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Spatial and Temporal Variations of Monthly Maximum and Minimum Temperatures in South Africa from 1958 to 2020

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Abstract

Since the 20th century, climate change has been one of the most pressing and widespread issues that human societies on Earth have faced. South Africa's susceptibility to climate variability and change is considerably pronounced as a result of the nation's significant reliance on rain-fed agriculture and natural resources, elevated poverty rates, especially in rural regions, and a limited capacity for adaptation. To that end, trend analysis has been employed to inspect the change of maximum and minimum temperature in South Africa using 18 meteorological stations were used to gather monthly maximum and minimum temperature data. The long-term trends and changes in annual and seasonal maximum and minimum temperature series for all stations were examined. According to Mann-Kendall tests, there is a prevailing positive temperature trend over much of South Africa, with the rate of change ranging between 0.2-0.3 and 0.1-0.2 °C/decade for maximum and minimum temperatures, respectively. South Africa has already seen considerable temperature increases since the 1960s, with more marked increases across arid, inland areas of the country. The rate of temperature change has varied, with the highest rates of increase in the mid 1970s to early 1980s and again in the late 1990s to mid 2000s. Results of the study have led to the following main conclusions: (1) statistically significant increasing (warming) trends were found in mean maximum and minimum temperatures. (2) Statistically significant and the strongest warming trend showed up mainly in maximum and minimum temperatures at all stations in all seasons; (3) Increasing trends in maximum temperatures were not as strong as in mean minimum temperatures at all stations; (4) Warmer than long-term average temperature conditions in the series was evident especially after the year 2020; (5) Also, the maximum temperature increase (0.3°C/decade) is greater than minimum temperature (0.2 °C/decade). A more definite trend of warming occurs in winter and autumn than summer and spring of maximum temperature. Moreover, the results show that the warm climate regions in South Africa are warming at a higher rate than cold climate regions.

Keywords: Maximum and minimum temperature; variability trend analysis; Sen's and Man-Kendall and South Africa.

1. Introduction

Understanding the behaviour of surface air temperature, which can vary spatially and temporally at various local, regional, and global scales, is crucial because it is one of the most crucial factors in weather and climate forecasting. The International Panel on Climate Change (IPCC) has unequivocally determined that between 1880 and 2012, global temperature trends show a warming of 0.85 (0.65– 1.06 °C) [1]. As a result, both domestic and international academics have paid close attention to extreme climate change. From the 20th century to the start of the 21st century, there has been a clear warming trend in the global scope as evidenced by the highest trend for the minimum temperature indices, an increase in extreme temperatures, and a decrease in cold extreme values. On a global scale, there have been fewer cold days and nights since 1950, while there are more warm ones [2]. The scientific community has recently paid a great deal of attention to climate change because of its potential effects on Earth system processes at various scales. Domestic and overseas pupils have surprisingly mature researches on the spatio-temporal modifications and traits of excessive temperatures, and there are additionally greater researches on the spatio-temporal adjustments of intense temperatures in Africa and arid areas in South Africa. Research

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confirmed that in the previous 50 years, research on temperature show a general rising trend (warming) in global mean surface temperature over the past century, with a varied pace between 0.3°C and 0.6°C [3]. According to estimates, the temperature has risen by 0.6 degrees Celsius on average over the past century and could rise by 1.4 to 5.8 degrees Celsius by the year 2100 [4]. Additionally, according to [5], regardless of the time of year, West Africa, East Africa, South Africa, and the Sahara are expected to suffer a temperature increase of 3°C to 4°C between 1900 and 2100. In example, according to a regional research [6], South Africa will experience an average temperature increase of 1.5°C near the coast and 2°C to 3°C inland in the coastal mountains by 2050. Additionally, the study by Kruger and Shongwe demonstrates that the average temperature increased by 0.13°C between 1960 and 2003 [7]. In South Africa, the effects of climatic changes around the world are getting worse quickly. Temperatures could increase more than (4°C) over the interior of southern Africa by 2100 and (6°C) over South Africa's western, central, and northern regions if no coordinated action is taken to reduce greenhouse gas emissions [8].

In South Africa, the temperature followed a similar pattern [4]. Human activity was responsible for the warming that has been experienced over the past 50 years, and if carbon dioxide and other greenhouse gas emissions are not reined in, more rises are anticipated [9]. As a result, the anticipated rise in temperature may change the equilibrium between the Earth and the atmosphere resulting in changes to the hydrological cycle, relative humidity, soil moisture, and evaporation. While the ability to tolerate and adapt is not always strong, the effects of climate change could be quite high, especially since water resources are already severely stressed in many locations [10]. South Africa faces this problem, hence current information is required for effective planning [11]. Southern Africa's climate has warmed dramatically, and it may continue to do so at a rate of up to 0.02 degrees Celsius every year. Continued warming is indicated by spatial maps of ensemble mean predicted trends for temperature and rainfall for the years 1980–2050, especially over the Kalahari (0.4°C/ decade). Over a large portion of the western interior region, projected rainfall trends are mild but somewhat negative [12, 13].

Weather patterns over southern Africa in the age of satellites. In the MIROC A1B model simulations, the temperature trend was over 0.4 °C/year; in the NCDC, HADCRU, CFS-R, and NCEPe datasets, it was between 0.02 °C/year and 0.03 °C/year; in the GHCN observations, it was 0.1 °C/ decade; and in the ECMWF data set, it was close to zero. In both the model simulations and the NCDC measurements, temperature increases were the most significant ($r > 0.5$) [14].

Sen's slope estimator was used to calculate the long-term average rates of change in the parameters, and the non-parametric Mann-Kendall test method was employed to determine the trend analysis' significance. Tshiala et al. investigated temperatures over the province of Limpopo in South Africa. For the 30 catchments that were studied, the results showed an increase in the mean annual temperature of 0.12°C each decade. The study also indicated that, of the 30 catchments, 13% exhibited a negative trend in their yearly mean temperature while 87% showed a positive trend. In winter, there was an average temperature increase of 0.18°C every decade, and in summer, it was 0.09°C per decade [4]. 26 South African weather stations were used by Kruger and Shongwe to study temperature trends between 1960 and 2003. The analysis discovered that 21 of the 23 sites had an upward trend in yearly mean minimum temperatures. Positive trends were seen in the 24 station set of average annual temperature data. The average trend for the autumn showed a maximum and the spring showed a minimum, proving that temperature trends are not constant throughout the entire year [7]. In order to identify trends in mean, minimum, and maximum temperatures, Muhlenbruch-Tegen examined the long-term surface temperature changes in South Africa. The years 1940 to 1989 were taken into account. Results indicated a considerable rise in maximum temperatures and a significant decline in lowest temperatures. Additionally, it appeared that patterns changed with the season; in the spring, a negative trend for maximum temperatures and a positive trend for minimum temperatures were seen. Autumn saw favorable adjustments to maximum temperatures with negative changes to lowest temperatures [15]. It is clear from the literature research that was done above that temperature trend analysis has been done all around the world, including South Africa. The Klip river watershed in KwaZulu Natal still lacks data on temperature trends and variability, though. Understanding temperature patterns in the study area, according to [16], would help with planning for upcoming extreme circumstances as well as evaluating the efficacy of policies and measures for mitigating climate change. By examining trends and seasonal components in the time series data of the climatic factors (T-Max and T-Min) and the periodicity in the recent decades (1958-2020) on monthly and annual data, The outcomes of this paper are expected to facilitate not only a better understanding of extremes of maximum, minimum temperature and their nonlinear trends over South

Africa for the period 1958–2020 but also thus provide an update that will complement previous trends analyses.

2. Material and Methods

2.1. Study area

South Africa is bounded by the Atlantic Ocean to the west and southwest, the Indian Ocean to the south and southeast, and longitudes 17-33°E and latitudes 22-35°S. Along with enclosing Lesotho, it shares political borders with Mozambique, Zimbabwe, Botswana, Namibia, and Swaziland (Figure 1). Temperature is primarily governed by the complex interactions of the subtropical location, the altitude of the central plateau, the position of the subcontinent with respect to the main atmospheric circulation characteristics, and the oceans on all sides save the north [4]. Convective storms dominate rainfall in the north of the subcontinent, which is located in the subtropics, whereas mid-latitude cyclones dominate rainfall in the south. The impact of tropical and temperate pressure regimes, as well as the intra-annual migration of the inter-tropical convergence zone, results in seasonal fluctuations in rainfall and temperature patterns over South Africa by the intertropical convergence zone (ITCZ). The ITCZ changes every month. The temperatures close to the shore are influenced by the oceans that encircle South Africa. While the eastern barrier, the Benguela Current, cools the Atlantic to the west, the western limit, the Agulhas Current, heats the Indian Ocean to the east. These factors work together to produce a significant east-west temperature gradient, with the Northern Cape experiencing the nation's lowest rainfall and highest temperatures [15, 17].

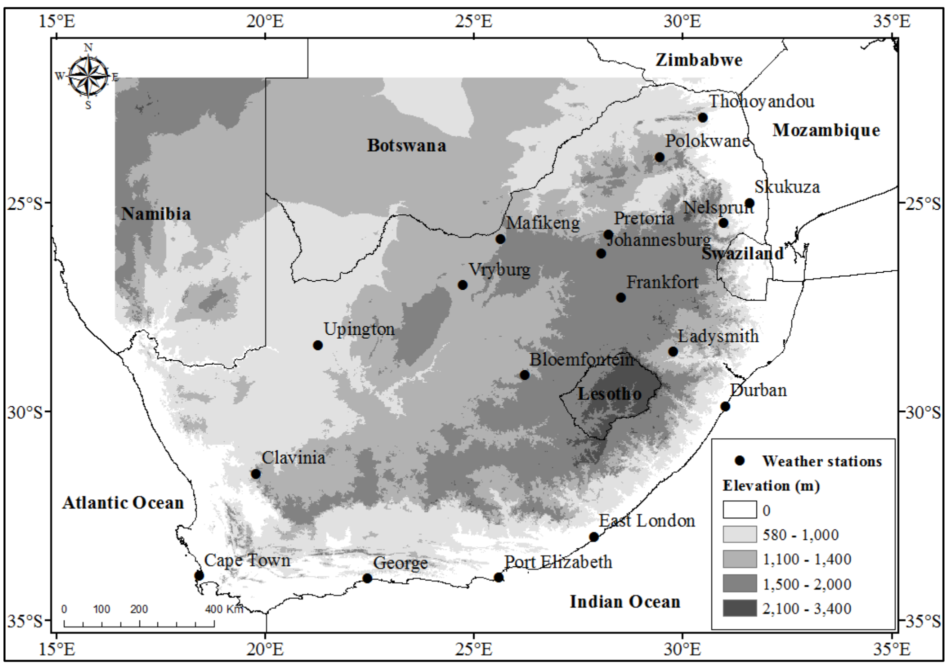


Figure (1): Location map of stations used for the analysis

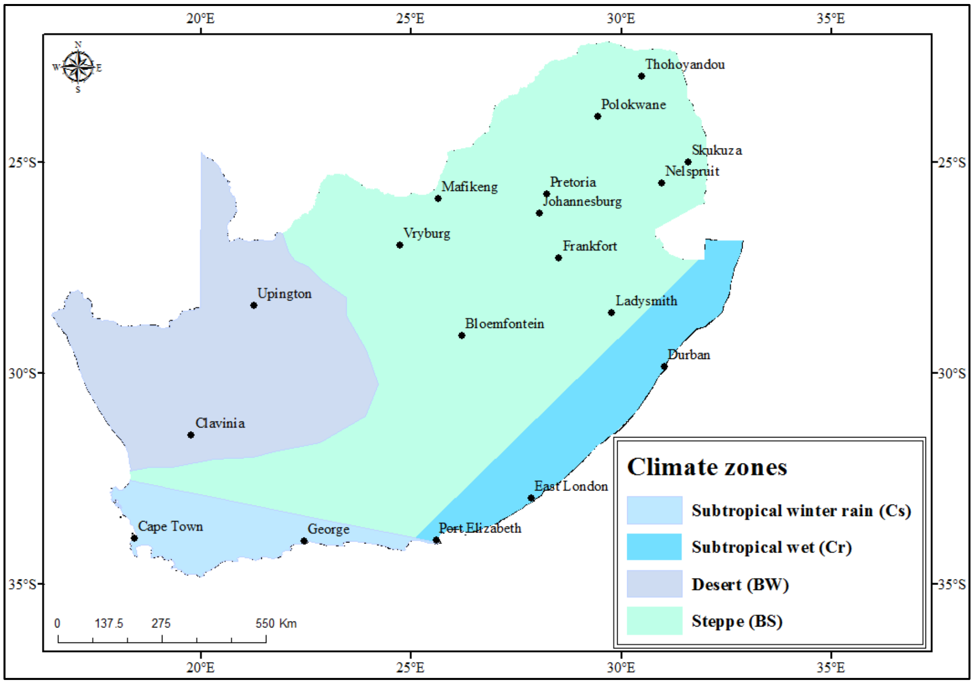


Figure (2): The Climatic zones of South Africa [18]

2.2. Climate of the study area

South Africa, which is regarded to be in a "drought belt," is the fifth-least water-rich nation in sub-Saharan Africa. The geography of the country is diverse, ranging from semi-desert to desert in the drier northwest to sub-humid and moist near the eastern coast; over 50% of the country is classed as arid. Subtropical and temperate climates coexist in South Africa (figure 2) [18]. The east and west coasts of the country as well as the interior plateaus are influenced by the ocean, which results in a cool and rainy climate in the Drakensberg region while a warm, subtropical climate in the northeast [19]. In the southwest of the nation, there is a Mediterranean climate in the centre, in the northwest, there is a warm, dry desert climate. The Western Cape receives the majority of its rainfall in winter (June to August), whereas the remainder of the country receives summer rainfall (December to February). South Africa receives an average of 456 (mm) of rainfall annually. Due to the country's strong reliance on rain-fed agriculture and natural resources, high levels of poverty, particularly in rural regions, and a limited capacity for adaptation in South Africa is particularly sensitive to climatic variability and change. Along with the Benguela, El Nino southern oscillation (ENSO), the Southern Annular Mode (SAM), and sea-surface temperature (SST) dipole events in the Indian and South Atlantic Oceans all have a significant impact on the climate in southern Africa. Water is a scarce resource due to the high rate of evaporation of already dry soils and the virtual absence of permanent surface water over large portions of the nation. Some projections suggest that even in the absence of climate change, the nation is likely to exhaust its current surface water resources in the near future [7, 20].

2.3. Datasets description

The climatic stations were selected based on the extent to which they covered South Africa and the length of time for which reliable historical climate data were available (1958-2020). To compare current climatological trends to past trends or to the "normal trend," which is based on the arithmetic average of a climatic element (for example, temperature) over a 30-year period, climatologists use historical data. It is believed that a 30-year period is sufficient to identify any annual abnormalities [21]. However, it is advised to use data spanning more than 30 years for climatic patterns. Since it is inappropriate to examine temperature changes in subintervals shorter than 30 years, data were available for all chosen stations. On the basis of sufficiently lengthy records for the monthly data and placements to cover as many climate zones in South Africa as possible, 18 stations were chosen. The South African weather service and NASA POWER reanalysis products for monthly surface maximum and minimum temperatures with observed data from 18 distributed weather stations across South Africa supplied the climate data. The characteristics of the data used in the study are reanalyzed data. The NASA POWER system combines information from several sources; direct measured data, satellite data, wind soundings, and data derived from assimilated data systems. Results from some research showed that there is good agreement between NASA POWER reanalysis and observed data for all parameters, except for wind speed [22, 23]

Table (1) station locations are listed and figure (1) displays these sites on a map of South Africa. The mean monthly maximum temperature (T-Max) and minimum temperature (T-Min). On the basis of the monthly maximum and minimum temperature data, the trends were assessed using the Man-Kendell test. Mann Kendall has been used for analysis of trend in T-Max and T-Min data available for the period spanning from 1958 to 2020 in South Africa. A non-parametric technique called the Mann-Kendall test is used to find trends in time series data. The fact that the data do not have to follow any certain distribution is one advantage of this test. It is not a presupposition method in terms of data distribution i.e. there are no necessary assumptions about the data distribution as the prerequisite of this method known as nonparametric method. Therefore, there is no uncertainty associated with the data distribution It is directly applicable to climate data for a given month or season [24].

Table (1): Selected weather stations of South Africa and their general geographic information.

No.	WMO ID	Station	Longitude (E)	Latitude (S)	Altitude (m)	Record period
1	68183	Thohoyandou	30.48	22.95	773.07	1958-2020
2	68174	Polokwane	29.45	23.9	1257	1958-2020
3	68262	Pretoria	28.23	25.75	1370.41	1958-2020
4	68368	Johannesburg	28.05	26.2	1755.08	1958-2020
5	68242	Mafikeng	25.64	25.86	1283.89	1958-2020
6	68289	Vryburg	24.73	26.96	1196.96	1958-2020
7	68289	Nelspruit	30.97	25.48	679.57	1958-2020
8	68295	Skukuza	31.6	24.99	282.85	1958-2020
9	68362	Frankfort	28.52	27.27	1564.95	1958-2020
10	68442	Bloemfontein	26.22	29.12	1384.64	1958-2020
11	68825	Ladysmith	29.78	28.56	1009.53	1958-2020
12	68588	Durban	31.02	29.86	5.81	1958-2020
13	68424	Upington	21.27	28.4	841	1958-2020
14	68618	Clavinia	19.78	31.48	982.63	1958-2020
15	68817	Cape Town	18.42	33.92	13.87	1958-2020
16	68828	George	22.45	33.99	190.5	1958-2020
17	68842	Port Elizabeth	25.6	33.96	88.74	1958-2020
18	68858	East London	27.87	32.98	134	1958-2020

2.4. Methods

2.4.1. Shapiro–Wilk test

The Shapiro-Wilk test which was created by Shapiro and Wilk in 1965 is a useful tool for determining the validity of the assumption of normality. Through a series of Monte Carlo simulations which [25, 26] demonstrated that the Shapiro–Wilk (SW) test is more effective than the Kolmogorov-Smirnov, Lilliefors, and Anderson-Darling tests. The SW test should be used to both environmental and climatic information [27]; they provided a very explicit step-by-step approach for doing so. In general an increasing ordered sample (y1y2.....yn) can be obtained by sorting in ascending order so that y1 and yn are the smallest and greatest sample values, respectively, given a random sample of size n 50 (x1, x2,...., xn). The following is a definition of the test statistic (W):

$$W=\frac{b^2}{S^2}=\frac{\left(\sum_{i=1}^{k}a_{n-i+1}(y_{n-i+1}-y_i)\right)^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2} \quad [27]$$

Where Shaphiro and Wilk (1965) provided the coefficient values for a (n-i+1), and k = n/2 (if n is even) or k = (n - 1)/2 (if n is odd). Between 0 and 1 is the range for the test statistic (W) value. Small W values signify deviations from normality. If the test statistic (W) value is fewer than the percentage points specified by the null hypothesis of the normal distribution, the null hypothesis can be rejected at the significant level [27].

2.4.2. Trend analysis methods

Non-Parametric test used for studying the spatial variation and temporal trends of climatic series. The Mann-Kendall trend and Sen's slope estimations test are used to identify and estimate trends in the time series of annual maximum and lowest temperature readings. Excel templates were created for Sen's slope estimation and the Mann-Kendall test for trend. Trend analysis comprises two stages: determining whether there is a monotonic upward or downward trend and estimating the slope of a linear trend. Both of the cases nonparametric tests were applied. For monotonic trend analysis the nonparametric Mann-Kendall test and for slope of linear trend estimation the nonparametric Sen's slope estimator used [28]. A non-parametric test is taken into consideration as it can evade the problem roused by data skew [29]. Mann-Kendall test is preferred when more than one station were tested in a single study [30]. Non-parametric test for trend detection and the test statistics distribution for testing non-linear trend and turning point had been formulated by Mann (1945) and Kendall (1975). Non-parametric approaches have a number of benefits over parametric ones. The benefits are precisely listed as follows, while non-parametric approaches perform better when the measurements are not precise enough to use parametric methods. Non-parametric approaches are suitable for use with so-called dirty data (outliers, etc.) [31, 32]. Mann-Kendall and Kendall-tau tests are used to determine the statistical significance of trends [33, 34]. For the upcoming analyses only trends that pass both tests and are statistically significant at a 95% level or higher are taken into account. A procedure based on the binomial distribution, using the signs of local trends, and presuming the absence of a field trend as a null hypothesis can be used to validate the field significance of trends [35]. Quantifying the importance of trends in meteorological time series has commonly been done using the MK statistical test [34]. After Mann (1945) completed the initial research, Kendall (1975) calculated the test statistic distribution. Calculations for the MK test statistic S [36, 37] are as follows:

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

(1)

The trend test was applied to two time series: x i, ranked from I = 1, 2,... n-1, and x j, ranked from j = I = 1, 2,... n. Each data point x i used as a benchmark for comparison with the remaining data points x j so that:

$$Sgn\left(x_j - x_i\right) = \begin{cases} +1 \; if \; (x_j - x_i) > 0 \\ 0 \; if \; \left(x_j - x_i\right) = 0 \\ -1 \; if \; (x_j - x_i) < 0 \end{cases}$$

(2)

Where x_i and x_j are the annual values in years i and j (j > i) respectively (2).

It has been established that the statistic "S" is roughly normally distributed with the mean when there are more than 10 observations (n 10), and E(S) becomes 0. [33]. The variance statistic in this instance is reported as follows:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_1(t_1-1)(2t_1+5)}{18}$$

(3)

Where t i is the duration of the sample time series and n is the number of observations (3). Following are the test statistics Z c:

$$Z = \begin{cases} \frac{S-1}{\sigma} if \quad S > 0 \\ 0 \;\; if \quad S = 0 \\ \frac{S+1}{\sigma} if \quad S < 0 \end{cases}$$

(4)

A positive Z c and a negative Z c represent an upward and a downward trend during the time, respectively, where Z c has a normal distribution (4). Sen's technique is used in Sen's Slope estimation test to determine the slope (also known as the linear rate of change) and intercepts. [38] slope estimator approaches can anticipate the size of the trend. An "upward trend" (rising values over time) indicated by a positive value of, whereas a "downward trend" showed by a negative value of. Here of it , all data pairs' slopes (Ti) are calculated as [38]. In general, it is possible to infer the slope Ti between any two values of a time series x from:

$$T_i = \frac{x_j - x_i}{j-i} \qquad (5)$$

Where x j and x k, respectively (5) regarded as data values at times j and k (j > I Sen's estimator of a slope was used to calculate the median of these N values of Ti. If N appears odd, it was calculated as Q (med=) T ((N+1)) 2, and if it appears even, it was calculated as Q (med=) [(T (N2) +T (((N+2)))] 2. An upward or increasing trend in the time series was indicated by a positive value for Qi, whilst a downward or falling trend was shown by a negative value for Qi.

3. Results and Discussions

3.1. Variations of the monthly mean of maximum and minimum temperature

All of the study's stations are typical of South Africa's various climate regions. Following is a summary of the overall changes in T-Max and T-Min values over the course of the study. Over the course of the 63-year period, the monthly absolute maximum and minimum temperatures were determined and are displayed (Tables 2 and 3). For 63 years, the yearly mean's standard deviations were also computed. The inland station Upington captured the year's highest mean temperature. Upington, Skukuza, Nelspruit, and Vryburg all reported high temperatures of 30.9±0.6, 30.1±0.5, 29±0.6, and 28.8±0.8 respectively. Frankfort noted the T-Max minimum value for each station. The minimum temperatures that were observed were 7.4°C in Bloemfontein, 7.8°C in Clavinia, and 6.6°C in Frankfort.

The maximum temperature ranged from a maximum of 29.2±0.6°C in Upington to a minimum of 21.9±0.3°C in Cape Town, according to the yearly mean. For all sites, the corresponding T-Min variations ranged from 6.9±0.3 °C in Frankfort to 16.8±0.1 °C in Durban.

On the other hand, it is feasible to ascertain if the overall instability is brought on by short-term variations or other long-term changes by assessing both short- and long-term instability (using short- and long-term mean square successive difference (MSSD). It is determined by squaring the sum of the differences between successive observations. It is crucial to pinpoint the cause of temporal variability and instability so that variables affecting variability and instability can be investigated. The MSSD of T-Max produced variations between five stations with a maximum of 0.3 over and six stations with a minimum of 0.1. Table (2) T-Max demonstrates changes; it was discovered that the study period had MSSD values between (0.1 and 0.3), a standard deviation between (0.3 - 0.8), and a variance between 2.3 -3.7. The study period was determined to have MSSD values between (0.1 and 0.2), standard deviation (0.1-0.5), and variance (2-7.4), even though T-Min displays variability in table (3).

The globe is rising at the same rate as the mean temperature. The findings predicted the variables that affect fluctuations in surface air temperature based on latitude, height, and proximity to significant bodies of water. It's interesting to observe, though, how T-Max and T-Min increase at distinct rates. In comparison to T-min, T-max increased more quickly at all locations. Except for the stations in Durban, Port Elizabeth and East London, all stations have increased T-Max and T-Min. The greenhouse effect, as well as other factors like increased cloud formation, factory smog, and burning woods and fields that could occur owing to increased urbanisation, may be to blame for these positive trends in temperature.

Analysis of the global air temperature has showed that a decline in the global diurnal temperature range (DTR) for many regions of the world has been caused by the daily minimum temperature increasing more quickly or declining more slowly than the daily maximum. These positive temperature increases were also noted in the 2013 global temperature anomaly report, with the exception of the years 2008 and 2000, which showed a cooling trend. Based on a 30-year average from 1981 to 2010, this global study. With the exception of positive anomalies in 1987, 1988, 1991, and 1995, the period 1983–1997 also had a global negative anomaly. However, the warming in 2016 is more pronounced in South African cities than it was in 1998, which came in first place globally among the warmest years.

Table (2): Descriptive statistics of eighteen stations of T-Max

Station	N	Min.	Max.	Mean	SD	Variance	MSSD
Thohoyandou	63	26	27.8	26.5	0.5	2.7	0.2
Polokwane	63	24.5	26.8	25.1	0.6	3	0.2
Pretoria	63	26.1	28.5	26.7	0.7	3.2	0.3
Johannesburg	63	22.4	24.8	23	0.7	3.7	0.3
Mafikeng	63	26.2	28.6	26.8	0.8	3.2	0.3
Vryburg	63	26.6	28.8	27.2	0.8	3.2	0.3
Nelspruit	63	26.7	29	27.3	0.6	2.8	0.2
Skukuza	63	27.8	30.1	28.5	0.5	2.6	0.2
Frankfort	63	22.9	25.2	23.5	0.7	3.6	0.3
Bloemfontein	63	24.3	26.5	24.8	0.7	3.3	0.3
Ladysmith	63	25.7	27.7	26.2	0.5	2.8	0.2
Durban	63	25.1	26.8	25.5	0.4	2.4	0.1
Upington	63	28.7	30.9	29.2	0.6	2.6	0.2
Clavinia	63	24	25.8	24.5	0.4	2.6	0.1
Cape Town	63	21.5	23.1	21.9	0.3	2.5	0.1
George	63	21.7	23.4	22.1	0.3	2.4	0.1
Port Elizabeth	63	22.4	24.2	22.8	0.3	2.3	0.1
East London	63	22.9	24.9	23.3	0.3	2.4	0.1

N: Number of years, D: Standard deviation, and MSSD: Mean of successive squared differences.

Table (3): Descriptive statistics of eighteen stations of T-Min

Station	N	Min.	Max.	Mean	SD	Variance	MSSD
Thohoyandou	63	14.5	16.2	15	0.3	3.6	0.1
Polokwane	63	11.4	13.1	11.8	0.3	4.4	0.1
Pretoria	63	10.3	12.6	10.8	0.3	5.1	0.1
Johannesburg	63	8.9	10	9.3	0.2	4.8	0.1
Mafikeng	63	10.4	12.6	10.8	0.3	4.8	0.1
Vryburg	63	9.5	11.7	9.9	0.3	5.4	0.1
Nelspruit	63	14	15.4	14.3	0.2	3.3	0.1
Skukuza	63	15.1	16.5	15.4	0.2	3.1	0.1
Frankfort	63	6.6	8.6	6.9	0.3	7.4	0.1
Bloemfontein	63	7.4	8.7	7.7	0.2	6.1	0.1
Ladysmith	63	10.2	12	10.6	0.2	4.2	0.1
Durban	63	16.5	17.7	16.8	0.1	2	0.1
Upington	63	11.6	13.9	12	0.5	5.7	0.2
Clavinia	63	7.8	9.4	8.2	0.2	6.1	0.1
Cape Town	63	11.5	12.9	11.9	0.2	4.1	0.1
George	63	12	13.5	12.3	0.2	3.9	0.1
Port Elizabeth	63	12.5	13.6	12.8	0.1	2.8	0.1
East London	63	14.3	15.3	14.6	0.1	2.2	0.1

3.2. Normality test of T-Max and T-Min

In studies of climatology and hydrology, a thorough study of statistical characteristics plays a key role. Although typically limited to the detection and identification of trend components in a particular time series, the application of statistical approaches in such area is nonetheless common. In the current study the annual maximum and minimum temperatures were analysed using number of robust statistical techniques in order to look into the trend. All of the observed temperature recorded then put through a normality and homogeneity test using the Shapiro-Wilk and Buishand range test before moving on to the analysis of potential trends using the renowned Mann-Kendall test, Sens slope estimator, and trend-free pre-whitening.

The study made an effort to examine the annual high and low temperatures including variability, trend, and normalcy. In the investigation we initially used a Shapiro-Wilk test to determine whether the maximum and lowest temperature distributions were out of the ordinary [39]. Regional-average time series were subjected to a Shapiro-Wilk test of normality, which shows that the majority of annual-average series may be classified as normal at the 5% significance level (Table 4). The Shapiro-Wilk test of normality applied to regional average time series of annual scale shows that it is not possible to assume normality in simulated temperatures and that comprehensive assessments of changes in the characteristics of distributions cannot be made from parametric tests, which can have low power if distributions are not normal. We use a nonparametric quantile technique to look into changes in temperature distributions [34].

The majority of the temperature data are most likely normal according to the SW test's results for the normality test. The majority of the temperature data have strong evidence of departures from homogeneity, according to the BR test. However, it is still unclear what the primary sources of these in homogeneities are. For further research it is advisable to provide historical metadata. The bulk of annual temperature records showed significantly increasing trends, as determined by the traditional/modified Mann-Kendall test and Sens slope estimator.

While this is going on, the use of spatial interpolation in conjunction with statistical trend tests to look into spatio-temporal trend possibilities also reveals a significant rise in all temperature anomalies (especially for the minimum temperature from 1981 to 2020), suggesting a significant warming trend in South Africa over the past three decades. Therefore, it is advised to use a high-resolution gridded dataset for the spatio-temporal analysis (such as CRU TS). In the context of climate change and variability, such a station- and grid-wise trend analysis will produce a significant number of scientific benefits of climate-related investigations.

Table (4): Tests of normality of T-Max and T-Min

Station	Maximum temperature						Minimum temperature					
	Kolmogorov-Smirnova			Shapiro-Wilk			Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.	Statistic	df	Sig.	Statistic	df	Sig.
Thohoyandou	0.12	63	0.025*	0.961	63	0.044*	0.08	63	0.200+	0.98	63	0.394
Polokwane	0.077	63	0.200+	0.974	63	0.205	0.09	63	0.200+	0.97	63	0.174
Pretoria	0.079	63	0.200+	0.973	63	0.182	0.09	63	0.200+	0.94	63	0.003**
Johannesburg	0.081	63	0.200+	0.973	63	0.19	0.11	63	0.049*	0.95	63	0.011*
Mafikeng	0.069	63	0.200+	0.984	63	0.597	0.1	63	0.200+	0.91	63	0.000**
Vryburg	0.067	63	0.200+	0.982	63	0.483	0.1	63	0.09	0.93	63	0.002**
Nelspruit	0.09	63	0.200+	0.976	63	0.244	0.08	63	0.200+	0.97	63	0.148
Skukuza	0.091	63	0.200+	0.969	63	0.108	0.08	63	0.200+	0.97	63	0.116
Frankfort	0.058	63	0.200+	0.979	63	0.368	0.11	63	0.069	0.93	63	0.002**
Bloemfontein	0.067	63	0.200+	0.987	63	0.753	0.08	63	0.200+	0.98	63	0.374
Ladysmith	0.11	63	0.056	0.96	63	0.040*	0.09	63	0.200+	0.95	63	0.017*
Durban	0.114	63	0.040*	0.952	63	0.015*	0.07	63	0.200+	0.99	63	0.733
Upington	0.093	63	0.200+	0.976	63	0.258	0.08	63	0.200+	0.97	63	0.108
Clavinia	0.086	63	0.200+	0.978	63	0.324	0.08	63	0.200+	0.98	63	0.391
Cape Town	0.063	63	0.200+	0.986	63	0.686	0.07	63	0.200+	0.99	63	0.761
George	0.141	63	0.003**	0.959	63	0.036*	0.1	63	0.200+	0.98	63	0.616
Port Elizabeth	0.118	63	0.030*	0.964	63	0.065	0.13	63	0.007**	0.98	63	0.253
East London	0.118	63	0.028*	0.963	63	0.057	0.14	63	0.002**	0.97	63	0.200+

Sig. = the statistically significant levels as: P < 0.05 *, P < 0.01 ** and P < 0.001***, * = 5% level, df: Degree of freedom, + This is a lower bound of the true significance.

Table (5): Trends of maximum and minimum temperature for the climatic stations analyzed in South Africa during 1958-2020 (˚C/ decade)

	n	T-Max (°C)				T-Min (°C)			
		Mann-Kendall trend		Sen's slope estimate		Mann-Kendall trend		Sen's slope estimate	
		Test Z	Sig.	Q	B	Test Z	Sig.	Q	B
Thohoyandou	63	5.7	***	0.3	25.66	5.01	***	0.2	14.4
Polokwane	63	5.4	***	0.3	24.25	4.6	***	0.2	11.26
Pretoria	63	5.2	***	0.3	25.83	5.22	***	0.2	10.22
Johannesburg	63	5.5	***	0.3	22.14	5.21	***	0.2	8.75
Mafikeng	63	5.7	***	0.3	25.84	4.91	***	0.2	10.3
Vryburg	63	6.1	***	0.3	26.3	4.53	***	0.2	9.44
Nelspruit	63	5.9	***	0.3	26.39	5.37	***	0.2	13.83
Skukuza	63	6	***	0.3	27.56	5.55	***	0.2	14.83
Frankfort	63	5.8	***	0.3	22.58	5.38	***	0.2	6.33
Bloemfontein	63	5.6	***	0.3	24.02	3.44	***	0.1	7.33
Ladysmith	63	5.3	***	0.3	25.4	5.51	***	0.1	10.09
Durban	63	5.3	***	0.2	24.82	4.98	***	0.1	16.4
Upington	63	5.8	***	0.3	28.37	5.65	***	0.2	11.32
Clavinia	63	6.8	***	0.3	23.6	6.13	***	0.2	7.52
Cape Town	63	5.9	***	0.2	21.21	7.28	***	0.2	11.24
George	63	6.2	***	0.2	21.46	6.29	***	0.2	11.74
Port Elizabeth	63	5.9	***	0.2	22.16	3.97	***	0.1	12.42
East London	63	5.7	***	0.2	22.69	3.71	***	0.1	14.26

Sig. = the statistically significant levels as: $P < 0.05$ *, $P < 0.01$ ** and $P < 0.001$***.

Table (6): Seasonal trends of maximum temperature for the climatic stations analyzed in South Africa during 1958-2020 (˚C/ decade)

Station	Winter				Summer				Spring				Autumn			
	Mann-Kendall trend		Sen's slope estimate		Mann-Kendall trend		Sen's slope estimate		Mann-Kendall trend		Sen's slope estimate		Mann-Kendall trend		Sen's slope estimate	
	Test Z	Sig.	Q	B	Test Z	Sig.	Q	B	Test Z	Sig.	Q	B	Test Z	Sig.	Q	B
Thohoyandou	5.9	***	0.3	21.96	3.94	***	0.2	28.03	4.54	***	0.3	26.93	3.32	***	0.2	25.72
Polokwane	5.64	***	0.3	20.1	3.46	***	0.2	27.19	4.41	***	0.3	25.7	3.36	***	0.3	24.13
Pretoria	5.44	***	0.3	21.53	3.29	***	0.2	28.8	4.2	***	0.3	27.73	4	***	0.3	25.18
Johannesburg	5.4	***	0.4	17.27	3.27	**	0.2	25.66	4.14	***	0.3	23.77	4.21	***	0.4	21.69
Mafikeng	5.73	***	0.3	20.75	3.21	**	0.3	29.34	4.7	***	0.3	28.27	4.27	***	0.4	24.78
Vryburg	5.7	***	0.3	20.2	3.32	***	0.3	30.91	5.13	***	0.3	28.57	4.51	***	0.4	25.04
Nelspruit	5.93	***	0.4	23.06	3.71	***	0.2	29.11	4.56	***	0.3	27.04	4.14	***	0.3	26.53
Skukuza	6.02	***	0.4	24.03	4.04	***	0.2	30.34	4.82	***	0.3	28.18	4.19	***	0.3	27.75
Frankfort	5.69	***	0.4	17.39	3.44	***	0.2	26.52	4.69	***	0.3	24.44	4.28	***	0.4	22.05
Bloemfontein	4.93	***	0.3	17.4	2.78	**	0.2	29.38	4.82	***	0.3	26.01	4.39	***	0.4	22.83
Ladysmith	5.63	***	0.3	20.97	3.55	***	0.2	28.89	4.45	***	0.3	26.47	4.61	***	0.4	24.73
Durban	5.37	***	0.3	22.11	3.65	***	0.2	27.58	4.31	***	0.2	24.12	4.92	***	0.3	25.3
Upington	3.03	**	0.2	21.38	3.44	***	0.2	34.71	4	***	0.2	29.77	4.79	***	0.4	27.5
Clavinia	2.45	*	0.2	16.9	6.06	***	0.2	30.15	3.87	***	0.3	23.63	6.16	***	0.4	24.05
Cape Town	2.45	*	0.1	17.46	5.81	***	0.3	24.9	3.8	***	0.2	20.62	5.56	***	0.3	21.86
George	3.05	**	0.1	19.51	5.53	***	0.2	24.11	4.16	***	0.2	20.37	6.12	***	0.3	21.92
Port Elizabeth	2.96	**	0.2	19.88	5.21	***	0.2	24.79	4.78	***	0.2	21.05	5.91	***	0.3	22.58
East London	3.46	***	0.2	20.8	4.66	***	0.2	24.9	4.99	***	0.2	21.55	5.61	***	0.3	23.03

Sig. = the statistically significant levels as: $P < 0.05$ *, $P < 0.01$ ** and $P < 0.001$***.

Table (7): Seasonal trends of minimum temperature for the climatic stations analyzed in South Africa during 1958-2020 (˚C/ decade)

Station	**Winter**				**Summer**				**Spring**				**Autumn**			
	Mann-Kendall trend		Sen's slope estimate		Mann-Kendall trend		Sen's slope estimate		Mann-Kendall trend		Sen's slope estimate		Mann-Kendall trend		Sen's slope estimate	
	Test Z	Sig.	Q	B	Test Z	Sig.	Q	B	Test Z	Sig.	Q	B	Test Z	Sig.	Q	B
Thohoyandou	4.02	***	0.2	9.2	3.87	***	0.2	18.27	3.33	***	0.1	15.64	3.87	***	0.2	14.54
Polokwane	3.67	***	0.2	4.68	4.02	***	0.2	16.33	2.56	*	0.1	12.74	3.52	***	0.2	11.19
Pretoria	4.56	***	0.2	3.03	5.17	***	0.2	15.56	2.79	**	0.1	12.18	4.03	***	0.2	9.93
Johannesburg	4.53	***	0.2	2.23	5.22	***	0.2	13.85	2.46	*	0.1	10.45	4.01	***	0.2	8.55
Mafikeng	4.16	***	0.2	2.87	4.47	***	0.2	15.99	2.15	*	0.1	12.43	3.8	***	0.2	9.76
Vryburg	3.63	***	0.2	0.87	4.52	***	0.2	16.06	1.85		0.1	11.16	4.31	***	0.2	9.38
Nelspruit	4.49	***	0.2	7.58	4.83	***	0.2	18.66	2.66	**	0.1	14.97	4.03	***	0.2	14.01
Skukuza	4.4	***	0.2	8.95	4.91	***	0.1	19.63	3.08	**	0.1	15.77	4.21	***	0.2	15.2
Frankfort	4.47	***	0.2	-2.18	5.27	***	0.2	12.97	2.05	*	0.1	8.42	3.13	**	0.2	6.12
Bloemfontein	2.73	**	0.1	-0.96	3.22	**	0.1	14.22	1.45		0.1	8.5	2.94	**	0.2	7.19
Ladysmith	4.94	***	0.2	2.91	5.06	***	0.2	15.6	2.18	*	0.1	11.66	3.76	***	0.2	10.03
Durban	4.12	***	0.1	11.63	4.2	***	0.1	20.44	1.92		0.1	16.76	3.16	**	0.1	16.74
Upington	3.72	***	0.2	3.37	5.48	***	0.2	18.31	2.49	*	0.2	11.89	6.21	***	0.3	11.43
Clavinia	3.7	***	0.2	2.57	4.91	***	0.2	12.59	3.54	***	0.2	6.88	5.99	***	0.3	8.04
Cape Town	4.33	***	0.2	8.16	6.35	***	0.3	14.33	5.28	***	0.2	10.51	6.37	***	0.3	11.82
George	3.63	***	0.1	8.4	6.56	***	0.2	15.2	4.01	***	0.2	10.93	5.93	***	0.2	12.3
Port Elizabeth	2.11	*	0.1	8.21	3.74	***	0.1	16.49	2.48	*	0.1	12.14	3.42	***	0.1	12.98
East London	1.56		0.1	10.39	3.77	***	0.1	17.91	1.86		0.1	13.92	3.18	**	0.1	15

Sig. = the statistically significant levels as: P < 0.05 *, P < 0.01 ** and P < 0.001***

Table (8): Comparison between periods (1958-1988) and (1989-2020) as regarding T-Max and T-Min

Station	T-Max				T-Min			
	P1 (1958-1988)	P2 (1989-2020)	T test	P value	P1 (1958-1988)	P2 (1989-2020)	T test	P value
Thohoyandou	26.0±0.5	27.0±0.6	-6.9	0.001**	14.6±0.4	15.3±0.5	-6.6	0.001**
Polokwane	24.7±0.5	25.6±0.7	-5.8	0.001**	11.5±0.4	12.0±0.5	-5.1	0.001**
Pretoria	26.3±0.5	27.1±0.9	-4.7	0.001**	10.5±0.4	11.1±0.5	-5.5	0.001**
Johannesburg	22.6±0.5	23.5±0.9	-4.9	0.001**	9.1±0.4	9.5±0.3	-5.1	0.001**
Mafikeng	26.4±0.6	27.3±0.8	-5.1	0.001**	10.5±0.4	11.0±0.6	-4.1	0.001**
Vryburg	26.7±0.7	27.7±0.8	-5.6	0.001**	9.7±0.4	10.2±0.6	-3.6	0.001**
Nelspruit	26.9±0.5	27.8±0.7	-5.5	0.001**	14.0±0.4	14.6±0.4	-5.9	0.001**
Skukuza	28.0±0.5	28.9±0.7	-5.8	0.001**	15.1±0.3	15.7±0.4	-6.5	0.001**
Frankfort	23.0±0.6	24.0±0.8	-5.4	0.001**	6.7±0.4	7.1±0.5	-3.7	0.001**
Bloemfontein	24.4±0.6	25.3±0.7	-5.1	0.001**	7.6±0.5	7.8±0.4	-2.3	0.026*
Ladysmith	25.8±0.4	26.6±0.8	-4.8	0.001**	10.3±0.3	10.8±0.4	-4.9	0.001**
Durban	25.2±0.4	25.9±0.6	-5.2	0.001**	16.6±0.3	16.9±0.3	-4.1	0.001**
Upington	28.8±0.6	29.5±0.7	-4.3	0.001**	11.6±0.5	12.4±0.6	-5.5	0.001**
Clavinia	24.1±0.5	24.8±0.5	-5.7	0.001**	7.9±0.4	8.4±0.4	-5.3	0.001**
Cape Town	21.6±0.4	22.2±0.5	-5	0.001**	11.5±0.4	12.2±0.4	-7.3	0.001**
George	21.8±0.3	22.4±0.5	-5.3	0.001**	12.1±0.4	12.6±0.4	-4.5	0.001**
Port Elizabeth	22.5±0.3	23.1±0.5	-5.6	0.001**	12.7±0.4	12.9±0.3	-2.1	0.037*
East London	23.0±0.3	23.7±0.6	-5.9	0.001**	14.5±0.3	14.6±0.3	-2.4	0.022*

Sig. = the statistically significant levels as: P < 0.05 *, P < 0.01 ** and P < 0.001***

Table (9): Extreme events for analyzed trends as per the occurrences between 1958 and 2020 in T-Max

	1958-1969 (n=12)		1970-1979 (n=10)		1980-1989 (n=10)		1990-1999 (n=10)		2000-2009 (n=10)		2010-2020 (n=11)	
	<Mean	>Mean	<Mean	>Mean	<Mean	>Mean	<Mean	>Mean	<Mean	>Mean	<Mean	>Mean
Thohoyandou	10	2	9	1	7	3	5	5	3	7	0	11
Polokwane	10	2	9	1	6	4	5	5	3	7	0	11
Pretoria	11	1	9	1	7	3	6	4	3	7	0	11
Johannesburg	11	1	9	1	6	4	6	4	3	7	0	11
Mafikeng	11	1	9	1	5	5	6	4	3	7	0	11
Vryburg	11	1	9	1	4	6	5	5	3	7	0	11
Nelspruit	11	1	9	1	5	5	5	5	3	7	0	11
Skukuza	11	1	9	1	5	5	6	4	3	7	0	11
Frankfort	11	1	9	1	5	5	4	6	3	7	0	11
Bloemfontein	11	1	10	0	5	5	5	5	3	7	1	10
Ladysmith	10	2	9	1	7	3	6	4	3	7	0	11
Durban	10	2	9	1	7	3	5	5	3	7	0	11
Upington	11	1	10	0	3	7	7	3	4	6	0	11
Clavinia	12	0	7	3	5	5	6	4	2	8	0	11
Cape Town	11	1	8	2	6	4	7	3	2	8	0	11
George	12	0	9	1	5	5	7	3	2	8	2	9
Port Elizabeth	12	0	10	0	6	4	7	3	2	8	2	9
East London	10	2	10	0	6	4	5	5	2	8	0	11
Total	196	20	163	17	100	80	103	77	50	130	5	193

Table (10): Extreme events for analyzed trends as per the occurrences between 1958 and 2020 in T-Min

	1958-1969 (n=12)		1970-1979 (n=10)		1980-1989 (n=10)		1990-1999 (n=10)		2000-2009 (n=10)		2010-2020 (n=11)	
	<Mean	>Mean	<Mean	>Mean	<Mean	>Mean	<Mean	>Mean	<Mean	>Mean	<Mean	>Mean
Thohoyandou	11	1	10	0	7	3	4	6	2	8	3	8
Polokwane	11	1	10	0	6	4	4	6	3	7	4	7
Pretoria	12	0	9	1	4	6	1	9	2	8	3	8
Johannesburg	12	0	9	1	4	6	3	7	2	8	3	8
Mafikeng	10	2	9	1	5	5	4	6	3	7	4	7
Vryburg	9	3	8	2	4	6	4	6	3	7	3	8
Nelspruit	9	3	10	0	5	5	2	8	2	8	3	8
Skukuza	9	3	10	0	8	2	2	8	2	8	3	8
Frankfort	11	1	9	1	4	6	4	6	5	5	3	8
Bloemfontein	9	3	9	1	4	6	5	5	5	5	3	8
Ladysmith	12	0	10	0	5	5	2	8	5	5	3	8
Durban	11	1	10	0	5	5	4	6	6	4	3	8
Upington	11	1	10	0	4	6	4	6	2	8	3	8
Clavinia	11	1	10	0	7	3	5	5	3	7	1	10
Cape Town	11	1	10	0	6	4	5	5	2	8	0	11
George	11	1	8	2	3	7	6	4	4	6	0	11
Port Elizabeth	12	0	8	2	4	6	6	4	8	2	3	8
East London	11	1	9	1	4	6	6	4	9	1	3	8
Total	**193**	**23**	**168**	**12**	**89**	**91**	**71**	**109**	**68**	**112**	**48**	**150**

3.3. Trends in annual mean of T-Max and T-Min

The Mann-Kendall statistic test was used to conduct a trend analysis on long-term (1958–2020) temperature data obtained in South Africa in order to determine the presence of trend under changing climatic conditions. The outcomes of maximum and minimum temperature indices were analysed through the nonlinear trends (e nonlinear trends and their statistical significance were also calculated using the regression equation and Test Z for each station at annual scales in table 5. Annual mean maximum and minimum temperatures both revealed a statistically significant upward trend (0.3° and 0.2 °C/decade, respectively). All seasons increases in minimum temperatures was shown for the majority of the country [19]. A comparison of the observed trends with statistically downscaled global climate model simulations reveals that the models do not replicate the observed cooling trend of minimum temperatures in the central interior.

Kruger and Sekele demonstrated that changes in South African annual extremes, such as those in days falling between the 10^{th} and 90^{th} percentiles of minimum and maximum temperature do not correspond to global warming. Annual extreme events are rare, annual solitary occurrences, and positive trends suggest that these occurrences will becoming more intense over time. Although the likelihood of extremely hot events increases with climate change, the magnitudes of individual events are not necessarily directly comparable to the overall warming depicted in the time series [20].

Longer time series should generally exhibit favourable trends as well, especially for very short time series. Contrary to Kruger and Sekele (2013), it was discovered that this was the case since the vast majority of stations' trends for yearly extreme temperatures followed the general warming trend [7, 20].

Distribution of the maximum temperature trend values over the study area in figure 3. The average of all statistically significant yearly trends was used to calculate the annual trend for each station, expressed in degrees centigrade per decade. The number of T-Max and T-Min calendar years with notable positive or negative trends is shown in table 5 for each station. Over the past century, there has been an average global surface temperature increase of 0.6 0.2°C, and by 2100, the increase is predicted to be between 1.4 and 5.8°C [9]. Global temperature fluctuations have not been consistent; instead, they have fluctuated between areas and the lower atmosphere [4].

All climatic stations (100%) showed positive trends in the annual mean maximum temperature, and all stations showed similar trends in the annual mean lowest temperature, according to table (5). (Figure 4). The findings of the generally favourable temperature trends in South Africa are consistent with [4]. The largest positive trend of annual mean temperature reported among the 18 stations over South Africa was 0.03°C/decade, while the lowest positive trend was 0.2 °C/decade, according to a detailed examination of mean annual maximum temperatures. In South Africa, not all regions showed the same tendencies; the northwestern regions warmed up the quickest. The general trend of rising temperatures may have an impact on South Africa's water management and evaporation. Using the Mann-Kendall test as previously mentioned, trends averaged across all stations were examined. At a 0.001 significance level, it was determined that all of the trends in the mean annual maximum and minimum temperature were statistically significant. The trends that were found to be positive across all cases were averaged across the stations. Figures 3 and 4 demonstrate that T-Max and T-Min showed positive trends at 100% of the climatic stations.

The mean annual minimum temperatures in South Africa from 1958 to 2020 are depicted in table 5 as trends. The province's southwest has seen the strongest trends, and minimum temperature trends are often weaker than maximum temperature trends (Figures 7 and 8). A research by Mukheibir and Sparks found that by 2050, temperatures in SA are predicted to rise by roughly 1.5 °C along the coast and 2 to 3 °C inland of the coastal highlands [6]. Additionally, a research by Kruger and Shongwe shows that SA's mean temperature increased by 0.13 °C between 1960 and 2003. Other temperature studies carried out in SA also support the same trend of rising temperatures [4, 20].

The time period from 1962 to 2009 was the primary focus of the index analysis [20]. For stations with additional data available, the consistency of the station trends over longer periods was examined. It was possible to demonstrate that the warming trend accelerated for the majority of these stations starting in the 1960s. The time series of the yearly mean maximum temperature of the 18 stations is displayed. This result was consistent with the mean global temperature trend. Over the time frame, every station displayed a positive trend. Durban, Cape Town, George, Port Elizabeth, and East London were the five stations with the smallest increase in T-Max, with a value of 0.2 °C/ decade.

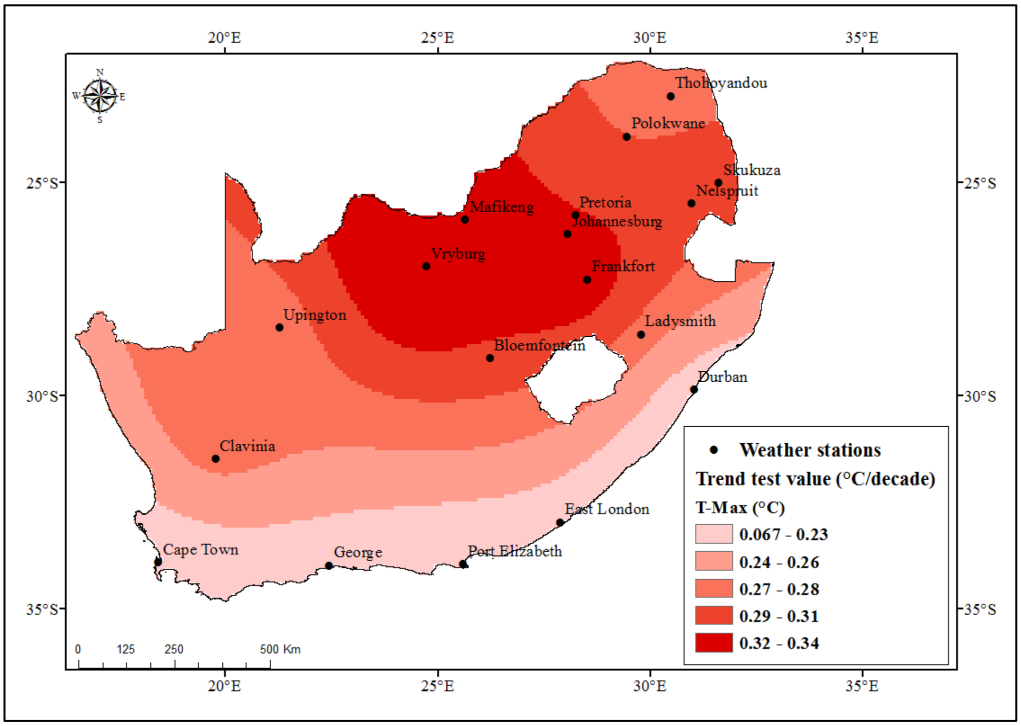


Figure (3): The spatial distribution of the trends of T-Max (°C/ decade) over SA during 1958-2020.

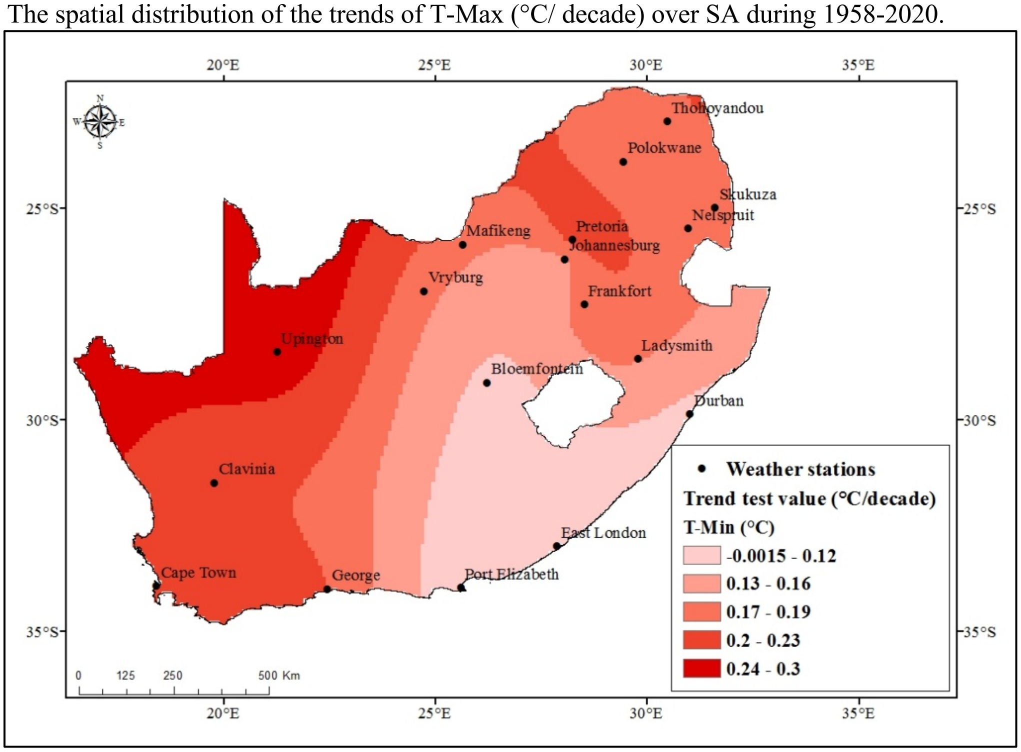


Figure (4): The spatial distribution of the trends of T-Min (°C/ decade) over SA during 1958-2020.

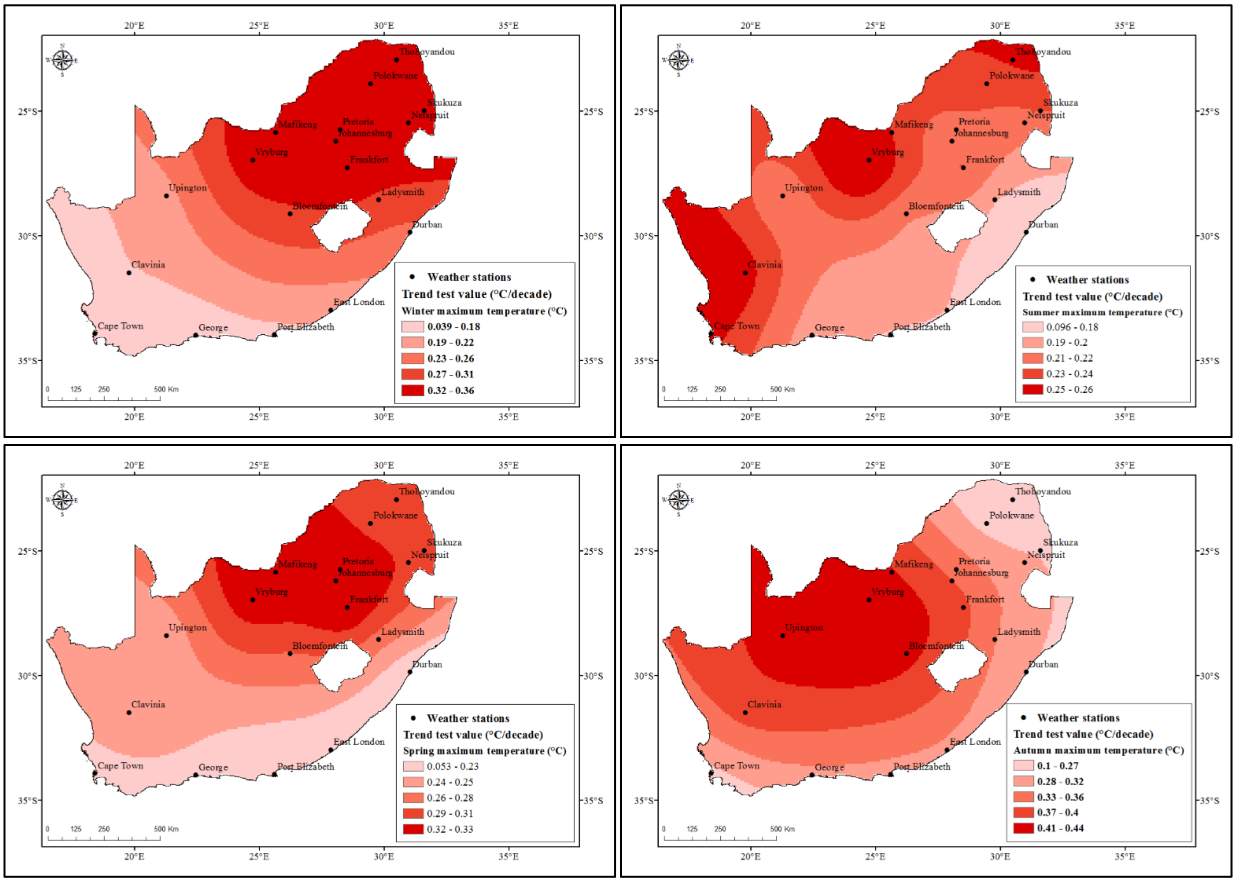
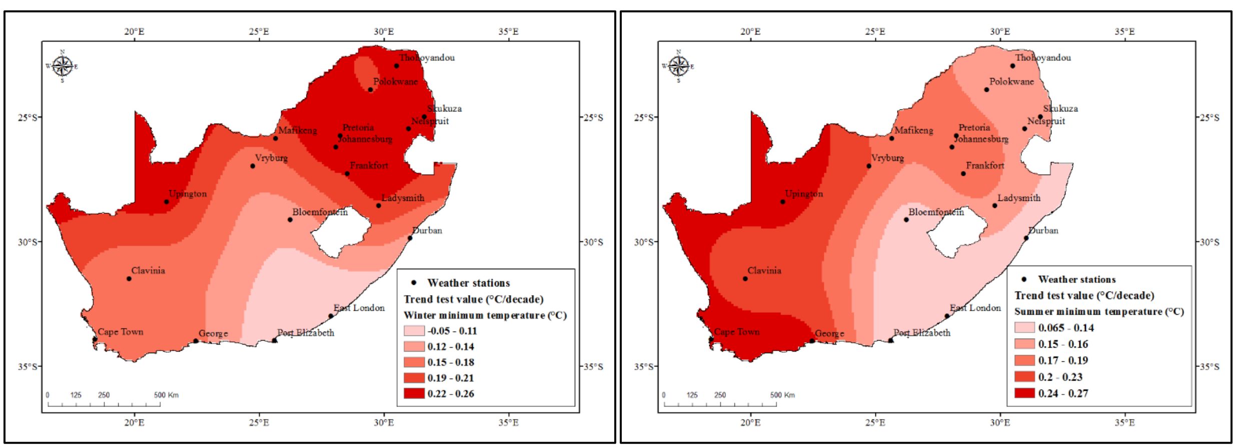


Figure (5): The spatial distribution of the trends of seasonal T-Max (°C/decade) over SA during 1958-2020.



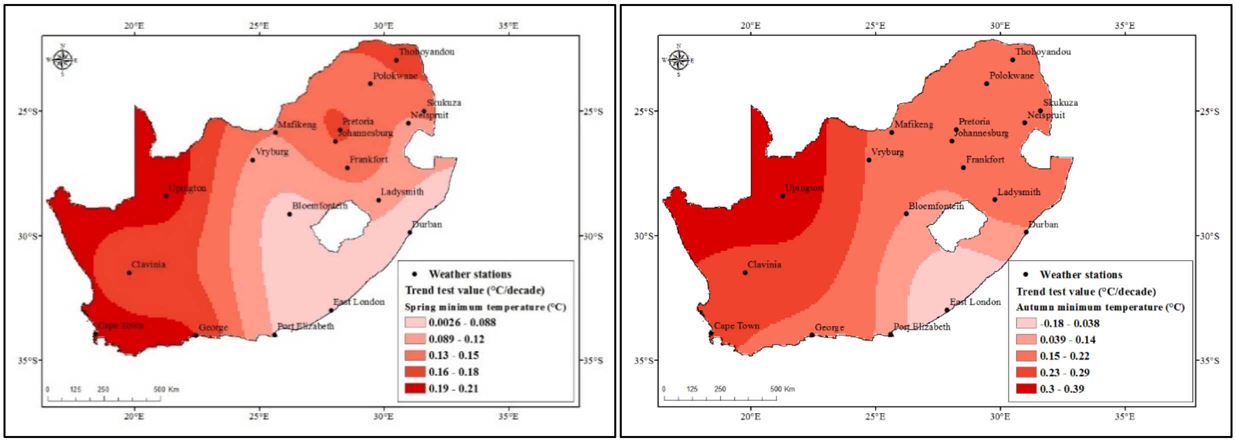
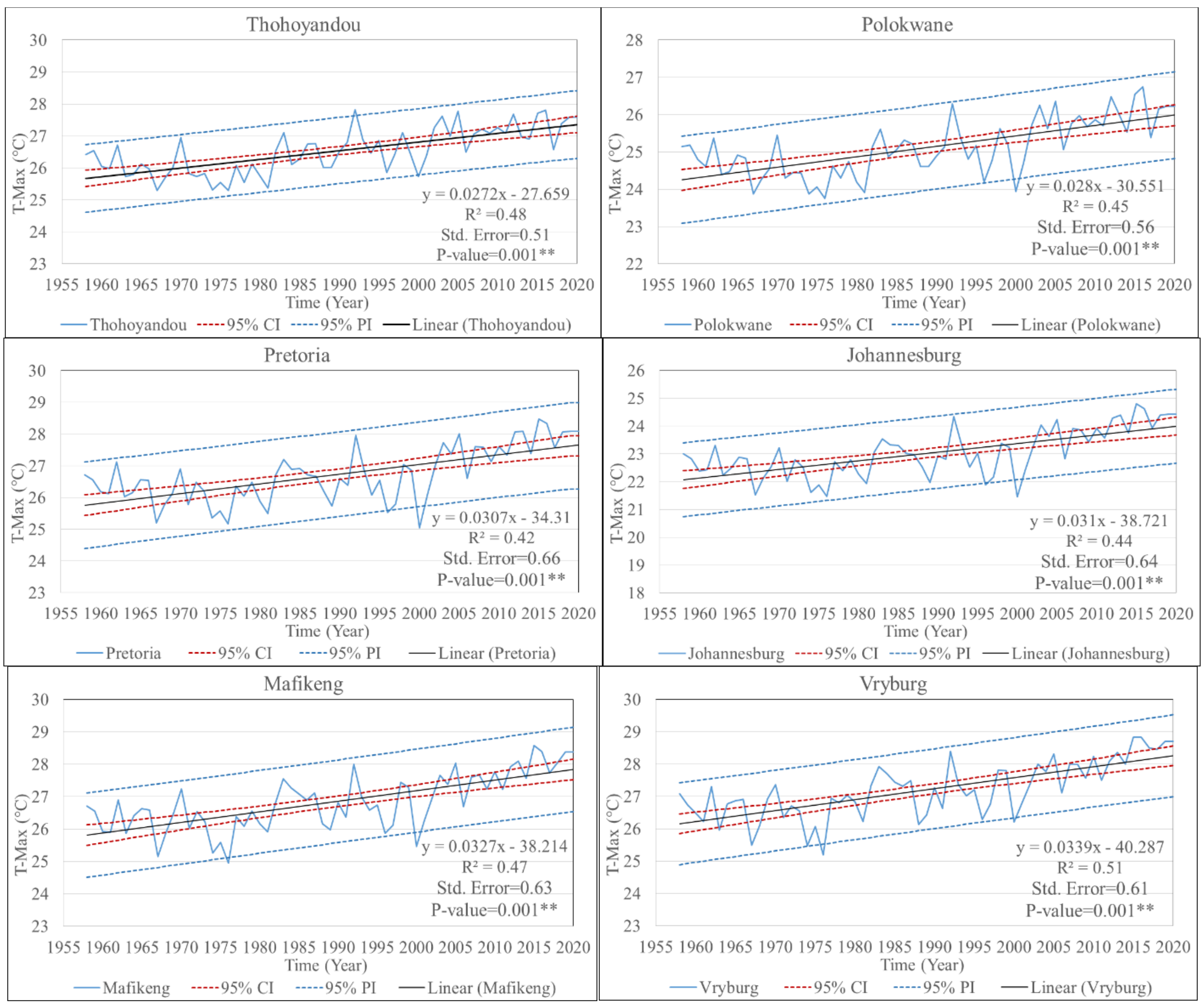
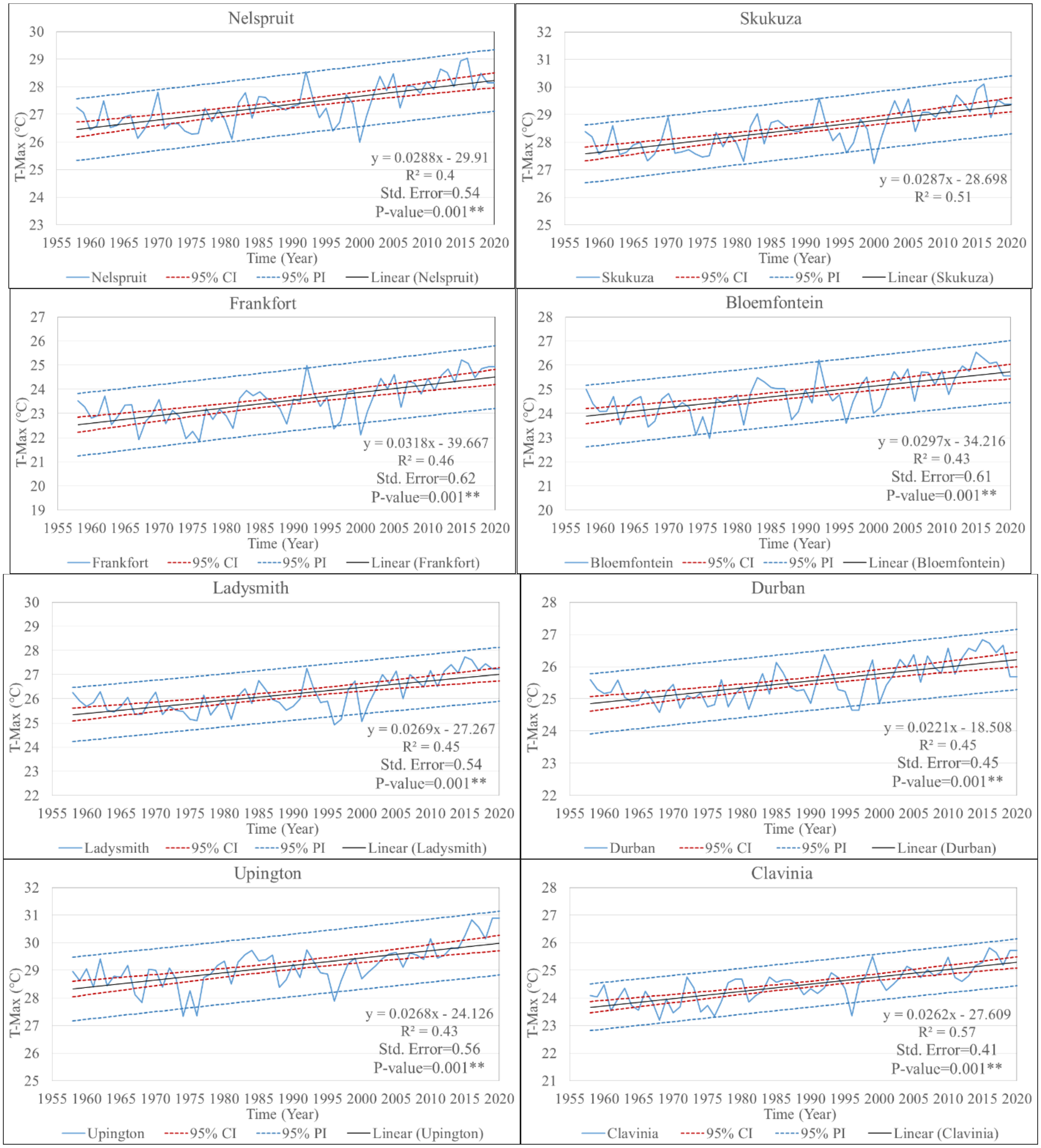


Figure (6): The spatial distribution of the trends of seasonal T-Min (°C/ decade) over SA during 1958-2020.




Nelspruit
y = 0.0288x - 29.91
R² = 0.4
Std. Error=0.54
P-value=0.001**
T-Max (°C)
Time (Year)
Nelspruit
95% CI
95% PI
Linear (Nelspruit)
Skukuza
y = 0.0287x - 28.698
R² = 0.51
Skukuza
Linear (Skukuza)
Frankfort
y = 0.0318x - 39.667
R² = 0.46
Std. Error=0.62
P-value=0.001**
Frankfort
Linear (Frankfort)
Bloemfontein
y = 0.0297x - 34.216
R² = 0.43
Std. Error=0.61
P-value=0.001**
Bloemfontein
Linear (Bloemfontein)
Ladysmith
y = 0.0269x - 27.267
R² = 0.45
Std. Error=0.54
P-value=0.001**
Ladysmith
Linear (Ladysmith)
Durban
y = 0.0221x - 18.508
R² = 0.45
Std. Error=0.45
P-value=0.001**
Durban
Linear (Durban)
Upington
y = 0.0268x - 24.126
R² = 0.43
Std. Error=0.56
P-value=0.001**
Upington
Linear (Upington)
Clavinia
y = 0.0262x - 27.609
R² = 0.57
Std. Error=0.41
P-value=0.001**
Clavinia
Linear (Clavinia)

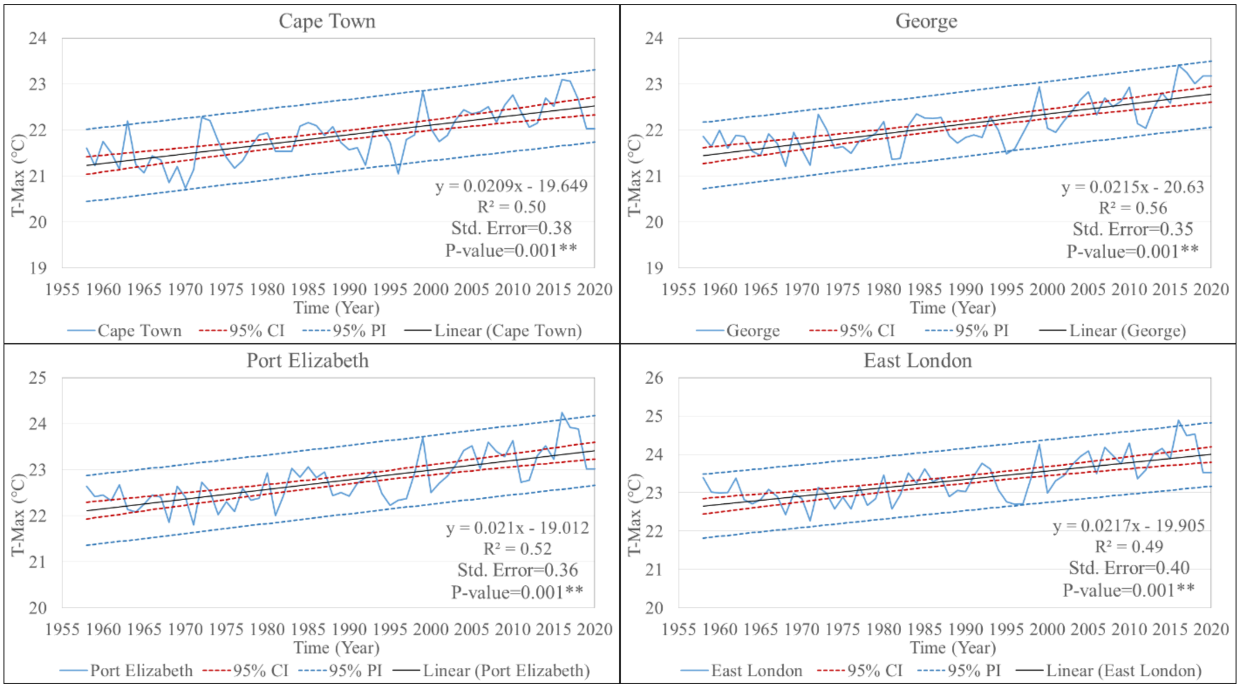
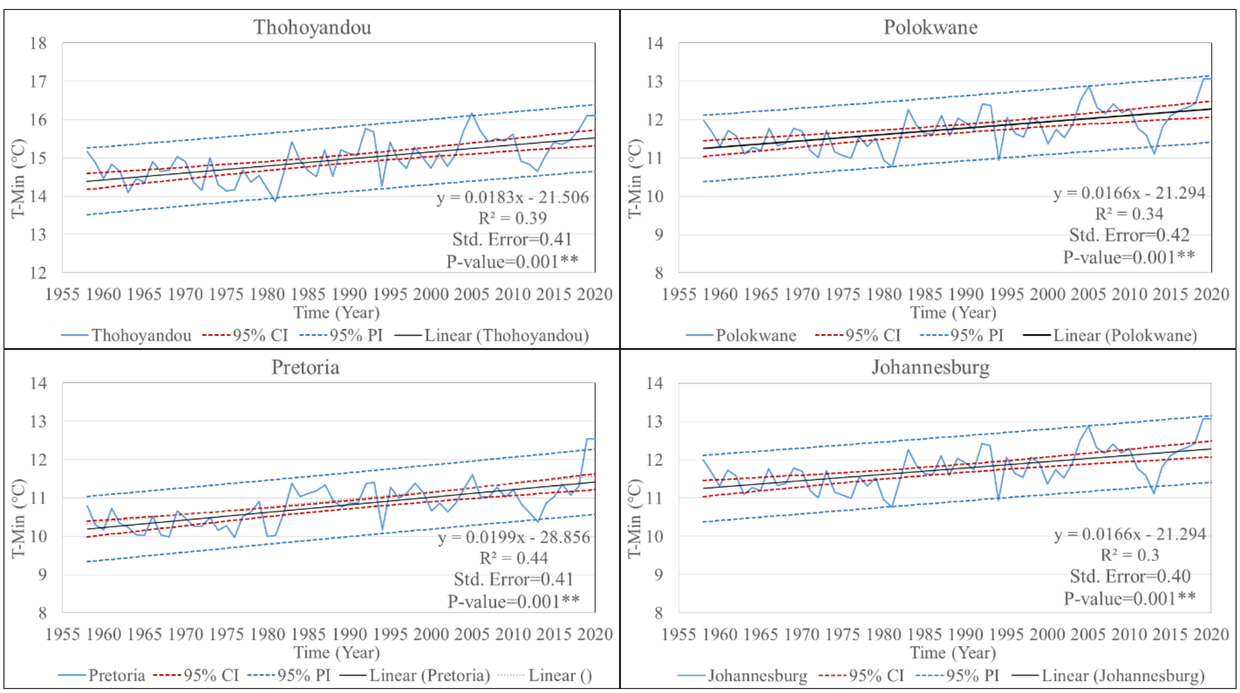
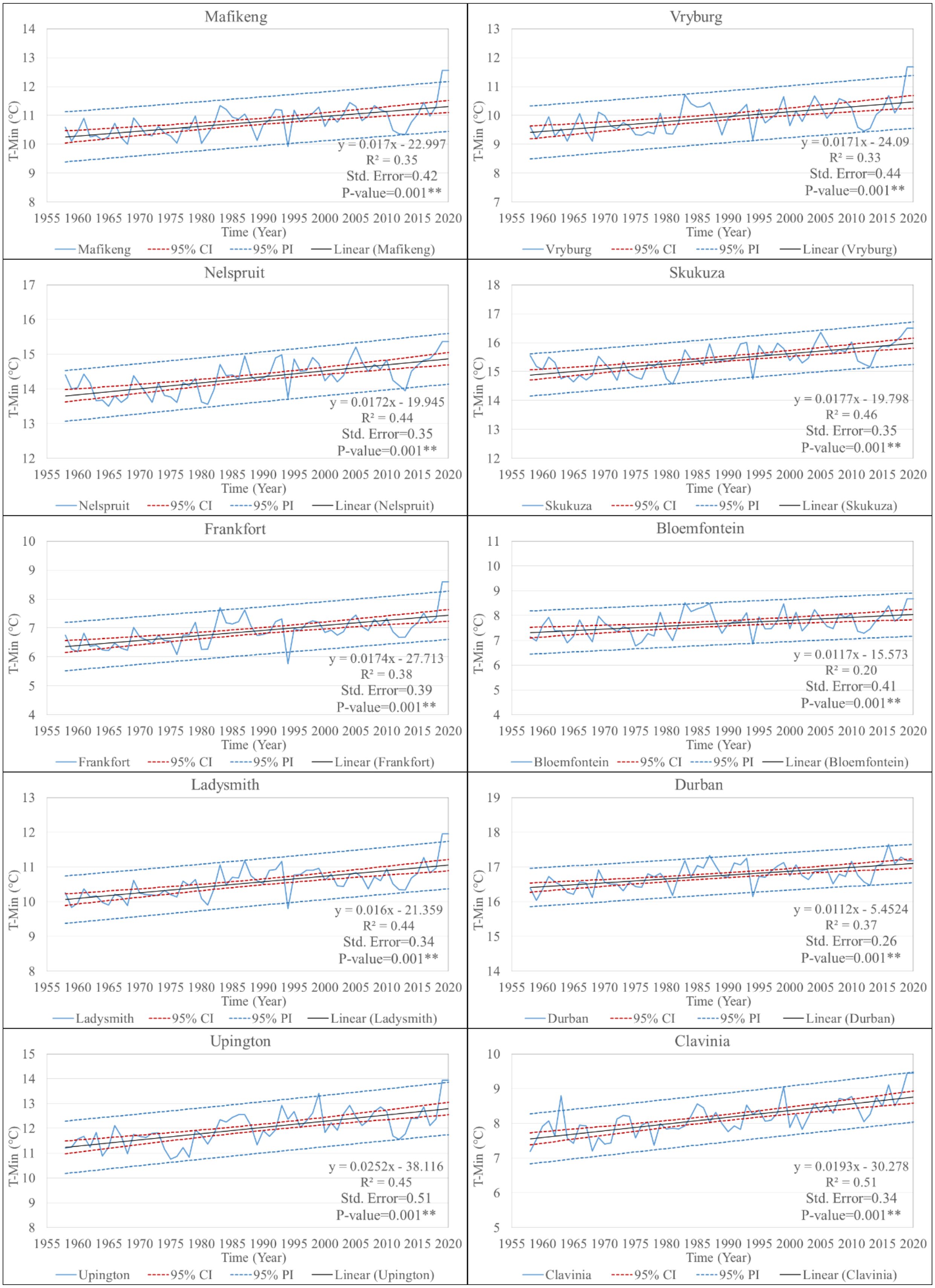


Figure (7): Trend of T-Max for the period 1958-2020




Mafikeng
y = 0.017x - 22.997
R² = 0.35
Std. Error=0.42
P-value=0.001**
Vryburg
y = 0.0171x - 24.09
R² = 0.33
Std. Error=0.44
P-value=0.001**
Nelspruit
y = 0.0172x - 19.945
R² = 0.44
Std. Error=0.35
P-value=0.001**
Skukuza
y = 0.0177x - 19.798
R² = 0.46
Std. Error=0.35
P-value=0.001**
Frankfort
y = 0.0174x - 27.713
R² = 0.38
Std. Error=0.39
P-value=0.001**
Bloemfontein
y = 0.0117x - 15.573
R² = 0.20
Std. Error=0.41
P-value=0.001**
Ladysmith
y = 0.016x - 21.359
R² = 0.44
Std. Error=0.34
P-value=0.001**
Durban
y = 0.0112x - 5.4524
R² = 0.37
Std. Error=0.26
P-value=0.001**
Upington
y = 0.0252x - 38.116
R² = 0.45
Std. Error=0.51
P-value=0.001**
Clavinia
y = 0.0193x - 30.278
R² = 0.51
Std. Error=0.34
P-value=0.001**
T-Min (°C)
Time (Year)
95% CI
95% PI

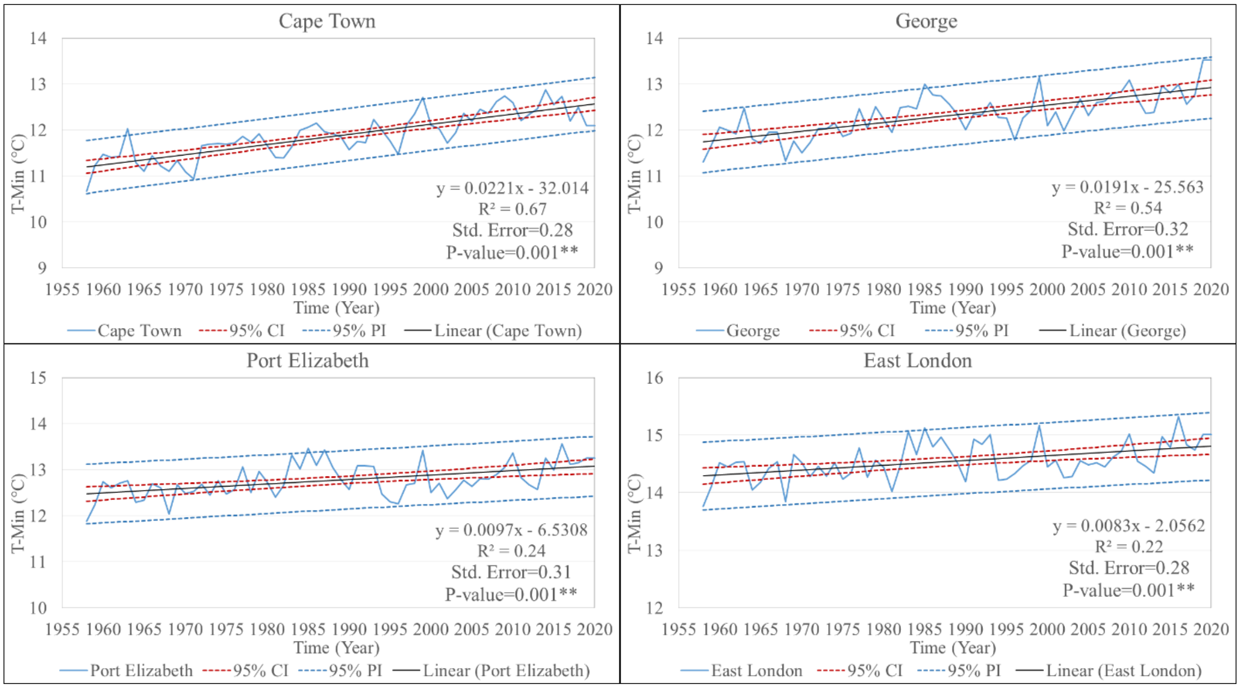


Figure (8): Trend of T-Min for the period 1958-2020

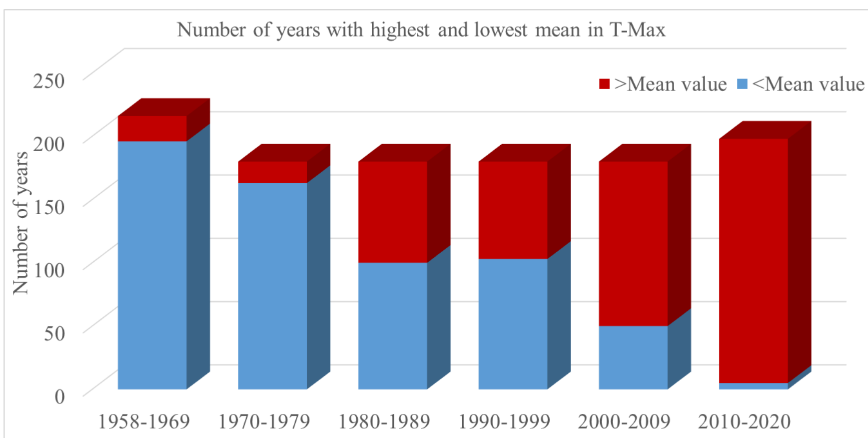


Figure (9): Comparison between number of years with highest and lowest mean as per the occurrences between 1958 and 2020 in T-Max.

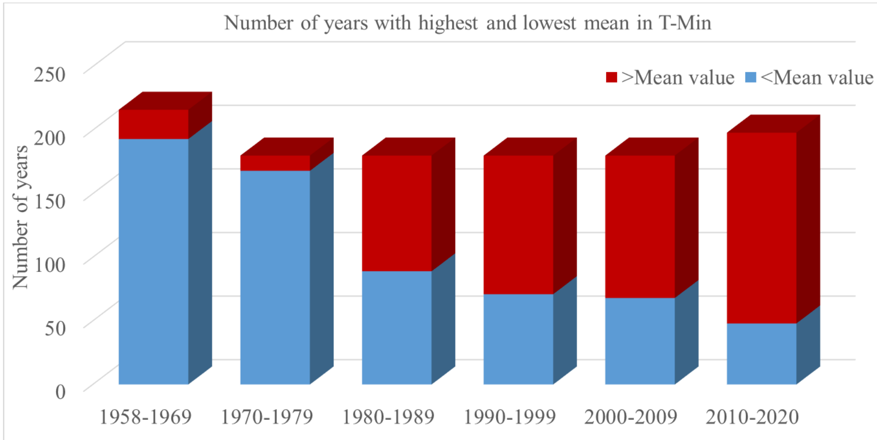


Figure (10): Comparison between number of years with highest and lowest mean as per the occurrences between 1958 and 2020 in T-Min.

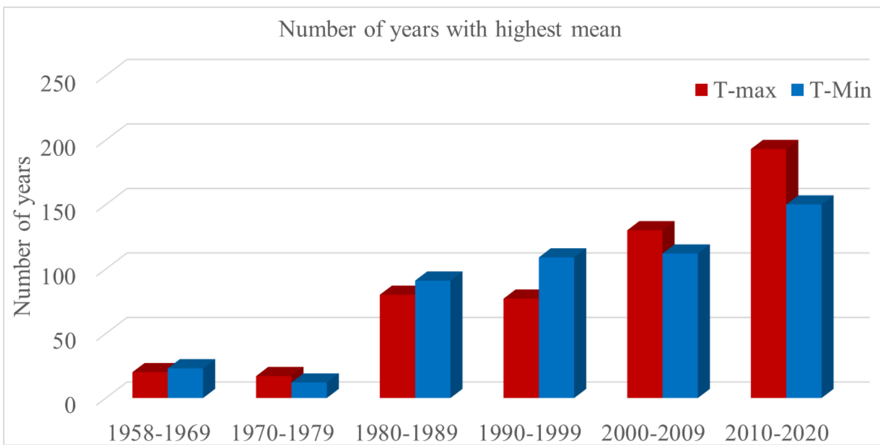


Figure (11): Comparison between T-Max and T-Min as regarding number of years with highest mean as per the occurrences between 1958 and 2020.

3.4. Trends in seasonal mean of T-Max and T-Min

This study examined trends in maximum and minimum temperature data for South Africa during a 63-year period, from 1958 to 2020. On derived mean observed temperature data, Non-parametric Sen's and Man-Kendall tests were run to determine trends for seasonal and yearly. Results showed that at a 95% confidence level, the maximum and lowest seasonal temperatures showed an increasing statistically significant trend (at a<0.05). With the exception of Upington, George, and Port Elizabeth stations (at a<0.01**), Clavinia, and Cape Town stations (at a<0.05*), the winter season maximum temperature trends were statistically significant (a<0.001).

Tables 6 and 7 illustrate the results of the aforementioned seasons. These findings clearly showed a rise in temperature trends following the 1970s, with considerable seasonal variation in station temperatures. Results of the non-parametric Mann-Kendall trend test revealed a significant trend in South Africa's seasonal minimum and maximum temperature average from 1958 to 2020.

The Mann-Kendall test for trend (Table 6) showed that all of the stations under study showed rising summertime maximum temperature trends over the long term. Except for Johannesburg, Mafikeng, and Bloemfontein stations, which were significant at 0.01 level, the trends, which ranged between 0.2 and 0.3°C/ decade, were significant at 0.001 level. The maximum temperature trends in the spring and fall were statistically significant (a <0.001) (figure 5).

Table (7) showed that the trends at all stations were significant at (a<0.001) for the Mann-Kendall test for the winter minimum temperature trend, with the exception of East London station, whereas Bloemfontein (a<0.01) and Port Elizabeth (a<0.05). With the exception of Bloemfontein station, which was significant at (a<0.05), positive trends in the summer minimum temperature were seen at all research stations and were significant at (a<0.001). The upward trends varied from 0.1 to 0.2 °C/ decade (figure 6).

Tables 6 and 7 showed how seasonal temperature trends (summer and fall). Over the past 63 years, the minimum temperature has generally increased for both seasons. In particular relevant in spring and summer, with values reaching 0.1-0.3 °C/decade, and also notable for T-Max in winter (0.7 °C/decade), the data show overall increasing annual trends of annual T-Max and T-Min (0.1-0.4 °C/decade). T-Max and T-Min, however, are expected to rise in the fall (0.01-0.04 °C/decade), according to average patterns.
The Mann Kendall rank test is used to examine time-series of T-Max and T-Min with related trends at a 100% significance level. The time series of all cities before and after 1989 shows two distinct tendencies. For the trend analysis, we split the whole period in half, with the first half (P1: 1958–1988) and the second half (P2: 1989–2020). The fact that there was greater industrial growth in P2 than P1 may be the reason for the stronger upward trend. Table (8) showed the difference between the averages. T-Max and T-Min are increasing more quickly overall at all stations, according to the average over two distinct time periods (P1: 1958–1988 and P2: 1989–2020). The temperature increased significantly in all stations for both T-Max and T-Min during P2 more than P1, according to a month-by-month trend study. Table 8 provides the typical temperatures for the P1 and P2 periods for comparison. It is clear that P2 saw a greater increase in T-Max and T-Min across all stations than P1. This appears to demonstrate the impact of global warming. The average of T-Max and T-Min between 1989 and the present was compared using the t-test for independent samples. The primary test to compare the means of two periods is the t-test. Because the Wilcoxon paired signedrank test assumes that the two datasets come from symmetric distributions, which is not always the case, it is recommended [40]. At all sites in SA, the study revealed a significant mean difference at a 99% significance level. In terms of statistical significance, the highest average of T-Max at Upington station for the years 1989 to 2020 (m = 29.5; SD = 0.7) was greater than the average of T-Max with larger variability for the years 1958 to 1988 (m = 16.9; SD = 0.3). In terms of statistical significance, the maximum average of T-Min at the Durban station for the years 1989 to 2020 (m = 16.6; SD = 0.3) was higher than the average of T-Min with greater variability during the years 1958 to 1988 (m = 28.8; SD = 0.6).
For the study period, the overall T-Max and T-Min trends follow seasonal distributions, and each season exhibits a positive trend. Regarding its possible effects on Earth system processes, climate change has recently drawn a lot of interest from the scientific community at many scales. On derived mean observed T-Max and T-Min data, Sen's and Man-Kendall non-parametric tests were run to determine trends for monthly, seasonal, yearly, and 63 years (1958-2020) climatic regimes. Comparing the number of years with the highest and lowest mean events based on occurrences between 1958 and 2020 in T-Max and T-Min was shown in tables 9 and 10. At a 99.9% confidence level, the T-Max and T-Min data demonstrate a statistically significant (at a 0.001) increasing trend. These findings were in line with Collins' (2011) assertion that South Africa saw a rapid warming trend beginning in the 1970s [5]. The T-Max data set showed a statistically significant trend with an increasing tendency for all seasons. Additionally, the highest MK test value occurred in the autumn (0.04). Additionally, the era (2000-2020) saw a lot of extreme events during the entire study period (Figures 9 and 10). In general, the seasonal trends revealed significant variability in T-Max and T-Min that increased over the months and years.
We note that the number of years above average in maximum temperatures during the last decade of the study was higher than that of minimum temperatures for (193 and 150 year, respectively). Therefore, we find that the maximum temperature was higher than the minimum temperature during the last period of the study years (figure 11). The rates of increase in annual warm years frequencies between 2010 to 2020 were nearly double the warm years occurrences during the period 2000 to 2010 in T-Max, while the number of warm years frequencies between 1990 to 2000 in T-Min was highest the same period in T-Max. Long-term increasing trends in maximum temperatures of all stations were statistically significant, some change points were determined in 2000, all of which reach was significant with period of warming (Figure 11). As for the all stations, change points were detected in 1980 for minimum temperatures. The trends of maximum temperatures had reached a warming period very recently at the end of the series. Consequently, there is a need of further time period or years to adjust these increasing trends observed at the end of the series whether they would continue or not in the future.

4. Conclusions and recommendations

In recent years due to the significant effects that extreme climate changes on nature, human production and life, extreme weather events have recently drawn attention from all over the world. Analyzing the temporal and spatial change trend of maximum and minimum temperature extremes is crucial to comprehending how extreme climate change affect societies and ecosystems. More uncontrollable than precipitation is the temperature change. Global temperature variations have not been consistent, instrumental observations during the previous few years reveal an increase in global surface temperatures with significant regional variability. In this study we examined how maximum and minimum temperatures in South Africa changed spatially and temporally over 63 years (1958– 2020). The study included that exploration of the changes in average maximum and minimum temperature over 18 stations in South Africa using an updated monthly temperature dataset for the period 1958–2020. Also, changes in frequency trends of extreme events are analyzed at seasonal and annual time scales. Over the past century there has been an average global surface temperature increase of 0.2-0.6°C/ decade, and by 2100, the increase is predicted to be between 1.4 and 5.8 °C/ decade.

The previous century has seen two periods of warming for the world average: a milder period from the 1910s to the 1940s (0.35°C), and a stronger period from the 1970s to the present (0.55°C). Over the past 25 years, the rate of warming has accelerated, with the last 12 years seeing 11 of the 12 warmest years ever recorded. Global observations above the surface suggest that the troposphere has warmed at a somewhat faster rate than the surface since the late 1950s, but the stratosphere has substantially cooled since 1979 [41]. A temperature increase has been reported in South Africa by [7, 20].

In the present study, the trends in maximum and minimum temperature (annually and seasonally) were determined for the 18 stations of South Africa. The Trends analysis is extremely helpful to search out the probably influence of activity on hydrologic circle, environmental resources and future water resources management of the South Africa. This was carried out using the non-parametric Mann–Kendall (MK) test. The Sen's slope and percentage changes in temperature were also estimated over the study period (1958-2020). Positive trend were observed in seasonal and annual maximum and minimum temperature.

This study differs from others conducted over South Africa in that it provides more spatial detail of temperature trends. As a result, it significantly advances our knowledge of potential implications of temperature changes. Mann-Kendall test was used for T-Max and T-Min series data, and they revealed an increase over significant sites in South Africa. A rising tendency in the temperatures series of the 18 stations was revealed by the data analysis. The study's findings revealed regional variation and pointed to a general warming of the research area.

Maximum and minimum temperatures nationwide demonstrated a warming trend. The first warm phase, which lasted from the early 1950s to the late 1970s, and the second, which lasted from the early 1980s to the conclusion of the research period, were both recognised. Global temperatures were generally seen to be continuing their upward trend, according to data. The average minimum and maximum temperatures were shown in figure 7 and 8. From the aforementioned statistics, it is clear that South Africa has generally exhibited a positive tendency in the times-series from 1958 to 2020.

Across the several catchments, there was a non-linear pattern of temperature fluctuations. The detailed analysis of monthly T-Max and T-Min in South Africa (years 1975–2004) showed strong warming indications, which is consistent with other studies that emphasised the role of rising global greenhouse gas effect as the primary driver of global warming. At the 99% confidence level, the maximum and minimum annual mean temperature data exhibit a statistically significant (at 0.01) ascending trend. These findings are in line with [5], who claimed that South Africa experienced rapid warming beginning in 1970.

Computing the nonlinear trends in the data records has represented the long-term variation in maximum temperature. Although there is a regional dependence in the variability of maximum temperature changes, the trends are undeniably present, and the warming is substantial enough to have an impact on the region's precipitation and ecosystems. For the research period, the total maximum temperature trend follows the seasonal distributions, and each season exhibits a rising tendency. For the data from 1958 to 2020, the maximum and minimum annual mean temperatures both revealed a statistically significant upward trend at 0.001, 0.01, and 0.05.

This finding is consistent with [42] what noticed on Namulonge in Uganda (1947–2009) and warming trends in Africa, respectively. Statistically significant seasonal trends were observed for every mean maximum and minimum temperature (T-Max and T-Min) values (at a 0.001, 0.01, and 0.05). T-Min for the summer, on the other hand, exhibits a growing statistically significant trend at a 0.001 level. For T-Max and T-Min, favourable trends are also inferred for all seasons. It should be noted that the majority of the endpoints are important. Additional research on temperature trends in various SA regions can be mentioned [19, 20].

The positive T-Max trends clearly predominate during the spring and fall seasons, and all of the trends were statistically significant at 99.9% level. The average trends were respectively 0.2 -0.3 and 0.2 - 0.4 °C/decade. At the same time, summer had the highest mean T-Max trend, whereas autumn has the highest trend. This is in line with the findings for the 1960–2003 and 1949–1989 time periods from [7, 15]. The average temperatures of the P1 (1958–1988) and P2 (1989–2020) eras was shown for comparison. It is clear that P2 saw a greater increase in T-Max and T-Min across all stations than P1. This appears to demonstrate the impact of global warming. There is no scientific question that South Africa's local weather is warming up; as a result, significant changes in the country's wide range of extreme temperature activities have already been noticed, particularly increased in warm waves in the Western Cape, and wildfires additionally since 1990, each of the last three decades has been warmer than the one before it.

This study recommends more investigation into the underlying regional elements affecting the region's climate, the reasons for variations in monthly mean temperatures the actual impacts of ENSO on rainfall totals and the influence of the Indian Ocean over the West Bank and East region. At the same time several aspects of how urbanisation and global warming affect the micro temperature also need more research.

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