Impact of climate change on the rainfall pattern of Klip River catchment in Ladysmith, KwaZulu Natal, South Africa

D T Chabalala¹, J M Ndambuki², R W Salim³ and S S Rwanga⁴

¹Department of Civil Engineering, University of South Africa, Pretoria, South Africa
²,³Department of Civil Engineering, Tshwane University of Technology, Pretoria, South Africa
⁴Department of Civil Engineering, Vaal University of Technology, Vanderbijlpark, South Africa

Email: chabadt@unisa.ac.za

Abstract. Rainfall trend analysis has been of major focus in the past century because of the attention given to climate change by the science and engineering community. According to some latest studies, rainfall is one of the main parameters in any catchment which plays a significant role in flood frequency, flood control as well as water resources planning and management. Ladysmith town in South Africa is flooded almost every year resulting in loss of lives as well as properties and businesses. Thus, this study aimed at determining the monthly and annual rainfall pattern in relation to climate change. The monthly, seasonal and annual rainfall trends for the period 1985 – 2018 were analyzed using Mann-Kendall test and Sen’s slope estimation. Results of this study indicated a variability in seasonal rainfall, with a rainfall increase during December and January of summer months whose Mann-Kendall test results were 1.88 and 0.73, and a major decrease showed in autumn months (March, April, and May) with Mann-Kendall test values of -2.76, -3.53 and -4.09. Therefore, the overall results suggest a minor significant change for both Ladysmith and upstream of the Klip river catchment. Based on the analysis, it can be concluded that climate change has an impact on the rainfall spatial pattern of the study area. This correlates well with similar analysis carried out in other areas around the world.

Keywords: Climate change, Rainfall trend analysis, Mann-Kendall Test, Sen’s slope Estimator, Klip River catchment.

1. Introduction

Rainfall is an important factor of the hydrologic cycle and any changes in its pattern may directly influence the water resources of the concerned regions. This is because changes in rainfall response as a result of climate change are now a cause of concern to policymakers, scholars and several research institutes [1], [2]. Moreover, change in rainfall quantity and frequency can alter the pattern of streamflows and demands as well as spatial and temporal distribution of runoff [1]. Thus, it is important to understand whether the rainfall in the study area is decreasing or increasing, as any drastic change would lead to hazardous events like flood or drought [1], [3]. Since last century, several studies have addressed the important issue of trends in rainfall in the world. In Greece, [4] found an overall decreasing trend in annual rainfall from 1974–2007 rainfall data. In India, [1] reported significant increase in precipitation trend in both seasonal and annual rainfall over a period of 102 years. In Rwanda, [5] reported a significant increase over the northern region...
and the number of rainy days decreased significantly over the eastern and central plateau. The mean rainfall was found to increase sharply in most parts, especially in the regions around Kivu Lake during the short rainy seasons. In the central part of Rwanda a diminishing trend in rainfall totals was reported in January and February. In South Africa, a study by [6] indicated a significant change in precipitation over the period 1910 to 2004. Areas with significant decreases in annual precipitation were the northern part of Limpopo, southern part of Mpumalanga, northeastern Free State, western KwaZulu-Natal, southeastern Eastern Cape as well as the south coast of South Africa. Areas with significant increases in annual precipitation included the northern part of North-West province, Western Cape Province, Northern Cape and Eastern Cape Province. A study by [7] using an hourly precipitation data from 1998 to 2007 spread across 102 stations revealed a predominantly positive trend during summer, with the strongest trends concentrated in the coastal areas in the southeast of South Africa. The spatial variations in the trends were reversed during the winter season, with negative trends observed in the coastal areas and positive trends occurring in the interior. Another study by [8] found that evidence of significant increases in the annual extremes between the periods 1931 to 1960 and 1961 to 1990 on the eastern part of South Africa. In view of the above, the current study aimed at determining the monthly, seasonal and annual rainfall pattern within the study area in order to investigate the impact of climate change and have a better understanding of its hydrological status.

2. **Study Area**

The Klip River catchment is one of the major sub-catchment in the uThukela catchment and it is located in the uThukela District municipality in the KwaZulu-Natal province. The Klip River is the main tributary of the Tugela River in KwaZulu-Natal. The river originates on the west side of KwaZulu-Natal and it flows into the Windsor Dam and then into the larger Qedusizi Dam. The river passes through Ladysmith and has a drainage area of approximately 2157 km$^2$. Ladysmith town is located downstream of the Klip River catchment, as a result, any hydrological changes upstream may have effects on flood inundation in the lowlands of Ladysmith [9].

![Figure 1. Location Map of Klip River catchment [10]](image)

The study area is characterized by warm weather in summer and cold weather in winter. The area experiences an average minimum and maximum temperatures of 3°C and 30°C respectively. This study area receives an average annual rainfall of 700 mm per annum with a coefficient of variation of about 69%. The highest temperature is experienced during the month of January and July is the coldest month of the
year with temperatures dropping to 3°C on average during the night [11]. Rainfall becomes a lot more frequent in the summer period (from December to February) and the river water levels rise tremendously [10].

3. Materials and Methods

The daily rainfall data of six stations around Ladysmith were considered in this study. The monthly precipitation data for 34 years (1985 – 2018) from six (6) rain gauge stations of Klip River catchment namely Chelmsford, Eendracht, Wagendrift, Rhenosterfontein, Ladysmith, and Van Reenen (Table 1) were collected from the Department of Water and Sanitation, and South African Weather Services.

Table 1. Details of selected stations used in the study

| Station Name                  | Station ID | Latitude | Longitude | Period of record | Source       | Remarks                                      |
|-------------------------------|------------|----------|-----------|------------------|--------------|----------------------------------------------|
| Chelmsford @ Chelmsford Dam   | V3E002     | -27.9546 | 29.94974  | 1985 to 2018     | DWA          | Fall outside the catchment                   |
| Eendracht @ Driel Barrage     | V1E008     | -28.76705| 29.28722  | 1985 to 2018     | DWA          |                                              |
| Wagendrift @ Wagendrift Dam   | V3E003     | -29.03787| 29.85807  | 1985 to 2018     | DWA          |                                              |
| Rhenosterfontein @ Spioenkop Dam | V1E010 | -28.67734| 29.51389  | 1992 to 2018     | DWA          |                                              |
| Ladysmith                     | 0300454 3 | -28.575  | 29.750    | 1993 to 2018     | SWS          | Fall within the catchment                    |
| Van Reenen                    | V1E005     | -28.36619| 29.37836  | 1985 to 2018     | DWA          |                                              |

In this study, the normal ratio method was used to estimate the missing rainfall data. This method is used if any neighboring gauges have an average annual rainfall over and above 10% of the considered gauge [12]. The missing data for the each station was estimated and filled up by the rainfall data of a neighboring rain gauge station using equation 1.

\[
P_A = \frac{\sum_{i=1}^{N} N_R_A \times P_i}{N_R_i} \quad (1)
\]

Where,
- \( P_A \) = Estimate for the ungauged station
- \( P_i \) = Rainfall at surrounding stations
- \( N_R_A \) = Normal monthly or seasonal rainfall at station A
- \( N_R_i \) = Normal monthly or seasonal rainfall at station i
- \( n \) = Number of surrounding stations whose data are used for estimation.

The study used the Mann-Kendall Sen’s test to investigate trend and variations of rainfall over time at the Klip river catchment [13]. The Mann-Kendall Sen’s test has been widely used in various studies to detect monthly, seasonal and annual trends in hydrological and meteorological data such as wind speed, rainfall,
streamflow and temperature [3]. The advantage of Mann-Kendall Sen’s test is that it is applicable for both non-monotonic and monotonic trends [14] and is simple and robust as well as being able to deal with values below maximum detection and missing values [15]. On the other hand, this test can also achieve both the detection test statistics “S” and a normalized test (Z) statistics [16]. The Mann-Kendall trend starts with the estimation of the test statistic, S in equation 2.

\[
S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} Sgn \left( X_j - X_i \right)
\] (2)

Here \( N \) represent the number of data points and \( X_i \) is the actual time data for a time series of \( i = 1, 2, 3 \ldots \) \( N \). Assuming \((X_j - X_i) = \theta\), the value of \( Sgn(\theta) \) is calculated using equation 3.

\[
Sgn(\theta) = \begin{cases} 
1 & \text{if } (X_j - X_i) > \theta \\
0 & \text{if } (X_j - X_i) = \theta \\
-1 & \text{if } (X_j - X_i) < \theta 
\end{cases}
\] (3)

If the data points are greater or equals to 10, the S statistic will follow the normal distribution. Meanwhile the mean of \( E(S) = 0 \) and the variance are calculated using equation 4, taking \( t_i \) as the ties of the sample time series.

\[
Var(S) = \frac{N(N-1)(2N+5) - \sum_{k=1}^{N} t_k (t_k - 1)(2t_k + 5)}{18}
\] (4)

Here, the test statistics Z is estimated using equation 5, where Z follows a standard distribution with a positive Z representing an increasing trend while a negative represents a decreasing trend.
Sen’s Slope Estimator
In order to estimate the true slope, the Sen’s non-parametric method is used [16]. This method is used to
detect the magnitude of the trend and is calculated using equation 6.

\[
T = \frac{X_j - X_k}{j - k}
\]  

(6)

Here \( X_j \) and \( X_k \) represent data values at time \( j \) and \( k \) \((j > k)\) respectively. Hence, the slope each observation
is estimated using equation 7. Whereas median is calculated from \( N \) observations of the Sen’s Slope using
equation 8.

\[
Q = Q\frac{N + 1}{2} \quad \text{if} \quad N \text{ is odd}
\]

(7)

\[
Q = \left( \frac{1}{2} \right) Q\left[ \frac{N}{2} \right] + Q \quad \text{if} \quad N \left[ \frac{N + 2}{2} \right] \quad \text{if} \quad N \text{ is even}
\]

(8)

Here \( N \) Slope observations are shown as Odd, whereas the Sen’s Estimator is calculated as \( Q_{\text{med}} = (N+1)/2 \),
whereas the even times of observations, the Slope estimate is calculated as \( Q_{\text{med}} = [(N/2) + ((N+2)/2)]/2 \). In
order to achieve the true slope for the non-parametric test in the series, the two-sided test is carried out at
100(1 – \( \alpha \)) % of the confidence interval. Therefore, the positive or negative slope \( Q \) is achieved as upward
(increasing) or downward (decreasing) trend [16].

4. Results and Discussion
4.1 Trend analysis
The purpose of this study was to determine the monthly, seasonal and annual rainfall pattern in relation to
climate change. The analysis was done using the Mann-Kendall Sen’s test. In addition, manual analysis
was carried out with the aid of Excel worksheet.

The results of average monthly rainfall distribution for both Ladysmith and Van Reenen gauging stations
are presented in Figure 2. The average values of rainfall ranged from 32.10 to 56.41 mm during the autumn
season, while during spring season average values lay between 54.6 and 74.85 mm. In contrast, both of
these areas experienced the lowest values during the winter season, whose values were 8.5 and 14.02 mm.
Hence, the largest value was observed during summer season mainly between December and February with
average values between 122.24 and 134.60 mm. It appears that most of the increase in rainfall was in spring and summer seasons. These findings suggest that the study area is potentially at risk of flooding during the summer season.

Figure 2. Annual precipitation data variation for Ladysmith and Van Reenen rain gauge stations upstream and downstream of the Klip River Catchment (1985-2018)

Results of the mean annual rainfall are presented in Figure 3 and 4. From figure 3, the highest average value of 1618.8 mm was recorded in 1996 while the lowest value of 783.8 mm recorded in 1992. The average rainfall for these 34 years was calculated as 1136.7 mm. The estimated linear model equation for the mean annual rainfall was obtained as $y = 4.4757x - 7821.4$. From figure 4, it is shown that the rain gauge with the highest annual average rainfall of 2801.06 mm was in Van Reenen. Chelmsford, Eendracht, Rhenosterfontein, Ladysmith and Wagendrift revealed below normal average annual rainfall with values 830.67 mm, 902.86 mm, 820.11 mm, 698.48 mm and 766.73 mm respectively. The average annual rainfall linear model equations for Ladysmith and Van Reenen were established as $y = -10.441x + 881.2$ and $y = 50.1x + 1924.3$ respectively.

Figure 3. Mean annual rainfall of the study area (1985-2018)
4.2 Trend analysis for the period 1985-2018 for monthly rainfall

Table 2 shows the results of Mann Kendall test for the study period for individual months. Result showed that Ladysmith had a decreasing rainfall in February, March, April, May, June and July and increasing rainfall in January, August, September, October, November and December. From these statistically values, it is shown that six months had a positive rainfall trend and the other six months had negative rainfall trend which represent a non-significant condition. Similarly, for Ladysmith Sen’s Slope, there is a positive trend for January, August, September, October, November and December with Q values 0.058, 0.090, 1.326, 0.802, 2.705 and 1.050 respectively. The other six months showed a negative trend. However, the Mann-Kendall test result is different for Van Reenen which shows seven months increasing rainfall trend in January, February August, September, October, November and December and decreasing rainfall in March, April, May, June and July. Hence, the Sen’s Slope show a positive trend in January, February, August, September, October, November and December months whose Sen’s slope values (Q) results were 0.073, 0.0253, 0.091, 0.364, 0.569, 1.933 and 2.90 respectively.

Table 2. The results of Mann Kendall test for Monthly rainfall (1985-2018)

| Month   | Chelmsford | Wagendrift | Van Reenen | Ladysmith | Eendracht | Rhenosterfontein |
|---------|------------|------------|------------|-----------|-----------|------------------|
| Z       | Q          | Z          | Q          | Z         | Q         | Q                |
| JANUARY | -2.70      | -2.14      | -1.33      | 0.04      | 0.073     | 0.73             | -1.84 | -1.338 | -1.63 | -1.262 |
| FEBRUARY| -0.09      | -0.15      | -0.65      | 0.12      | 0.253     | -0.86           | -0.30 | -0.184 | -1.47 | -1.061 |
| MARCH   | 0.98       | 1.08       | -0.34      | -1.20     | -1.575    | -2.76           | -2.209| 0.87   | 0.904| -0.46  | -0.425 |
| APRIL   | 0.50       | 0.88       | -0.78      | -2.95     | -2.300    | -3.53           | -3.187| -0.24  | -0.313| -0.16  | -0.323 |
| MAY     | -3.17      | -3.54      | -1.73      | -3.43     | -2.975    | -4.09           | -2.956| -1.90  | -2.167| -1.53  | -1.848 |
| JUNE    | 0.15       | 0.06       | -0.53      | -2.36     | -0.800    | -3.16           | -1.867| -1.01  | -0.900| 0.19   | 0.164  |
| JULY    | 0.83       | 0.45       | -0.09      | -0.53     | -1.116    | -2.38           | -0.267| -0.58  | -0.221| 0.27   | 0.098  |
| AUGUST  | -0.27      | 0.00       | 1.47       | 0.27      | 1.30      | 0.091           | 0.61  | 0.053 | 0.81  | 0.050 | 0.58   | 0.053 |
| SEPTEMBER| -1.15     | 0.00       | -0.89      | -0.07     | 1.28      | 0.364           | 0.40  | 0.090 | -0.54 | 0.000 | -1.91  | -0.198 |
| OCTOBER | 0.51       | 0.00       | -0.08      | 0.00      | 0.88      | 0.569           | 2.27  | 1.326 | -0.85 | 0.000 | -0.19  | 0.000 |
| NOVEMBER| -0.12      | 0.00       | 0.43       | 0.01      | 1.63      | 1.933           | 0.85  | 0.802 | -0.68 | -0.143| -0.51  | -0.062 |
| DECEMBER| 1.04       | 0.31       | 0.31       | 0.06      | 1.82      | 2.900           | 1.88  | 2.705 | -0.31 | -0.050| -0.24  | -0.075|

Figure 4. Comparison of mean annual rainfall for six (6) stations in and around Klip River catchment (1985-2018)
4.3 Trend analysis for the period 1985-2018 for seasonal and annual rainfall

Table 3 shows the results of seasonal and annual rainfall determined by the Mann-Kendall test for the six meteorological stations. For seasonal analysis, the seasons during the year were divided into four seasons, namely winter (June, July, August), spring (September, October, November), summer (December, January, February), and autumn (March, April, May). The Mann-Kendall test found that generally all stations in the study area showed decreasing annual rainfall trends during the evaluated period. Also, all stations showed major decreasing rainfall during the autumn season. In winter, a decrease in rainfall was confirmed in Van Reenen, Ladysmith, Wagersdrift and Eendracht, while Chelmsford and Rhenosterfontein stations showed an increasing trend in rainfall. The Mann-Kendall test also found minor positive rainfall trends during spring and summer in Ladysmith, Wagersdrift and Van Reenen. Thus, the decreasing trends in rainfall are dominant during autumn and winter compared to spring and summer.

Table 3. The results of Mann Kendall test for seasonal and annual rainfall (1985-2018)

| Stations      | Annual | Autumn | Winter | Spring | Summer |
|---------------|--------|--------|--------|--------|--------|
| Van Reenen    | -2.18  | -3.57  | -2.06  | 1.16   | 0.73   |
| Ladysmith     | -3.05  | -4.12  | -3.19  | 1.32   | 0.92   |
| Wagersdrift   | -0.68  | -1.33  | -1.41  | 0.52   | 0.18   |
| Chelmsford    | -0.68  | -0.50  | 0.59   | -1.14  | -1.54  |
| Rhenosterfontein | -1.38  | -1.38  | 0.87   | -0.67  | -2.09  |
| Eendracht     | -0.68  | -0.98  | -0.99  | -0.31  | -1.16  |

5. Conclusions

The purpose of the current study was to determine the monthly and annual rainfall pattern in relation to climate change. The trends analysis of the monthly, seasonal and annual rainfall were analyzed with the Mann–Kendall test and the Sen’s slope estimator for 6 stations in the Klip River catchment during 1985–2018. Results of this study indicated a combination of positive and negative trends at various stations. In Ladysmith, rainfall trends were positive in January, August, September, October, November and December and were negative in February, March, April, May, June and July. However, the Mann-Kendall test result revealed a different for Van Reenen which shows seven months increasing rainfall trend in August, September, October, November, December, January, and February and decreasing rainfall trend in March, April, May, June, and July. Seasonally, a major significant decreasing trends were detected in autumn and winter in Ladysmith and Van Reenen. On the other hand, a minor increasing trends were seen in spring and summer seasons in Ladysmith and Van Reenen. Although the results presented here do not show a major significant increase in seasonal rainfall, they are potentially large enough to affect the flood in Ladysmith town. Based on the analysis, it can be concluded that climate change has an impact on the rainfall spatial pattern of the study area. This results correlates well with similar analysis carried out in other areas around the world. However, further research in other parameters such as temperature and evaporation are essential in confirming whether climatic changes might have affected the temperature pattern in the study area.
Acknowledgments
The author acknowledge financial support from University of South Africa and Tshwane University of Technology. I also acknowledge the South African Weather Services, and Department of Water and Sanitation for providing the data used in this study.

References
[1] Gajbhiye S, Meshram C, Singh S K, Srivastava P K and Islam T 2016 Precipitation trend analysis of Sindh River basin, India, from 102-year record (1901–2002) *Atmospheric Science Letters* 17 1 71-77
[2] Kassile T 2013 Trend analysis of monthly rainfall data in central zone *Journal of Mathematics and Statistics* 9 1 1
[3] Suhaila J, Deni S M, Zin W Z W and Jemain A A 2010 Spatial patterns and trends of daily rainfall regime in Peninsular Malaysia during the southwest and northeast monsoons: 1975–2004 *Meteorology and Atmospheric Physics* 110 1-2 1-18
[4] Karpouzos D.K, Kavalieratou S and Babajimopoulos C 2010 Trend analysis of precipitation data in Pieria Region (Greece) *European Water* 30 31-40
[5] Muhire I and Ahmed F 2015 Spatio-temporal trend analysis of precipitation data over Rwanda *South African Geographical Journal* 97 1 50-68
[6] Kruger A C 2006 Observed trends in daily precipitation indices in South Africa: 1910–2004 *International Journal of Climatology: A Journal of the Royal Meteorological Society* 26 15 2275-2285
[7] Roy S S and Rouault M 2013 Spatial patterns of seasonal scale trends in extreme hourly precipitation in South Africa *Applied Geography* 39 151-157
[8] Mason S J, Waylen P R, Mimmack G M, Rajaratnam B and Harrison J M 1999 Changes in extreme rainfall events in South Africa *Climatic Change* 41 2 249-257
[9] Mason F G and Bell T R 1998 The problem of flooding in Ladysmith, Natal, South Africa *Geological Society, London, Engineering Geology Special Publications* 15 3-10
[10] Roor A M, Rottink M E, Schep B A, Spielmann P, Waqué A E, Zande B J, van de 2016 *Project Ladysmith CIE4300*. Delft University of Technology, Nederland
[11] ELMSEPT 2012 Ladysmith/Emnambithi Municipality Spatial Development Framework Consolidated. Report: First Draft. Ladysmith/Emnambithi Municipality, South Africa
[12] De Silva R P, Dayawansa N D K and Ratnasiri M D 2007 A comparison of methods used in estimating missing rainfall data *Journal of agricultural sciences* 3 1 2 249-257
[13] Salmi T, Määttä A, Anttila P, Ruoho-Airola T and Amnell T 2002 Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen’s slope estimates *Publication on air quality, Finish Meteorological Institute* 35 Google Scholar
[14] Ali M H, Abustan I, Rahman M A and Haque A A M 2012 Sustainability of groundwater resources in the North-Eastern Region of Bangladesh *Water resources management* 26 3 623-641
[15] Zeleneáková M, Purcz P, Blištán P, Vranayová Z, Hlavatá H, Diaconu D and Portela M 2018 Trends in Precipitation and Temperatures in Eastern Slovakia (1962–2014) *Water* 10 6 727
[16] Sarkar A A and Ali M H 2009 Water table dynamics of Dhaka city and its long-term trend analysis using the “MAKESENS” model *Water International* 34 3 373-382