College of Science and Technology

School of Architecture and Built Environment

MSc in Geo-Information Science for Environment and Sustainable Development

Analysis of Climate Variability in Rwanda as Indicated by Temperature Records Since 1930s

MSc Dissertation submitted in partial fulfillment of the requirements for the award of the Master of Science in Geo-Information for Environment and sustainable Development.

Submitted by:
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August 2025

DECLARATION

I declare that this MSc dissertation entitled **"Analysis of climate variability in Rwanda as indicated by temperature records since 1930s",** submitted for an award of Master's degree in Geo-Information Science for Environment and Sustainable Development, is my own original work and has never been submitted in any higher learning institution or elsewhere.

Protais SESHABA

……………………………. Date: …..../……. /……..

APPROVAL

This is to certify that the study entitled **"Analysis of climate variability in Rwanda as indicated by temperature records since 1930s"**, was conducted by Protais SESHABA in partial fulfillment of the requirements for the award of the Degree of Master of Science in Geo-Information Science for Environment and Sustainable Development, in the School of Architecture and Built Environment.

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Dr. Josephine MALONZA

Signature: …………………………… Date: ……../………. /………

DEDICATION

This dissertation is dedicated to

My late Dad and my Mother,

my beloved Wife, my Brother, my Sisters and all my Nephews.

ACKNOWLEDGEMENTS

My overwhelming gratitude is directed to the almighty God for being by my side for the achievement of this master's program. Without His mercy, I should not have completed this great and valuable work.

I am sincerely thankful to the Rwanda Meteorological Agency to allow me having access to climatic data used for this research.

My thanks to the founder of WATOTO Foundation Magda Słodzinka, especially the family of David and Paulina for their love, financial, spiritual and moral supports. May God bless you!

I highly thank my Supervisor Prof. Donat NSABIMANA for his tireless guidance, critical comments and his valuable scientific advice on this work. In spite of his heavy duties, he didn't deny to supervise me. Your sacrifice, devotion, academic strength, competence and frank collaboration are the subjects of my sincere recognition. On the other hand, I can't forget to thank all lecturers who taught me all along this MSc. program.

I finally thank all my classmates, for their sincere help, be it academic, or social.
To you all, who contributed in any way to my studies and to the achievement of this MSc. Program, I say: "Thank you".

Protais SESHABA

LIST OF SYMBOLS AND ACRONYMS

AERO: Aerodrome (airport)

ASL: Above Sea Level

CD: Cold Days

CN: Cold Nights

DFID: Department For International Development

GHGs: Green House Gases

GoR: Government of Rwanda

HD: Hot Days

HN: Hot Nights

IPCC: Intergovernmental Panel on Climate Change

Meteo-Station: Meteorological Station

MSc: Master of Science

^{o}C: Degrees Celcius

^{o}F: Degrees Fahrenheit

NS: Non Significant

REMA: Rwanda Environmental Management Authority

RMA: Rwanda Meteorological Agency

S: Significant

T*x*: Maximum air temperature

T*n*: Minimum air temperature

UHI: Urban Heat Island

WGII: Working Group II

WMO: World Meteorological Organization

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Near surface air temperature is one of the most important elements in weather and climate forecasting, so examination of its behavior is important for the understanding of climate variability which can vary spatially and temporally at local, regional and global scales. Various studies on air temperature recently indicated that the Earth's near surface air temperature increased by 0.6°C – 0.8°C throughout the 20th century. This study analyzed climate variability in Rwanda since the 1930s until 2014 using the temperature records from 10 meteorological stations. The air temperature data were provided by Rwanda Meteorological Agency and quality control was performed on raw data before analysis using Excel 2007 and INSTAT Software. The analysis of maxima and minima indicated that trends of maximum of maximum air temperature were positive and significant at 8 meteorological stations whereas the trends for minimum of minimum air temperature at 10 meteorological stations were all positive and significant. For all parameters analyzed, Kigali Airport meteorological station indicated higher significance of the trends. The majority of meteorological stations presented an increase in both hot days and nights which confirm a warming in Rwanda over time. The analysis of average seasonal air temperature showed almost similar trends even though not all significant. This similarity in trends may be due to the fact that the short and long dry seasons intercept with rain periods in Rwanda.

Key words: *Climate variability, Air temperature, Solar Radiation, Meteorological station.*

1. INTRODUCTION

1.1. Background

Climate variability refers to variations in the existing state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events (IPCC, 2014a). As noted in IPCC (1996) and IPCC WGII Fifth Assessment Report-Glossary (IPCC, 2014a), such variability is largely attributed to both natural and anthropogenic factors. Natural factors such as solar variations and volcanic activities occur beyond human involvement. Anthropogenic factors are human based activities causing changes in earth's atmosphere such as greenhouse gases (GHGs) emissions, land use change, etc. According to Rosenzweig *et al.* (2007), these effects of climate variability are already being observed and are affecting human health, ecosystems and species in all regions of the world.

As defined by the World Meteorological Organization (WMO) and recommended by the Intergovernmental Panel on Climate Change (IPCC), a 30 year period is recommended for use as a baseline period for defining a region's climate (Carter et al., 1994).

According to WMO (1992), for meteorological purposes, temperatures are measured for a number of media. Apart from other temperature variables such as ground, soil, grass minimum and seawater temperature, air temperature is the most common variable measured at various heights. WMO (1992) defines air temperature as "*the temperature indicated by a thermometer exposed to the air in a place sheltered from direct solar radiation*". Thermometers which indicate the prevailing temperature are often known as ordinary thermometers, while those which indicate extreme temperature over a period of time are called maximum or minimum thermometers. Enz *et al.* (2014) indicated that the measured air temperature around the Earth's surface originates from the sun that emits its radiation of high temperature (5,727^{o}C or 10,341^{o}F) which consists of very short wavelengths that carry large amounts of energy. The Earth after being heated itself by the sun radiation becomes a radiating body and it radiates energy to the atmosphere in long wave form that carry only small amounts of energy, compared with that carried by solar radiation.

It was mentioned that air temperature is in most of the time maximum at daytime and minimum by the sunset as temperature falls rapidly and continues to fall at a decreasing rate throughout the night because the Earth's surface keeps emitting the energy received in daytime more than it receives (Enz *et al.,* 2014). The WMO (2002) noted that measurements of air temperature do not show the same results in all places around the world and however, temperature distribution of air at any place is influenced by various factors such as: (i) the latitude of the place, (ii) the altitude of the place, (iii) distance from the sea, the air mass circulation, (iv) the presence of warm and cold ocean currents and (v) local aspects.

IPCC (2007a) reports that the signs of warming of the climate system are clear and prevailing, as it is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level. The average global surface air temperature has warmed 0.8°C in the past century and 0.6°C in the past three decades (Hansen *et al*., 2006), in large part because of human activities (IPCC, 2007b). However, Katz and Brown (1992) noted that this warming was not spatially or temporally uniform. The IPCC has projected that if greenhouse gas emissions, the leading cause of climate change, continue to rise, the mean global temperatures will increase 1.4–5.8°C by the end of the 21st century (IPCC, 2007c).

Observational records show that during the 20th century the continent of Africa has been warming at a rate of about 0.05°C per decade with slightly larger warming in the June–November seasons than in December–May (Hulme *et al.,* 2001). By 2000, the five warmest years in Africa had all occurred since 1988, with 1988 and 1995 being the two warmest years. This rate of warming is not dissimilar to that experienced globally, and the periods of most rapid warming, the 1910s to 1930s and the post-1970s, occuring simultaneously in Africa and the rest of the world (IPCC 2001). Warming projections under medium scenarios indicate that extensive areas of Africa exceeds 2°C during the last 2 decades of this century relative to the late 20th century mean annual temperature and all of Africa under high emission scenarios (Niang *et al.,* 2014).

DFID (2009) noted that countries of Eastern Africa are exposed to extreme climatic events such as droughts. Back in the past for a long period, these events have caused severe negative impacts and exacerbated the socioeconomic sectors of the economies of most countries in the sub region. Example is seen in the late 1970s and 1980s where droughts caused widespread famine and economic hardships in many countries of the sub region. Upon the above experience, the report says that there is evidence that future climate change may lead to a change in the frequency or severity of such extreme weather events, potentially worsening these impacts. According to DFID (2009) and Nash and Ngabitsinze (2013), these changes will have potentially important effects across all economic and social sectors in the region, possibly affecting agricultural production, health status, water availability, energy use, biodiversity and ecosystem services including tourism on the East African region.

Different researches carried out on long-term variations of climate in various regions of the earth indicate that it is sure that climate change impacts have the potential to challenge and even, undo progress made in improving the socio-economic well-being of many of the African countries (WWF, 2006). It was indeed shown that Rwanda has experienced temperature increases higher than the global average (1.4°C since 1970), accompanied with air temperature extremes that generated negative impacts throughout the country (GoR, 2011). Hence the current study aimed at analysis of patterns of climate variability in Rwanda as indicated by air temperature records (maximum and minimum) and determine related impacts on socio-economic sector.

1.2. Problem statement

In Rwanda, different researches on climate variability have been conducted but they mainly referred to Kigali meteorological station only (Byamukama et *al.*, 2011). However, this represents a lack of information from all representative climatic zones in Rwanda. For example, Safari (2012) analyzed mean annual temperature during the last 52 years in Rwanda using only five meteorological stations, such as Kigali, Gitarama, Rubona, Kibuye and Gisenyi. Additionally, Habiyaremye et *al.* (2012) have also studied precipitation, temperature and humidity variability in Rwanda during 30 years using only data from Kigali Aero meteorological station.

It is observed that these studies did not cover the whole climatic zones of Rwanda that would contribute to show the real image of climate variability of the country. In addition, mean annual temperature variability studied by safari (2012) does not reflect the impact that could be caused by temperature below or above fixed thresholds on biodiversity such as high drought that could cause plants to dry, low temperature that could cause crops injury through hail process and impacts on human health especially high temperature that could cause death to elder people especially.

1.3. Objectives

1.3.1. *General objective*

Extreme weather conditions generate serious threats to biodiversity and human being because they present new environmental conditions which are completely different to the existing one and this may disrupt a given species survival because of weak adaptation capacity. It is in this context that the main objective of the current study was to evaluate and analyze climatic variability in terms of temperature records along the past 83 years.

1.3.2. *Specific objectives*

1) Analyze the trends of minimum and maximum air temperature;

2) Determine and discuss impacts of climate variability in Rwanda.

2. MATERIALS AND METHODS

2.1. Description of the study Area

Rwanda is a small, landlocked country in equatorial East Africa covering 26,338 km^2, located at 02°00 Latitude South and 30°00 Longitude East. It is bordered by the Democratic Republic of Congo (DRC), Burundi, Uganda and Tanzania respectively at Western, Southern, Northern and Eastern parts. Rwanda is known as the "*land of a thousand hills*" as its topography is characterized by steep slopes and green hills, upon which its predominantly rural population survives on subsistence agriculture (Byamukama et *al*., 2011). The average temperature for Rwanda is around 20°C and varies topographically (Figure 1), with short dry season happening in January–February and long dry season occurring in June-August (Safari, 2012).

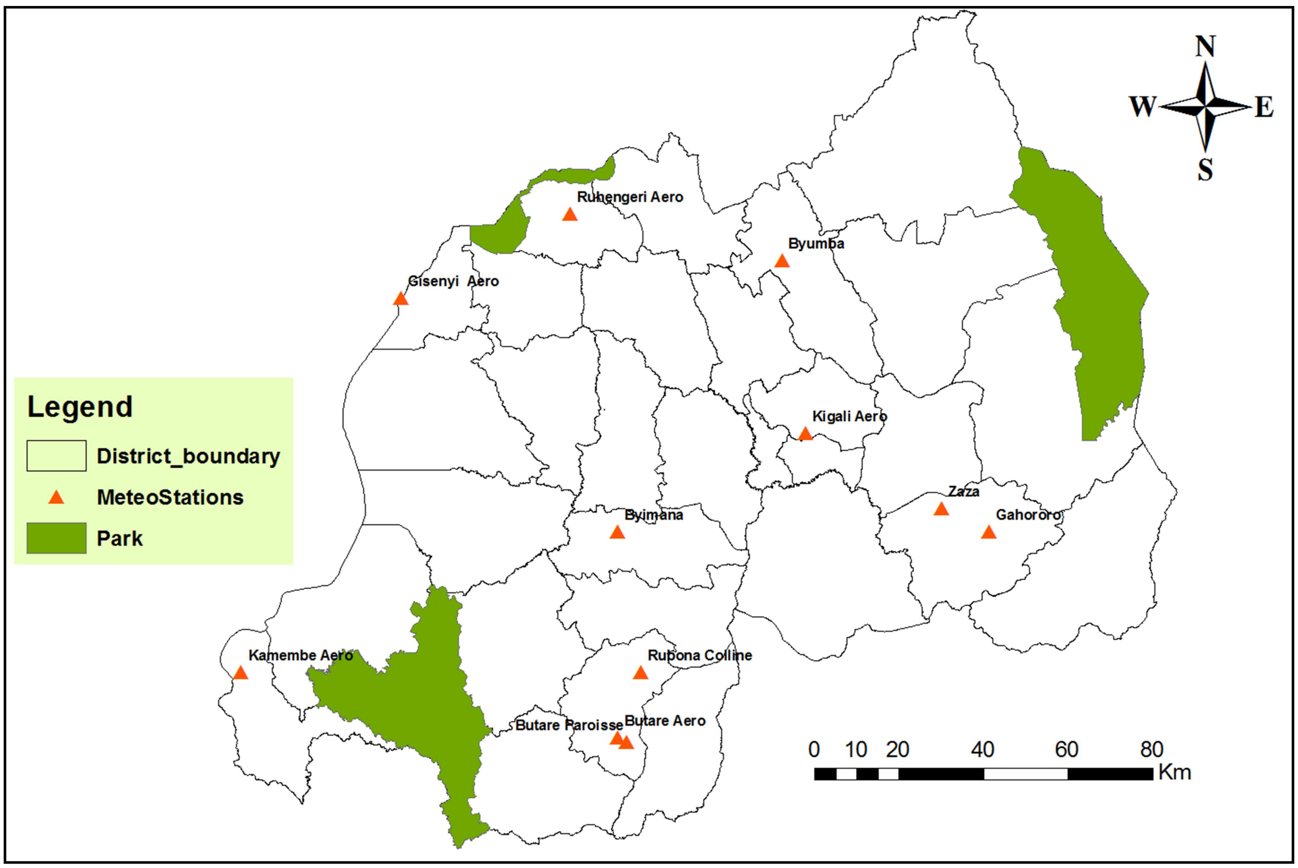


Figure 1: *Geographical location of Meteorological stations for the study.*

Source: SESHABA, 2026.

The table below lists meteorological stations whose temperature records were considered during this study.

Table 1: List of meteorological stations used in this study

Meteo-Station	Longitude	Latitude	Elevation (m)	District	Province
Butare Paroisse	29.73	-2.61	1760	Huye	South
Butare Aerodrome	29.71	-2.6	1760	Huye	South
Rubona Colline	29.76	-2.46	1706	Huye	South
Byimana	29.71	-2.16	1750	Ruhango	South
Kamembe Aerodrome	28.91	-2.46	1591	Rusizi	West
Gisenyi Aerodrome	29.25	-1.66	1554	Rubavu	West
Ruhengeri Aerodrome	29.61	-1.48	1878	Musanze	North
Byumba Pref	30.06	-1.58	2235	Gicumbi	North
Kigali Aero	30.11	-1.95	1490	Gasabo	Kigali City
Zaza	30.4	-2.11	1515	Ngoma	East
Gahororo	30.5	-2.16		Ngoma	East

2.2. Research Design

2.2.1. Data source and analysis

This research is both qualitative and quantitative. The data collected from the National Meteorological Service were described and summarized quantitatively and qualitatively. The literature review of this study was based on scientific review made by other researchers on the region and or worldwide basis.

2.2.1.1. Sampling Techniques

Until today, the total number of meteorological stations that existed plus those still functioning in Rwanda is about 183. The 1990-1994 Tutsi genocide and war in Rwanda destroyed more than 80% of meteorological infrastructures and a few of them reopened afterward (REMA, 2010).

During the sampling process, meteorological stations for the current study were purposively selected, based on, availability of daily minimum and maximum temperature data, period of records and fair distribution of the station across Rwanda. The most important criterion in consideration was to select the meteorological station that presents at least 20 years of observation period.

The data of Butare Paroisse and Butare Aero meteorological stations were combined not only because they are located at the same elevation (1760 m, ASL), but also because Butare Paroisse meteorological station stopped working in 1967 and was shifted at Butare Aerodrome in 1971, and the distance between two locations is less than 1 km. The meteorological stations in Rwanda were not established in the same period and not all are still functioning. Hence, a sub-period based analysis of air temperature consisted in selecting meteorological stations that present complete temperature dataset at the same sub-period in order to make a realistic comparison of air temperature trends.

2.2.1.2. Data collection techniques

During this study, the time-series of temperature records were obtained from Rwanda Meteorological Agency based in Kigali. Quality control was performed on raw data before analysis in Excel 2007 and INSTAT Software, and the last presents the ability to analyze climatic variables. The analysis was based on daily minimum and maximum temperature data series which were summarized into monthly data to study seasonal variability.

2.3. Extreme temperature and thresholds

Changes in annual frequencies of the amount of days and nights with maximum and minimum temperatures in defined categories have been investigated based on some of the indices developed by Collins *et al.,* (2000) (*Table 2*), but also it is important to keep in mind that climate seems to be somehow complex; i.e. temperatures can vary differently throughout different places depending on various factors. However, for our study it was important to consider the temperature categories employed by the forecasting section of Rwanda Meteorological Agency (RMA), with which temperature thresholds are defined for forecasting purposes (*Table 3*), e.g. when a day or a night is defined as hot or cold.

Table 2: Temperature indices used in the analysis of extreme temperatures developed by Collins et al., 2000. (T_x: maximum temperature; T_n: minimum temperature.

Maximum temperature extreme indices	**Minimum temperature extreme indices**
Very hot days: $T_x \geq 35^oC$	Hot nights: $T_n \geq 20^oC$
Hot days: $30^oC \leq T_x < 35^oC$	Warm nights: $15^oC \leq T_n < 20^oC$
Cold days: $T_x \leq 15^oC$	Very cold nights: $T_n \leq 0^oC$
Cool days: $15^oC < T_x \leq 19^oC$	Cold nights: $0^oC < T_n \leq 5^0C$

Table 3: Temperature indices used in the analysis of extreme temperatures developed by RMA. (Tx: maximum temperature; Tn: minimum temperature).

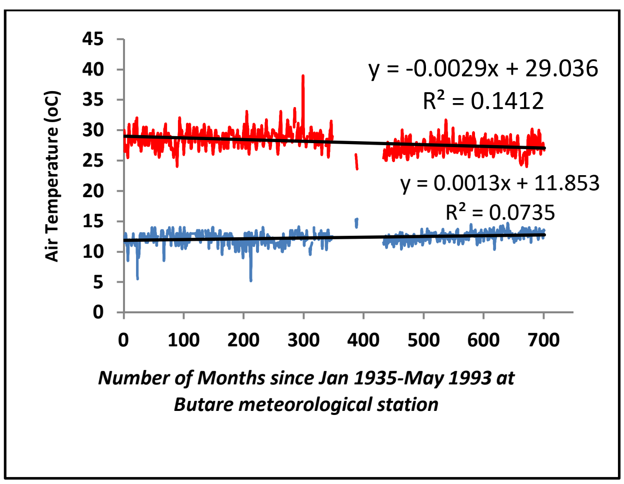
Maximum temperature extreme indices	**Minimum temperature extreme indices**
Hot days: $Tx \geq 28^oC$	Hot nights: $Tn \geq 18^oC$
Cold days: $Tx \leq 25^oC$	Cold nights: $0^oC < Tn \leq 16^oC$

3. RESULTS

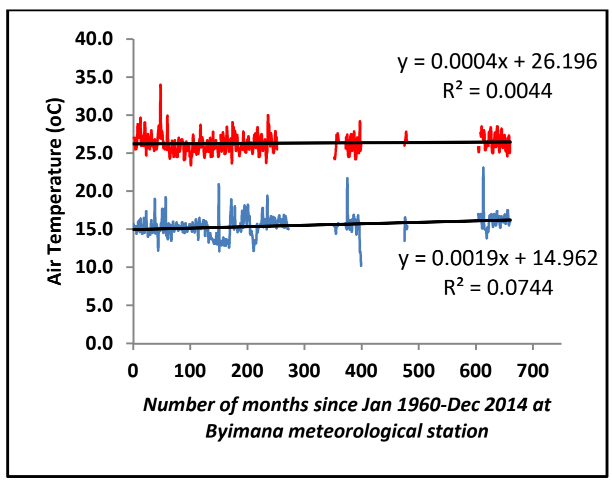
3.1. Monthly maxima and minima in air temperature

The results showed the trends for maximum of maximum air temperature. Among 10 meteorological stations, 8 indicated positive trends which were significant. The 2 remaining meteo-stations (Butare and Gahororo) showed negative trends one significant and the other non significant respectively. Kigali meteorological station presented greater increase in temperature (*R^2= 0.2013, p = 0.000*).

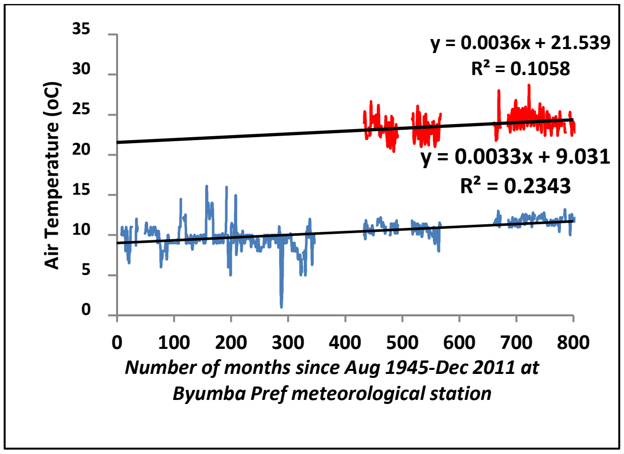
All the 10 meteorological stations showed positive and significant trends for minimum of minimum air temperature, with Kigali presenting again higher value of R square and highly significant trend (*R^2= 0.3702*, p = 0.000). The figure 2 (a-j) indicates trends of monthly maxima and minima air temperature measured at the 10 meteorological stations in Rwanda throughout different periods. Major stations indicate that minimum temperatures are warming more rapidly than maximum temperatures as indicated by the regression coefficients. Table 4 clearly indicates the aspect, regression coefficients and the significance of trends for both maximum and minimum air temperature.

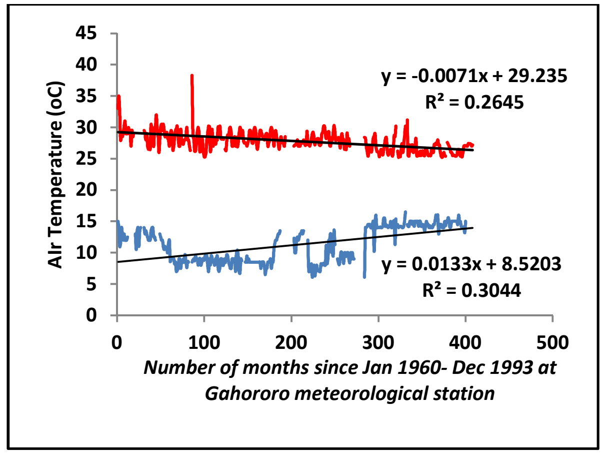


(a)



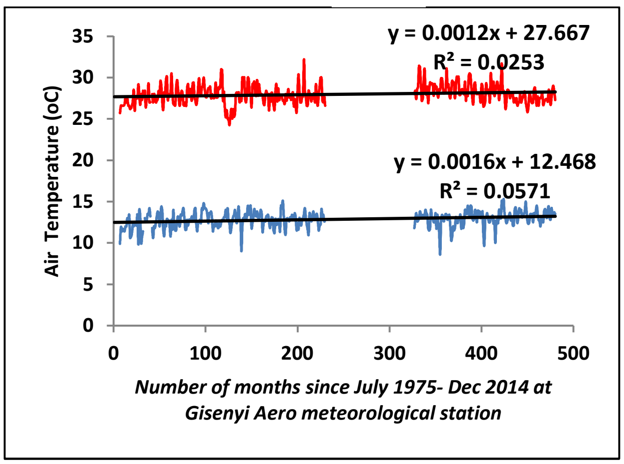
(b)

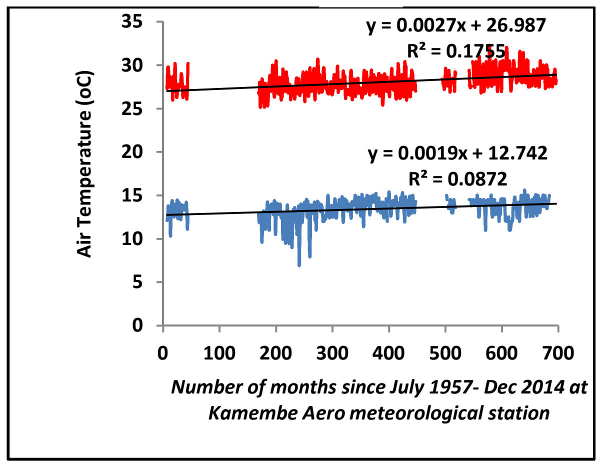

y = 0.0036x + 21.539
R² = 0.1058
y = 0.0033x + 9.031
R² = 0.2343
Air Temperature (oC)
35
30
25
20
15
10
5
0
0 100 200 300 400 500 600 700 800
Number of months since Aug 1945-Dec 2011 at Byumba Pref meteorological station


y = -0.0071x + 29.235
R² = 0.2645
y = 0.0133x + 8.5203
R² = 0.3044
Air Temperature (oC)
45
40
35
30
25
20
15
10
5
0
0 100 200 300 400 500
Number of months since Jan 1960- Dec 1993 at Gahororo meteorological station

(c)

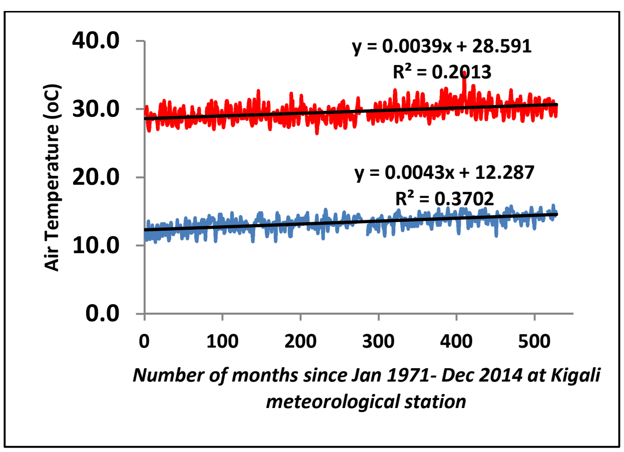
(d)

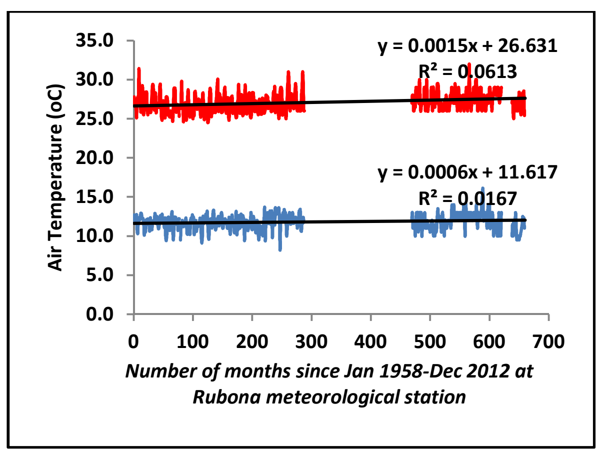

y = 0.0012x + 27.667
R² = 0.0253
y = 0.0016x + 12.468
R² = 0.0571
Air Temperature (oC)
35
30
25
20
15
10
5
0
0 100 200 300 400 500
Number of months since July 1975- Dec 2014 at Gisenyi Aero meteorological station


y = 0.0027x + 26.987
R² = 0.1755
y = 0.0019x + 12.742
R² = 0.0872
Air Temperature (oC)
35
30
25
20
15
10
5
0
0 100 200 300 400 500 600 700
Number of months since July 1957- Dec 2014 at Kamembe Aero meteorological station

(e)

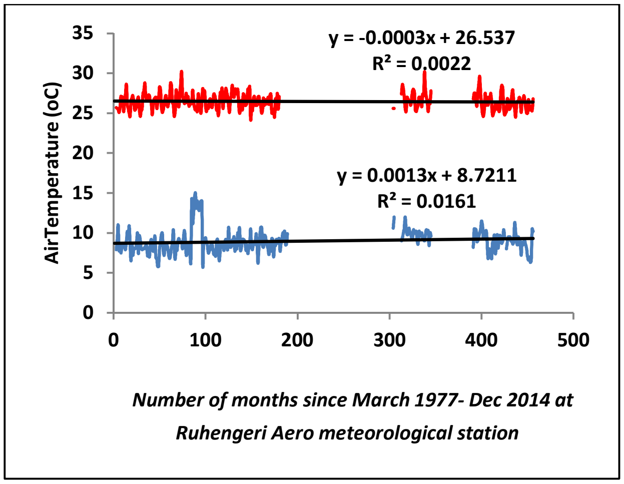
(f)


y = 0.0039x + 28.591
R² = 0.2013
y = 0.0043x + 12.287
R² = 0.3702
Air Temperature (oC)
40.0
30.0
20.0
10.0
0.0
0 100 200 300 400 500
Number of months since Jan 1971- Dec 2014 at Kigali meteorological station

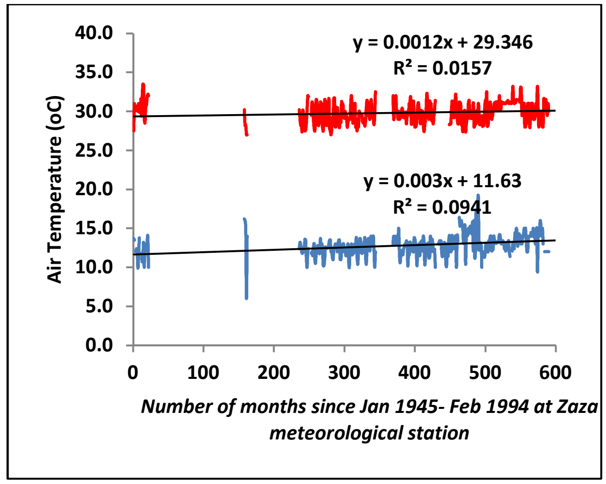

y = 0.0015x + 26.631
R² = 0.0613
y = 0.0006x + 11.617
R² = 0.0167
Air Temperature (oC)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0 100 200 300 400 500 600 700
Number of months since Jan 1958-Dec 2012 at Rubona meteorological station

(g)

(h)



(i)



(j)

Figure 2 (a-j): Trends of monthly maxima and minima in air temperature at 10 meteorological stations.

Table 4: Regression analysis of monthly extreme air temperature at 10 meteorological stations.

Meteo-Station	Extremes of air temperature	Trend	R square	p-value	Remark
Butare	Minimum of minimum	*Positive*	0.07	0.000	S
	Maximum of maximum	*Negative*	0.14	0.000	S
Byimana	Minimum of minimum	*Positive*	0.07	0.000	S
	Maximum of maximum	*Positive*	0.00	0.215	NS
Byumba pref	Minimum of minimum	*Positive*	0.23	0.000	S
	Maximum of maximum	*Positive*	0.11	0.000	S
Gahororo	Minimum of minimum	*Positive*	0.30	0.000	S
	Maximum of maximum	*Negative*	0.26	0.000	S
Gisenyi Aero	Minimum of minimum	*Positive*	0.06	0.000	S
	Maximum of maximum	*Positive*	0.03	0.002	S
Kamembe Aero	Minimum of minimum	*Positive*	0.09	0.000	S
	Maximum of maximum	*Positive*	0.18	0.000	S
Kigali Aero	Minimum of minimum	*Positive*	0.37	0.000	S
	Maximum of maximum	*Positive*	0.20	0.000	S
Rubona	Minimum of minimum	*Positive*	0.02	0.005	S
	Maximum of maximum	*Positive*	0.06	0.000	S
Ruhengeri Aero	Minimum of minimum	*Positive*	0.02	0.032	S
	Maximum of maximum	*Negative*	0.00	0.432	NS
Zaza	Minimum of minimum	*Positive*	0.09	0.000	S
	Maximum of maximum	*Positive*	0.02	0.022	S

At each meteorological station, hottest and coldest days and nights have been summarized according to the periods of observation.

Table 5: Hottest and coldest days and night as indices of extreme air temperatures

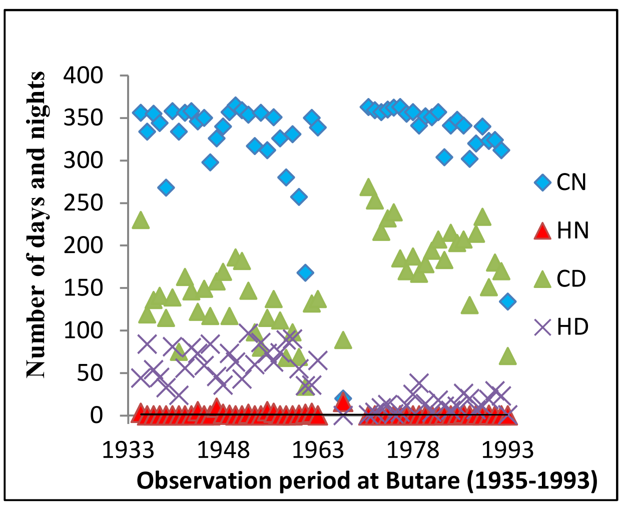
Meteorological Stations	Maximum of maximum air temperature		Minimum of maximum air temperature		Maximum of minimum air temperature		Minimum of minimum air temperature	
	Value (°C)	Month and year	Value (°C)	Month and year	Value (°C)	Month and year	Value (°C)	Month and year
Butare (Parish)	39	Nov. 1959	15	Apr. 1950	20.5	Jul. 1935	5.2	Nov. 1936
Rubona	32	Feb. 2005	16	Mar. 2005	16.6	Aug. 1967	8.2	Jul. 1978
Byimana	34	Dec. 1963	12.9	Dec. 1963	23.1	Jan. 2011	4.7	Jul. 1973
Kamembe Aero	32.3	Feb. 2005	16.3	Aug. 1978	19.9	Nov.2007	7	Jan. 1977
Gisenyi Aero	32.2	Mar. 1992	16.1	Dec. 2014	19.2	Mar. 1992	9	Aug.1986
Kigali Aero	35.4	Feb. 2005	17	Sep. 2014	20.5	Jan. 2013	10.5	Feb. 1972
Gahororo	38.3	Feb.1967	14	Nov.1963	27 ; 26.5	Feb.1960; Nov.1961	6.1 ; 6.3	Aug.; Nov. 1978
Zaza	33.5	Feb. 1946	15	Oct. 1959	23.2	May. 1983	6	May 1958
Byumba Pref	28.7	Feb. 2005	12.8	Apr. 2000	20.5	Apr. 1964	1	Dec. 1968
Ruhengeri Aero	30.2	Feb. 1983; 2005	15.8	Sept. 2014	19.2	Dec. 1987	5.8 ^{o}C	Jan. 1985

The findings indicated that 5 of 10 meteorological stations (Rubona, Kamembe Aero, Kigali Aero, Byumba Pref and Ruhengeri Aero) presented their maximum of maximum air temperature in 2005, whereas the remaining 5 meteorological stations had their maximum of maximum air temperature distributed in various years. The month of February hosted a big number of maxima throughout various years but mostly in 2005 for Rubona, Kamembe Aero, Kigali Aero, Byumba Pref and Ruhengeri Aero whereas for Gahororo it was in 1967 and lastly Zaza in 1946. The highest maximum of maximum air temperature that has been ever measured at the 10 meteorological stations was 39^{o}C, recorded at Butare parish meteorological station in November 1959. The minimum of maximum temperature have been varying in different years and months with the lowest value of 12.8^{o}C recorded at Byumba pref meteorological station in April 2000.

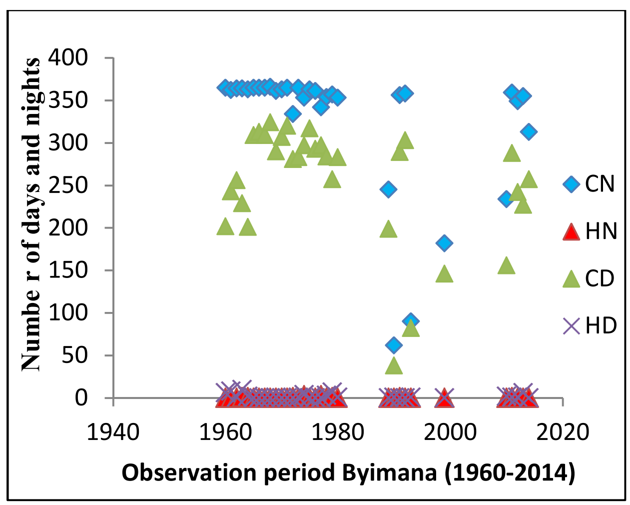
The minimum of minimum air temperature also showed a varying pattern with air temperature ranging between 10.5 °C and 1°C. This lowest value was measured at Byumba Pref meteorological station in December 1968. Generally, the month of December 1968 at Byumba Pref meteorological station indicated lower air temperature values compared to other months for air temperature measurements.

3.2. Variability in hot, cold days and nights

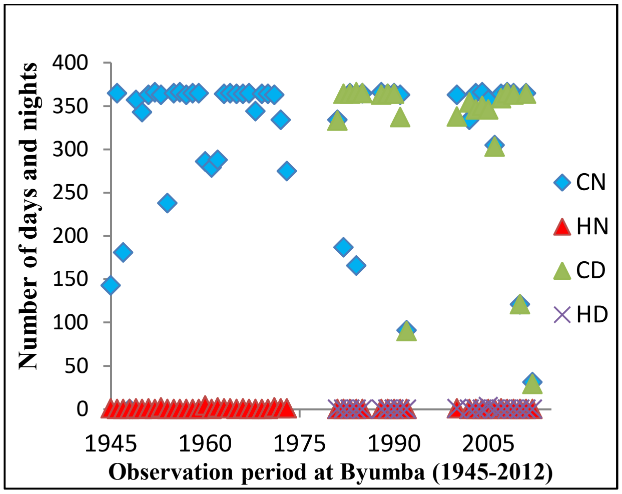
The analysis of 10 meteorological stations showed that there were variability in trends of hot, cold days and nights as well. As it is visible in figure 3 (a-j), the trends of daily and night extreme air temperature were displayed in the following way: Byimana and Gahororo meteo-stations presented negative trends for cold days and nights as well as for hot days and nights. Butare meteo-station showed only positive trend for cold days whereas positive trend was noticed for hot days at Byumba meteo-station. On the other hand, at Gisenyi Aero, Kamembe Aero, Kigali Aero, Rubona and Zaza meteorological stations, the number of hot days and nights were increasing contrary to cold days and nights.

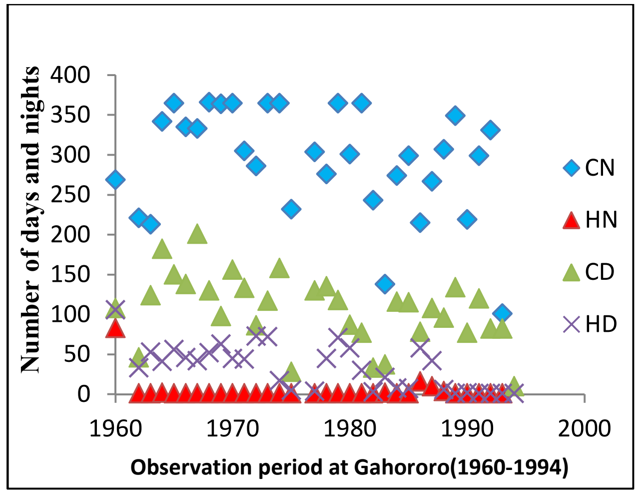


(a)



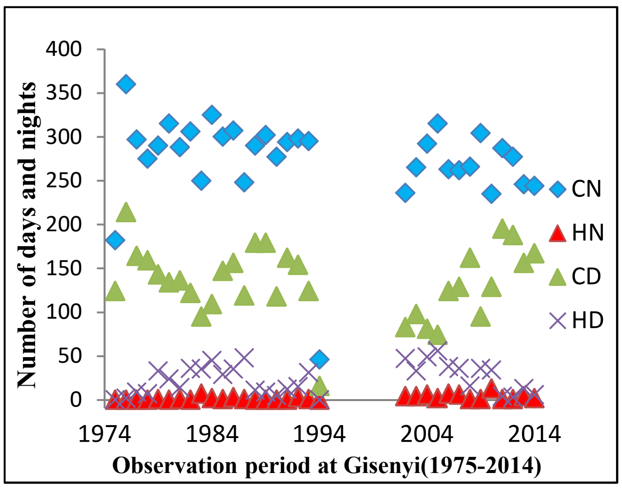
(b)

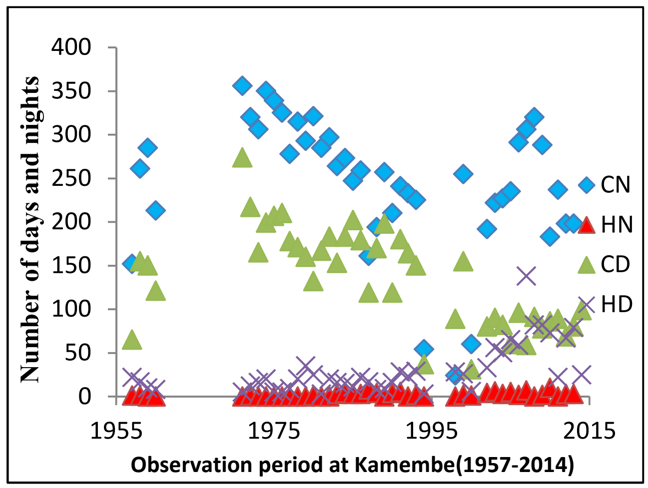

Number of days and nights
400
350
300
250
200
150
100
50
0
1945
1960
1975
1990
2005
Observation period at Byumba (1945-2012)
CN
HN
CD
HD


Number of days and nights
400
350
300
250
200
150
100
50
0
1960
1970
1980
1990
2000
Observation period at Gahororo(1960-1994)
CN
HN
CD
HD

(c)

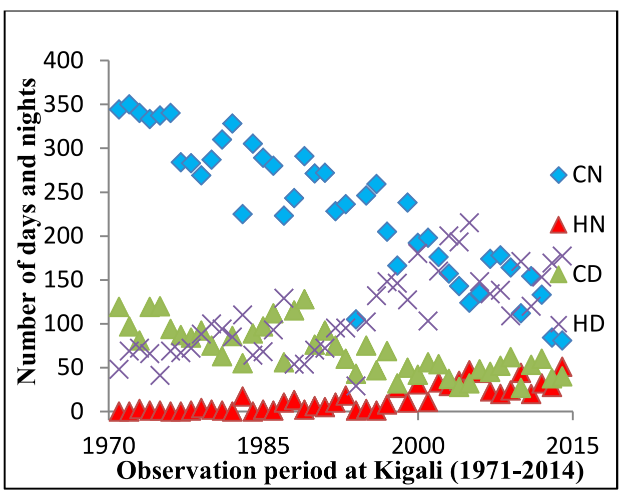
(d)

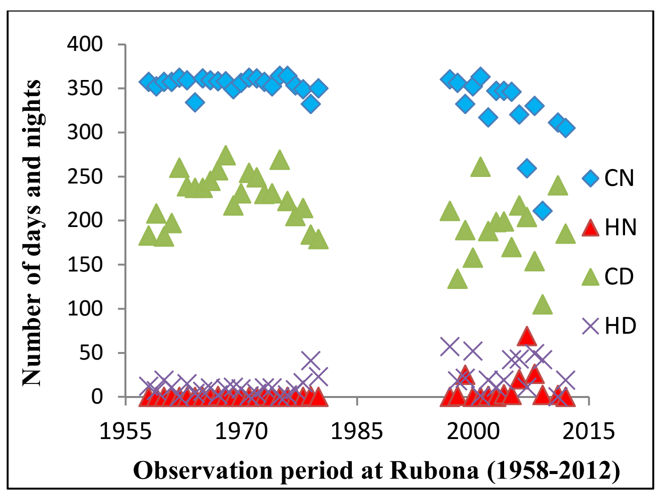

Number of days and nights
400
350
300
250
200
150
100
50
0
1974
1984
1994
2004
2014
Observation period at Gisenyi(1975-2014)
CN
HN
CD
HD


Number of days and nights
400
350
300
250
200
150
100
50
0
1955
1975
1995
2015
Observation period at Kamembe(1957-2014)
CN
HN
CD
HD

(e)

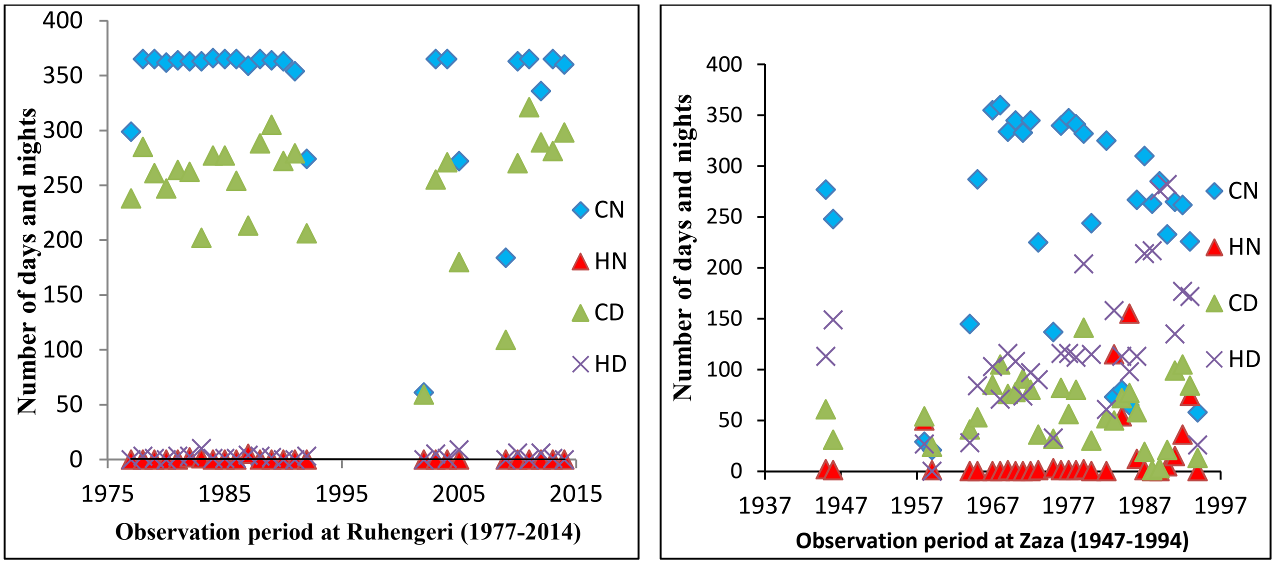
(f)


Number of days and nights
400
350
300
250
200
150
100
50
0
1970
1985
2000
2015
Observation period at Kigali (1971-2014)
CN
HN
CD
HD


Number of days and nights
400
350
300
250
200
150
100
50
0
1955
1970
1985
2000
2015
Observation period at Rubona (1958-2012)
CN
HN
CD
HD

(g)

(h)



(i) *(j)*

Figure 3: Trends of daily and night extreme air temperatures at 10 meteorological stations

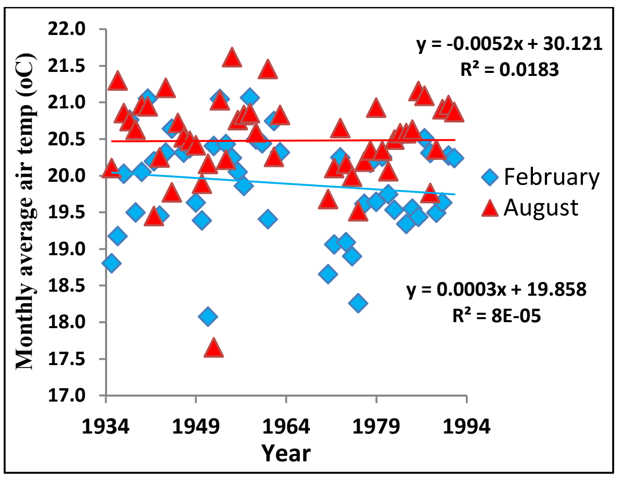
The table 6 gives more details about the trends and significance of daily and night extreme air temperature at the 10 meteorological stations under study.

Table 6: Regression analysis of daily and night extreme air temperature at 10 meteo-station

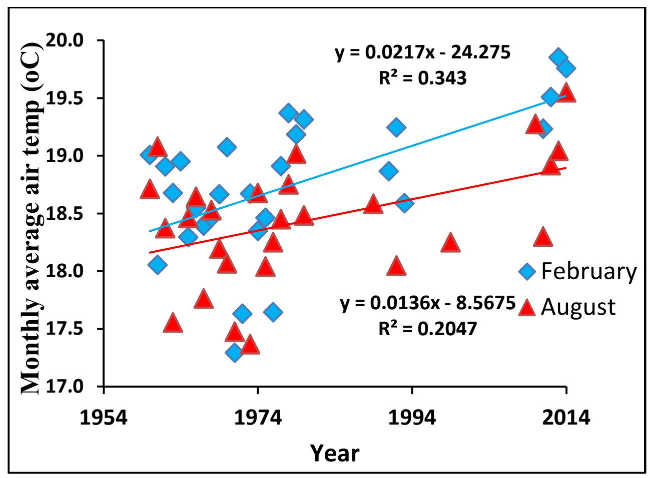
Meteo-Station		Trend	R square	P-Value	Remark
Butare	CN	*Negative*	0.015	0.374	NS
	HN	*Negative*	0.014	0.405	NS
	CD	*Positive*	0.157	0.003	S
	HD	*Negative*	0.495	0.000	S
Byimana	CN	*Negative*	0.160	0.023	S
	HN	*Negative*	0.007	0.639	NS
	CD	*Negative*	0.120	0.052	S
	HD	*Negative*	0.029	0.348	NS
Byumba pref	CN	*Negative*	0.000	0.931	NS
	HN	*Negative*	0.063	0.075	NS
	CD	*Negative*	0.095	0.163	NS
	HD	*Positive*	0.029	0.452	NS
Gahororo	CN	*Negative*	0.089	0.097	NS
	HN	*Negative*	0.065	0.159	NS
	CD	*Negative*	0.186	0.012	S
	HD	*Negative*	0.457	0.000	S
Gisenyi Aero	CN	*Negative*	0.030	0.333	NS
	HN	*Positive*	0.213	0.007	S
	CD	*Negative*	0.009	0.608	NS
	HD	*Positive*	0.021	0.416	NS
Kamembe Aero	CN	*Negative*	0.092	0.048	S
	HN	*Positive*	0.209	0.002	S
	CD	*Negative*	0.354	0.000	S
	HD	*Positive*	0.410	0.000	S
Kigali Aero	CN	*Negative*	0.833	0.000	S
	HN	*Positive*	0.646	0.000	S
	CD	*Negative*	0.570	0.000	S
	HD	*Positive*	0.573	0.000	S
Rubona	CN	*Negative*	0.330	0.000	S
	HN	*Positive*	0.158	0.014	S
	CD	*Negative*	0.234	0.002	S
	HD	*Positive*	0.264	0.001	S
Ruhengeri Aero	CN	*Negative*	0.064	0.212	NS
	HN	*Negative*	0.041	0.321	NS
	CD	*Negative*	0.007	0.687	NS
	HD	*Positive*	0.005	0.735	NS
Zaza	CN	*Negative*	0.001	0.882	NS
	HN	*Positive*	0.069	0.145	NS
	CD	*Negative*	0.001	0.875	NS
	HD	*Positive*	0.207	0.009	S

3.3. Change in average seasonal air temperature

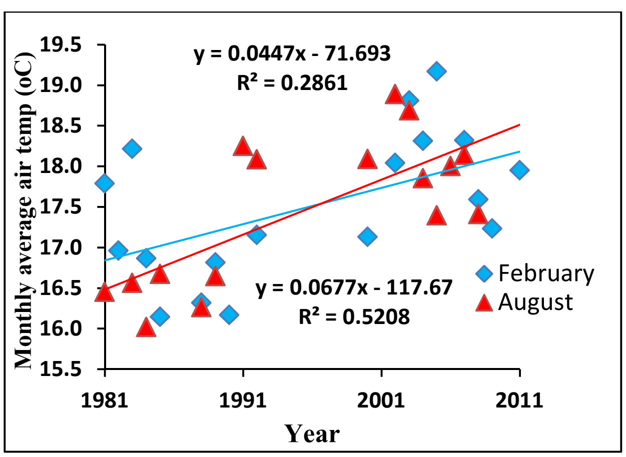
The analysis assessed the similarity and difference in air temperature trends for one month belonging to short dry season (February) and another belonging to long dry season (August). As indicated on Figure 4, except Butare which showed negative trend for the short dry season, other meteorological stations presented an increase in trends of monthly mean air temperature for both short dry and long dry seasons.



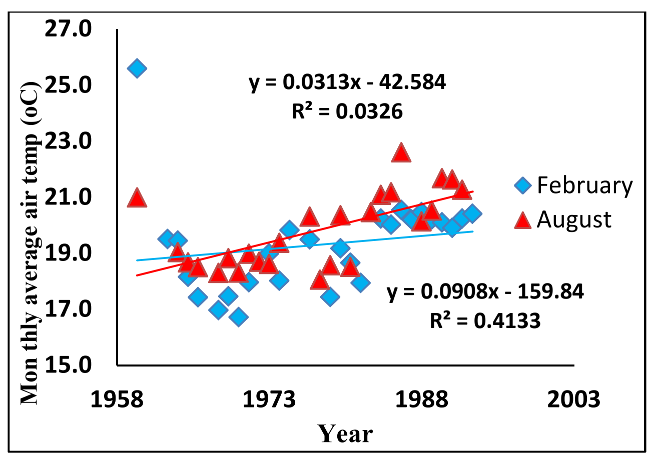
(a) Air temperature trends at Butare Aero met. station



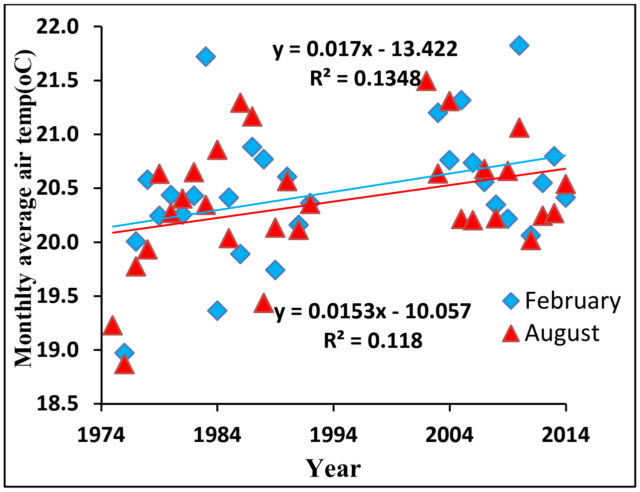
(b) Air temperature trends at Byimana met. Station



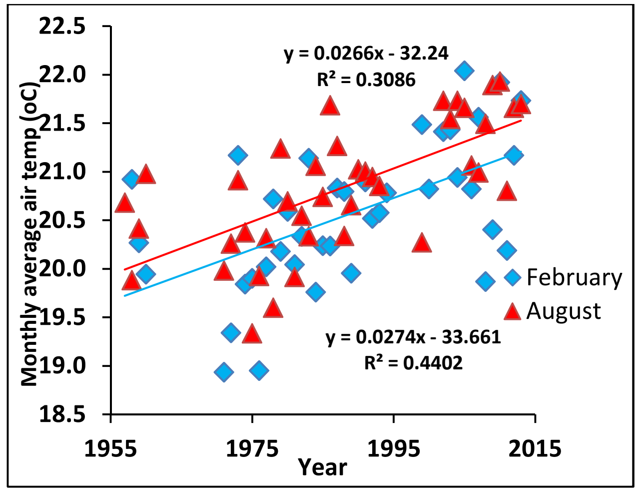
(c) *Air temperature trends at Byumba pref met. station*



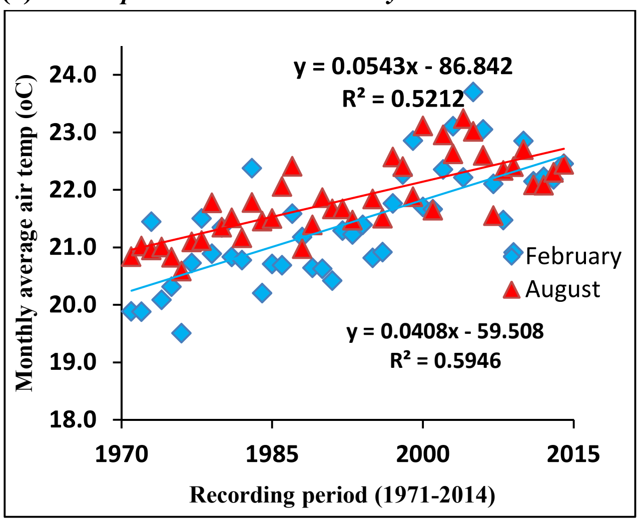
(d) Air temperature trends at Gahororo met. station



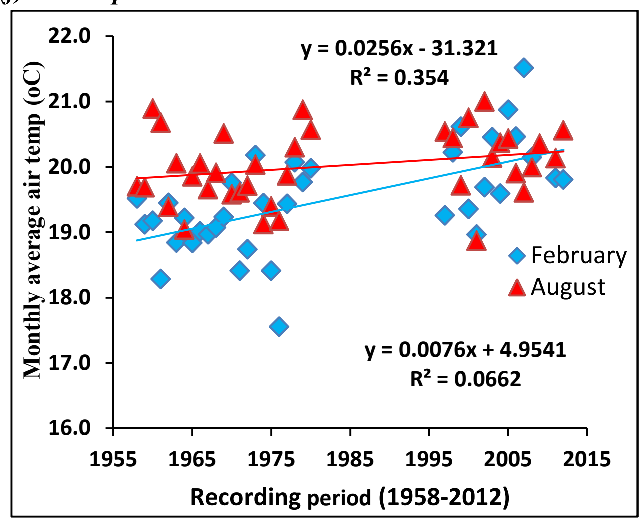
(e) *Air temperature trends at Gisenyi Aero met. station*



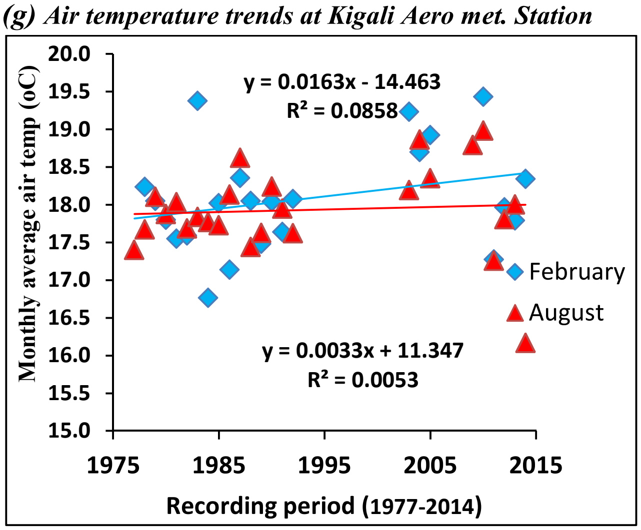
(f) Air temperature trends at Kamembe Aero met. Station



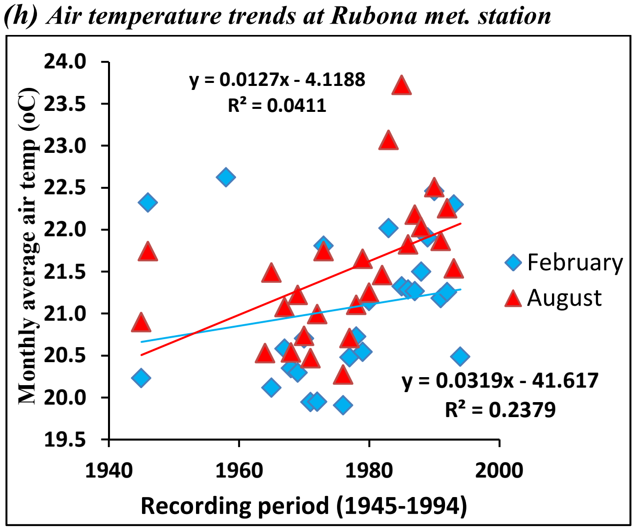
(g) Air temperature trends at Kigali Aero met. Station



(h) Air temperature trends at Rubona met. station



(i) Air temperature trends at Ruhengeri Aero met. Station



(j) Air temperature trends at Ruhengeri Aero met. station

Figure 4: Trends of monthly average air temperature in February and August at 10 meteorological stations

The output of regression analysis for the 10 meteorological stations showed that the trend of seasonal air temperature was much positive and highly significant at Kigali Aero meteorological station compared to remaining meteo-stations (Table 7). According to the same results the trends for both short and long dry seasons at Ruhengeri meteo-station were in no case significant even though they were positive. The trends of seasonal air temperature were negative for short dry season and positive for long dry season but both were not significant.

Table 7: Regression analysis for seasonal air temperature

Meteo-Station	Season	Trend	R square	P-Value	Remark
Butare	Short dry	*Negative*	0.018	0.349	NS
	Long dry	*Positive*	0.000	0.950	NS
Byimana	Short dry	*Positive*	0.343	0.001	S
	Long dry	*Positive*	0.205	0.018	S
Byumba	Short dry	*Positive*	0.286	0.022	S
	Long dry	*Positive*	0.521	0.002	S
Gahororo	Short dry	*Positive*	0.033	0.367	NS
	Long dry	*Positive*	0.413	0.001	S
Gisenyi Aero	Short dry	*Positive*	0.135	0.050	S
	Long dry	*Positive*	0.118	0.058	NS
Kamembe Aero	Short dry	*Positive*	0.309	0.000	S
	Long dry	*Positive*	0.440	0.000	S
Kigali Aero	Short dry	*Positive*	0.521	0.000	S
	Long dry	*Positive*	0.595	0.000	S
Rubona	Short dry	*Positive*	0.354	0.000	S
	Long dry	*Positive*	0.066	0.119	NS
Ruhengeri Aero	Short dry	*Positive*	0.086	0.175	NS
	Long dry	*Positive*	0.005	0.730	NS
Zaza	Short dry	*Positive*	0.041	0.311	NS
	Long dry	*Positive*	0.238	0.011	S

4. DISCUSSION

The analysis of 10 meteorological stations (*Figure 2*) showed that 8 of 10 stations indicated positive trends for maximum of maximum air temperature whereas all the 10 meteorological stations showed positive trends for minimum of minimum air temperature. It was reported by various authors that the minimum air temperature increased faster than maximum air temperature because of different factors. Folland et al. (2001) noted that minimum air temperature increased about twice as fast as maximum temperature over global land areas since 1950, resulting in a broad decline in the diurnal temperature range (DTR: Difference of maximum and minimum air temperature). Among factors that could affect the minimum air temperature we note changes in cloud cover, precipitation, soil moisture, and atmospheric circulation likely accounted for much of the trend differential during a given period (e.g., Przybylak, 2000; Braganza et al., 2004). Changes in land use also impacted the DTR in some areas (e.g., Balling et al., 1998; Bonan, 1999; Small et al., 2001). As indicated by Christy et al. (2008), there are differences between *Tx* and *Tn* trends, especially recently, as they may reflect a response to complex changes in the boundary-layer dynamics. They added that the *Tx* represents the significantly greater daytime vertical connection to the deep atmosphere, whereas *Tn* often represents only a shallow layer whose air temperature is more dependent on the turbulent state than on the temperature in upper atmosphere and this turbulent state in the stable boundary layer is highly dependent on local land use and perhaps locally produced aerosols, and the significant human development of the surface may be responsible for the rising *Tn* while having little impact on *Tx*. Byamukama et *al.* (2011) indicated that land use change in Rwanda (forest, grass and wetlands conversion to arable land) is also among contributors to the GHGs emissions. This may affect the real and natural patterns of air temperature trends in Rwanda especially minimum air temperature. For both monthly maxima and minima of air temperature analyzed, it was noticeable that the air temperature trends for Kigali Aero meteorological station indicated positive and significant trends with greater coefficients of determination (R^2). This may be related to level at which urbanization involves artificial changes to the land surface and grows energy consumption. It was shown that urbanization affects the surface energy budget and land-atmosphere interaction, resulting in the 'urban heat island' effect (UHI) Arnfield (2003); Collier, 2006).

Parker (2010) also argued that urbanization usually induces a warming trend in the observed surface air temperature series, in a way similar to that of the increasing concentration of atmospheric greenhouse gases and however the effect of urbanization has become a matter of concern in the field of climate change detection. Some authors highlighted that the urban influence on the global air temperature series is negligible (Folland et al. 2001; Parker 2006), but the urbanization-induced warming in local (or regional) air temperature observations could be considerable (Lin and Yu 2005; Yan et al. 2010). For example, Portman (1993) showed that urban meteorological station in North China experienced an urban-induced warming trend of 0.15–0.26 °C/30 yr during 1954–1983.

Although Safari (2012) worked on annual mean air temperature in Rwanda, his findings at a 30 year sub-period (1958-1977) showed that Kigali Aero meteorological station (Capital city of Rwanda) presented a positive trend with very high coefficient of determination (R^2 = 0.67). He also concluded that the observed warming is most likely explained by the growing population accompanied by the increasing emission of green house gases, and the growing urbanization and industrialization the country has experienced, especially the City of Kigali, during some last decades.

Our findings (*Table 4*) showed that half of meteorological stations presented their highest extremes of monthly maximum air temperature in the year 2005. In fact, as noted by Byamukama (2011), the year 2005 was among the hottest years in Rwanda, such as 1999, 2000 and 2006. This high level of recorded air temperature created severe droughts in some regions of the country, particularly in the east (Bugesera, Umutara and Mayaga regions), where agricultural production has been undermined. Gabriel (2012) and Nash and Ngabitsinze (2013), also noted that the year 2005 was marked with severe drought in Rwanda. A decadal based air temperature analysis by WMO (2013) shows that the period 2001–2010 was the warmest decade on record since modern meteorological records began around the year 1850. The report indicates that the year 2005 was hotter above the land in southern hemisphere whereas it was hotter above ocean in northern hemisphere. The analysis of minimum air temperature indicated that Byumba Pref meteorological station showed the lowest extremes of monthly minimum air temperature. This may be due to the fact Byumba Pref meteorological station is located in the region with highest altitude (2235 m, ASL) considering other meteorological stations used for this study.

The logic behind the later statement was also highlighted by Airbus (2000) that the air temperature decreases with altitude at a constant rate of about -6.5° C/1000 m up to the tropopause.

The trends of daily and night extreme air temperature were obtained in a varying pattern. The majority of the trends showed an increasing number of hot days and nights but not always significant (*Table 6*). Regardless to the non significance of trends in hot days and nights, on the other hand they show a picture of warming that has been occurring in Rwanda over time.

The analysis of average seasonal air temperature showed almost similar trends even though not all significant (Table 7). For the trends of short and long dry season at the 10 meteorological stations, only Butare presented negative and non significant trend for the short dry season. Most of the trends were statistically significant and very few were not. The similarity of these trends described above is due to the fact that the months of February and August belong to the periods that intercept with rainfall time in Rwanda.

4.1. Impacts of observed warming in Rwanda

A number of studies conducted recently in Rwanda have recognized that climate variability and change were happening and were coupled with significant impacts on the country's natural resources including agriculture which is the main source of livelihood in rural areas (WFP/FEWS-NET, 2003). It was indicated that the climate variability in Rwanda was expressed in the occurrence of higher and changes in frequency, intensity, persistence of extremes such as drought (Watkiss *et al.,* 2009). For example MINITERE (2006) reported that eastern region of the country has been experiencing severe rainfall deficits over the last decades with high vulnerability of population in the region. It also noted that the observation made from 1961 to 2005 showed that the period between 1991 and 2000 has been the driest since 1961. These observations showed a marked prolonged drought in 1992, 1993, 1996, 1999 and 2000. The similar results were obtained by Nash and Ngabitsinze (2013), and included the years 2005 and 2006 on the list of years with severe droughts in Rwanda. They indicated that these temperature extremes seriously affected Bugesera, Umutara and Mayaga regions. DFID (2009) compared the period of 2005/2006 to be equivalent to the famous Ruzagayura famine during 1943 to 1945. In addition, REMA (2007) reported that the eastern province especially Bugesera region experienced severe droughts in 1999, 2006 and more recently in November 2008.

The report shows that the livelihoods of people in Bugesera are dependent on agriculture. Consequently, long dry spells had and will have great impacts on their livelihoods and welfare if nothing is done to cope with this changing climate. REMA (2007) mentioned that the crop failure during the 2000 drought meant that the entire region had to depend on external food supplies. The length and intensity of land degradation have also weakened the lands' resilience; and when it comes to be combined with overgrazing and poor cultivation practices, drought has led to deterioration in pasture and arable land to the point where they have been abandoned. In the report it was indicated that a decline in food crop production because of low moisture content was no doubt associated to changing climatic conditions in Rwanda.

5. CONCLUSION

This study shows that generally, the analysis of both daily maximum and minimum air temperatures indicated visible patterns of climate variability in Rwanda. The analysis of monthly extreme air temperature showed that the year 2005 hosted higher number of hottest days mostly observed in the month of February. On the other hand the minima (coldest days) in air temperature were recorded in Byumba, a region with higher altitude comparing to locations of meteorological stations used for this study. Throughout this study, it was noticed that the number of hot days and nights increased for the majority of analyzed meteorological stations and consequently the reduction in number of cold days and nights. The trends of seasonal air temperature were not far different, and this is due to the short and long dry seasons intercept with rainfall in Rwanda. Impacts of warming have been observed in Rwanda since long time ago. Various researchers argued that these impacts expressed in form of severe droughts were observed especially in eastern part of the country affecting massive people who had to rely on external supply because of the failure in crop production. This past climate variability which has been accompanied with various and catastrophic impacts in Rwanda should trigger further and deep researches for forecasting purpose. The development of early meteorological warning system will help Rwandan people especially farmers to change the way things were used to be done in order to cope with this changing climate.

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