-Monsoon | -0.95 | -0.454 | ↓ | Non-significant |
| Winter | 0.62 | 0.107 | ↑ | Non-significant |
| Annual | 1.31 | 1.668 | ↑ | Non-significant |

**Pre-monsoon session**

- The Z-statistic value as given in table 1 above for pre-monsoon session indicates a significant increasing trend of rainfall.
- The given Sen's slope value for pre-monsoon session indicates the increasing trend (0.498mm/year) of rainfall.

**Monsoon Session**

- The Z-statistic value as given in table 1 above for Monsoon session indicates a non-significant increasing trend of rainfall.

- Sen's slope value for Monsoon session indicates the increasing trend (1.643mm/year) of rainfall.

**Post-monsoon Session**

- The Z-statistic value as given in table 1 above for post-monsoon session indicates decreasing trend of rainfall which is not significant.
- The given Sen's slope value for post-monsoon session indicates the decreasing trend (-0.454mm/year) of rainfall.

**Winter Session**

- The Z-statistic value as given in table 1 above for winter session indicates increasing trend of rainfall which is not significant.
- The given Sen's slope value for winter session indicates the increasing trend (0.107mm/year) of rainfall.

**Annual Rainfall**

- The Z-statistic value as given in table 1 above for annual session indicates increasing trend of rainfall which is not significant.
- The given Sen's slope value for annual session indicates the increasing trend (1.668mm/year) of rainfall.

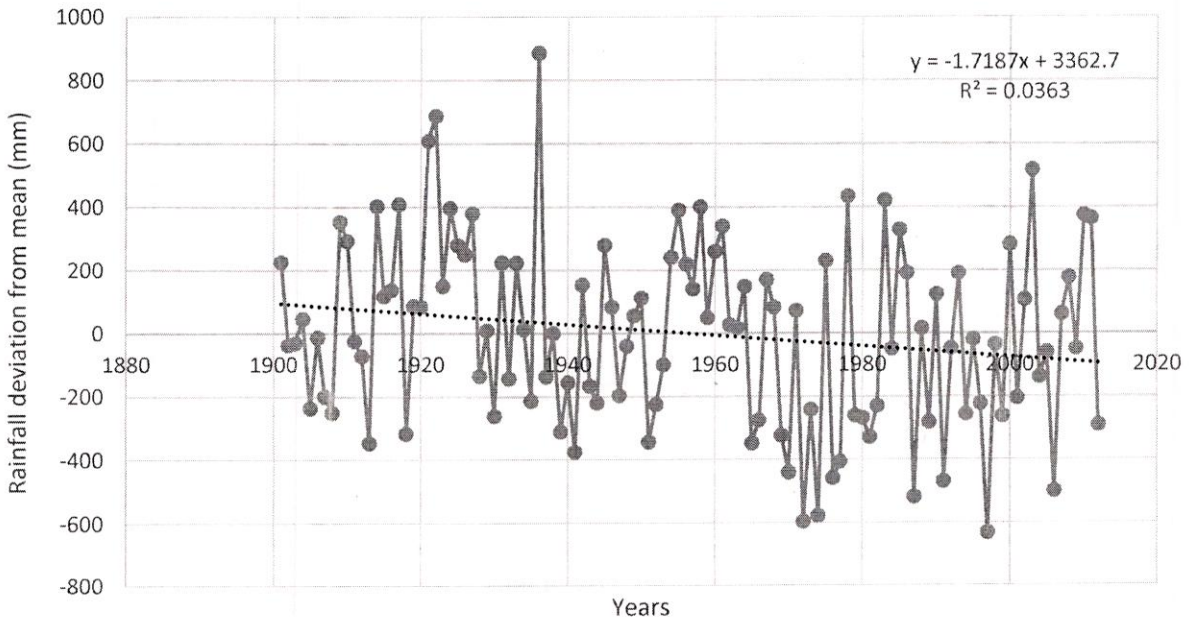



Fig. 1: Temporal variation of annual rainfall for Almora district with the trend line and the linear regression equation

## 2) For Bageshwar District

Table 2: Mann-Kendall Statistics and Sen's slope values for seasonal and annual rainfall for Bageshwar district

| Session | Z-Statistic | Sen's Slope | Trend acc. To Sen's Slope | Result |
|---|---|---|---|---|
| Pre-Monsoon | 1.81 | 1.631 | ↑ | Non-significant |
| Monsoon | 0.88 | 1.401 | ↑ | Non-significant |
| Post-Monsoon | -0.04 | -0.743 | ↓ | Non-significant |
| Winter | 1.49 | 0.53 | ↑ | Non-significant |
| Annual | 1.31 | 1.668 | ↑ | Non-significant |

**Pre-monsoon session**

- The Z-statistic value as given in table 2 above for pre-monsoon session indicates increasing trend of rainfall which is not significant.
- The given Sen's slope value for pre-monsoon session indicates the increasing trend (1.631mm/year) of rainfall.

**Monsoon Session**

- The Z-statistic value as given in table 2 above for Monsoon session indicates increasing trend of rainfall which is not significant.
- The given Sen's slope value for Monsoon session indicates the increasing trend (1.401mm/year) of rainfall.

**Post-monsoon Session**

- The Z-statistic value as given in table 2 above for post-monsoon session indicates decreasing trend of rainfall which is not significant.
- The given Sen's slope value for post-monsoon session indicates the decreasing trend (-0.743mm/year) of rainfall.

**Winter Session**

- The Z-statistic value as given in table 2 above for winter session indicates increasing trend of rainfall which is not significant

- The given Sen's slope value for winter session indicates the increasing trend (0.53mm/year) of rainfall.

**Annual Rainfall**

- The Z-statistic value as given in table 2 above for annual session indicates increasing trend of rainfall which is not significant.
- The given Sen's slope value for annual session indicates the increasing trend (1.668mm/year) of rainfall.

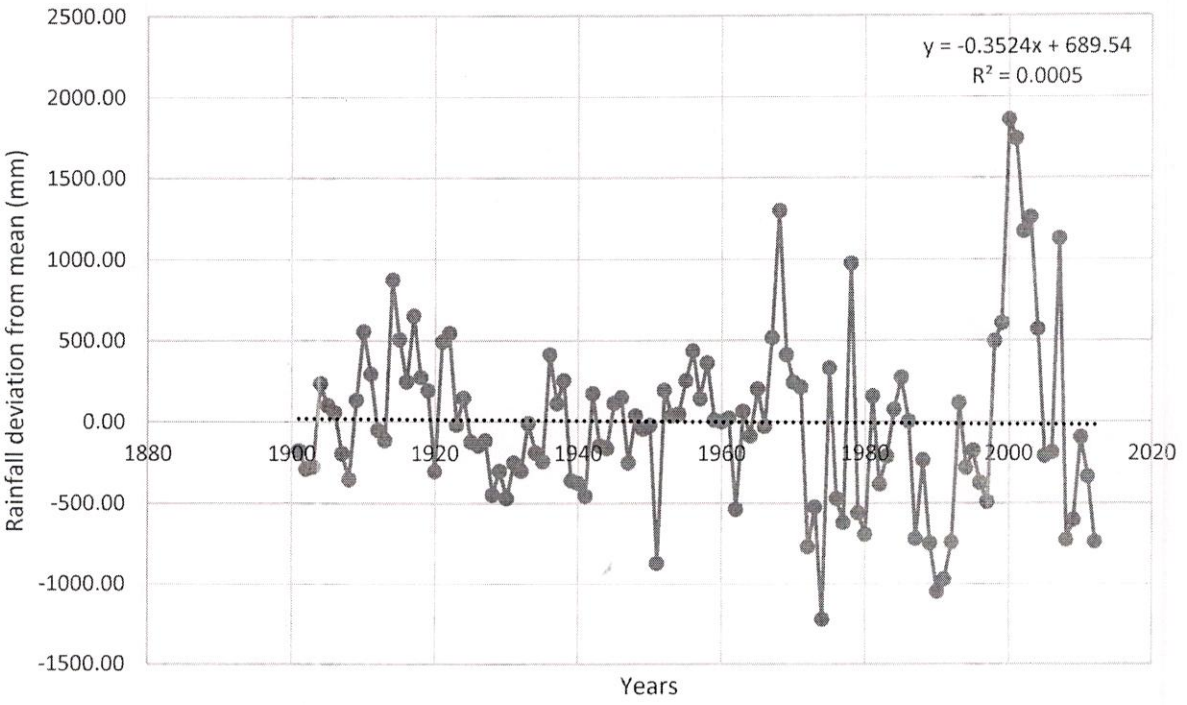



Fig. 2: Temporal variation of annual rainfall for Bageshwar district with the trend line and the linear regression equation

## 3) For Chamoli District

Table 4: Mann-Kendall Statistics and Sen's slope values for seasonal and annual rainfall for Chamoli district

| Session | Z-Statistic | Sen's Slope | Trend acc. To Sen's Slope | Result |
|---|---|---|---|---|
| Pre-Monsoon | **2.73** | **1.406** | ↑ | Significant |
| Monsoon | **3.08** | **4.12** | ↑ | Significant |
| Post-Monsoon | -0.56 | -0.585 | ↓ | Non-significant |
| Winter | 1.44 | 0.387 | ↑ | Non-significant |
| Annual | **2.45** | **5.502** | ↑ | Significant |

**Pre-monsoon session**

- The Z-statistic value as given in table 4 above for pre-monsoon session indicates a significant increasing trend of rainfall.
- The given Sen's slope value for pre-monsoon session indicates the increasing trend (1.406mm/year) of rainfall.

**Monsoon Session**

- The Z-statistic value as given in table 4 above for Monsoon session indicates a significant increasing trend of rainfall.
- The given Sen's slope value for Monsoon session indicates the increasing trend (4.12mm/year) of rainfall.

**Post-monsoon Session**

- The Z-statistic value as given in table 4 above for post-monsoon session indicates a non-significant decreasing trend of rainfall.
- The given Sen's slope value for post-monsoon session indicates the decreasing trend (-0.585mm/year) of rainfall.

**Winter Session**

- The Z-statistic value as given in table 4 above for winter session indicates a non-significant increasing trend of rainfall.

- The given Sen's slope value for winter session indicates the increasing trend (0.387mm/year) of rainfall.

**Annual Rainfall**

- The Z-statistic value as given in table 4 above for annual session indicates a significant increasing trend of rainfall.
- The given Sen's slope value for annual session indicates the increasing trend (5.502mm/year) of rainfall.

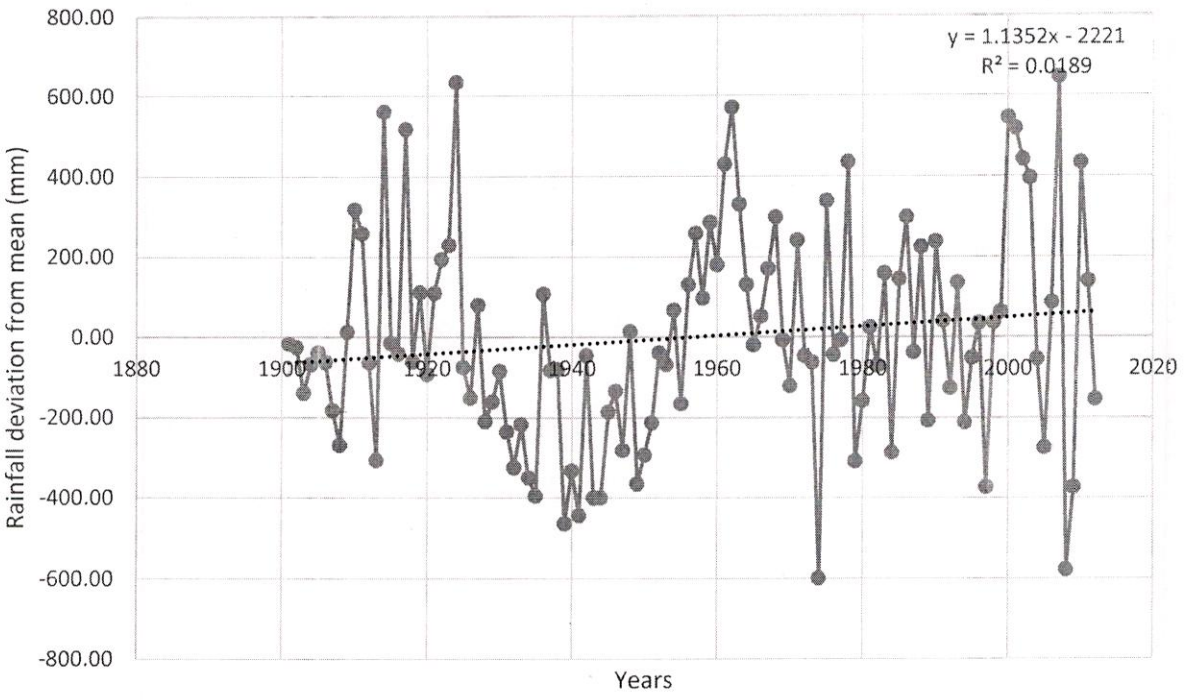



Fig. 4: Temporal variation of annual rainfall for Chamoli district with the trend line and the linear regression equation

## 4) For Champawat District

Table 3: Mann-Kendall Statistics and Sen's slope values for seasonal and annual rainfall for Champawat district

| Session | Z-Statistic | Sen's Slope | Trend acc. To Sen's Slope | Result |
|---|---|---|---|---|
| Pre-Monsoon | **2.09** | **0.767** | ↑ | Significant |
| Monsoon | **1.96** | **5.093** | ↑ | Significant |
| Post-Monsoon | -0.51 | -0.638 | ↓ | Non-significant |
| Winter | 0.62 | 0.12 | ↑ | Non-significant |
| Annual | 1.62 | 5.585 | ↑ | Non-significant |

### Pre-monsoon session

- The Z-statistic value as given in table 3 above for pre-monsoon session indicates a significant increasing trend of rainfall.
- The given Sen's slope value for pre-monsoon session indicates the increasing trend (0.767mm/year) of rainfall.

### Monsoon Session

- The Z-statistic value as given in table 3 above for Monsoon session indicates a significant increasing trend of rainfall.
- The given Sen's slope value for Monsoon session indicates the increasing trend (5.093mm/year) of rainfall.

### Post-monsoon Session

- The Z-statistic value as given in table 3 above for post-monsoon session indicates decreasing trend of rainfall which is not significant.
- The given Sen's slope value for post-monsoon session indicates the decreasing trend (-0.638mm/year) of rainfall.

### Winter Session

- The Z-statistic value as given in table 3 above for winter session indicates increasing trend of rainfall which is not significant.

- The given Sen's slope value for winter session indicates the increasing trend (0.12mm/year) of rainfall.

**Annual Rainfall**

- The Z-statistic value as given in table 3 above for annual session indicates increasing trend of rainfall which is not significant.
- The given Sen's slope value for annual session indicates the increasing trend (5.585mm/year) of rainfall.

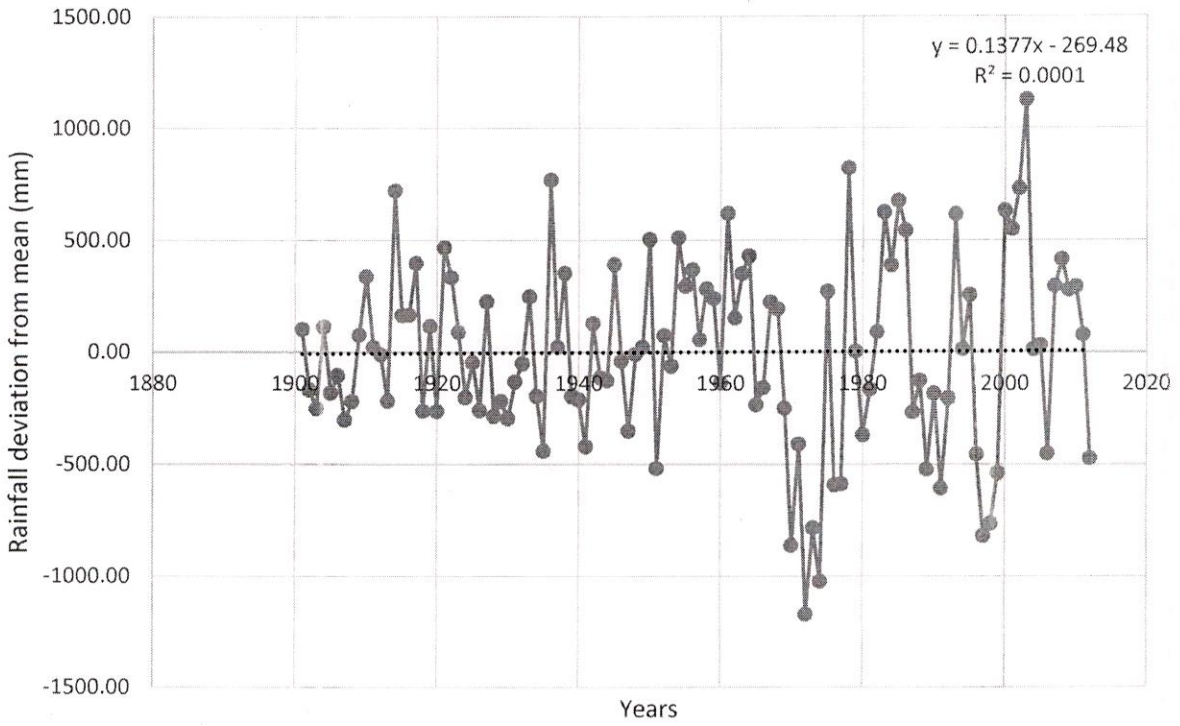



Fig. 3: Temporal variation of annual rainfall for Champawat district with the trend line and the linear regression equation

## 5) For Dehradun District

Table 5: Mann-Kendall Statistics and Sen's slope values for seasonal and annual rainfall for Dehradun district

| Session | Z-Statistic | Sen's Slope | Trend acc. To Sen's Slope | Result |
|---|---|---|---|---|
| Pre-Monsoon | **2.37** | **1.406** | ↑ | Significant |
| Monsoon | -0.2 | -1.406 | ↓ | Non-significant |
| Post-Monsoon | -0.56 | -0.738 | ↓ | Non-significant |
| Winter | 0.95 | 0.193 | ↑ | Non-significant |
| Annual | 0.06 | -4.726 | ↓ | Non-Significant |

### Pre-monsoon session

- The Z-statistic value as given in table 5 above for pre-monsoon session indicates a significant increasing trend of rainfall.
- The given Sen's slope value for pre-monsoon session indicates the increasing trend (1.406mm/year) of rainfall.

### Monsoon Session

- The Z-statistic value as given in table 5 above for Monsoon session indicates decreasing trend of rainfall which is not significant.
- The given Sen's slope value for Monsoon session indicates the decreasing trend (-1.406mm/year) of rainfall.

### Post-monsoon Session

- The Z-statistic value as given in table 5 above for post-monsoon session indicates decreasing trend of rainfall which is not significant.
- The given Sen's slope value for post-monsoon session indicates the decreasing trend (-0.738mm/year) of rainfall.

### Winter Session

- The Z-statistic value as given in table 5 above for winter session indicates increasing trend of rainfall which is not significant.

- The given Sen's slope value for winter session indicates the increasing trend (0.193mm/year) of rainfall.

**Annual Rainfall**

- The Z-statistic value as given in table 5 above for annual session indicates increasing trend of rainfall which is not significant.
- The given Sen's slope value for annual session indicates the decreasing trend (-4.726mm/year) of rainfall.

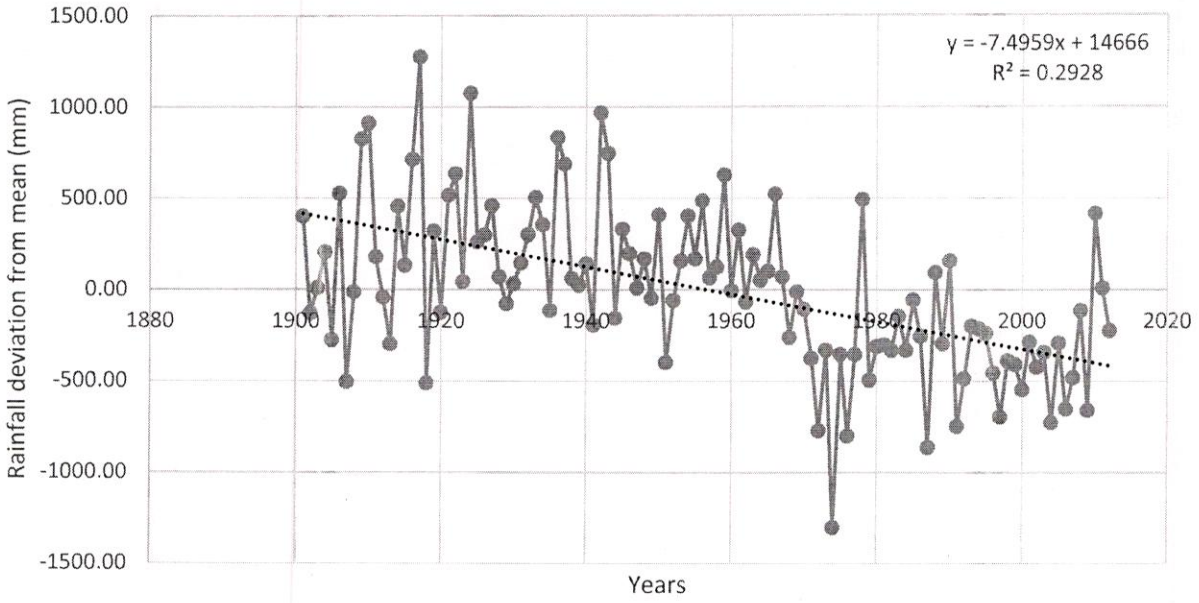



Fig. 5: Temporal variation of annual rainfall for Dehradun district with the trend line and the linear regression equation

## 6) For Haridwar District

Table 6: Mann-Kendall Statistics and Sen's slope values for seasonal and annual rainfall for Haridwar district

| Session | Z-Statistic | Sen's Slope | Trend acc. To Sen's Slope | Result |
|---|---|---|---|---|
| Pre-Monsoon | **2.87** | **0.465** | ↑ | Significant |
| Monsoon | 1.93 | 2.973 | ↑ | Non-significant |
| Post-Monsoon | -0.24 | -0.478 | ↓ | Non-significant |
| Winter | 1.63 | 0.26 | ↑ | Non-significant |
| Annual | 1.55 | 2.62 | ↑ | Non-significant |

### Pre-monsoon session

- The Z-statistic value as given in table 6 above for pre-monsoon session indicates a significant increasing trend of rainfall.
- The given Sen's slope value for pre-monsoon session indicates the increasing trend (0.465mm/year) of rainfall.

### Monsoon Session

- The Z-statistic value as given in table 6 above for Monsoon session indicates non-significant increasing trend of rainfall.
- The given Sen's slope value for Monsoon session indicates the increasing trend (2.973mm/year) of rainfall.

### Post-monsoon Session

- The Z-statistic value as given in table 6 above for post-monsoon session indicates decreasing trend of rainfall which is not significant.
- The given Sen's slope value for post-monsoon session indicates the decreasing trend (-0.478mm/year) of rainfall.

### Winter Session

- The Z-statistic value as given in table 6 above for winter session indicates increasing trend of rainfall which is not significant.

- The given Sen's slope value for winter session indicates the increasing trend (0.26mm/year) of rainfall.

**Annual Rainfall**

- The Z-statistic value as given in table 6 above for annual session indicates increasing trend of rainfall which is not significant.
- The given Sen's slope value for annual session indicates the increasing trend (2.62mm/year) of rainfall.

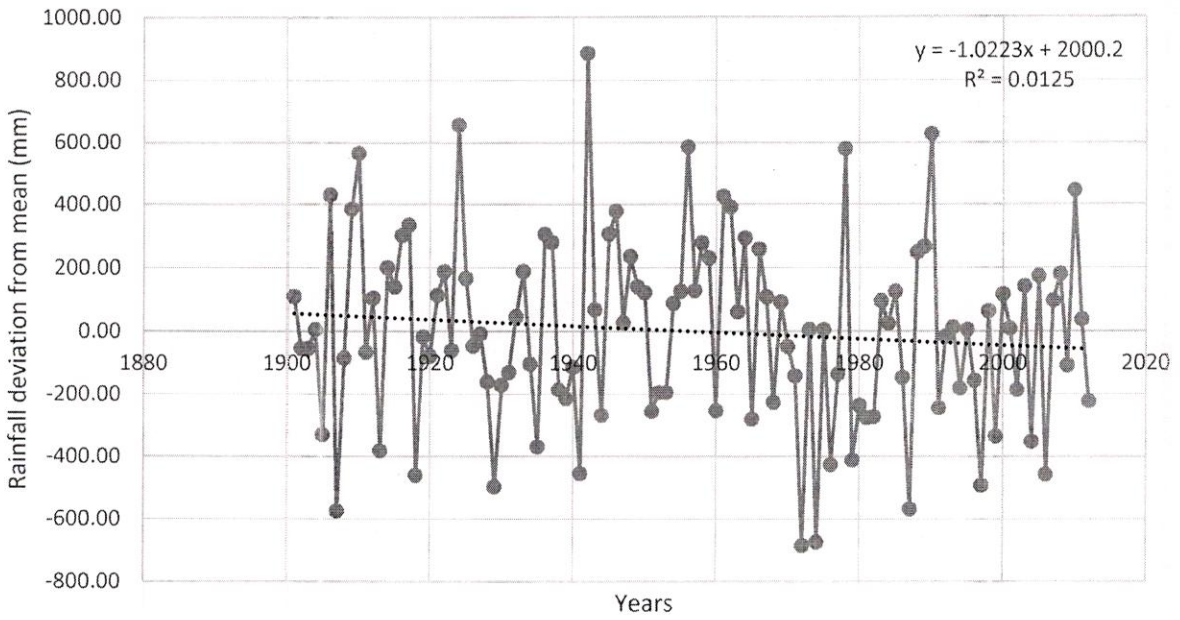



Fig. 6: Temporal variation of annual rainfall for Haridwar district with the trend line and the linear regression equation

## 7) For Nainital District

Table 7: Mann-Kendall Statistics and Sen's slope values for seasonal and annual rainfall for Nainital district

| Session | Z-Statistic | Sen's Slope | Trend acc. To Sen's Slope | Result |
|---|---|---|---|---|
| Pre-Monsoon | **2.5** | **0.606** | ↑ | Significant |
| Monsoon | 0.35 | -1.222 | ↓ | Non-significant |
| Post-Monsoon | -0.76 | -0.581 | ↓ | Non-significant |
| Winter | 0.71 | 0.122 | ↑ | Non-significant |
| Annual | 0.62 | -1.086 | ↓ | Non-significant |

**Pre-monsoon session**

- The Z-statistic value as given in table 7 above for pre-monsoon session indicates significant increasing trend of rainfall.
- The given Sen's slope value for pre-monsoon session also indicates the increasing trend (0.606mm/year) of rainfall.

**Monsoon Session**

- The Z-statistic value as given in table 7 above for Monsoon session indicates non-significant increasing trend of rainfall.
- The given Sen's slope value for Monsoon session indicates the decreasing trend (-1.222mm/year) of rainfall.

**Post-monsoon Session**

- The Z-statistic value as given in table 7 above for post-monsoon session indicates decreasing trend of rainfall which is not significant.
- The given Sen's slope value for post-monsoon session also indicates the decreasing trend (-0.581mm/year) of rainfall.

**Winter Session**

- The Z-statistic value as given in table 7 above for winter session indicates increasing trend of rainfall which is not significant.

- The given Sen's slope value for winter session also indicates the increasing trend (0.122mm/year) of rainfall.

**Annual Rainfall**

- The Z-statistic value as given in table 7 above for annual session indicates a non-significant increasing trend of rainfall.
- The given Sen's slope value for annual session indicates the decreasing trend (-1.086mm/year) of rainfall.

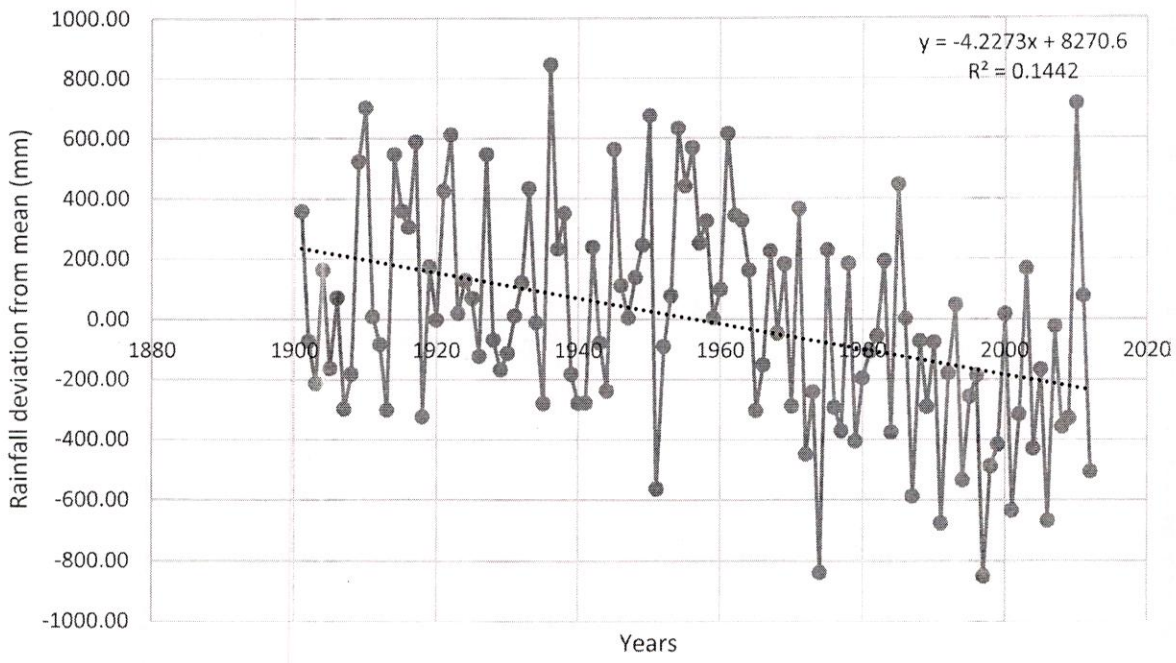



Fig. 7: Temporal variation of annual rainfall for Nainital district with the trend line and the linear regression equation

## 8) For Pauri Garhwal District

Table 8: Mann-Kendall Statistics and Sen's slope values for seasonal and annual rainfall for Pauri Garhwal district

| Session | Z-Statistic | Sen's Slope | Trend acc. To Sen's Slope | Result |
|---|---|---|---|---|
| Pre-Monsoon | 1.74 | 0.417 | ↑ | Non-significant |
| Monsoon | 0.1 | -1.738 | ↓ | Non-significant |
| Post-Monsoon | -0.51 | -0.562 | ↓ | Non-significant |
| Winter | 0.61 | 0.106 | ↑ | Non-significant |
| Annual | 0.36 | -2.362 | ↓ | Non-significant |

**Pre-monsoon session**

- The Z-statistic value as given in table 8 above for pre-monsoon session indicates increasing trend of rainfall which is not significant.
- The given Sen's slope value for pre-monsoon session also indicates the increasing trend (0.417mm/year) of rainfall.

**Monsoon Session**

- The Z-statistic value as given in table 8 above for Monsoon session indicates increasing trend of rainfall which is not significant.
- The given Sen's slope value for Monsoon session indicates the decreasing trend (-1.738mm/year) of rainfall.

**Post-monsoon Session**

- The Z-statistic value as given in table 8 above for post-monsoon session indicates decreasing trend of rainfall which is not significant.
- The given Sen's slope value for post-monsoon session also indicates the decreasing trend (-0.562mm/year) of rainfall.

**Winter Session**

- The Z-statistic value as given in table 8 above for winter session indicates a non-significant increasing trend of rainfall.

- The given Sen's slope value for winter session also indicates the increasing trend (0.106mm/year) of rainfall.

**Annual Rainfall**

- The Z-statistic value as given in table 8 above for annual session indicates increasing trend of rainfall which is not significant.
- The given Sen's slope value for annual session indicates the decreasing trend (-2.362mm/year) of rainfall.

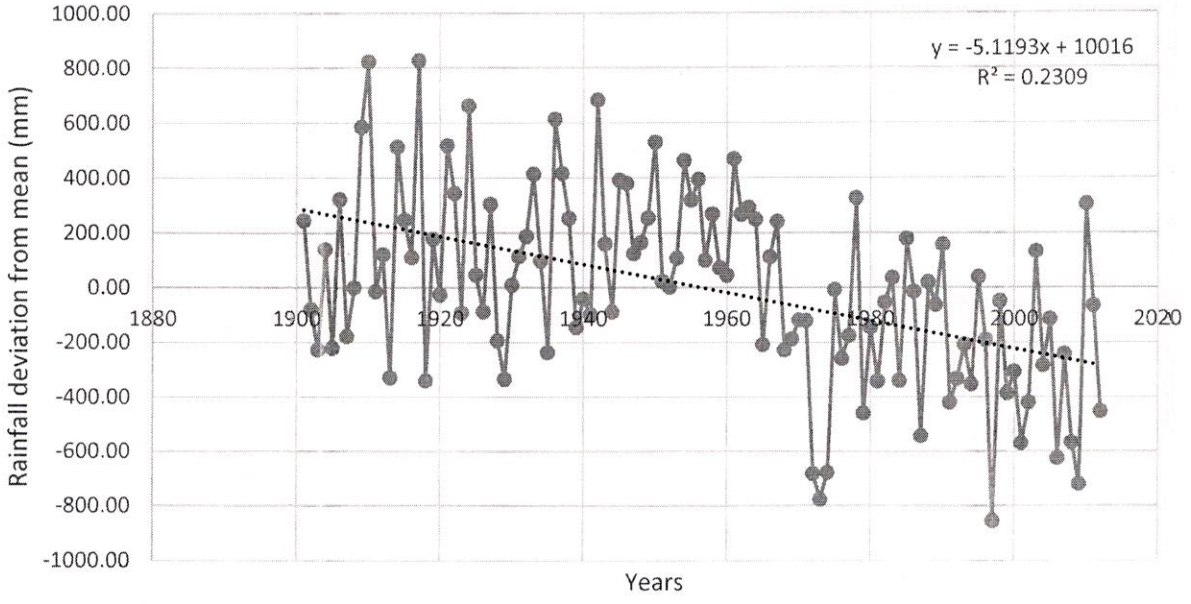



Fig. 8: Temporal variation of annual rainfall for Pauri Garhwal district with the trend line and the linear regression equation

## 9) For Pithoragarh District

Table 9: Mann-Kendall Statistics and Sen's slope values for seasonal and annual rainfall for Pithoragarh district

| Session | Z-Statistic | Sen's Slope | Trend acc. To Sen's Slope | Result |
|---|---|---|---|---|
| Pre-Monsoon | **2.36** | **1.854** | ↑ | Significant |
| Monsoon | 1.38 | 4.019 | ↑ | Non-significant |
| Post-Monsoon | 0.63 | -0.78 | ↓ | Non-significant |
| Winter | **2.32** | **0.656** | ↑ | Significant |
| Annual | 1.66 | 6.498 | ↑ | Non-significant |

### Pre-monsoon session

- The Z-statistic value as given in table 9 above for pre-monsoon session indicates a significant increasing trend of rainfall.
- The given Sen's slope value for pre-monsoon session also indicates the increasing trend (1.854mm/year) of rainfall.

### Monsoon Session

- The Z-statistic value as given in table 9 above for Monsoon session indicates a non-significant increasing trend of rainfall.
- The given Sen's slope value for monsoon session also indicates the increasing trend (4.019mm/year) of rainfall.

### Post-monsoon Session

- The Z-statistic value as given in table 9 above for post-monsoon session indicates a non-significant increasing trend of rainfall.
- The given Sen's slope value for post-monsoon session also indicates the decreasing trend (-0.78mm/year) of rainfall.

### Winter Session

- The Z-statistic value as given in table 9 above for winter session indicates a significant increasing trend of rainfall.

- The given Sen's slope value for winter session also indicates the increasing trend (0.656mm/year) of rainfall.

**Annual Rainfall**

- The Z-statistic value as given in table 9 above for annual session indicates increasing trend of rainfall which is not significant.
- The given Sen's slope value for annual session indicates the increasing trend (6.498mm/year) of rainfall.

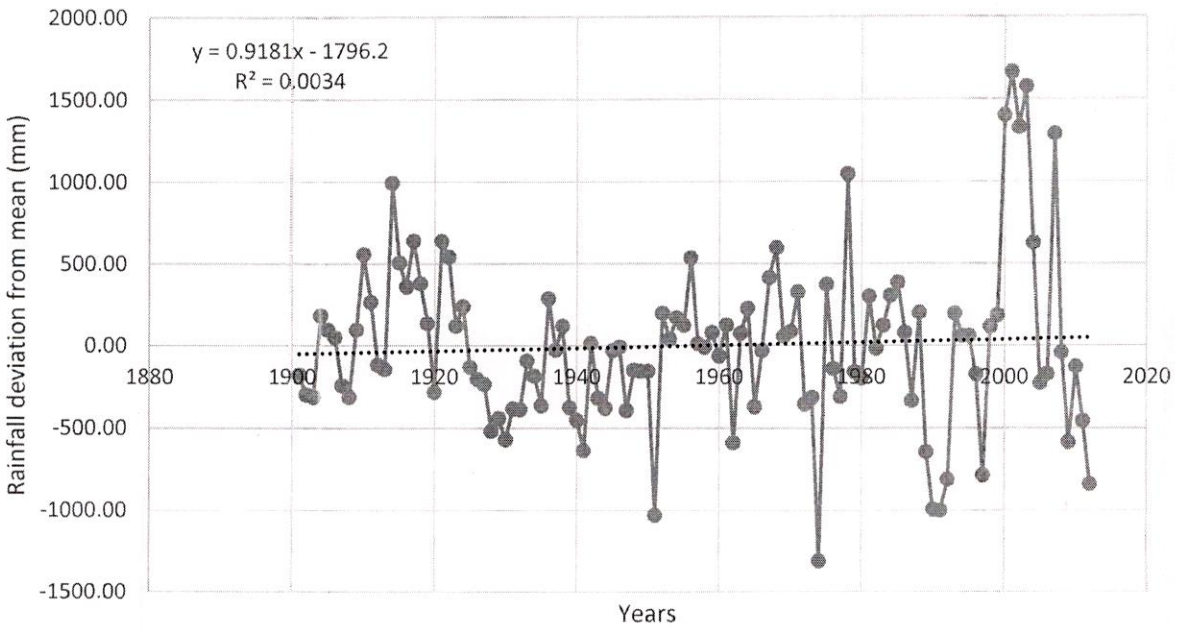



Fig. 9: Temporal variation of annual rainfall for Pithoragarh district with the trend line and the linear regression equation

## 10) For Rudra Prayag District

Table 10: Mann-Kendall Statistics and Sen's slope values for seasonal and annual rainfall for Rudra Prayag district

| Session | Z-Statistic | Sen's Slope | Trend acc. To Sen's Slope | Result |
|---|---|---|---|---|
| Pre-Monsoon | **3.03** | **1.273** | ↑ | Significant |
| Monsoon | **3.09** | **4.479** | ↑ | Significant |
| Post-Monsoon | **-1.98** | **-0.571** | ↓ | Non-Significant |
| Winter | 1.48 | 0.362 | ↑ | Non-significant |
| Annual | **2.61** | **5.668** | ↑ | Significant |

### Pre-monsoon session

- The Z-statistic value as given in table 10 above for pre-monsoon session indicates a highly significant increasing trend of rainfall.
- The given Sen's slope value for pre-monsoon session also indicates the increasing trend (1.273mm/year) of rainfall.

### Monsoon Session

- The Z-statistic value as given in table 10 above for Monsoon session indicates a highly significant increasing trend of rainfall.
- The given Sen's slope value for Monsoon session also indicates the increasing trend (4.479mm/year) of rainfall.

### Post-monsoon Session

- The Z-statistic value as given in table 10 above for post-monsoon session indicates a significant decreasing trend of rainfall.
- The given Sen's slope value for post-monsoon session also indicates the decreasing trend (-0.571mm/year) of rainfall.

### Winter Session

- The Z-statistic value as given in table 10 above for winter session indicates increasing trend of rainfall which is not significant.
- The given Sen's slope value for winter session also indicates the increasing trend (0.362mm/year) of rainfall.

**Annual Rainfall**

- The Z-statistic value as given in table 10 above for annual session indicates a significant increasing trend of rainfall.
- The given Sen's slope value for annual session indicates the increasing trend (5.668mm/year) of rainfall.

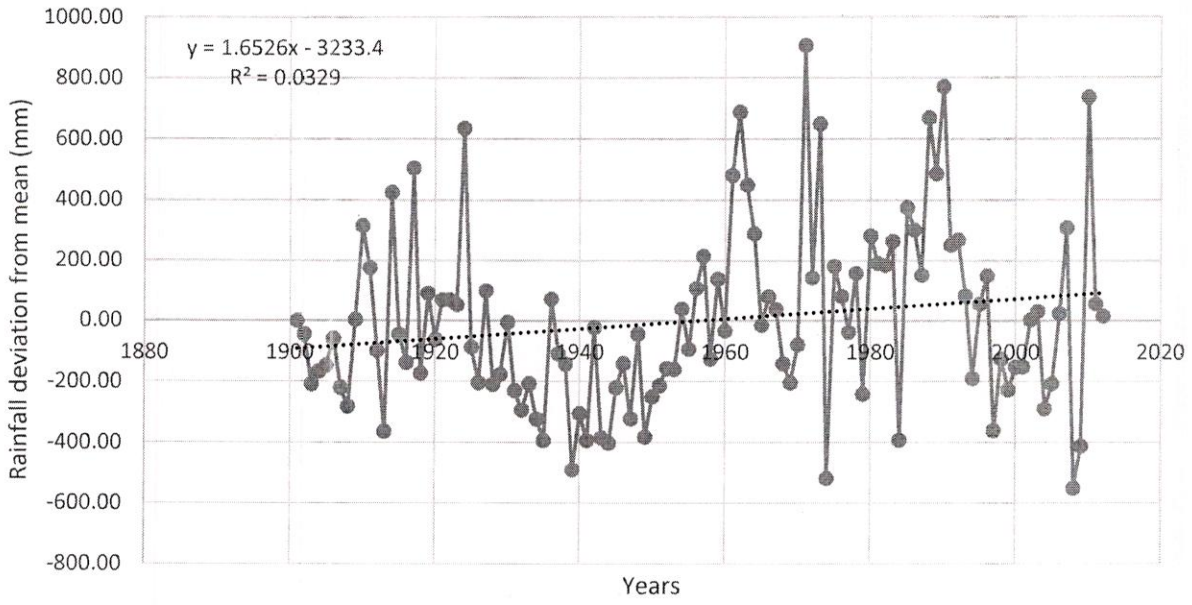



Fig. 10: Temporal variation of annual rainfall for Rudra Prayag district with the trend line and the linear regression equation

## 11) For Tehri Garhwal District

Table 11: Mann-Kendall Statistics and Sen's slope values for seasonal and annual rainfall for Tehri Garhwal district

| Session | Z-Statistic | Sen's Slope | Trend acc. To Sen's Slope | Result |
|---|---|---|---|---|
| Pre-Monsoon | **3.29** | **1.153** | ↑ | Significant |
| Monsoon | 0.47 | -0.672 | ↓ | Non-significant |
| Post-Monsoon | -1.14 | -0.606 | ↓ | Non-significant |
| Winter | **2.32** | **0.509** | ↑ | Significant |
| Annual | 0.91 | -0.306 | ↓ | Non-significant |

### Pre-monsoon session

- The Z-statistic value as given in table 11 above for pre-monsoon session indicates a highly significant increasing trend of rainfall.
- The given Sen's slope value for pre-monsoon session also indicates the increasing trend (1.153mm/year) of rainfall.

### Monsoon Session

- The Z-statistic value as given in table 11 above for Monsoon session indicates a non-significant increasing trend of rainfall.
- The given Sen's slope value for Monsoon session indicates the decreasing trend (-0.672mm/year) of rainfall.

### Post-monsoon Session

- The Z-statistic value as given in table 11 above for post-monsoon session indicates decreasing trend of rainfall which is not significant.
- The given Sen's slope value for post-monsoon session also indicates the decreasing trend (-0.606mm/year) of rainfall.

### Winter Session

- The Z-statistic value as given in table 11 above for winter session indicates a significant increasing trend of rainfall.
- The given Sen's slope value for winter session also indicates the increasing trend (0.509mm/year) of rainfall.

**Annual Rainfall**

- The Z-statistic value as given in table 11 above for annual session indicates a non-significant increasing trend of rainfall.
- The given Sen's slope value for annual session indicates the decreasing trend (-0.306mm/year) of rainfall.

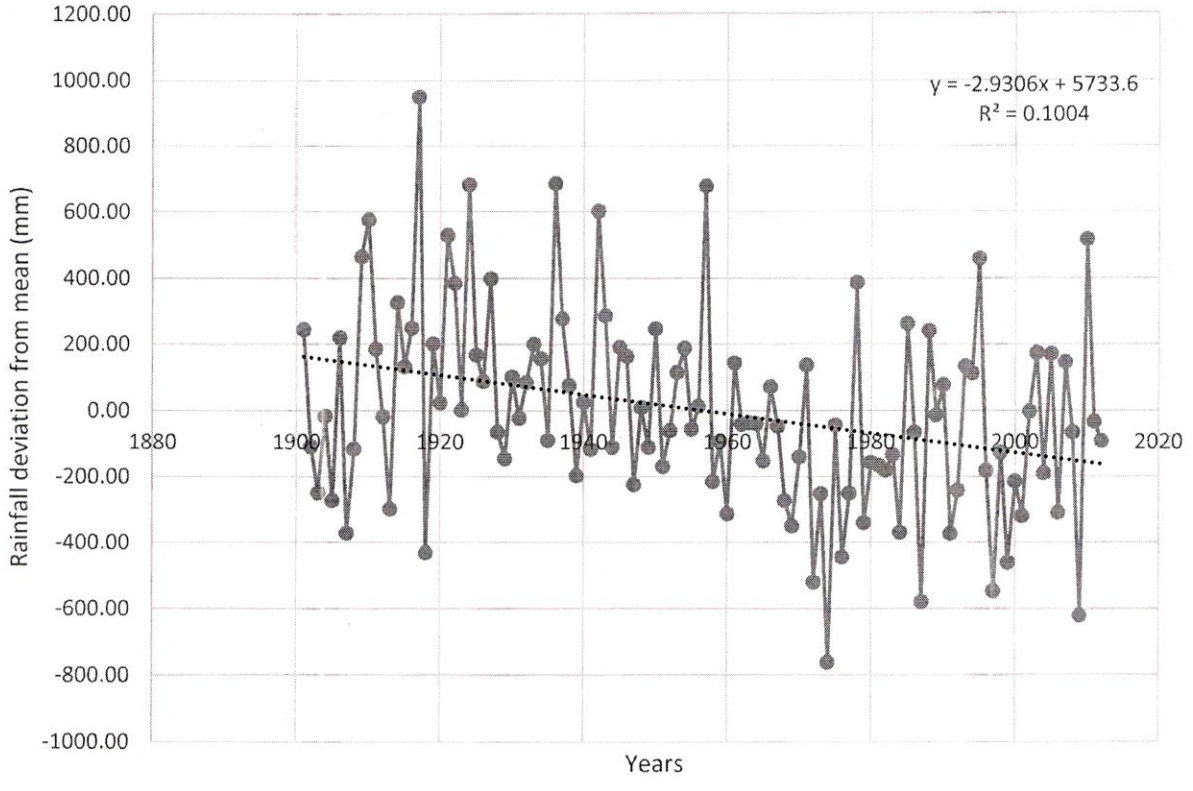



Fig. 11: Temporal variation of annual rainfall for Tehri Garhwal district with the trend line and the linear regression equation

## 12) For Udham Singh Nagar District

Table 12: Mann-Kendall Statistics and Sen's slope values for seasonal and annual rainfall for Udham Singh Nagar district

| Session | Z-Statistic | Sen's Slope | Trend acc. To Sen's Slope | Result |
|---|---|---|---|---|
| Pre-Monsoon | **2.73** | **0.38** | ↑ | Significant |
| Monsoon | 1.07 | 1.353 | ↑ | Non-significant |
| Post-Monsoon | 0.02 | -0.517 | ↓ | Non-significant |
| Winter | 0.11 | 0.018 | ↑ | Non-significant |
| Annual | 1.02 | 1.321 | ↑ | Non-significant |

**Pre-monsoon session**

- The Z-statistic value as given in table 12 above for pre-monsoon session indicates a significant increasing trend of rainfall.
- The given Sen's slope value for pre-monsoon session also indicates the increasing trend (0.38mm/year) of rainfall.

**Monsoon Session**

- The Z-statistic value as given in table 12 above for Monsoon session indicates a non-significant increasing trend of rainfall.
- The given Sen's slope value for Monsoon session also indicates the increasing trend (1.353mm/year) of rainfall.

**Post-monsoon Session**

- The Z-statistic value as given in table 12 above for post-monsoon session indicates a non-significant increasing trend of rainfall.
- The given Sen's slope value for post-monsoon session also indicates the decreasing trend (-0.517mm/year) of rainfall.

**Winter Session**

- The Z-statistic value as given in table 12 above for winter session indicates a non-significant increasing trend of rainfall.
- The given Sen's slope value for winter session also indicates the increasing trend (0.018mm/year) of rainfall.

**Annual Rainfall**

- The Z-statistic value as given in table 12 above for annual session indicates a non-significant increasing trend of rainfall.
- The given Sen's slope value for annual session indicates the increasing trend (1.321mm/year) of rainfall.

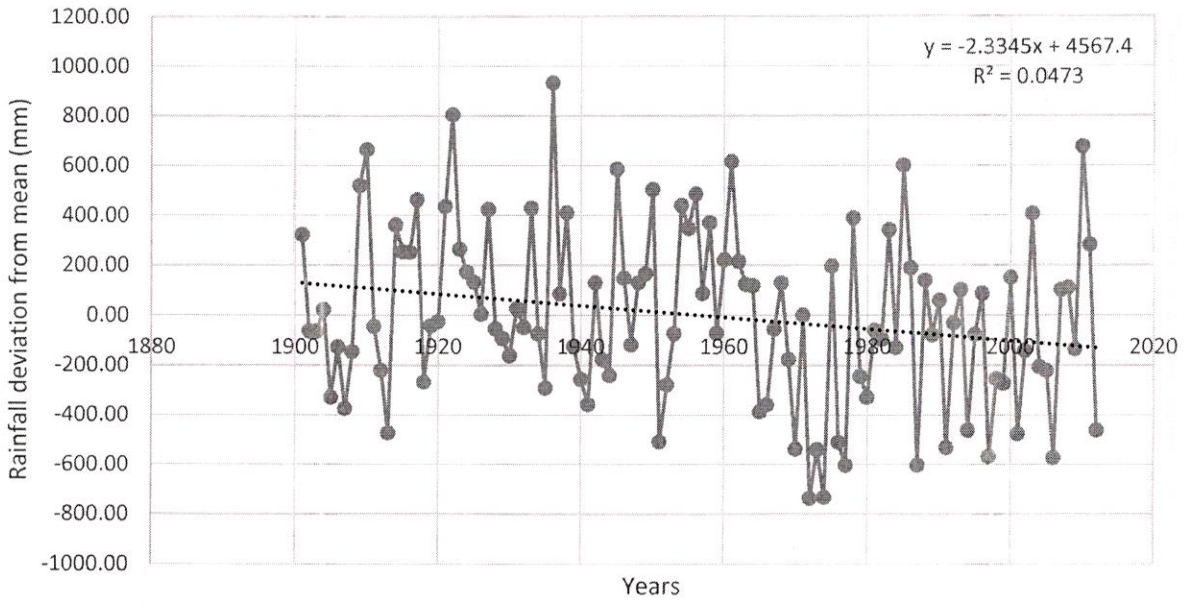



Fig. 12: Temporal variation of annual rainfall for Udham Singh Nagar district with the trend line and the linear regression equation

## 13) For Uttarkashi District

Table 13: Mann-Kendall Statistics and Sen's slope values for seasonal and annual rainfall for Uttarkashi district

| Session | Z-Statistic | Sen's Slope | Trend acc. To Sen's Slope | Result |
|---|---|---|---|---|
| Pre-Monsoon | **2.99** | **1.194** | ↑ | Significant |
| Monsoon | 0.88 | 0.147 | ↑ | Non-significant |
| Post-Monsoon | **-2.22** | **-0.674** | ↓ | Significant |
| Winter | 1.69 | 0.497 | ↑ | Non-significant |
| Annual | 1.13 | 0.668 | ↑ | Non-significant |

**Pre-monsoon session**

- The Z-statistic value as given in table 13 above for pre-monsoon session indicates a significant increasing trend of rainfall.
- The given Sen's slope value for pre-monsoon session also indicates the increasing trend (1.194mm/year) of rainfall.

**Monsoon Session**

- The Z-statistic value as given in table 13 above for Monsoon session indicates a non-significant increasing trend of rainfall.
- The given Sen's slope value for Monsoon session also indicates the increasing trend (0.147mm/year) of rainfall.

**Post-monsoon Session**

- The Z-statistic value as given in table 13 above for post-monsoon session indicates a significant decreasing trend of rainfall.
- The given Sen's slope value for post-monsoon session also indicates the decreasing trend (-0.674mm/year) of rainfall.

**Winter Session**

- The Z-statistic value as given in table 13 above for winter session indicates a non-significant increasing trend of rainfall.
- The given Sen's slope value for winter session also indicates the increasing trend (0.497mm/year) of rainfall.

**Annual Rainfall**

- The Z-statistic value as given in table 13 above for annual session indicates a non-significant increasing trend of rainfall.
- The given Sen's slope value for annual session indicates the increasing trend (0.668mm/year) of rainfall.

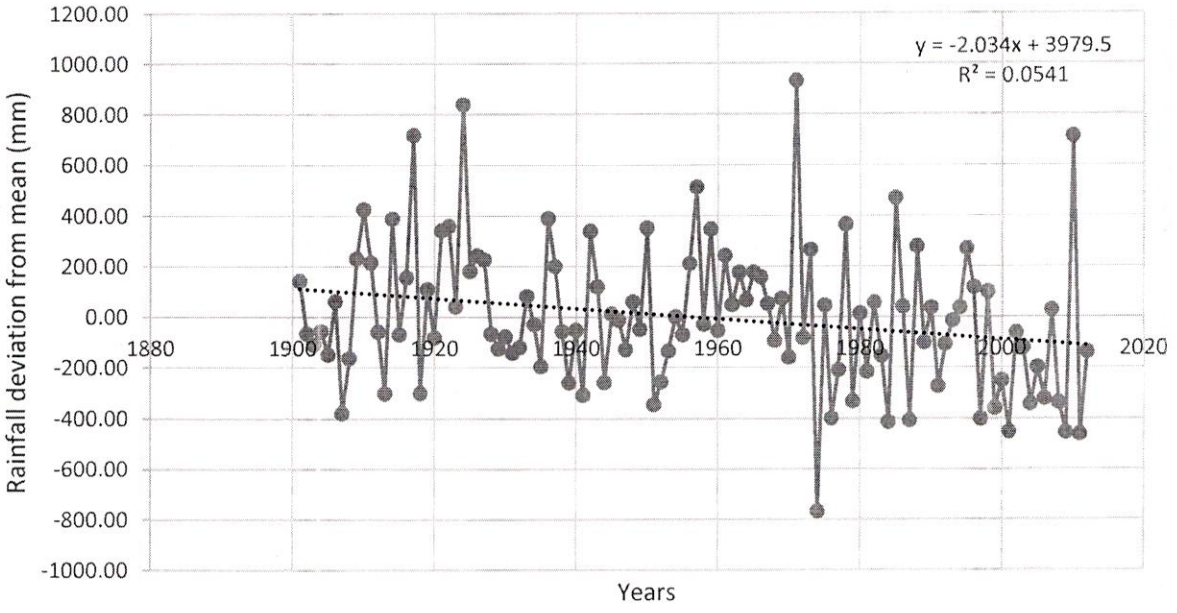



Fig. 13: Temporal variation of annual rainfall for Uttarkashi district with the trend line and the linear regression equation

# 6. CONCLUSION

The analysis was performed to determine the climate change in Uttarakhand region using daily based gridded rainfall data series at a high resolution of 0.25°*0.25°. In the present study the spatial and temporal trend analyses are made for the Uttarakhand state at the district level for seasonal and annual rainfall data for the period of 112 years (1901-2012). The trend analysis have been performed using parametric (linear regression method) and non-parametric (Mann-Kendall and Sen's slope estimator test). The results reveals an increasing rainfall trend in Almora, Bageshwar, Champawat, Haridwar, Pithoragarh, Udham Singh Nagar and Uttarkashi Districts which not significant whereas a significant increasing rainfall trend is observed in the districts of Chamoli and Rudra Prayag for Monsoon season. A non-significant decreasing trend is observed in the districts of Dehradun, Nainital, Pauri Garhwal and Tehri Garhwal. At the annual session a significant increasing rainfall trend is observed in the districts of Chamoli and Rudra Prayag while a non-significant increasing rainfall trend is revealed in the districts of Almora, Bageshwar, Champawat, Haridwar, Pithoragarh and Uttarkashi. A non-significant decreasing trend is observed in Dehradun, Nainital, Pauri Garhwal, and Tehri Garhwal districts.

An upward rainfall trend has been observed in the Uttarakhand state on an average, with the maximum significant increasing trend in Chamoli and Rudra Prayag districts with the magnitude of 5.502 mm and 5.666 mm rainfall/year respectively. On the other hand there is a decreasing trend of rainfall in Dehradun, Nainital, Pauri Garhwal and Tehri Garhwal districts with the magnitude of -4.726 mm, -1.086 mm, -2.362 mm, and -0.306 mm/year respectively which is not significant.

# BIBLIOGRAPHY


- Kumar V., Jain S.K., Singh Y., 2010, "Analysis of Long-Term rainfall trends in India", National Institute of Hydrology, Roorkee.
- Swain S., Verma M., Verma M.K., 2015 "Statistical trend analysis of monthly rainfall for Raipur district, Chhattisgarh", International Journal of Advanced Engineering Research and Studies.
- "National Disaster Risk Reduction Portal", National Institute of Disaster Management, Uttarakhand.
- Jhajaria D., Yadav B.K., Maske S., Chattopadhyay S., Kar A.K., 2011, Elsevier Mansson SAS.
- Singh R.B., Mal S., 2014, "Trends and variability of Monsoon and other rainfall seasons in Western Himalaya, India", Royal Metereological Society, Wiley Online Library.