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Analysis of Temperature Trend in the Klip River catchment, KwaZulu Natal, South Africa

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ABSTRACT: Detecting changes in temperature is necessary in order to develop sustainable adaptation and mitigation measures at a regional and local scale. The impact of climate variability on communities has different effects such as natural disasters, including floods pose serious risks to communities. Lady smith town experiences flood almost every year in the past 110 years, this has had major socio-economic effects particularly in the central business district as well as on some surrounding urban areas.Thus, this study analyses and detects trends in monthly, seasonal, and annual temperature for the Klip river catchment using a non-parametric Mann-Kendall and Sen's Slope Estimator. Historical minimum and maximum temperature data for the period from 1993 to 2018 were obtained from the South African Weather Service (SAWS). The study results showed slight warming or increasing trend in average seasonal minimum and maximum temperatures, with the Mann-Kendall test values of 1.45 °C, 0.71 °C, 1.43 °C, and 1.23 °C during summer, spring, autumn, and winter respectively. Monthly, a positive trend in temperature is depicted throughout the year. These results will assist policymakers to improve their national and local strategies to minimize risks associated with climate change.

Keywords: Klip River catchment, Ladysmith, Mann-Kendall Test, Non-parametric, Sen's Slope Estimator, Temperature.

I. INTRODUCTION

Temperature trend analysis has been a major focus in the recent past because of the attention given to climate change by the scientist and engineering community. As a result, ithas been considered as one of the most significant components of climatic parameters, and also, a starting point towards the study of hydrology, climatology, and meteorology throughout the world [1]. According to Ojo and Ilunga [2], the global average temperature is expected to increase by 1.8°C to 4°C by the end of the 21st century. In Africa, a range of models indicated that temperature would increase by 3 to 4°C by the end of the same century, 2100 [3]. While in South Africa, temperature generally warmed by 2°C over the past 100 years and is projected to increase by 4°C before the end of the 21st century [4]. An increase in temperature may result in heat-wave incidents, cause diseases and deaths in susceptible populations. Moreover, an increase in temperature may lead to more evaporation and cloud formation, which, in turn, increases rainfall [1], as a result, increase the intensity and frequency of flash flooding [5]. According to [6], over the past 110 years, Ladysmith experiences floods almost every year, with the most recent floods occurred in February 1994 and January 2011. These have resulted in the loss of lives and disruption of businesses particularly in the central business district as well as in some surrounding urban areas. Ngcobo [7] reported that an increase in temperatures is likely to continue in Ladysmith, and flooding to become more frequent and intense. To solve this problem, policymakers should have proper planning and management of future flood risk [8]. Thus, an insight into the temperature trends is essential for the proper planning and management of future climatic conditions [9]. Trend analysis has become an important tool in understanding how temperature change with time [10]. Various statistical test techniques are used to detect temperature trends and are classified as parametric and non-parametrictests [10]. Totaro *et al.,* and Mirabbasi *et al.,* [11, 12] explained the reasons for the use of non-parametric as opposed to parametric method in analyzing trends. According to Totaro *et al.,* [11], non-parametric tests do not require knowledge of the parent distribution, and their properties strongly rely on the choice of the null hypothesis. Whileparametric methods require the selection of the parent distribution and the estimation of its parameters but are not necessarily associated with a specific null hypothesis [12]. Ahmad *et al.,* [13] reported that parametric methods are very sensitive to the presence of outliers in the data series, whereas non-parametric methods can be applied to both the linear time series, as well as the non-linear time series, andproduce much better results than parametric ones. Various studies have been given high attention in detecting the trend in climate variables, including temperature. In Turkey, Kadioğlu *et al.,* [14] examined the seasonal and annual maximum and minimum temperatures using the Mann–Kendall test. The findings contained in the study suggest that the mean annual temperature records in Turkey have a warming trend over the period between 1939 and 1989, and the cooling trend from 1955 to 1989. Djaman *et al.,* [15] performed trend analysis in the historic data sets of annual precipitation, maximum and minimum temperatures across the southwest United States. Eighteen ground-based weather stations were considered across the southwest United States period from 1902 to 2017. The non-parametric Mann–Kendall test method was used for trend analysis and Sen's slope estimator was used to derive the long-term average rates of change in the parameters. The results showed an increasing trend in annual maximum temperature at rates that varied from 0.6 to 3.1 °C per century. While cooling varied from 0.2 to 1.0 °C per century. The average annual minimum temperature had increased at rates that varied from 0.1 to 8 °C over the last century. In Africa, Nsubuga *et al.,* [16] analyzed the rainfall and temperature trends at Namulonge parish, in the Wakiso district of Uganda using the Mann-Kendall test and linear regression techniques. Results showed an increase in maximum temperatures during the months between April and September, displaying an increasing trend at 5% confidence level. Ragatoa *et al.,* [17] investigated the seasonal, annual temperature, and rainfall trends in Nigeria using parametric (Linear regression) and non-parametric (Mann-Kendall and Sen's slope) tests. Meteorological data spanning from 1970 to 2010 were used for analysis. The result of the linear regression on temperatures and rainfall showed increasing trends in most of the locations across the country. Similarly, Mann-Kendall and Sen's slope analysis showed a significant increasing trend in most areas across the country. In Ethiopia, Mohamed and El-Mahdy [18] investigated the annual and monthly temperature trends in the Blue Nile basin using ten meteorological station data from the period from 1950 to 2018. The statistical significance of the trend was calculated using the Mann-Kendall test. Results showed that the annual maximum and minimum temperatures were increasing significantly with a magnitude of 0.037 °C and 0.025°C per decade respectively. The study further revealed an increasing trend in maximum and minimum temperatures during the study period. Sibanda *et al.,* [19] examined the Spatio-temporal temperature and extreme weather events in the Mzingwane catchment of southern Zimbabwe for the period spanning from 1967 to 2015. The non-parametric Mann–Kendall test method was used for the significance of the trend analysis and Sen's slope estimator was used to derive the long-term average rates of change in the parameters. The results for annual anomalies showed a strong positive anomaly (44°C warmer) at all stations for the summer months, while winter months recorded cool anomaly averaging 28°C. In South Africa, Tshiala *et al.,* [20] conducted a study on temperatures over Limpopo Province. The results depicted an increase of 0.12°C per decade in the mean annual temperature for the 30 catchments analyzed. The study further revealed that out of the 30 catchments, 13% showed a negative trend while 87% showed a positive trend in their yearly mean temperature. An increase was recorded in the mean temperature of about 0.18°C per decade during winter and 0.09ºC per decade during summer. Another study carried out by Kalumba *et al.,* [21] on rainfall and temperature records for the West Bank in the East London area covering the period between 1975–2011. The findings showed that minimum and maximum annual mean temperatures experienced an increasingly statistically significant trend of less than 0.05 at 95% confidence level. While February recorded the highest mean monthly temperature of 21.8°C, July recorded the lowest temperature value of 12.6 °C. Seasonal mean maximum temperature trends were statistically not significant with a value of 0.10. However, autumn minimum temperatures revealed a statistically significant trend value of less than 0.1°C. Kruger and Shongwe [22] studied the temperature trends of using 26 stations in South Africa covering the period from 1960 and 2003. Out of 23 stations, the study found that 21 stations showed a positive trend in annual mean minimum temperatures. The average yearly temperature data series of 24 stations showed positive trends. Trends of mean seasonal temperature showed that temperature trends are not consistent throughout the entire year, with an average trend for autumn showing a maximum and spring a minimum. Muhlenbruchtegen [23] studied the long-term surface changes in temperature in South Africa to establish trends in mean, minimum, and maximum temperatures. The period considered was from 1940 to 1989. Results showed a significant increase in maximum temperatures, while minimum temperatures showed a significant downward trend. Also, the trends seemed to change with the season; in spring the maximum temperatures trend were negative and minimum temperatures trends were positive. In autumn, changes in maximum temperatures were positive and minimum temperatures were negative. From the above literature reviewed, it is evident that temperature trend analysis was conducted in different parts of the world, including South Africa. However, there is still a lack of information on trends and variability of temperature in the Klip river catchment, KwaZulu Natal. According to Thapa *et al.*, [9], understanding temperature trends in the study area will assist in planning for future extreme conditions as well as assessing the effectiveness of climate change mitigation policies and strategies. Therefore, this study aimed at using the non-parametric Mann-Kendall and Sen's slope test to detect a trend in temperature from 1993 to 2018. Mann-Kendall Test was selected for the analysis because of its relevance for a time series distribution. Furthermore, the test is suitable for both non-monotonic and monotonic trends, simple and robust as well as able to deal with values below maximum detection and missing values. This test can also achieve both the detection test statistics "S" and normalized test (Z) statistics. Mann-Kendall and Sen's slope test give much better results than parametric ones.

II. MATERIALS AND METHODS

The Klip River catchment is one of the major sub-catchments in the uThukela catchment. It is situated in the uThukela District municipality in the KwaZulu-Natal province between latitudes 28°39′53″ south and 29°57′42″ east, with an area of 1670 km^2 (Fig. 1). The Klip River is the main tributary of the Tugela River in

KwaZulu-Natal. The river originates from the west side of KwaZulu-Natal and it flows into the Windsor Dam until the larger Qedusizi Dam. The river passes through Ladysmith and has a drainage area of approximately 1670 km^2. The town of Ladysmith is located downstream of the Klip River catchment, and as a result, any hydrological changes upstream may have an impact on flood inundation in the lowlands of Ladysmith [24].

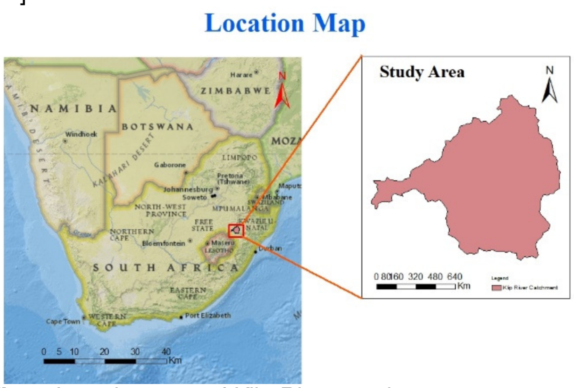


Fig.1. Location map of Klip River catchment.

This catchment is characterized by warm weather conditions during the summer season and cold weather during the winter season. In winter, temperatures range from minimum of 0.7 ℃ to 23 ℃ whereas, in summer, temperatures range from a minimum of 9.3 ℃ to a maximum of 28.5 ℃. The highest temperatures are experienced in January, and the low temperature in July dropping to the average value of 3 ℃ during the night. The mean annual precipitation of this study area has been reported to be between 700 mm and 1000 mm per year by Chabalala *et al.,* [24].

A. Data Sources and Statistical Analysis Techniques

Temperature Data

In this study, historical long-term temperature data were used in the analyses of temperature trends for the period between 1993 and 2018 in the Klip River catchment in Ladysmith. The long-term temperature data was collected from the South African Weather Services (SAWS), and only two stations, namely Ladysmith and Van Reenen were considered (Table 1). These stations are situated inside the study area and they all have similar altitudes varying between 1069 m and 1683 m.

Table 1: Details of meteorological stations in the study area.

Geographical parameters			
Stations	**Latitude**	**Longitude**	**Period**
Ladysmith	-28.575	29.750	1993 to 2018
Van Reenen	-28.366	29.378	1993 to 2018

B. Trend Analysis

Trend analysis is considered as one of the most important topics in solving problems related to changing climatic parameters such as temperature, wind speed, and rainfall. An analysis of station by station historical records revealed differences in almost all the records available. As such, all the stations that had less than 10% of missing data were used in this study. Also, in stations where missing data was encountered, the average value of the previous and following values was used to fill the gap as proposed by Gyamfi *et al.,* [25].

In this study, the magnitude and the significance of the trend in a time series were determined using a nonparametric method known as Mann–Kendall and Sen's estimator test [26]. The Mann-Kendall test statistic procedure has been explained [26, 27, 28]. The Mann–Kendall test has been extensively used in various studies to detect monthly, seasonal and annual trends in hydrological and climatic data such as wind speed, streamflow, as well as temperature [29]. The advantage of using the Mann-Kendall Sen's test is that it is appropriate for both non-monotonic and monotonic trends [24] and is simple and robust as well as able to deal with values below maximum detection and missing values [30]. On the other hand, this test can also achieve both the detection test statistics "S" and normalized test (Z) statistics [24]. The Mann-Kendall trend starts with the estimation of the test statistic (S) using equation 1 [24].

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} Sgn\left(X_j - X_i\right) \quad \ldots(1)$$

In equation (1), N stands for the number of data points and X_i being the actual time for a time series of i = 1, 2, 3… N. Assuming $(X_j - X_i) = \theta$, the value of Sgn (θ) is calculated using equation 2.

$$Sgn(\theta) = \begin{Bmatrix} 1 & if & (X_j - X_i) & > \theta \\ 0 & if & (X_j - X_i) & = \theta \\ -1 & if & (X_j - X_i) & < \theta \end{Bmatrix} \quad \ldots(2)$$

In equation (2), if the data points are greater or equal to 10, then, S statistic will follow the normal distribution. Meanwhile, the mean of E(S) = 0 and the variance are calculated using equation 3, taking t_i as the ties of the sample time series.

$$Var(S) = \frac{N(N-1)(2N+5) - \sum_{k=1}^{N} t_k (t_k - 1)(2t_k + 5)}{18} \quad \ldots(3)$$

Then, the normalized statistic (Z) is estimated using equation 4, where Z falls in a normal distribution with a positive Z representing an increasing trend while a negative Z represents a decreasing trend.

$$Z = \begin{Bmatrix} \frac{S-1}{\sqrt{Var(S)}} & if & S > 0 \\ 0 & if & S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if & S < 0 \end{Bmatrix} \quad \ldots(4)$$

C. Sen's Slope Estimator

Sen's slope estimator is a non-parametric method and it is used to estimate the true slope of an existing linear trend using equation 5 [15].

$$T = \frac{X_j - X_k}{j - k} \quad \ldots(5)$$

In equation (5), X_J and X_k represents the data values in j and k where j > k. Hence, the slope of each observation is estimated using equation 6. The median is calculated from N observations of the Sen's Slope using equation 7.

$$Q = Q\frac{N+1}{2} \quad if \quad N \quad is \quad odd \quad \ldots(6)$$

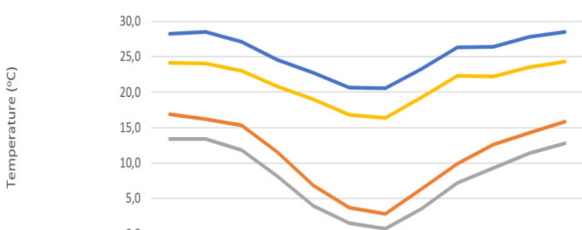
$$Q = \left(\frac{1}{2}\right)Q\left[\frac{N}{2}\right] + Q \quad if \quad N\left[\frac{N+2}{2}\right] \quad if\, N \quad is \quad even \quad \ldots(7)$$

In equations (6) and (7), N represents the slope of observations and are shown as odd numbers, and Q represents the Sen's Estimator and is calculated as $\boldsymbol{d} = \frac{\boldsymbol{N+1}}{\boldsymbol{2}}$. The Slope estimate for the even observations is calculated as $\boldsymbol{Qmed} = \left[\left(\frac{N}{2}\right) + \left(\frac{N+2}{2}\right)\right]/\boldsymbol{2}$. To achieve the non-parametric slope test, the two-sided test is achieved at 100(1 – α) % of the confidence interval. Therefore, positive or negative Q_i is achieved as an upward (increasing) or downward (decreasing) trend.

III. RESULTS AND DISCUSSION

A. Trend analysis

The main objective of this study was to analyse and detect trends in the long-term minimum and maximum temperatures using the Mann-Kendall Sen's test. Also, a manual analysis was carried out with the aid of an Excel® worksheet. The results of the monthly minimum and maximum temperatures for both Ladysmith and Van Reenen stations are presented in Fig. 2.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lasysmith maximum	28,3	28,5	27,1	24,5	22,7	20,7	20,5	23,3	26,3	26,4	27,8	28,5
Lasysmith minimum	16,9	16,2	15,3	11,6	6,9	3,7	2,8	6,3	9,9	12,6	14,3	15,8
Van Reenen minimum	13,4	13,4	11,8	8,1	3,9	1,5	0,7	3,6	7,2	9,3	11,3	12,8
Van Reenen maximum	24,1	24,1	23,0	20,8	18,9	16,8	16,4	19,2	22,3	22,2	23,5	24,3

Fig. 2. Monthly minimum and maximum temperature for Ladysmith and Van Reenen stations.

The figure shows that the temperature is low in June and July, starts increasing from August reaching its peak in February. Also, it can be observed that both stations have similar temperatures pattern although the temperatures at Ladysmith station are higher than at Van Reenen station. The figure further shows that maximum temperatures occurred during December and January for Ladysmith station with values approximately 28.5˚C and 28.3˚C respectively, whereas Van Reenen recorded the maximum temperatures of values approximately 24.3˚C and 24.1˚C respectively during December and February.

Also, Van Reenen recorded the lowest temperatures of 1.5˚C, 0.7˚C, and 3.6˚C in June, July, and August respectively.

The results of the annual minimum, maximum, and average temperatures between 1993 and 2018 are summarized in Fig. 3 and 4. Ladysmith station showed the maximum temperature record of 28℃ in 2015, whereas Van Reenen station recorded a maximum temperature of 22.9℃ in the same year 2015. The estimated linear model equation for the average annual temperature obtained was y = 0,0233x + 16,132.

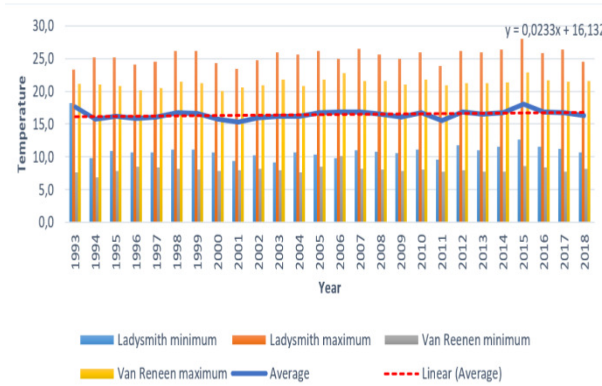


Fig. 3. The annualminimum, maximum, and the average temperatures of the study area (1993-2018).

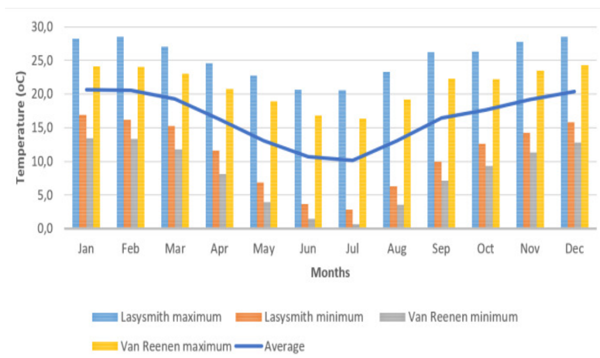


Fig. 4. Comparison of average, minimum and maximum monthly temperatures (1993-2018).

The Mann Kendall test was applied at Klip River catchment for each monthly minimum and maximum temperature for the period from 1993 to 2018. The results presented in Table 2 shows that there is an increasing temperature trend throughout the year. It can be observed that the highest maximum temperature occurred during December and January where the temperature recorded was about 28.5℃ and 28.3℃ at Ladysmith station. Van Reenen station observed the highest maximum temperature during December and February where the temperature recorded was about 24.3℃ and 24.1℃. Van Reenen station recorded the lowest minimum temperature in June, July, and August with values of about 1.5℃, 0.7℃, and 3.6℃ respectively. The trend in average annual revealed that temperature is increasing, also, the annual average temperature, maximum temperature shows an increasing trend.

Table 2: Trend analysis for the period 1993-2018 for monthly temperature.

	Temperature (℃)		
Months	**Maximum Z-Values**	**Minimum Z-Values**	**Average Z-Values**
January	0.97	1.28	1.13
February	1.29	0.43	0.86
March	1.61	0.79	1.20
April	0.96	0.53	0.74
May	1.90	1.04	1.47
June	1.50	1.40	1.45
July	0.57	0.01	0.29
August	1.16	0.61	0.88
September	1.36	0.47	0.92
October	1.39	-1.14	0.13
November	1.32	0.14	0.73
December	0.52	0.93	0.72

B. Comparison of the seasonal and annual average temperature for two stations (1993-2018)

Table 3 shows the results of the annual and seasonal minimum, maximum, and average temperatures determined by the Mann-Kendall test for the two stations. In South Africa, seasons are divided into four with three months each. These seasons are known as winter (June, July, August), spring (September, October, November), summer (December, January, February), and autumn (March, April, May). The trend statistics for the seasonal temperatures (Table 3) show that there is an increasing trend in minimum temperatures during autumn, spring, and summer. Hence, the minimum temperature during the spring season showed a decreasing trend at the time when the maximum temperature had an increasing trend. The maximum temperature recorded an increase in autumn, winter, spring, and summer with Mann-Kendall values of 1.57℃, 1.76℃, 1.95℃, and 1.71℃ respectively. The lowest temperature occurs during the spring season, while the highest temperature occurs during the same season (spring) with amounts of -0.54 and 1.95 respectively. The lowest amount of average temperature in this season occurs in spring, and the highest amount of rainfall also occurs in spring as reported by Chabalala *et al.,* [24].

Table 3: The results of the Mann Kendall test for average seasonal and annual temperature (1993-2018).

	Temperature (°C)		
	Maximum Z-Values	**Minimum Z-Values**	**Average Z-Values**
Annual	2.27	0.79	1.53
Autumn	1.57	1.29	1.43
Winter	1.76	0.71	1.23
Spring	1.95	-0.54	0.71
Summer	1.71	1.19	1.45

Therefore, these results correlate well with similar analyses carried in South Africa. For example, Van der Walt and Fitchett [31], applied the Mann-Kendall test, Spearman rank correlation coefficient, and Sen's slope to determine temperature trend using the data covering the period 1960 to 2016. They found that the annual maximum temperature in South Africa had increased by 0.02℃ per year. Another identical result was found in the work of Lakhraj-Govender and Grab who applied a modified Mann-Kendall test to determine the temperature trends for the entire KwaZulu Natal province. The Mann-Kendall test results showed an increasing trend of 0.07 ℃/decade for both annual minimum and maximum temperature for the period from 1930 to 2015 [32].

IV. CONCLUSION

The objective of this study was to analyse and detect monthly, seasonal, annual minimum, and maximum temperature trendsusing the Mann-Kendall and Sen's slope estimator. This paper presents trend results for the period from 1993 to 2018 of minimum and maximum temperatures obtained from two stations in the Klip River catchment. From the analysis, it has been observed that the seasonal temperatures show slight warming or increasing trend in average seasonal minimum and maximum temperatures, with the Mann-Kendall test values of 1.45 °C, 0.71 °C, 1.43 °C, and 1.23 °C during summer, spring, autumn, and winter respectively. Also, on average, the temperature over the entire catchment increased by 1.56℃ per year. Considering all the seasons (autumn, winter, spring, and summer), the study also revealed an increasing trend in minimum temperature in all seasons except spring which showed a minor decrease of 0.54℃ over the study area. Therefore, it can be concluded that the catchment is experiencing an increase in temperature during the study period. These results will be useful for understanding the temperature changes in the Klip river catchment.Also, assist policymakers to improve their national and local strategies to minimize risks associated with climate change.

V. FUTURE SCOPE

The current study will be helpful to policymakers such as governments and research organizations to understand the seasonal variation of temperatures in different seasons. This study can also contribute to the future climate change mitigation policies by governments and organizations.

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Conflict of Interest: The authors confirm that there are no conflicts of interest.

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