“Variability of extreme temperature in Kigali during the recent decades”

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"Variability of Extreme temperature in Kigali during the recent decades"

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Declaration

I declare that this Dissertation contains my own work except where specifically acknowledged

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Signed………………………………………..

Date…………………………………………..

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ABSTRACT

The climate change is among the main problem the world is facing nowadays. In Rwanda, researches have shown the increase of temperature during the last decades. The observed warming is most likely explained by the growing population accompanied by the increasing emission of greenhouse gases, and the escalating urbanization and industrialization the country has experienced during the last decades, especially in Kigali as country Capital. This study was focused on examining the variability extreme temperature in Kigali during Recent decades. Among 27 climate extreme indices recommended by ETCCDI (Expert team on Climate change detection and Indices), only the indices which could be relevant to Rwanda (especially in Kigali) were selected. The positive trend (Z=4.37) at α = 0.001 level of significance for maximum Temperature and the positive trend (Z= 6.33) at α = 0.001 level of significance for Minimum temperature was found. The slope value was 0.043^{o}C/year for Maximum temperature and 0.056^{o}C/year for Minimum Temperature for the period 1980-2015. More significant positive trend for Minimum temperature was observed compared to Maximum Temperature. Thus, the trend for The Diurnal Temperature Range is negative (Z= -1.16) at significant level greater than 0.1 with the slope value of -0.010^{o}C/year. All temperature indices have shown the significant increase during last recent decades especially indices related to minimum temperature. The increase in warm days and warm nights together with the decrease in cool nights and cool days were observed.

In general the results for annual mean Temperature show that the temperature has increased significantly in Kigali in the period 1980-2015 with the slope value of 0.044^{o}C/year**.** All results show that Kigali has experienced the significant warming during recent decades especially in the last two decades. The observed warming is explained by the increase of urbanization, industrialization, high density of population accompanied with the increase in greenhouse gases emission.

KEY WORDS: Climate change, Extreme temperature indices, Trend, Mann-Kendall, Kigali.

LIST OF SYMBOLS AND ACRONYMS

CDT: Climate Data Tools

CSDI: Cold Spell Duration Index

DTR: Diurnal Temperature Range

ETCCDI: Expert Team on Climate Change Detection and Indices

GHA: Greater Horn of Africa

IPCC: Intergovernmental Panel on Climate Change

MAKESENS: Mann-Kendall test for trend and Sen's slope estimates

NISR: National Institute of Statistics of Rwanda

SNHT: Standard normal homogeneity test

SU: Summer days

Tmax: Maximum Temperature

Tmin: Minimum Temperature

TN10p: Cool nights: Percentage of days when TN <10th percentile

TN90p: Warm nights: Percentage of days when TN >90th percentile

TNn: Monthly minimum value of daily minimum temperature.

TNx: Monthly maximum value of daily minimum temperature.

TX10p: Cool days: Percentage of days when TX <10th percentile

TX90p: Warm days: Percentage of days when TX >90th percentile

TXn: Monthly minimum value of daily maximum temperature

TXx: Monthly maximum value of daily maximum temperature.

WSDI: warm spell duration index

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CHAP I.INTRODUCTION

I.1. Background

The climate change is among the main problem the world is facing nowadays. The increase of global mean temperature is one of the characteristics of Climate change.

The warming of the climate system and the climate change in many regions of the planet is driven primarily by the increase of anthropogenic greenhouse gases' concentration due to human activities such as deforestation, burning fossil fuel and the conversion of the Earth's land to urban and this goes with the rapid growth of the Earth's human population. (1)

The total emissions of anthropogenic greenhouse gas have increased over a period of 1970 to 2010 but even though policies on climate change mitigation are growing, the IPCC synthesis report of 2014 has shown that anthropogenic greenhouse gas emissions have increased more largely between 2000 and 2010 (2)

Researches have shown that change in the mean temperatures may be related to change in extremes events, which is more closely related to the impacts of climate on human society and environment (3).The increase in mean surface temperature lead necessarily to rise in extreme events. (4)

There is no doubt that changes in frequency and intensity of extreme weather and climate events have more likely to increase impacts on environment and the society. (5)

Many evidences that climate is changing have led to many scientific studies on weather and climate extremes. One study on global scale showed that Maximum and minimum temperature increased in almost all parts of the globe during both periods but Tmin increased considerably (6).Other research on temperature and precipitation extreme indices since the beginning of the twentieth century has shown a significant warming trends related to temperature extremes indices and mostly stronger for indices based on daily minimum temperature than for indices based on daily maximum temperatures (7).In South Africa, the maximum temperature indices have shown in general the increase in warm extremes while the minimum temperature indices have shown the decrease in cold extremes in the period 1962–2009 (8).

In Rwanda, Research has shown the increase of temperature during last decades. The observed warming is most likely explained by the growing population accompanied by the increasing emission of greenhouse gases, and the escalating urbanization and industrialization the country has experienced during the last decades, especially in Kigali as country Capital (1).

Therefore, there is a need to investigate on how extremes in temperature are affecting the climate of Kigali as the most vulnerable to climate change in Rwanda.

I.2. Problem statement

The fact that Kigali is the administrative and commercial Capital and the largest City of the country make it vulnerable to the climate change. The increase of Surface Temperature is one of the effects of climate change. In the last decade, Rwanda especially in Kigali, the economic sector has improved. More industries and increase of urban areas has been the cause of increasing the emission of some greenhouse gases leading to the warming of surface.

The geographical location and the topography of Kigali are also the cause of high temperature observed in Kigali. The development of Rwanda is increasing considerably and Kigali continues to be the top of development in Rwanda. This makes it more vulnerable to climate change which is manifested by the variability in near surface temperature.

I.3. Objectives

The main objective of the present study is to examine the variability of the extreme temperature in Kigali during the recent decades.

Specific objectives:

- To provide an overview on temporal variations of temperature extremes under the rapid warming during the past few decades over Kigali, Rwanda.
- To show the behavior of indices of extreme temperature over Kigali,Rwanda.
- To show which extremes of temperature are influencing more the warming of Kigali,Rwanda.

I.4. Justification of the study

Kigali city is located in center of Rwanda as illustrated on figure2 and is the capital of Rwanda. During recent decades, Kigali has experienced a rapid increase of population density together with the increase of urbanization and a lot of many anthropogenic activities which lead to the increase of greenhouse gases emissions contributing to the Global warming. For this reason, we have oriented our study on assessing the variability of extreme temperature in Kigali during recent decades in order to see if Kigali is experiencing the global warming as other cities on the globe.

I.5.Study area and its climate characteristic

Kigali is the administrative and commercial Capital and the largest City of the country. The total land area of Kigali is about 730 km^2.By the year 2012, the population of Kigali was 1,132,686 which was about 10.77% of the whole population of Rwanda.

Kigali is situated in the Centre of Rwanda. It is built on hilly landscape sprawling across ridges and wetlands with an altitude varying between 1300-2100m. The Nyarugenge District is dominated by strong linear ridge running north-south with a maximum altitude of 1900m and softens towards the flat alluvial planes of the Nyabarongo River on the west. The Gasabo District constitutes of more aggressive relief due to the tight rectilinear ridges oriented northwest with a maximum altitude of 2100m to 1900m and gentle relief along the Nyabugogo River and southern part of the district. The Kicukiro District is composed of gentle slope plateaus, avereging less than 1700m of altitude and the slopes gently settle into the alluvial plains of the Nyabarongo River. (9)

Kigali is bordered by four Provinces: Eastern Province on East and South side, North Province on North side, and South Province in West side.The city is bounded by the Nyabarongo River along the western and southern edge, and partly by Lake Muhazi in the north eastern edge (10) .

Its coordinates are 1.9706° S, 30.1044° E

The figure 1. illustrates the contribution of the three districts on the land area of Kigali (11).

Figure 1.distribution of land area of Kigali in three districts

Figure 2.Administrative map of Kigali city.

CHAP II. LITERATURE REVIEW

II.1.Climate variability & change

Our climate system is globally changing and human influence on this changing is very considerable by increasing the anthropogenic greenhouse gas emission in atmosphere. The impact of this warming affects both humans and natural systems. Since 1950s, there many observed changes on the global climate change like the warming of the atmosphere and the oceans, the decrease in amount of snow and ice and the rise in sea level. The population and economic growth have influenced on the increase of greenhouse gases emission than ever. There was an increase in carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) concentrations. The impact of these gases and other anthropogenic drivers is very high on the climate change. The total emissions of anthropogenic greenhouse gas have increased over a period of 1970 to 2010 but even though policies on climate change mitigation are growing, the IPCC synthesis report of 2014 has shown that anthropogenic greenhouse gas emissions have increased more largely between 2000 and 2010 (12).

The main characteristics of climate change are increases in average global temperature (global warming); changes in cloud cover and precipitation particularly over land; melting of ice caps and glaciers and reduced snow cover; and increases in ocean temperatures and ocean acidity due to seawater absorbing heat and carbon dioxide from the atmosphere. (13)

As the problem of climate change is a global issue, Rwanda also may be affected. Rwanda has a moderate climate and relatively high rainfall. Climate change may affect Rwanda in different ways: The increase in Temperature, Intensified rainfall, prolonged dry seasons. The mountainous west of the country will be subject to erosion, parts of the central north and south will experience severe floods, and the east and southeast will suffer from droughts and desertification. In terms of food security, the four most vulnerable regions (out of twelve) are the Eastern Agro-Pastoral Zone, the Eastern Semi-Arid Agro-Pastoral Zone, the Bugesera Cassava Zone in the south, and parts of the Eastern Congo-Nile Highland Subsistence Farming Zone. Some climate change effects, such as the lowering level of lakes and water flows and forest degradation, are expected to occur throughout the country (14).

The increase of global mean temperature is the main characteristic of climate change.

Increase in anthropogenic greenhouse gases' concentrations in the atmosphere mainly due to human activities such as deforestation and burning fossil fuel and the conversion of the Earth's land to urban uses driven largely by the rapid growth of the Earth's human population are one of the causes of the warming of the climate system and of the process of climate change in several regions of the planet. In Rwanda, Research has shown the increase of temperature during last decades. The warming observed is explained likely by the increase in population together with the increasing in greenhouse gases emission, and the rapid urbanization and industrialization increase the country has experienced during the last decades, especially in Kigali as country Capital (1)

Rwanda's average temperature varies according its topography. A study on climate change and natural disasters (Twagiramungu, 2006) has shown that Low temperatures are observed in the regions of high altitude with average temperatures ranging between 15 and 17°C. In some parts of the volcanic region, temperatures can go below 0°C. Moderate temperatures are found in areas with intermediary altitude where average temperatures vary between 19 and 21°C. In the lowlands (east and southwest), temperatures are higher and the extreme can go beyond 30°C in February and July-August (15)

II.2.Extreme temperature

The occurrence of extreme weather inevitably leads to questions about whether the frequency or intensity of such events has changed. Common understanding of an extreme event is based on the assumption that a "normal" state exists which is generally derived from a temporal series of observed conditions. As many aspects of climate are well represented by monthly means, most indices derived from daily data generally focus on extremes. The term "extreme" has been used in a wide number of formulations and contexts in many scientific literatures on climate extremes. It refers to events that may in fact not be all that extreme, such as the occurrence of a daily maximum temperature that exceeds the 90th percentile of daily variability as estimated from a climatological base period, or it may refer to rare events that lie in the far tails of the distribution of the phenomenon of interest. (16)

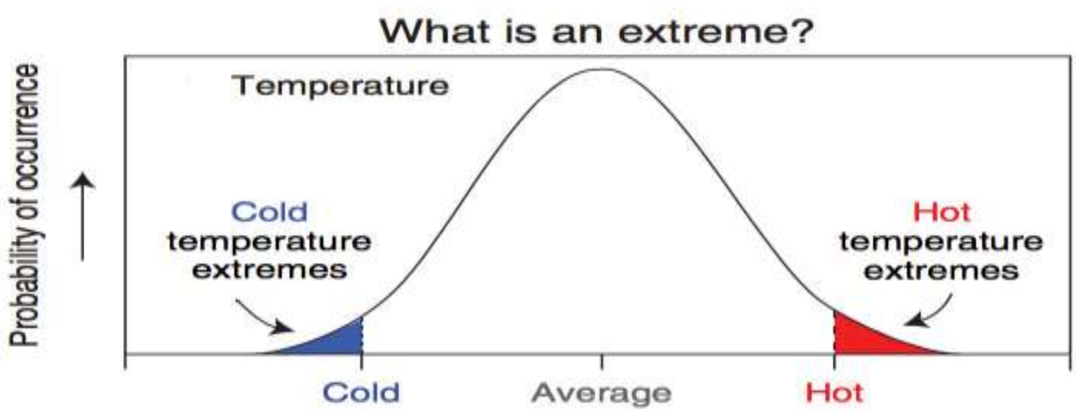

Figure 3.Probability distributions of daily temperature

The higher the black line, the more often weather with those characteristics occurs. The shaded areas denote extremes **(16)**

Extreme events not only cause property damage, injury, hunger, loss of life and threaten the existence of some species, but also drive changes in natural and human systems much more than average climate. Analysis of changes in extreme climate events, therefore, is important due to the potentially high social, economic and ecological impact of such events (17).

Many studies were conducted on Extreme temperature and extreme temperature indices on global scale and locally. The Report on the Activities of the Working Group on Climate Change Detection and Related Rapporteurs conducted from 1998 to2001 has shown that Most of the selected indices seem to be very relevant for temperature and give a regional overview of climate change. Many types of indices can be drawn up from daily data. There is a list of the climate indices that ClimDex computes. Some indices are based on thresholds, some on varying extremes while others are just normalized or combined indices. The indices are expressed in various ways to facilitate spatial and temporal trend detection and impact analysis. (18)

The study on Global observed changes in daily climate extremes of temperature and precipitation in 2006 has shown that there is a shift in the distribution of both maximum and minimum temperature extremes consistent with warming and that globally averaged minimum temperature extremes are warming faster than maximum temperature extremes (19). Thereafter in 2012, it has been shown that the distributions of both daily and seasonal temperatures have significantly shifted toward higher temperature values since the middle of the twentieth century. The main findings include widespread and significant warming trends related to temperature extremes indices, mostly stronger for indices based on daily minimum temperatures than for indices calculated from daily maximum temperatures. (7)

In Caribbean region, the analyses of the annual mean of daily maximum temperature (TXmean) have suggested a general warming of the daytime temperature over the 1961–2010 period. TXmean Caribbean-wide regional average indicates a significant warming of 0.19 ◦C decade^{-1}.The annual mean of daily minimum temperature (TNmean) suggest a significant and more pronounced warming of 0.28 ◦C decade^{-1} over the same period. Nighttime temperature (TNmean) trends at individual stations are generally greater than daytime temperature (TXmean) trends. This difference leads to a decrease in diurnal temperature range (DTR) (20).

The study on Trends in temperature extremes during 1951-1999 in China has shown the following results: Increasing trends were detected in the frequencies of warm days and warm nights, and the major increases were found to occur since the mid-1980s. The increasing trend in the frequency of warm nights was greater than that of warm days. A decreasing trend was found in the mean number of cool days for all of China, and an even stronger decreasing trend was found in the number of cool nights. Spatially, the frequency of warm days increased in northern and western China but decreased in much the central and southern parts of eastern China. However, frequency of warm nights increased significantly in most of China, and cool nights decreased over almost all China. (3)

The research on Variability of extreme temperature conducted in IRAN has shown negative trends for indices representing cold maximum and minimum temperature extremes i.e. ID, FD, TN10p and TX10p, and conversely, positive trends for indices representing warm maximum and minimum temperature extremes, i.e. SU25, TR20, TN90p and TX90p in many regions of the country (21).

The research conducted on Changes in temperature and precipitation extremes over the Greater Horn of Africa region from 1961 to 2010, has shown that the warm extremes were increasing while cold extremes decreasing, thus these series clearly indicate significant warming. The future occurrence of warm days and nights are projected to be more frequent in the entire GHA, while the occurrence of cold night events is likely to decrease (17).

In South Africa the results of the study on Trends in extreme temperature indices in South Africa between 1962 and 2009 indicate relatively stronger increases in warm extremes and decreases in cold extremes in the western, northeastern and extreme eastern parts of the country. This indicates that South Africa experienced general warming over the mentioned period. (8)

Recently in 2017, the research conducted in Tanzania on Spatial and Temporal Analysis of Rainfall and Temperature Extreme Indices in Tanzania has shown that both maximum and minimum temperature have exhibited statistical significant increasing trends at monthly and annual time scales. Spatial analysis of the observed temperature trend has indicated a coherent and widespread warming over the large part of the country, particularly over the eastern part, while a non-statistical significant decreasing temperature trends is depicted in some few areas over western part of the country (22).

In Rwanda, Weather records have shown that Rwanda was becoming hotter: the annual average temperature has increased 0.35°C per decade between 1971 and 2010. Minimum and maximum temperatures have increased over the past few decades, with the minimum temperature having a greater increase and thus implying a reduction in the diurnal temperature range (23).

CHAP III.DATA AND METHODOLOGY

III.1. Data

Data used have been collected from Rwanda Meteorological agency. They consist of time series of daily data of Minimum and Maximum temperature for the period ranging from 1980 to 2015. These data were recorded at Kigali International Airport synoptic station located in Kicukiro district at -1.95^{o}Latitude South and 30.11^{o} Longitude East, at elevation of 1490m above sea level.

III.2.Data Quality Control

A study of long term climate change must be homogenous (1). It is important that time series are as homogenous as possible, because without an assurance of homogeneity, estimates of trends will be unreliable (21) .

There is a number of methods to test homogeneity. In the research conducted by Safari (1), the Short-cut Bartlett homogeneity test was applied to the mean annual temperature data. The study on temporal variability of extreme temperature indices in Utah during the past few decades**,** RHtest software package has been used to test Homogeneity.

During this study, RHtest soable in CDT (Climate Data Tools) and Climdex for homogeneity test have been used. The test showed that our data were homogeneous.

III.3.Methodology

During this research, data obtained from Rwanda Meteorology was analysed.

III.3.1.Indices calculations

Among 27 climate extreme indices recommended by ETCCDI (Expert team on Climate change detection and Indices), only the indices which could be relevant to Rwanda (especially in Kigali) were selected. 10 indices referred to extreme temperature were calculated. CDT (Climate Data Tools) was used to calculate the Temperature indices. The Table2 shows the 10 indices computed and their definitions. (24)

III.3.2.TREND ANALYSIS

To identify the significance level of trends, Mann-Kendall test was used. There are a number of statistical tests that are used for the analysis of trend such as Spearman rank statistic test, Cramer's test, Pearson's test, Pettit's test, Buishand's test, Von Neumann's test, Standard normal homogeneity test (SNHT), Mann Kendall's Rank Statistic test. The latest is considered to be the most appropriate for the analysis of climatic changes in climatological time series or for the detection of climatic abrupt changes (1).

During this research we preferred to use an Excel template MAKESENS (Mann-Kendall test for trend and Sen's slope estimates).This is developed for detecting and estimating trends in the time series of the annual values of atmospheric and precipitation concentrations (25).

III.3.2.1.Calculation of the Mann-Kendall test and the magnitude of the trend with the Sen's method in MAKESENS

MAKESENS performs two types of statistical analyses. First the presence of a monotonic increasing or decreasing trend is tested with the nonparametric Mann-Kendall test and secondly the slope of a linear trend is estimated with the nonparametric Sen's method. These methods are here used in their basic forms; the Mann-Kendall test is suitable for cases where the trend may be assumed to be monotonic and thus no seasonal or other cycle is present in the data. The Sen's method uses a linear model to estimate the slope of the trend and the variance of the residuals should be constant in time. These methods offer many advantages that have made them useful in analysing atmospheric chemistry data. Missing values are allowed and the data need not conform to any particular distribution. Besides, the Sen's method is not greatly affected by single data errors or outliers.

1.1. Mann-Kendall test

The Mann-Kendall test is applicable in cases when the data values *xi* of a time series can be assumed to obey the model

$$x_i = f(t_i) + \varepsilon_i, \quad [1]$$

where $f(t)$ is a continuous monotonic increasing or decreasing function of time and the residuals ε_i can be assumed to be from the same distribution with zero mean. It is therefore assumed that the variance of the distribution is constant in time. We want to test the null hypothesis of no trend, H_o, i.e. the observations x_i are randomly ordered in time, against the alternative hypothesis, H_1, where there is an increasing or decreasing monotonic trend. In the computation of this statistical test MAKESENS exploits both the so called S statistics given in (26)and the normal approximation (Z statistics). For time series with less than 10 data points the S test is used, and for time series with 10 or more data points the normal approximation is used.

1.1.1 Number of data values less than 10

The number of annual values in the studied data series is denoted by n. Missing values are allowed and n can thus be smaller than the number of years in the studied time series.
The Mann-Kendall test statistic S is calculated using the formula

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

[2]

where x_j and x_k are the annual values in years j and k, $j > k$, respectively, and

$$\operatorname{sgn}(x_j - x_k) = \begin{cases} 1 & \text{if } x_j - x_k > 0 \\ 0 & \text{if } x_j - x_k = 0 \\ -1 & \text{if } x_j - x_k < 0 \end{cases}.$$

[3]

If n is 9 or less, the absolute value of S is compared directly to the theoretical distribution of S derived by Mann and Kendall (26). In MAKESENS the two-tailed test is used for four different significance levels α : 0.1, 0.05, 0.01 and 0.001. At certain probability level H_0 is rejected in favour of H_1 if the absolute value of S equals or exceeds a specified value $S_{\alpha/2}$, where $S_{\alpha/2}$ is the smallest S which has the probability less than $\alpha/2$ to appear in case of no trend. A positive (negative) value of S indicates an upward (downward) trend.

The minimum values of n with which these four significance levels can be reached are derived from the probability table for S as follows.

Significance level α	**required *n***
0.1	≥ 4
0.05	≥ 5
0.01	≥ 6
0.001	≥ 7

The significance level 0.001 means that there is a 0.1% probability that the values x_i are from a random distribution and with that probability we make a mistake when rejecting H_0 of no trend. Thus the significance level 0.001 means that the existence of a monotonic trend is very probable. Respectively the significance level 0.1 means that there is a 10% probability that we make a mistake when rejecting H_0.

1.1.2 Number of data values 10 or more

If n is at least 10 the normal approximation test is used. However, if there are several tied values (i.e. equal values) in the time series, it may reduce the validity of the normal approximation when the number of data values is close to 10.

First the variance of S is computed by the following equation which takes into account that ties may be present:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5) \right]. \quad \textbf{[4]}$$

Here q is the number of tied groups and tp is the number of data values in the p^{th} group.

The values of S and $VAR(S)$ are used to compute the test statistic Z as follows

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S < 0 \end{cases} \quad \textbf{[5]}$$

The presence of a statistically significant trend is evaluated using the *Z* value. A positive (negative) value of *Z* indicates an upward (downward) trend. The statistic *Z* has a normal distribution. To test for either an upward or downward monotone trend (a two-tailed test) at α level of significance, H_0 is rejected if the absolute value of *Z* is greater than $Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is obtained from the standard normal cumulative distribution tables. In MAKESENS the tested significance levels α are 0.001, 0.01, 0.05 and 0.1.

1.2 Sen's method

To estimate the true slope of an existing trend (as change per year) the Sen's nonparametric method is used. The Sen's method can be used in cases where the trend can be assumed to be linear. This means that *f(t)* in equation [1] is equal to

$f(t) = Qt + B$ **[6]**

where Q is the slope and B is a constant.

To get the slope estimate *Q* in equation [6] we first calculate the slopes of all data value pairs.

$$Q_i = \frac{x_j - x_k}{j-k}, \quad \textbf{[7]}$$

where $j>k$.

If there are *n* values x_j in the time series we get as many as $N = n(n-1)/2$ slope estimates Q_i. The Sen's estimator of slope is the median of these *N* values of Q_i. The *N* values of Q_i are ranked from the smallest to the largest and the Sen's estimator is

$Q = Q_{[(N+1)/2]}$, if *N* is odd

Or

$$Q = \frac{1}{2}\left(Q_{[N/2]} + Q_{[(N+2)/2]}\right)$$ if *N* is even.

[8]

A 100(1-α)% two-sided confidence interval about the slope estimate is obtained by the nonparametric technique based on the normal distribution. The method is valid for *n* as small as 10 unless there are many ties.

The procedure in MAKESENS computes the confidence interval at two different confidence levels; α = 0.01 and α = 0.05, resulting in two different confidence intervals.

At first we compute

$$C_\alpha = Z_{1-\alpha/2}\sqrt{VAR(S)}\ ,$$ **[9]**

where *VAR(S)* has been defined in equation (4), and Z1-α*/2* is obtained from the standard normal distribution.

Next $M_1 = (N - C_\alpha)/2$ and $M_2 = (N + C_\alpha)/2$ are computed. The lower and upper limits of the confidence interval, Q_{min} and Q_{max}, are the M_1^{th} largest and the $(M_2+1)^{th}$ largest of the N ordered slope estimates Q_i. If M_1 is not a whole number the lower limit is interpolated. Correspondingly, if M_2 is not a whole number the upper limit is interpolated.

To obtain an estimate of B in equation [6] the *n* values of differences $x_i - Qt_i$ are calculated. The median of these values gives an estimate of B .The estimates for the constant B of lines of the 99% and 95% confidence intervals are calculated by a similar procedure. (25)

CHAP IV. RESULTS AND DISCUSSION

IV.1.Variability of maximum and minimum temperature

The results have shown that the daily maximum temperature and minimum temperature has increased significantly in the period of 1980-2015 especially in the period of 1990-2005. The increase is more significant for daily minimum temperature.

IV.1.1.Maximum Temperature

The trend analysis for Maximum temperature using the mann-kendall test and sen's slope estimates has shown the positive trend (Z=4.37) at α = 0.001 level of significance with the slope value of 0.043^{o}C/year (Q). (See figure 4)

IV.1.2.Minimum Temperature

The trend analysis for Annual Minimum temperature using the mann-kendall test and sen's slope estimates have shown the positive trend (Z= 6.33) at α = 0.001 level of significance with the slope value of 0.056^{o}C/year (Q). These values are high compared to Annual Maximum Temperature. (see figure 5)

The Table 3 and 4 on the appendix show the summary of results from MAKENS template illustrating the trend significance by Mann-Kendall and sen's slope estimate for Tmax and Tmin

In MAKESENS worksheet,

- Test **S** is displayed if n is 9 or less in both tables, Here the S column is not displaced because **n**>9.
- The Test Z is displayed if If n is at least 10.Here n is equal to 36.
- A positive value of Z indicates an upward trend while a negative value of Z indicates a downward trend. In our time series, all Z values are positive which give the positive trend for both maximum temperature and minimum temperature.
- For the four tested significance levels the following symbols are used

in the template:

- *** if trend at α = 0.001 level of significance
- ** if trend at α = 0.01 level of significance
- * if trend at α= 0.05 level of significance
- + if trend at α= 0.1 level of significance

If the cell is blank, the significance level is greater than 0.1 (25).

The Q values express the sen's slope value slope value.

A significant warming trend was observed for the period after the year 1990 for both Maximum and Minimum Temperature.

IV.2.Temperature indices

IV.2.1. Maximum indices

The trend analysis for Monthly maximum value of daily maximum temperature using the mann-kendall test and sen's slope estimates has shown the positive trend (Z= 2.93) at α = 0.01 level of significance with the slope value of 0.042^{o}C/year (Q). (See figure 6)

The trend analysis for Monthly minimum value of daily maximum temperature using the mann-kendall test and sen's slope estimates has shown the positive trend (Z= 4.48) at α = 0.001 level of significance with the slope value of 0.043^{o}C/year (Q). (See figure 7)

The positive trend was observed in both plots. The plot for TXn presents more significantly the positive trend than TXx..

IV.2.2. Minimum indices

The trend analysis for Monthly maximum value of daily minimum temperature using the mann-kendall test and sen's slope estimates has shown the positive trend (Z= 6.36) at α = 0.001 level of significance with the slope value of 0.058^{o}C/year (Q). (See figure 8)

The trend analysis for Monthly minimum value of daily minimum temperature using the mann-kendall test and sen's slope estimates has shown the positive trend (Z= 5.71) at α = 0.001 level of significance with the slope value of 0.053^{o}C/year (Q). (See figure 9)

The significant increase was more observed for Monthly maximum value of daily minimum temperature.

IV.2.3. Cool nights and Warm nights

The trend analysis for cool nights using the mann-kendall test and sen's slope estimates has shown the negative trend (Z= -6.57 at α = 0.001 level of significance with the slope value of -0.536%/year (Q). (See figure 10)

The trend analysis for warm nights using the mann-kendall test and sen's slope estimates has shown the positive trend (Z= 5.93) at α = 0.001 level of significance with the slope value of 0.913%/year (Q). (See figure 11)

The significant decrease of cool nights followed by the increase in warm nights was observed during the recent decades explaining the significant increase in warming.

IV.2.4. Cool days and Warm days

The trend analysis for cool days using the mann-kendall test and sen's slope estimates has shown the negative trend (Z= -3.92) at α = 0.001 level of significance with the slope value of -0.204%/year (Q). **(**See figure 12)

The trend analysis for warm days using the mann-kendall test and sen's slope estimates has shown the positive trend (Z= 4.36) at α = 0.001 level of significance with the slope value of 0.586%/year (Q**).** (See figure 13)

The increase in Warm days and the decrease in cool days was observed especially since 1990.

IV.2.5. Diurnal Temperature Range

The trend analysis for Diurnal Temperature Range (DTR) using the mann-kendall test and sen's slope estimates has shown the negative trend (Z= -1.16) at significant level greater than 0.1. with the slope value of -0.010^{o}C/year (Q). The diurnal Temperature range is decreasing. This makes sense because the minimum temperature increase more than maximum temperature does. (See figure 14, 15)

IV.2.6. Summer Days

The trend analysis for summer days using the mann-kendall test and sen's slope estimates (b) hs shown the positive trend (Z= 4.13) at α = 0.001 level of significance with the slope value of 0.411%/year (Q).(See figure 16)

IV.3. Mean Annual Temperature of Kigali during recent decades

The trend analysis for Mean Annual temperature using the mann-kendall test and sen's slope estimates has shown the positive trend (Z= 5.63) at α = 0.001 level of significance with the slope value of 0.044^{o}C/year (Q) (See figure 17). The significant increase in temperature in Kigali was clearly observed. This has been also shown in other researches done on temperature in Rwanda **(23)**, **(1)**. The observed warming is most likely explained by the growing population accompanied by the increasing emission of greenhouse gases, and the escalating urbanization and industrialization the country has experienced during the last decades, especially the capital City Kigali, during the last decades **(1)**.

CHAP V.CONCLUSION AND RECOMMENDATION

V.1.Conclusion

In this research, the purpose was to examine the variability of the extreme temperature on the surface of Kigali during the last decade in general. Particularly, the aim was to show the behavior of indices of extreme temperature over Kigali, Rwanda. Among 27 climate extreme indices recommended by ETCCDI (Expert team on Climate change detection and Indices), only the indices which could be relevant to Kigali were selected. The significant warming trend was observed in both Maximum and minimum temperature. The positive trend (Z=4.37) at $\alpha = 0.001$ level of significance for maximum Temperature and the positive trend (Z= 6.33) at $\alpha = 0.001$ level of significance for Minimum temperature was found. The slope value is 0.043^{o}C/year for Maximum temperature and 0.056^{o}C/year for Minimum Temperature for the period 1980-2015. More significant positive trend for Minimum temperature was observed compared to Maximum Temperature. Thus, the trend for The Diurnal Temperature Range is negative (Z= -1.16) at significant level greater than 0.1 with the slope value of 0.010^{o}C/year. All temperature indices have shown the significant increase during last recent decades especially indices related to minimum temperature. The increase in warm days and warm nights together with the decrease in cool nights and cool days were observed. In general the results for annual mean Temperature show that the temperature has increased significantly in Kigali in the period 1980-2015 with the slope value of 0.044^{o}C/year **.**All results show that Kigali has experienced the significant warming during recent decades especially in the last two decades. The observed warming is explained by the increase of urbanization, industrialization, high density of population accompanied with the increase in greenhouse gases emission.

V.2.Recommendation

During this study, our focus was on assessment of the variability of different extreme temperature indices in Kigali as the most vulnerable city in Rwanda to be affected by the warming. So, as recommendation, this study needs also to be applied on the whole Rwanda to assess the spatial variability of extreme temperature in all regions of Rwanda. Decision makers have to encourage the reduction of greenhouse gases emission strategies such as: Capture the carbon emitted by power plants and store it underground; produce and use the renewable fuels—solar, wind, hydroelectric, and bio-fuels; halt deforestation and soil degradation in many areas of Kigali, while reforesting more areas.

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APPENDIX

Appendix1: Tables

Table 1.Summary of information about the station where data were recorded together with the mean minimum and maximum temperature values recorded.

Station name	Province	District	Longitude	Latitude	Mean Minimum Temperature (°C)	Mean Maximum Temperature (°C)	Period	Elevation
KIGALI AERO	Kigali City	Kicukiro	30.11	-1.95	15.83	26.95	1980-2015	1490

Table 2.Selected indices for analysis of extreme temperature in Kigali

No.	index	Definition	Unit
1	TXx	Max Tmax: Monthly maximum value of daily maximum temperature.	°C
2	TXn	Min Tmax: Monthly minimum value of daily maximum temperature.	°C
3	TNx	Max Tmin: Monthly maximum value of daily minimum temperature.	°C
4	TNn	Min Tmin: Monthly minimum value of daily minimum temperature.	°C
5	TN10p	Cool nights: Percentage of days when TN <10th percentile.	Days
6	TX10p	Cool days: Percentage of days when TX <10th percentile.	Days
7	TN90p	Warm nights: Percentage of days when TN >90th percentile.	Days
8	TX90p	Warm days: Percentage of days when TX >90th percentile	Days
9	DTR	Diurnal temperature range: Monthly mean difference between TX and TN	°C
10	SU	Summer days: Count of days where TX (daily maximum temperature)>25 ◦C	Days

Table 3. Summary of results from MAKENS template illustrating the trend significance by Mann-Kendall and sen's slope estimate for Tmax

Time series	*First year*	*Last Year*	*n*	*Test S*	*Test Z*	*Signific.*	**Q**
January	*1980*	*2015*	*36*		*4.43*	***	0.074
February	*1980*	*2015*	*36*		*3.12*	**	0.056
March	*1980*	*2015*	*36*		*3.12*	**	0.040
April	*1980*	*2015*	*36*		*2.44*	*	0.030
May	*1980*	*2015*	*36*		*4.18*	***	0.050
June	*1980*	*2015*	*36*		*2.00*	*	0.023
July	*1980*	*2015*	*36*		*3.83*	***	0.041
August	*1980*	*2015*	*36*		*2.27*	*	0.024
September	*1980*	*2015*	*36*		*1.16*		0.020
October	*1980*	*2015*	*36*		*3.45*	***	0.051
November	*1980*	*2015*	*36*		*3.06*	**	0.035
December	*1980*	*2015*	*36*		*3.64*	***	0.057
ANNUAL	*1980*	*2015*	*36*		*4.37*	***	0.043

Table 4.Summary of results from MAKENS template illustrating the trend significance by Mann-Kendall and sen's slope estimate for Tmin

Time series	*First year*	*Last Year*	*n*	*Test S*	*Test Z*	*Signific.*	*Test Q*
January	*1980*	*2015*	*36*		*5.24*	***	0.055
February	*1980*	*2015*	*36*		*4.51*	***	0.062
March	*1980*	*2015*	*36*		*4.89*	***	0.051
April	*1980*	*2015*	*36*		*4.94*	***	0.047
May	*1980*	*2015*	*36*		*5.41*	***	0.049
June	*1980*	*2015*	*36*		*4.26*	***	0.049

July	*1980*	*2015*	*36*		*4.40*	***	0.046
August	*1980*	*2015*	*36*		*4.56*	***	0.053
September	*1980*	*2015*	*36*		*5.79*	***	0.062
October	*1980*	*2015*	*36*		*5.34*	***	0.053
November	*1980*	*2015*	*36*		*5.59*	***	0.048
December	*1980*	*2015*	*36*		*5.54*	***	0.062
ANNUAL	*1980*	*2015*	*36*		*6.33*	***	0.056

Appendix2: Figures

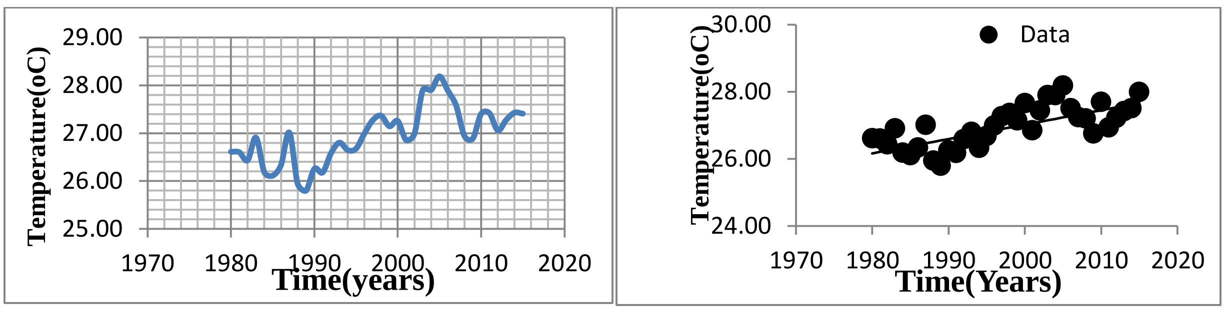

Figure 4.Plots for Maximum temperature

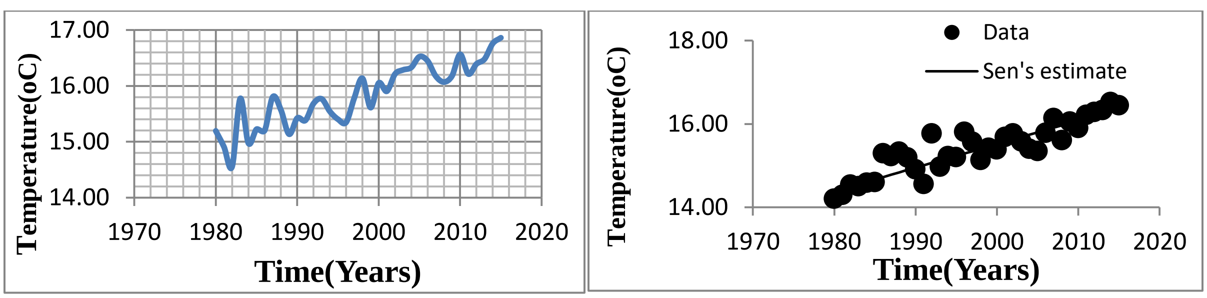

Figure 5. Plots for Minimum Temperature

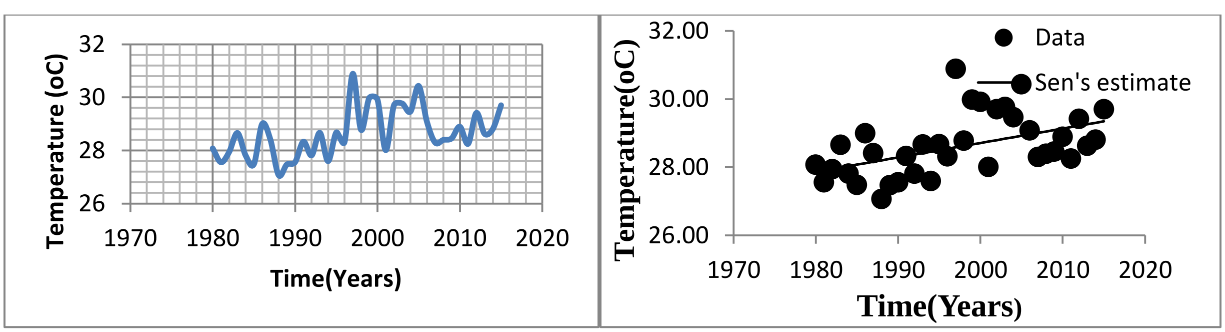

Figure 6.TXx: Monthly maximum value of daily maximum temperature

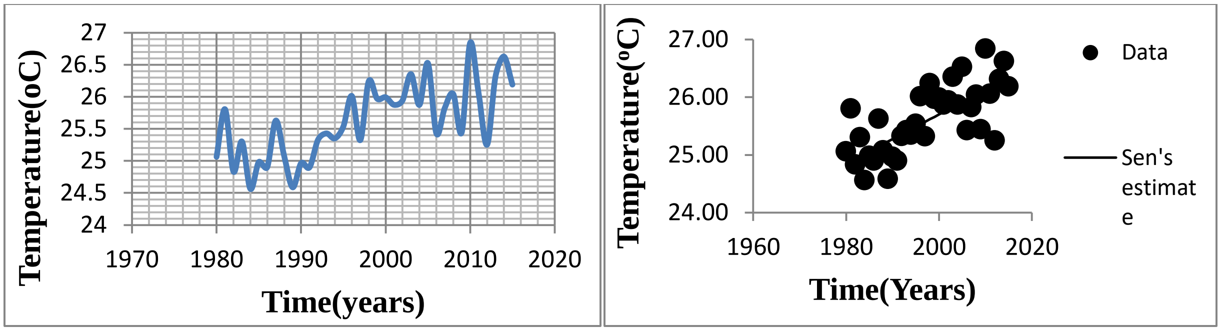

Figure 7.TXn: Monthly minimum value of daily maximum temperature

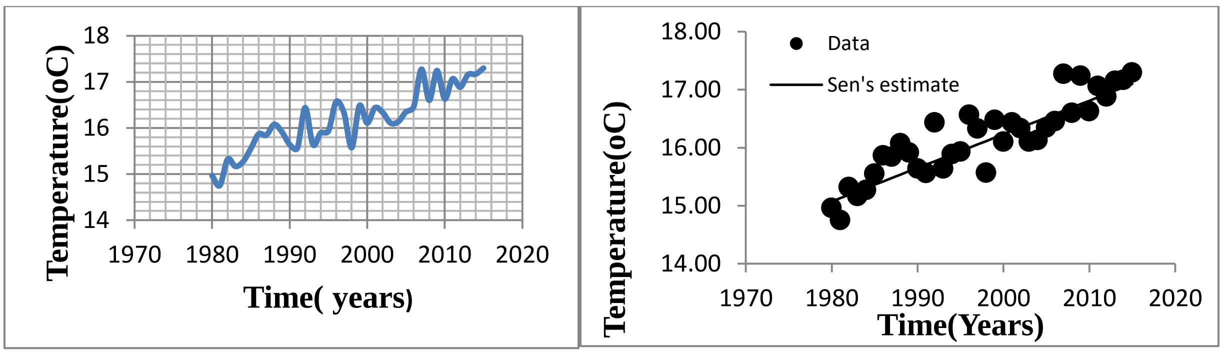

Figure 8.TNx: Monthly maximum value of daily minimum temperature

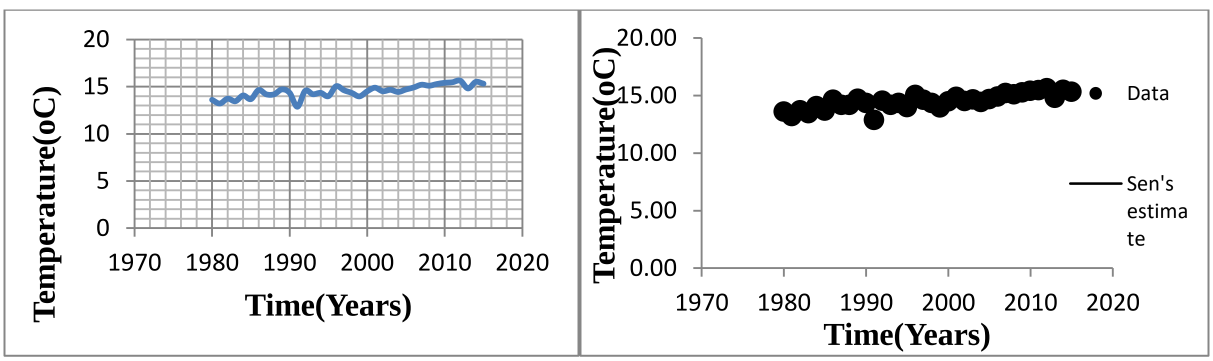

Figure 9.TNn: Monthly minimum value of daily minimum temperature

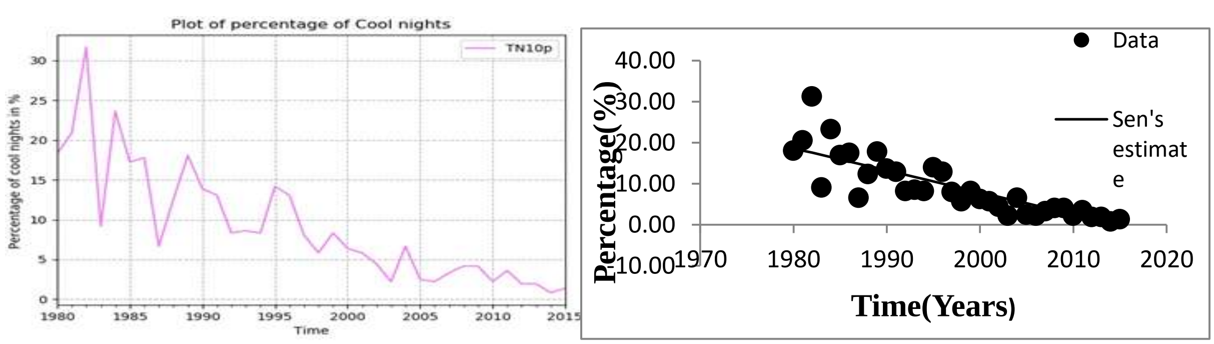

Figure 10.TN10p(cool nights): Percentage of days when TN <10th percentile

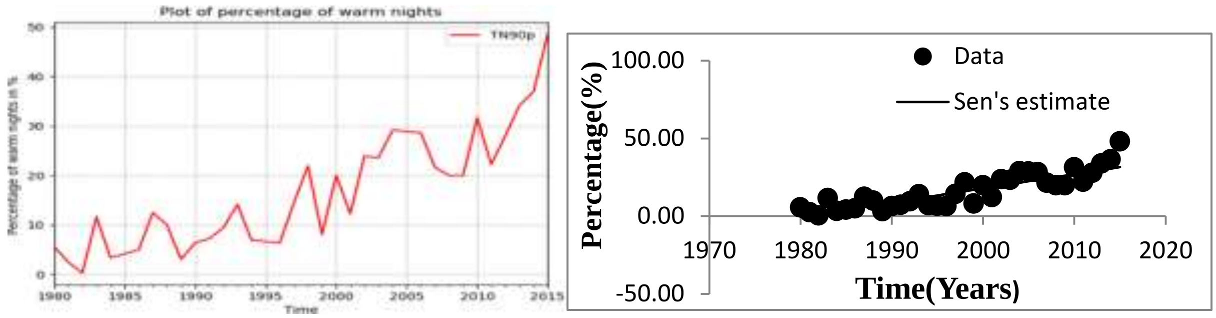

Figure 11.TN90p(warm nights): Percentage of days when TN >90th percentile

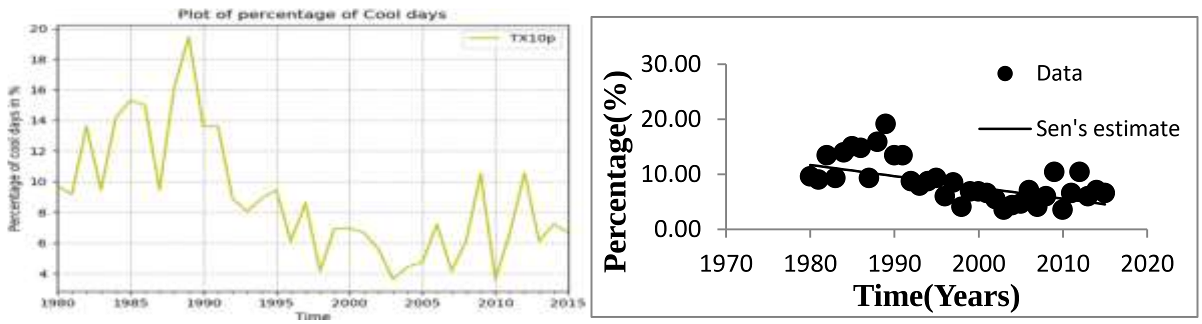

Figure 12.TX10p (cool days) : Percentage of days when TX <10th percentile

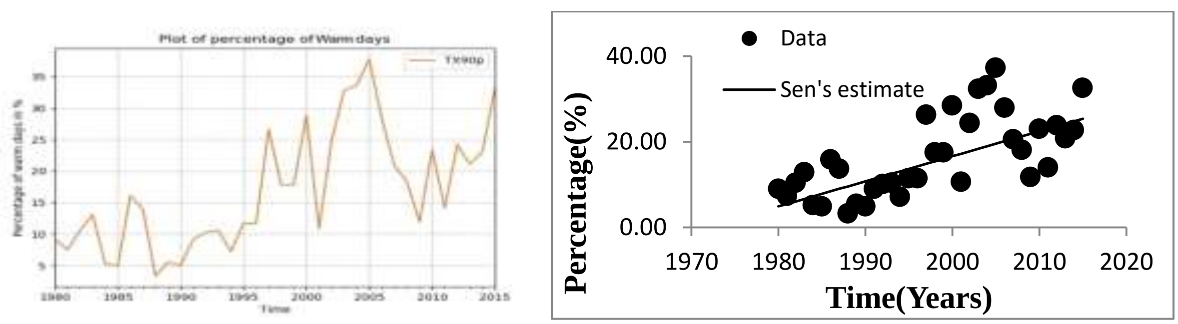

Figure 13.TX90p (warm days):Percentage of days when TX >90th percentile

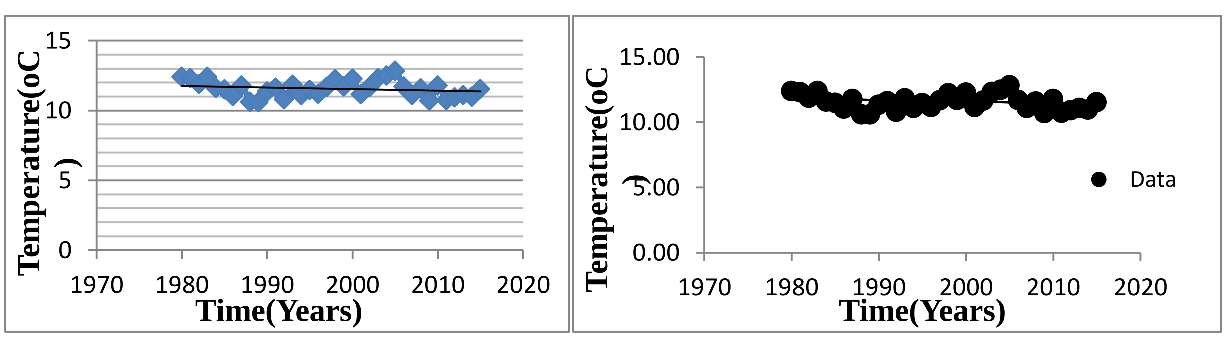

Figure 14.The Diurnal Temperature Range (DTR).

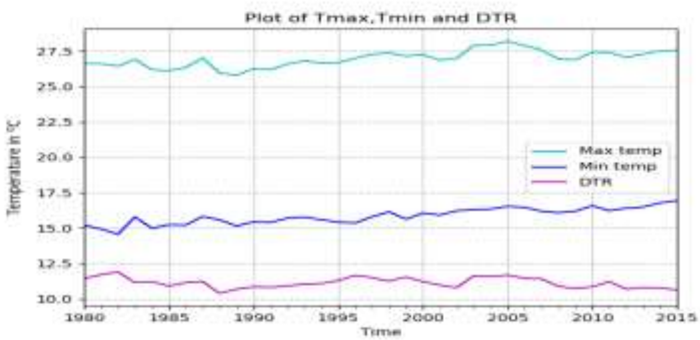

Figure 15.Time series for Maximum Temperature, Minimum Temperature and Diurnal Temperature Range

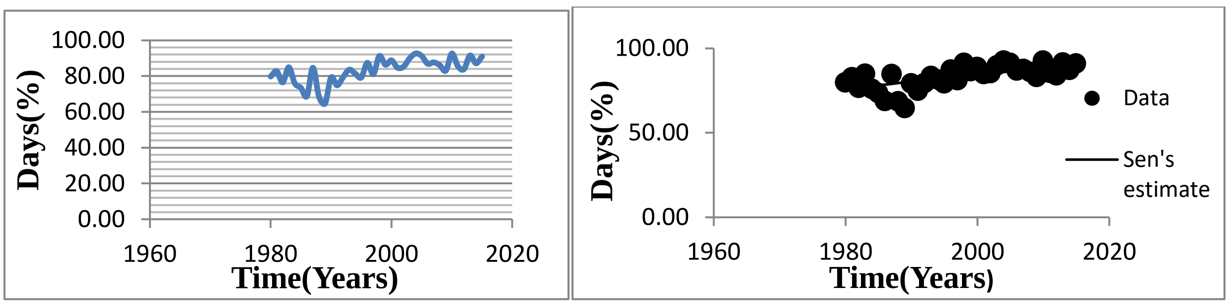

Figure 16.Summer days (Percentage of days where TX(daily maximum temperature)>25 ◦C.)

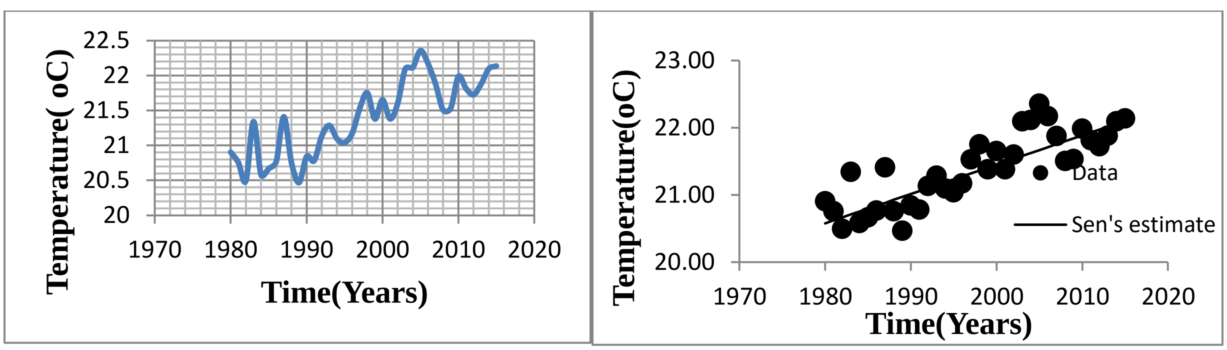

Figure 17.Time series of Mean Annual Temperature of Kigali during recent decades