Precipitation analysis for the East and South districts of Sikkim, India

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Abstract. This study emphasizes the rainfall analysis in the state of Sikkim located in the north east region of India, which covers up an area of 7097 km². The rainfall analysis of the two districts East Sikkim and South Sikkim for a period of 118 years (1901-2018) are computed. Various tests depicting the trends, homogeneity, slope and statistical data reveals the monthly, seasonally and annual rainfall pattern in these districts of Sikkim. For the annual rainfall, the coefficient of variance varies from 13% to 19% whereas the coefficient of variance for seasonal rainfall varies from 14% to 81% which indicates that seasonal variability is more than the annual variability. Southwest monsoon contributes 79% to the annual rainfall followed by pre-monsoon which contributes 14% to the annual rainfall. The trend analysis depicts an insignificant increasing trend annually but a significantly decreasing trend for the south west monsoon with a negative slope justifying the downward trend. The homogeneity test points out the specific year the trend of the rainfall begins which was found to be in the year 1955.

1. Introduction
Precipitation analysis plays a vital role in the agricultural sector as well as in the construction of the hydraulic structures. With the rise of the global population, the demand for water also significantly increasing thereby makes these kinds of study a necessity for human survival. Due to the global warming, various studies show that with the increase in temperature an alteration in the rainfall pattern was witnessed [1]. The places having excess rainfall and the deficit rainfall areas show an increasing trend of variation between them. A report by the Ministry of Earth Sciences, Government of India, states that there is a decrease in the annual precipitation for the last 30 years in seven states of India. The states experiencing this anomaly are Bihar, Himachal Pradesh, Nagaland, Meghalaya, Uttar Pradesh, Arunachal Pradesh and West Bengal. According to the Indian Meteorological Department (IMD), India had received the highest rainfall in 2019 monsoon since 1994, deviating 10 per cent more than the normal. The 2018 year floods in Kerala which resulted as one of the heaviest in nearly a century with flash floods clearly showed the impact of the climate change on the rainfall pattern. For the Himalayan basin, there is a rise and drop in rainfall trend in the eastern part and absence of consistent trend in central Himalayas and for the western Himalayas there is a drop in the rainfall trend. [2]. The Himalayan basin range is a land locked territory therefore it relies on the rainfall for their water supply. Runoff from the rainfall is stored for further use in domestic and industrial uses in...
huge reservoirs. Duration and quantity of rainfall plays an important factor as change in any of two can drastically affect the community. Natural calamities like flash flood and droughts have proven to take lives of many and destroyed property causing large amount of damage. By the middle century the precipitation is said to be increased by 18% and by the end of century likely by 13-24% [3]. Therefore, the importance to study the trend in rainfall is to understand its fluctuation and control damage.

1.1. Study Area
Sikkim is located in the northeastern part of India, on the foothills of the Eastern Himalayas. It has a mountainous terrain with the geographical coordinate of 22.53° N latitude and 88.51° E longitude. The entire state is hilly with two major rivers namely the Teesta River and the Rangeet River which flows throughout the state. As per the official website of Sikkim tourism and Civil Aviation Department, Government of Sikkim, the state experiences four types of season viz. the cold weather season (December-February), the Pre-monsoon season (March-May), the Southwest monsoon (June-September) and the Retreating monsoon season (October-November). The temperature of most of the inhabited region hardly exceeds 28°C in summer and has a mean annual temperature of 18°C. The state of Sikkim is divided in four districts viz. east, west, north and south with the north district having the largest area of 4226 km². Since all four districts showed similarity in their rainfall pattern hence the rainfall analysis was conducted only for the east and the south district.

2. Methodology
The annual monthly data for the two districts from 1987-2018 is obtained from the Indian Meteorological department [4]. and the remaining data for the years 1901-2002 from Indian Water Portal [5]. Homogeneity test was conducted for the monthly rainfall for the two different sources of data by the multiple comparison test and Levene’s test. Since the p (0.941) calculated is higher than the value of alpha (at 0.05 significance level), the homogeneity was confirmed [6]. With the data acquired statistical analysis of the normal rainfall, standard deviation (SD) and coefficient of variation (COV) were obtained for monthly, yearly and seasonal classification. The dependable monthly, annual, and seasonal rainfall at 50%, 75% and 90% probabilities were evaluated using the Weibull’s method [7]. The cumulative rainfall for the seasonal rainfall was also arrived [8].

The trend analysis for 117 years for the two districts was computed using the Mann-Kendall test. It is a statistical test wherein the null hypotheses assume that there is no trend in the rainfall and the alternate hypotheses assumes that a trend is witnessed [9]. For a trend in a linear time series, Sen’s slope test is conducted to find the slope of trend. The test is conducted in XLSTAT 2018 software, with the positive value indicating rise in slope and vice-versa. [10].

According to the Indian Meteorological Department (IMD), meteorological drought sets in when rainfall over a particular area is comparatively lesser than the climatological mean rainfall of that area. The departure analysis helps to understand the rainfall deficit years. The percentage departure is done seasonally and annually to understand the pattern or the drought [11]. Drought can be classified as mild, moderate or severe based on the rainfall deficit.

A given set of data is homogeneous when the circumstances surrounding each observation are exactly same. For a rainfall trend, homogeneity is difficult to maintain as each rainfall observations are done under different environment, observation procedures and measurement technique. Various methods are there to detect the inhomogeneity in the rainfall trend. Pettitt’s and Buishand’s test detects the break of homogeneity in the middle of the trend, whereas the SNHT detects break in the beginning and the end of the trend. These test helps in finding the break point in the trend of a rainfall [12].

3. Results and Discussion
### 3.1. Statistical parameters

East District: The detailed statistics of monthly, annual and seasonal rainfall from the year 1901-2018 for the East district is given in Table 1. For the East district the average rainfall is found as 2361 mm. The standard deviation for the month of July is 154 mm with normal rainfall as 595 mm therefore, it can be concluded that rainfall deviates highest from the normal also making it in the wettest month. We can infer that the inter-annual variation of rainfall is less as suggested by the low COV of 14% [13]. The high COV values ranging more than 100% from November to January signifies high variability. The month July (595 mm) and June (434 mm) has the highest contribution to the annual rainfall. Whereas the month of November (11 mm) and December (6 mm) has the least contribution to the annual rainfall with 0.47% and 0.25% respectively. More than 90% to the annual rainfall was contributed by the southwest monsoon (78.44%) and the pre-monsoon (14.99%). The 50%, 75% and 90% probable annual rainfall are 2336 mm, 2137 mm and 1952 mm respectively. Therefore, there is less dependability of rainfall on the winter and pre-monsoon season [14].

| Months    | Normal | SD  | COV  | 50% PROBABILITY | 75% PROBABILITY | 90% PROBABILITY | % contribution to annual rainfall |
|-----------|--------|-----|------|-----------------|-----------------|-----------------|----------------------------------|
| January   | 11     | 13  | 118  | 7               | 0               | 0               | 0.47                             |
| February  | 20     | 21  | 109  | 15              | 6               | 2               | 0.85                             |
| March     | 35     | 31  | 91   | 27              | 13              | 2               | 1.48                             |
| April     | 98     | 75  | 77   | 79              | 50              | 32              | 4.15                             |
| May       | 221    | 91  | 42   | 210             | 157             | 109             | 9.36                             |
| June      | 434    | 141 | 33   | 420             | 320             | 261             | 18.38                            |
| July      | 595    | 154 | 26   | 577             | 487             | 401             | 25.20                            |
| August    | 447    | 100 | 23   | 445             | 370             | 317             | 18.93                            |
| September | 375    | 107 | 29   | 370             | 292             | 244             | 15.88                            |
| October   | 108    | 85  | 79   | 85              | 55              | 26              | 4.57                             |
| November  | 11     | 14  | 123  | 4               | 0               | 0               | 0.47                             |
| December  | 6      | 10  | 179  | 1               | 0               | 0               | 0.25                             |
| Annual    | 2361   | 361 | 14   | 2336            | 2137            | 1952            | 100.00                           |
| Winter    | 36     | 29  | 81   | 29              | 17              | 11              | 1.52                             |
| Premonsoon| 354    | 159 | 45   | 320             | 254             | 198             | 14.99                            |
| Southwest Monsoon | 1852 | 265 | 14  | 1843            | 1663            | 1521            | 78.44                            |
| Retreating Monsoon | 119  | 86  | 72   | 536             | 459             | 131             | 5.04                             |

Figures 1 and 2 depict the time series of annual and seasonal rainfall for the East district of Sikkim from the years 1901-2018. From Figure 1 it can be seen that the year 2003 has the highest rainfall of 3165.167 mm and lowest rainfall on the year 1957 having a rainfall of 1565.03 mm. Figure 3 depicts the seasonal percentage contribution to the annual rainfall for the East district.
Figure 1. Time Series of annual rainfall over East district of Sikkim during 1901-2018; the average annual rainfall is denoted by the dashed lines.

Figure 2. Time series of seasonal rainfall (a) Winter (b) Pre-monsoon (c) Southwest monsoon (d)Retreating monsoon for East district of Sikkim.
South District: The detailed statistics of monthly, annual and seasonal rainfall from the year 1901-2002 and 2010-2018 for South district of Sikkim is given in Table 2. The average rainfall for the district of South Sikkim is 2084 mm with a low COV of 13 % which signifies low inter-annual variability in the rainfall. July is found to be the wettest month with normal rainfall of 544 mm and has the highest contribution to the annual rainfall about 26.10 %. The months of November, December and January have high COV 131%, 180% and 118% signifying high variability in rainfall for these months. The 50%, 75% and 90% probable annual rainfall are 2100 mm, 1902 mm and 1729 mm, and for winter, pre-monsoon, SWM and retreating monsoon season the 75% probable rainfall are 18 mm, 218 mm, 1512 mm and 53 mm. The SWM and pre-monsoon season have the highest contribution to the annual rainfall of 80% and 13.3% respectively, whereas the winter and retreating monsoon have the least contribution to the annual rainfall.

Figures 4 and 5 depict the time series of annual and seasonal rainfall for the South district of Sikkim for the years 1901-2002 and 2010-2018. From Figure 10 it is seen that the year 1938 has the highest rainfall of 2749.73 mm and lowest rainfall on the year 1965 having a rainfall of 1372.487 mm. Figure 6 depicts the seasonal percentage contribution to the annual rainfall for the South district.
Figure 4. Time Series of annual rainfall over South Sikkim during 1901-2002 and 2010-2018; the average annual rainfall is denoted by the dashed lines.

Table 2. Descriptive statistical values of monthly, annual and seasonal in (millimeters) over South district of Sikkim from 1901-2002 and 2010-2018

| Months    | Normal (mm) | SD (mm) | COV (%) | 50% PROBABILITY (mm) | 75% PROBABILITY (mm) | 90% PROBABILITY (mm) | % contribution to annual rainfall |
|-----------|-------------|---------|---------|----------------------|----------------------|----------------------|-------------------------------|
| January   | 11          | 13      | 118     | 7                    | 6                    | 1                    | 0.52                          |
| February  | 17          | 14      | 84      | 14                   | 6                    | 2                    | 0.81                          |
| March     | 28          | 22      | 80      | 22                   | 13                   | 6                    | 1.34                          |
| April     | 71          | 39      | 55      | 71                   | 40                   | 27                   | 3.40                          |
| May       | 179         | 75      | 42      | 172                  | 121                  | 89                   | 8.58                          |
| June      | 369         | 137     | 37      | 360                  | 262                  | 221                  | 17.70                         |
| July      | 544         | 148     | 27      | 358                  | 442                  | 358                  | 26.10                         |
| August    | 405         | 93      | 23      | 397                  | 347                  | 310                  | 19.43                         |
| September | 351         | 105     | 30      | 238                  | 278                  | 238                  | 16.84                         |
| October   | 93          | 68      | 73      | 72                   | 53                   | 28                   | 4.46                          |
| November  | 10          | 13      | 131     | 5                    | 1                    | 1                    | 0.47                          |
| December  | 6           | 11      | 180     | 2                    | 1                    | 0                    | 0.28                          |
| Annual    | 2084        | 276     | 13      | 2100                 | 1902                 | 1729                 | 100                           |
| Winter    | 34          | 21      | 63      | 30                   | 18                   | 13                   | 1.63                          |
| Pre-      | 278         | 97      | 35      | 275                  | 218                  | 171                  | 13.33                         |
| Southwest | 1669        | 249     | 15      | 1670                 | 1512                 | 1369                 | 80.08                         |
| Monsoon   | 103         | 70      | 67      | 84                   | 58                   | 34                   | 4.94                          |
Figure 5. Time series of seasonal rainfall (mm) during 1901-2002 and 2010-2018 (a) Winter; (b) Pre-monsoon; (c) Southwest monsoon; (d) Retreating monsoon for South district of Sikkim

Figure 6. Percentage contribution of the seasonal rainfall to the annual rainfall for South district of Sikkim.

3.2. Trends in Monthly, Seasonal and Annual Timescales
The monthly rainfall trends for the two districts were analyzed by the MK test and the slope was found by the Sen’s estimator test. The Z statistics between the range of -1.96 (decreasing) to +1.96 (increasing) indicate the presence of a significant trend for that particular month [15]. For the East and South district the results of the Mann-Kendall test statistics and Sen’s slope estimator is tabulated in Table 3.
East District: From the Table 3 it can be inferred that the months March, April and May displays a significant increasing trend and the months of January and November an insignificant increasing trend whereas rest of the months displays an insignificant decreasing trend [16]. The pre-monsoon season shows a significant increasing trend and the southwest monsoon shows a significant decreasing trend. The detected trend of the monthly and seasonal rainfall is supported by the slope found out by the Sen’s slope analysis, as the slope of the months March, April and May which have an increasing trend are found to have a positive slope [17].

South district: From the Table 3 it can be identified that the month of June shows a significant decreasing trend whereas all the other months shows an insignificant decreasing or increasing trend, the positive values means increasing trend and the negative value means decreasing trend. The pre-monsoon season shows significant increasing trend and the pre-monsoon, SWM and winter season shows an insignificant decreasing trend with a negative magnitude of slope by the Sen’s slope estimator

|                | December | January | February | March | April | May | June | July | August | September | October | November |
|----------------|----------|---------|----------|-------|-------|-----|------|------|--------|-----------|---------|----------|
| **East District** |          |         |          |       |       |     |      |      |        |           |         |          |
| **Annual**      | 0.665    | 1.144   | -0.251   | 2.967 | 2.9399| 3.516| -1.018| -1.52| -1.1257| -0.3116   | -1.29321| 1.008    |
| **Winter**      | 1.00755  | 0.019   | -0.008   | 0.185 | 0.411 | 0.874| -0.396| 0.676| 0.294  | -0.079    | -0.195  | 0.014    |
| **Pre-monsoon** | 4.00546  | 0.052   | 1.421    | 1.58  | 1.85  | 2.604| 1.386 | 1.264| 1.483  | 1.325     | 1.223   | 1.22     |
| **SWM**         | -2.11896 | -0.098  | -0.008   | -1.58 | -1.885| 1.697| 0.514 | 1.697| 1.885  | 0.514     | 1.378   |          |
| **Retreating monsoon** | -0.565246 | -0.098 | -0.008 | -1.58 | -1.885 | 1.697 | 0.514 | 1.697 | 1.885 | 0.514 | 1.378 |          |
| **South District** |          |         |          |       |       |     |      |      |        |           |         |          |
| **Annual**      | 0.524    | 0.019   | -0.008   | 0.185 | 0.411 | 0.874| -0.396| 0.676| 0.294  | -0.079    | -0.195  | 0.014    |
| **Winter**      | 0.052    | 0.019   | -0.008   | 0.185 | 0.411 | 0.874| -0.396| 0.676| 0.294  | -0.079    | -0.195  | 0.014    |
| **Pre-monsoon** | 1.421    | 1.421   | 1.421    | 1.58  | 1.58  | 1.483| 1.386 | 1.264| 1.483  | 1.325     | 1.223   | 1.22     |
| **SWM**         | -1.33    | 0.797   | -1.83    | 1.264 | 1.483 | 1.386| 2.604 | 1.126| 0.897  | 1.325     | 1.223   | 1.22     |
| **Retreating monsoon** | -1.123  | 0.015   | -0.059   | 0.062 | 0.17  | 0.321| -1.003| -0.472| -0.219 | 0.381     | -0.19   | -0.012   |

3.3. Rainfall Departure Analysis

For the time period of 1901-2018 i.e. 118 years for the East district and from 1901-2002 and 2010-2018 i.e. 111 years for the South district the number of years which had either deficit, excess or normal rainfall are calculated and tabulated in Table 4. According to the Indian Meteorological Department, for departure percentage of +19 to -19 the rainfall is considered normal, when it is in range of 21% to 59% the rainfall is considered to deficient and for the range of 20% or more the rainfall is excess.

East district: The number of years experiencing normal rainfall i.e. rainfall deviating +19 to -19 from the normal is 99 years. The number of years experiencing deficient rainfall i.e. rainfall deviating

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Table 3. Results for Mann Kendall Trend Test and Sen’s slope Test Estimator for East and South.
-20 to +59 from the normal rainfall is 14 years and the years having excess rainfall i.e. deviating +20 or more from the normal rainfall is 5 years.

South district: The number of years experiencing normal rainfall i.e. rainfall deviating +19 to -19 from the normal is 94 years. The number of years experiencing deficient rainfall i.e. rainfall deviating -20 to +59 from the normal rainfall is 14 years and the years having excess rainfall i.e. deviating +20 or more from the normal rainfall is 3 years.

| Table 4. Result of Rainfall Departure Analysis for East and South district of Sikkim. |
|-----------------------------------------|------------------|------------------|
|                                        | East Sikkim      | South Sikkim     |
| Normal Rainfall                        | 99 years         | 94 years         |
| Deficient Rainfall                    | 14 years         | 14 years         |
| Excess Rainfall                        | 5 years          | 3 years          |

3.4. Homogeneity Test

Homogeneity of the rainfall series indicates whether the annual rainfall series have a continuous trend or if a break in the trend occurs and it also points out the year the inhomogeneity or break begins [18]. Three methods are used to detect the homogeneity of the annual rainfall, the Pettitt’s test, Buishand’s test and the Standard Normal Homogeneity Test (SNHT) [19]. Table 5 shows the results of the three homogeneity test of the East and South district of Sikkim.

East district: For the southwest monsoon season which has the highest contribution to the annual rainfall, the rainfall is homogeneous till the year 1908 for Pettitt’s test and Buishand’s test and according to SNHT test till the year 1955. After these specified year there is a decrease in the trend as concluded from the MK Test. For the pre-monsoon season the break occurs in the year of 1975 for Pettitt’s test and Buishand’s test and in the years of 2002 for SNHT.

South District: The southwest monsoon season which has the highest contribution to the annual rainfall, the break point year is found to be 1955 for Buishand’s, SNHT and Pettitt’s test. After these specified year there is a decrease in the trend as concluded from the MK test. For the pre-monsoon season the break occurs in the year 1915 from Pettitt’s test and Buishand’s test.

| Table 5. Results of the Homogeneity test. |
|-----------------------------------------|-----------------|-----------------|
|                                        | East Sikkim     | South Sikkim    |
|                                        | Pettitt's test  | Buishand's test | SNHT test |
| Annual                                  | 1955            | 1955            | 2002      | 1956      | 1956      | 1956      |
| Winter                                  | 1978            | 1978            | 1978      | 1955      | 1947      | 1939      |
| Pre-monsoon                             | 1975            | 1975            | 2002      | 1915      | 1915      | 1996      |
| SWM                                     | 1908            | 1908            | 1955      | 1955      | 1955      | 1955      |
| Retreating monsoon                      | 2002            | 1999            | 1987      | 1952      | 1987      | 1987      |
4. Conclusion
Southwest monsoon of Sikkim has the highest contribution followed by pre-monsoon therefore making the rainfall pattern is irregular and mostly monsoon driven. The East district has the highest rainfall with an average of 2361 mm and the South district has an average of 2084 mm. In both the districts the COV value is low (< 19%) signifying that the inter-annual variability of the rainfall is low. East district experiences normal rainfall for 99 years, deficit rainfall for 14 years and excess rainfall for five years. The South district witnessed 94 years of normal rainfall, 14 years of deficit rainfall and three years of excess rainfall. The analysis reveals similar pattern of rainfall for both the districts. Since the trend for the southwest monsoon is considered to be vital for the whole state of Sikkim, both East and South Sikkim witnessed significant decreasing trend in the southwest monsoon from the year 1955. For the pre-monsoon season the trend shows a significant increasing trend.

5. References
[1] Ojo O I and Illunga M F 2017 The rainfall factor of climate change effects on the agricultural environment: A Review American Journal of Applied Sciences. 14 930-937
[2] Shrestha U B, Gautam S and Bawa K S 2012 Widespread Climate Change in the Himalayas and Associated Changes in Local Ecosystems 7 8-9.
[3] Chaudhary P and Bawa K S 2011 Local precipitation of climate change validated by scientific evidence in the Himalayas Biology Letters. 7 767-770
[4] IMD (Indian Meteorological Department). Data Supply http://www.imdsikkim.gov.in/dataSupply.html (Feb. 21, 2020)
[5] India Water Portal. Meteorological datasets https://www.indiawaterportal.org/met_data/ (Feb. 21, 2020)
[6] Maheras P and Kolyva-Machera F 1990 Temporal and spatial characteristics of annual precipitation over the Balkans in the twentieth century International Journal of Climatology 10 495-504
[7] Rangarajan S, Thattai D, Cherukuri A, Borah T A, Joseph J K and Subbiah A 2019 A Detailed Statistical Analysis of Rainfall of Thoothukudi District in Tamil Nadu (India) Water Resources and Environmental Engineering II 1-14
[8] Rangarajan S, Thattai D, Yellasiri S R R, Vytla R, Tedla N and Mandalemula B 2018 Detecting Changes in Annual and Seasonal Rainfall Patterns for Chennai, India, Journal of Hydraulic Engineering. 23 1-11
[9] Longobardi A and Villani P 2010 Trend analysis of annual and seasonal rainfall time series in the Mediterranean area International Journal of Climatology 30 1538-1546
[10] Panda A and Sahu N 2019 Trend analysis of seasonal rainfall and temperature pattern in Kalahandi, Bolangir and Koraput districts of Odisha, India Atmospheric Science Letters 20 1-10
[11] Kant S, Meshram S and Sahu K C 2014 Analysis of rainfall data for drought investigation at Agra U.P. Recent Research in Science and Technology 6 62-64.
[12] Kang H M and Yusof F 2012 Homogeneity tests on daily rainfall series in peninsular Malaysia International Journal of Contemporary Mathematics and Science 7 9-22
[13] Nyatuaume M, Owusu-Gyimah V and Ampiaw F 2014 Statistical Analysis of Rainfall Trend for Volta Region in Ghana International Journal of Atmospheric Sciences 20 1-11
[14] Satish N, Rangarajan S and Thattai D 2019 Spatial and temporal analysis of long term precipitation data for Karnataka State, India AIP Conference Proceeding 2122 1-11
[15] Yadav R, Tripathi S K, Pranuthi G and Dubey S K 2014 Trend analysis by Mann-Kendall test for precipitation and temperature for thirteen districts of Uttarakhand Journal of Agrometeorology 16 164-171
[16] Mondal A, Kundu S and Mukhopadhyay A 2012 Rainfall Trend Analysis by Mann-Kendall Test: A Case Study of North-Eastern Part of Cuttack District, Orissa International Journal of Geology, Earth and Environmental Sciences 2 70-78

[17] Shah S, Khare D, Mishra P K and Singh L 2017 Historical Trend Analysis of A Terai Himalayan District of Nepal: A Case Study Engineering and Technology 3 542-560

[18] Traore V B, Diouf R, Ndiaye M L, Godfroyd O R, Faye M, Malomar G, Sarr J, Diaw A T and Beye A C 2018 Detection Of Inhomogeneities and Break Points in Annual Rainfall Series of Senegal Regions Algerian Journal of Arid Environment 8 26-43

[19] Allami A, Kadhim Y and Al-Salihi A 2014 The homogeneity analysis of rainfall time series for selected meteorological stations in Iraq Diyala Journal for Pure Sciences 10 52-63

[20] Jain S K, Kumar V and Saharia M 2012 Analysis of rainfall and temperature trends in northeast India International Journal of Climatology 33 968-978