International Journal of Environment and Climate Change

10(6): 36-51, 2020; Article no.IJECC.56770
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Trend and Variability Analysis of Rainfall and Extreme Temperatures in Burundi

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Authors' contributions

This work was carried out in collaboration among all authors. Authors MN, AEL, BL and CM designed the study, developed the methodology and wrote the original manuscript. Author MN performed the field work and computer analysis. Author CM contributed to software used. Authors AEL and BL contributed to results analysis and interpretation. All the authors contributed equally to this paper.

Article Information

DOI: 10.9734/IJECC/2020/v10i630203
Editor(s):
(1) Dr. Hani Rezgallah Al-Hamed Al-Amoush, Al al-Bayt University, Jordan.
Reviewers:
(1) Ojo Joseph Sunday, The Federal University of Technology, Nigeria.
(2) Janilson Pinheiro de Assis, Federal Rural University of the Semi-Arid, Brazil.
Complete Peer review History: http://www.sdiarticle4.com/review-history/56770

Original Research Article

Received 02 March 2020
Accepted 07 May 2020
Published 24 May 2020

ABSTRACT

This study investigated the variability and trend of rainfall and extreme temperatures over three eastern and northeastern regions of Burundi during the period 1980-2015. Data used were collected from seven stations belonging to the geographical institute of Burundi. Annual and seasonal variability are assessed using standardized anomaly, coefficient of variance and precipitation concentration index. In addition, non parametric statistic tests Mann Kendall and Sen's slope estimator are used to detect trends in rainfall, maximum and minimum temperatures. The results reveal a high monthly and inter-annual variability of rainfall whereas the temperature does not show high fluctuation at monthly scale. The northern region presents the lowest amount of rainfall for the first rainfall season (October-January) when drought is frequently observed. No significant rainfall trend detected over all regions at seasonal and annual scales whereas

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significant increasing trend was observed for both maximum and minimum temperatures over all regions. The spatial distribution of rainfall and extreme temperatures displays also a wide variation across the region depending on topography of the study area.

Keywords: Burundi; variability; trend; rainfall; extreme temperatures.

1. INTRODUCTION

Climate change is currently a worldwide challenge which mobilizes many actors including scientists, government authorities and industrial leaders. More attention is concentrated on assessing the impact of climate change and evaluating the degree of vulnerability of local population in order to adopt strategies of adaptation and mitigation of climate disasters' impacts. Different extreme events, such as sea level rise, polar ice melting, intense storms, floods, droughts, heat waves, and others, are likely to occur as a result of climate change [1]. The average temperature trends on a global scale showed a warming trend of 0.85°C (from 0.65°C to 1.06°C) over the period 1880 to 2012. As a result of increasing temperature, the intensity and frequency of extreme climate events are likely to increase [2]. The rapid warming is mainly attributed to increase in greenhouse gases (GHGs) linked mainly to anthropogenic activities [3]. The ongoing global warming is unequivocal; however, its extent varies from one region to another [2,3].

In Africa, precipitation amounts are likely to decrease for most parts of Sub-Saharan Africa (SSA) while rainfall variability is expected to increase [2]. Due to low adaptive capacity and a high sensitivity of socioeconomic systems, Africa is one of the most vulnerable regions highly affected and to be affected by the impacts of climate change [2]. A study conducted by Adeyeri et al. [4] examines and predicts the susceptibility of the coastal region of Nigeria to flood hazard in changing climate using geo-spatial techniques. Results showed that the areas lying along the banks of Guinea coast are highly susceptible to flood hazards with the degree of susceptibility decreasing towards the north and eastern part of the area. These areas are classified as swamps (water-log) with low water retention which gives rise to high susceptibility of coastal flood hazards.

Many Studies have been conducted on local scale to highlight the variability and trends of climate parameters over long periods. In India, long-term changes and variability of monthly extreme temperatures are investigated. The results showed that the monthly maximum temperature increased, though unevenly, over the last century. Minimum temperature changes were more variable than maximum temperature changes, both temporally and spatially, with results of lesser significance [5]. Another study based on trend in observed and projected maximum and minimum temperature over N-W Himalayan basin (India) suggest that cooling observed in recent past 1970-2010 would be replaced by warming in the future. Increasing trends in maximum and minimum temperature have been detected during near future 2050 and far future 2080 under A1B and A2 scenarios [6]. Observed changes in climate extremes in Nigeria have been assessed using Expert Team on Climate Change Detection Indices (ETCCDI) [7]. Results show a significant increase in the frequencies of warm spell, warm days and nights and decreasing cold spell, cold days and nights over the three climatic zones. A significant increase in annual total precipitation was found in some stations across the Guinea coast and Sahel zones. Changes in consecutive dry days and consecutive wet days are non-significant in most stations. In Benin, a study on analysis of trends in the variability of monthly means minimum and maximum temperature and relative humidity in Benin city revealed a positive increase trend of temperature while humidity shows a decreasing trend with a negative slope [8]. Others studies on trends and variability of rainfall and extreme temperature time series have been carried out in Botswana [9] and Sri Lanka [10]. The results revealed a general decreasing trend in rainfall and warming trends in both maximum and minimum temperature.

In east Africa, similar studies have been carried out and presented climate change events and their impact on socio economic and livelihood of the population. Trend analysis of rainfall and temperature variability in arid environment of Turkana in Kenya has been investigated [11]. A significant increasing trend in seasonal and annual maximum and minimum temperature is detected between 1979 and 2012. On the other hand, rainfall has noticeably decreased during long rains season March to May (MAM) and a slight increase was observed in short rains season October to December (OND). Ongoma et al. [12] conducted a research on variability of temperature properties over Kenya based on observed and reanalyzed datasets. They used Mann-Kendall rank test, linear regression analysis, and Sen.'s slope estimator to detect trend of the mean and the extreme temperatures. The seasons show an overall warming trend since the early 1970s with abrupt and significant changes happening around the early 1990s. The warming is more significant in the highland regions as compared to their lowland counterparts. The percentage of warm days and warm nights is observed to increase, a further affirmation of warming. Other study has been conducted in the east African region and assessing surface temperature variations and their possible causes [13]. The results indicate that since 1905, and even recently, the trend of maximum temperature is not significantly different from zero. However, minimum temperature results suggest an accelerating temperature rise. Because the turbulent state in the stable boundary layer is highly dependent on local land use and perhaps locally produced aerosols, the significant human development of the surface may be responsible for the rising minimum temperature while having little impact on maximum temperature in East Africa.

In Ethiopia, several researchers analyzed variability and trend detection of climatic parameters in many regions of country [14-17]. Birara et al. [18] analyzed the trend and variability of rainfall and temperature in the Tana basin region, Ethiopia. The results indicated that the amount of rainfall decreased for the majority of the stations. The annual rainfall showed significant decreasing trends. However, a positive trend of annual rainfall was observed at Addis Zemen. The minimum, maximum and mean temperatures have increased significantly for most of the stations. An increasing trend of annual maximum temperature was obtained between 1980 and 2015. A similar study analyzed the trends of rainfall and its relationship with SST signals in the lake Tana basin, Ethiopia [19].

Few studies have been conducted in Burundi on variability and trend analysis of some climate factors and evaluated their impacts on energy resources generation. The findings indicate a decreasing rainfall trend and increase of temperature and wind speed [20,21]. These results revealed that climate change may alter negatively hydropower potential whereas wind power potential is projected to increase. A study on spatio-temporal analysis of climate change impact on future wind power potential in Burundi (East Africa) conducted by Manirakiza et al. [22] revealed an expected high wind power potential especially in the western lowlands region coastal to the lake Tanganyika. Another study on solar irradiance and temperature variability and projected trends analysis [23] carried out in eastern and northeastern regions of Burundi highlights the significant projected increasing trend in mean temperature and no significant trend detected on solar irradiance.

As an east African country, Burundi has the climate mainly influenced by the north-south movement of the Intertropical Convergence Zone (ITCZ), the topography of the country and El-Niño Southern Oscillation (ENSO). Burundi has experienced many extreme climate events which caused famine and climatic disasters that are still engraved in the memory of Burundians [24,25]. These include in particular the dryness in the north-east of the country, the torrential rains and especially floods in the city of Bujumbura and Bubanza, the rise by 4 m of the level of the Lake Tanganyika between 1961 and 1964 which caused the most important damage.

All these studies did not investigate either the variability of rainfall or extreme temperatures in the eastern part of Burundi. Besides, the drought burst in the northeastern part of Burundi caused many catastrophic consequences on smallholders including starvation, refugees, school dropout. Assessing variability and trend of climatic parameters is necessary to characterize features of climate change during recent last decades and adopt strategies of adaptation of the extreme climatic events. On the other hand, climatic parameters are the main factors in producing renewable energy like solar energy; hydropower and wind power. Burundi is one of eastern African country which experiences a chronic shortage and deficit of electrical energy. Indeed, energy resources are not enough to deal with increased demand for energy because these resources which are mainly of hydroelectric origins do no longer produce the amount of energy expected during the installation due to the significant decrease in the water level in the reservoir [23]. Furthermore there is no important plant of energy generation built in eastern region which can produce sufficient energy regarding the need of local population. According to these challenges, others studies for characterization of the fluctuation and trends of some climate factors are important and urgent. Our contribution in this study is to analyze spatial and temporal variability of rainfall and extreme temperatures in the recent past period. The main objective is based on characterization of variability and trend of these variables on annual and seasonal scale in three regions of eastern and northeastern of Burundi during the period 1980-2015. Specifically the study is conducted in eastern lowlands (ELL), northern lowlands (NLL) and eastern arid plateaus (EAP) of Burundi.

2. MATERIALS AND METHODS

2.1 Study Area

The area of study is the region covered by the east and northern east part of Burundi as shown in Fig. 1. Burundi is a small tropical country located in East Africa and lies between longitudes 28.8°–30.9° east and latitudes 2.3°–4.45° south [26]. Burundi is bounded to the west by the Democratic Republic of Congo, to the north by the Republic of Rwanda and to the east and south by the Republic of Tanzania. The area of Burundi is 27,834 km^2 and it belongs to two major watersheds: The Nile basin with an area of 13,800 km^2 and Congo River basin with 14,034 km^2 of area [27]. The climate in Burundi, as an east African country, is mainly influenced by the north-south movement of the Intertropical Convergence Zone (ITCZ), the topography of the country and El-Niño Southern Oscillation (ENSO) [20]. Then the annual mean of climate variables such as precipitation, temperature and wind speeds, depends mainly to the climate location zone.

The interested study area covers the east and northeast of Burundi and is split into three sub-regions considering their landforms: The eastern lowlands of Kumoso (ELL), the eastern arid plateaus (EAP) and the northern lowlands of Bugesera (NLL). The ELL is a region located to the extension of the border with Republic of Tanzania while NLL covers two provinces (Kirundo, Muyinga) located in northeastern of the country. The main different between the three regions is elevation as shown in Fig. 1. This elevation defines the climate of each region and then temperature is high in lowlands regions. The annual mean temperature varies from 19 °C for EAP to 22°C for ELL and NLL, and their altitudes also vary from 1,100–1,400 m for ELL and NLL to 1,400–2,000 m for EAP [27]. The precipitation in the study area is almost abundant and the annual mean rainfall varies from 1,000 mm to 1,200 mm even if there is no existing important hydropower plant located in this region.

2.2 Data Used

Monthly meteorological data from synoptic stations of the Geographical Institute of Burundi (IGEBU) have been used in this study from 1980 to 2015. Fig. 1 shows the spatial distribution of seven stations selected based on the length of record periods and the relative completeness of the data. Long time series of rainfall, maximum and minimum temperature observed data were collected at monthly scale.

Based on the World Meteorological Organization, a minimum of 30 years' data are required for searching the evidence of climatic change in time series. Then, 36 years of past meteorological data for the selected stations were used, as shown in Table 1. The missing values in the monthly station records were handily estimated by taking the average of same month's values of the preceding and succeeding years. But years with missing data were estimated by interpolating values from the completed nearby weather stations when the missing values were less than 5% of the total weather stations' records for the whole study period [18].

2.3 Variability Analysis

The coefficient of variation (CoV), which describes the variation within sample values, was used for the variability study. A coefficient of variation (*CoV*) for each individual month and annual time series for each region was determined by:

$$CoV = 100 * \frac{\sigma}{\mu} \quad (1)$$

where μ and σ are respectively mean and standard deviation of each set of data analyzed. A higher value of *CoV* is the indicator of larger variability. Then *CoV* is used to classify the degree of variability for rainfall events as less (*CoV< 20*), moderate (20 < CoV <30), and high (CoV >30) [15].

The discrimination of years and months with high or low values climate parameters (rainfall or temperature) was done using the normalized or standardized variable index (I) created by Mckee [28] and which was used by many authors [29,30]. The standardized variable index (I) is performed using the equation 2:

$$I(i) = \frac{\varphi_i - \overline{\varphi}_m}{\sigma} \quad (2)$$

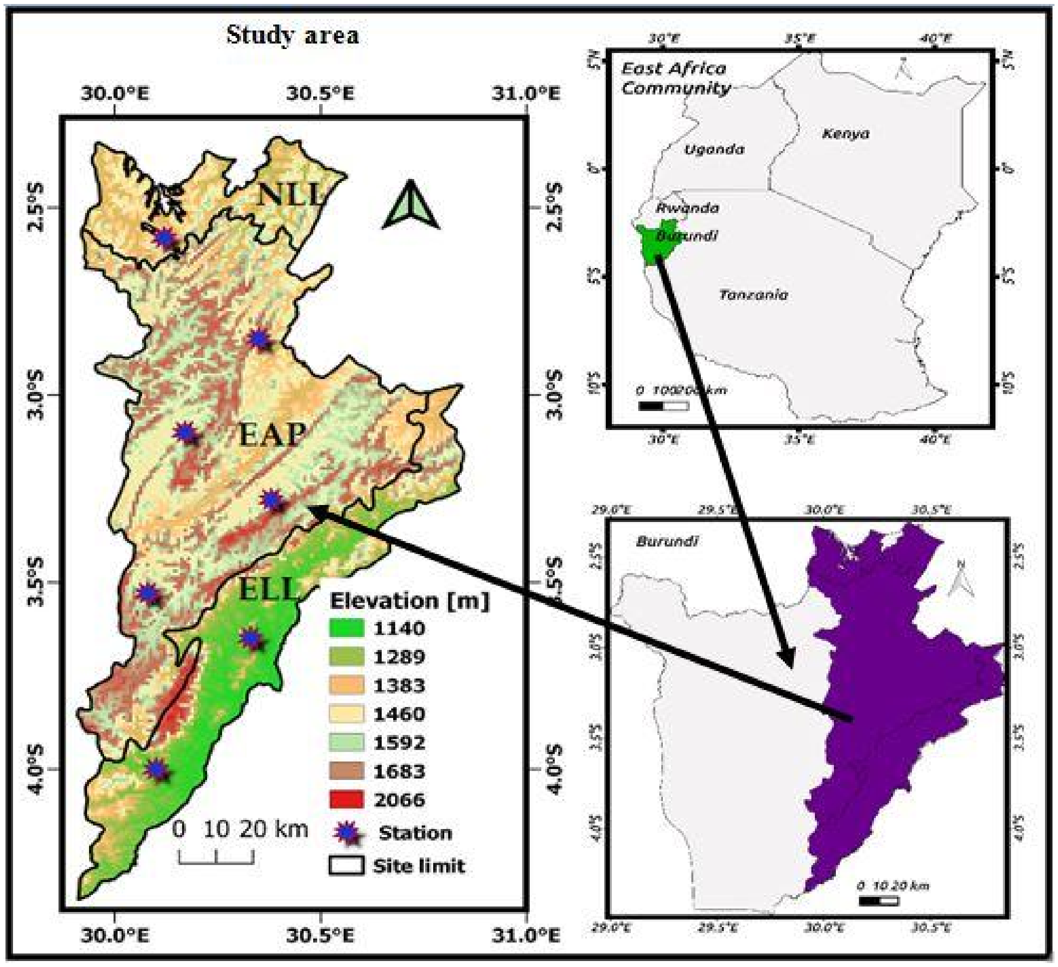


Fig. 1. Study area location

Table 1. Geographic characteristics of meteorological stations used

Name	B.W*	Region	Latitude South	Longitude East	Period
KIRUNDO	Nile	NLL	2.58	30.12	1980-2015
MUYINGA	Nile	EAP	2.85	30.35	1980-2015
CANKUZO	Nile	EAP	3.28	30.38	1980-2015
KARUZI	Nile	EAP	3.10	30.17	1980-2015
MURIZA	Nile	EAP	3.53	30.08	1980-2010
KINYINYA	Congo	ELL	3.65	30.33	1980-2010
MUSASA	Congo	ELL	4.00	30.10	1980-2015

B.W: Basin watershed*

where φ_i , $\bar{\varphi}_m$ and σ described respectively the value for the year or month *i*, the average and the standard deviation of the time series. Thus, in this study, a considered year or month is considered as normal if its index is between −0.5 and +0.5. It is considered in excess if its index is greater than +0.5 and in deficit if the value is below than −0.5. For temperature, the year or month is considered as hottest or coolest if the value is greater than +0.5 or less than -0.5, respectively. This interval is relatively weak but it allows to distinguish hottest years/month with coolest one [20].

In order to study monthly variability of rainfall in the study area of each region, a modified version of precipitation concentration index (PCI) [31] was used. The guidelines for interpretation of

PCI are presented in Table 2. Magnitude and variability of annual and monthly precipitation were investigated as PCI. The analysis was based on monthly and annual precipitation data of all regions in the study area. This index is described as:

$$PCI_{annual} = \left[\frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i\right)^2}\right] * 100 \tag{3}$$

where P_i is the rainfall amount of the i^{th} month, and Σ is the summation over the 12 months.

2.4 Trends Analysis

A number of tests exist and are available to estimate trends. Maximum and minimum temperatures and rainfall data are long-term time series. The non parametric Mann-Kendall (MK) test is the most used for testing trends in time series. Therefore, the long-term trends of the precipitation and temperature changes were estimated using a statistical test which is less sensitive to outliers. The MK test does not require data to be normally distributed. Indeed the test is a non-parametric statistic procedure that has low sensitive to abrupt breaks due to non-homogeneous time series [32]. The MK test checks increasing, decreasing or no trends of monthly or annually mean time series of the three regions of our study area. If there is a linear trend in the time series, the true slope has been estimated using Sen's slope method [18] which is a simple non- parametric found in many articles [33,34]. In this study, the spatial distribution of annual and seasonal mean rainfall and extreme temperatures (maximum and minimum) were performed using the inverse distance weighted (IDW) interpolation method with the software QGIS. The basic theory behind IDW is based on the assumption that the interpolated surface has the most influence of nearby points and least influence of distant points [18,14]. The IDW is flexible, and available within almost any GIS software and common spatial interpolation method.

3. RESULTS AND DISCUSSION

Burundi has two distinct seasons: the rainy season from October to May and dry season from June to September. The rainy season is so long and in the middle it appears a very short dry season (almost two weeks) at the end of January and the beginning of February. For this reason we consider two rain seasons in our study: first rain season from October to January named seasonal rainfall ONDJ, a second rain season from February to May which is named seasonal rainfall FMAM. The dry season is named dry season JJAS for the following of our study. These two rain seasons are also related to cultural seasons called cultural season A for season ONDJ and B for season FMAM [27].

3.1 Variability and Trends Analysis of Rainfall

3.1.1 Monthly and inter-annual variability of rainfall

Fig. 2 and Fig. 3 display monthly and inter-annual rainfall pattern and variability at EAP, ELL and NLL over the period 1980-2015. The variability of rainfall over three regions studied is analyzed with standardized anomalies of rainfall, coefficient of variance and precipitation concentration index. The analysis of monthly variability shows that four months are in deficit of rainfall: June, July, August and September over all regions. This is normal because this period corresponds to the dry season in Burundi as seen in Fig. 2a). The remained months are in excess of precipitation and the region receives the highest mean amount of rainfall in April. We remark also that February and October are normal. In fact, October is the beginning of rain season and February presents a small dry season (almost two weeks) which appears generally with the ends of January to the beginning of February. These reasons explain the low quantities of rainfall recorded in these months. The analysis of monthly rainfall pattern indicates that NLL region has small amount of rainfall during the first rain season ONDJ. This may explain the drought usually observed in this region at the starting of rainfall and causes the delay of cultural season. However NLL receives highest quantities of precipitation during JJAS dry season and FMAM rain season especially in April when the highest amount reaches 188.8 mm.

The analysis of the inter-annual standardized anomalies of rainfall at EAP, ELL and NLL over the period 1980-2015 points out a high variation of rainfall over this period. The features reveal that eight, twelve and fourteen years are in excess of rainfall respectively for EAP, ELL and NLL while ten years are in deficit of rainfall for EAP and eleven deficit years of rainfall for ELL and NLL. The regions ELL and NLL present high variability compared with NLL. Furthermore ELL points out two sub-periods including the first period 1980-1999 with more wet years and a second period 2000-2015 with dry years in deficit of rainfall except 2013 and 2015 which show an excess of precipitation. The findings show also that the year 2000 presents the lowest standardized anomaly rainfall in NLL whereas 1997 displays the highest standardized anomaly rainfall in EAP. The analysis of the features reveals that the regions EAP and ELL highlight a downward trend of precipitation while NLL illustrates no trend except a very high variability over the period 1980-2015.

As presented in Table 3 the coefficients of variation and precipitation concentration index are calculated with annual mean values of rainfall during 36 years. The results show that coefficients of variation are less than 20 for all regions except ELL which has a coefficient of variation of 21.74. According to [15], the degree of variability of rainfall events is less over EAP and NLL while it is moderate for ELL region.

Furthermore the annual precipitation concentration index computed are between 11 and 16 which imply a moderate distribution of precipitation (moderate concentration). On another hand Table 3 shows also that seasonal rainfall (season ONDJ and FMAM) contribute almost equally to annual amount whereas dry season‘s contribution is very small. Therefore rain season ONDJ presents the lowest amount of rainfall for northern region NLL where drought is frequently observed as said above. The results confirm that high variability of rainfall is experienced in NLL region.

3.1.2 Rainfall trend analysis

The result of the MK test was applied to analyze the mean annual and seasonal rainfall and temperature trend for the period of 1980–2015 over all regions in the eastern and northeastern of Burundi. Similarly, Sen’s slope method was used to examine the magnitude slope of the variables. The results of the MK trend and Sen’s slope method of rainfall are given in Table 4. The interpretation of Mann-Kendall test reveals that there is a monotonic trend when p-value is less than a threshold of 0.05. Mann-Kendall’s tau indicates the mean annual and seasonal rainfall increase (positive trend), decrease (negative trend), and no trend.

As presented in Table 4, annual rainfall shows no trend detected for all region because the p-value is greater than α=0.05 over the period 1980-2015. Then EAP reveals no significant decrease with Sen’s slope of -0.99 whereas NLL illustrates no significant increasing trend of rainfall with positive values of Sen’s slope. ELL shows a no significant downward trend with a p-value equals to 0.05 and a slope of -8.17. Accordingly, all seasonal rainfall show no significant trends for all regions except the season FMAM for EAP and

Table 2. Interpretation of PCI results [18]

PCI value	Interpretation
<10	Uniform distribution of precipitation (low concentration)
11–16	Moderate distribution of precipitation (moderate concentration)
16–20	Irregular distribution of precipitation distribution
>20	Strong irregularity of precipitation

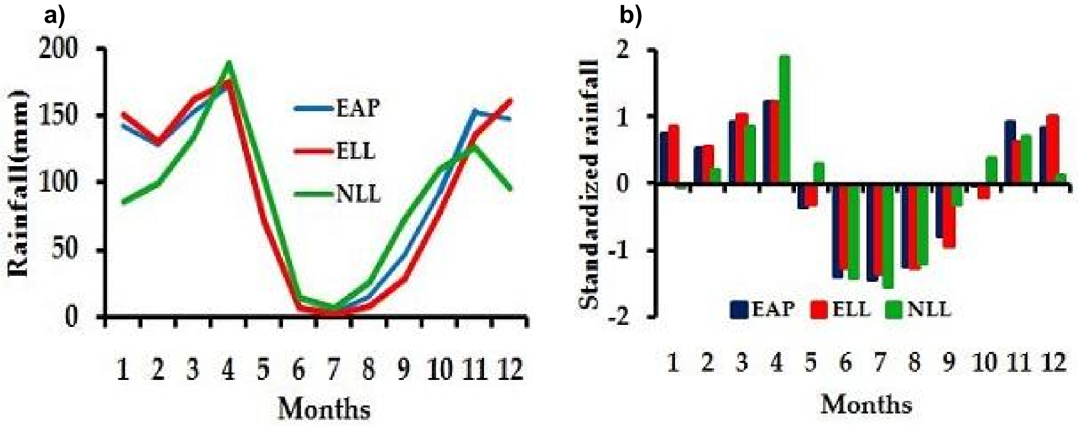


Fig. 2. Monthly pattern a) and variability b) of rainfall in EAP, ELL and NLL

Table 3. Annual and seasonal mean rainfall (mm), coefficient of variation and PCI over the period 1980–2015

Region	Annual mean	Season ONDJ mean	Season FMAM mean	Season JJAS mean	CoV	PCI
EAP	1137.4	535.3	527.4	65.4	12.7	11.8
ELL	1110.8	528.5	539.1	44.6	21.7	12.4
NLL	1072.7	421.2	526.7	127.4	11.3	11.1

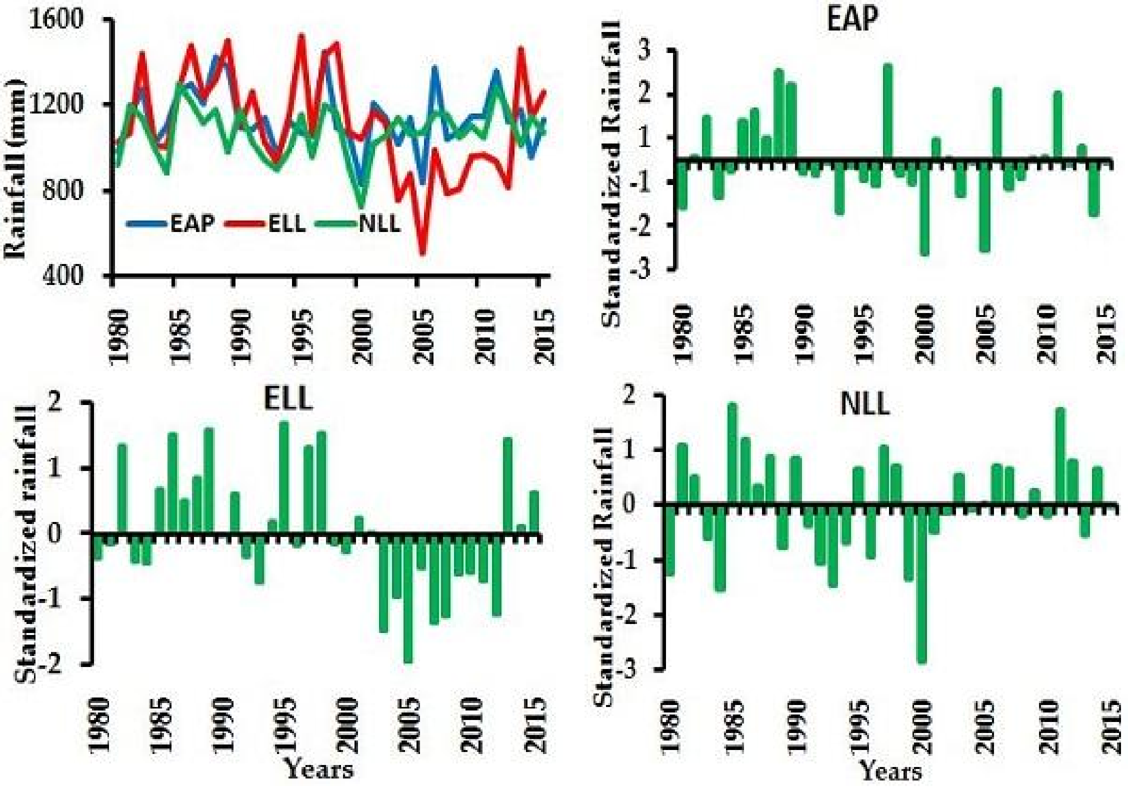


Fig. 3. Inter-annual pattern and variability of rainfall in EAP, ELL and NLL over the period 1980-2015

ELL where a significant downward trend is detected with 0.03 and 0.01 of p-values and -2.93 and -6.27 of Sen's slope values respectively. Otherwise no significant increasing trends are observed for the season FMAM in NLL and for the season JJAS in EAP and NLL. No significant decreasing trends are also presented over all regions for ONDJ and in ELL for the season JJAS.

3.2 Temperature Variability and Trends Analysis

3.2.1 Monthly and inter-annual variability of temperature

Fig. 4 presents the standardized index and pattern of monthly maximum and minimum temperature at EAP, ELL and NLL over the period 1980-2015. The maximum average temperature and standard deviation used to calculate standardized temperature anomalies are respectively 25.6°C & 0.9 for EAP, 28.7°C & 1.1 for ELL and 27.5°C & 0.8 for NLL. Furthermore minimum average temperature and standard deviation 13.6°C & 0.7, 15.5°C & 1.2 and 15.8°C & 0.4 were used respectively for EAP, ELL and NLL for computing standardized index of minimum temperature.

The analysis of maximum temperature shows that three months are hot: August, September and October over all regions of study and the hottest month is September. All remaining months of the year are normal or cool. The analysis of minimum temperature reveals three months with cool night: June, July and August with July as the coolest month for all regions. The remained months are normal or in excess of temperature regarding the minimum mean temperature over the region. The feature of these figures does not present high variability and shows an inverse pattern. The monthly pattern of maximum temperature shows that ELL region is the hottest whereas EAP presents low values of maximum temperature. The highest value of monthly maximum temperature appears in September for all regions. For minimum temperature, the coolest region is EAP with the minimum monthly value observed in July. ELL indicates minimum temperature which presents a significant decrease in dry season.

Fig. 5 shows inter-annual standardized minimum and maximum temperature at NLL, EAP, and ELL over the period 1980–2015. The analysis of these figures points out three sub-periods for all regions including 1980-1996, 1997-2009 and 2010-2015. The first period characterized by a downward trend has no excess temperature; the second period is the mixture of cool, normal and excess temperature while the last period is generally characterized by excess temperature. For maximum temperature, the analysis also shows 10 years of high temperature at EAP and 12 years of high temperature at ELL and NLL. The analysis of these features for minimum temperature reveals 8 years, 11 years and 12 years with high minimum temperature at EAP, ELL and NLL respectively. On the other hand, 13, 14 and 12 cool years with low maximum temperature respectively at EAP, ELL and NLL. The analysis of Fig. 5 shows also that EAP, ELL and NLL present 13, 14 and 9 years with low minimum temperature while 11; 13 and 12 years with high maximum temperature are observed respectively for EAP, ELL and NLL in twenty last years of the period of study.

These results revealed a downward trend of maximum and minimum temperatures for the first sub-period and an upward trend of extreme temperatures for the last sub-period. Furthermore, these findings agree with the results of many studies which show increases in temperature over the end of the last century, see reference [15]. More recently, the study [18] analyzed the trend and variability of rainfall and temperature in the Tana basin region, Ethiopia, for the period covers 1980–2015 and found the significant increases of maximum, minimum and mean temperature for most of the stations. An increasing trend of annual maximum temperature was obtained between 1980 and 2015; an increase of 1.08°C was observed.

Table 5 displays the mean, standard deviation and coefficients of variation calculated with annual mean values of maximum and minimum temperature over the period 1980-2015. As illustrated in Table 5, coefficients of variation computed are very small over all regions. According to [15], the degree of variability of extreme temperatures is less over all regions studied. These results demonstrate that the region does not experience very high variation of extreme temperature.

Indeed, minimum temperature shows higher values of coefficient of variation than maximum temperature which means that the variability of minimum temperature is higher than maximum temperature over all regions. Furthermore EAP shows high value of coefficient of variation than other regions considering minimum temperature.

3.2.2 Temperature trend analysis

Using the same process applied for rainfall, maximum and minimum temperature trends for the period of study (1980–2015) were analyzed over the studied regions. September is the hottest month with a maximum temperature of 31.1°C for ELL, 28.9°C for NLL and 27.5°C for EAP. The coolest month is July which presents a minimum temperature of 12.0°C at EAP, 12.9°C at ELL and 14.9°C at NLL.

For trend detection in maximum temperature presented in Table 6 at significance level $\alpha=0.05$, the Mann-Kendall's test (MK) reveals upward trend all over the regions for the period 1980-2015 with a very small p-value < 0.0001. Indeed, the Kendall's tau for both periods is likely the same and positive. In fact, the Kendall's tau equal to 0.51 for EAP, 0.59 for ELL and it is equal to 0.48 for NLL. Combined with the Sen's slope method, these statistical tests revealed upward trends of maximum temperature in the considered periods all over the regions of the study area.

In the same way, minimum temperature trend detection has been computed at significance level $\alpha=0.05$ as illustrated in Table 6. The Mann-Kendall's test (MK) revealed upward trend of annual minimum temperature all over the regions with a very small p-value < 0.0001 except EAP which presented no significant increasing trend with a p-value of 0.9. For annual minimum temperature, Kendall's tau is 0.015 for EAP

Table 4. Trend analysis of annual and seasonal rainfall (1980–2015)

Region	Annual rainfall			Season ONDJ			Season FMAM			Season JJAS		
	MK's tau	p- value	Sen's slope	MK's tau	p- value	Sen's slope	MK's tau	p- value	Sen's slope	MK's tau	p- value	Sen's slope
EAP	-0.07	0.56	-0.99	-0.11	0.37	-1.28	-0.26	0.03	-2.93	0.08	0.54	0.39
ELL	-0.22	0.05	-8.17	-0.17	0.16	-2.8	-0.30	0.01	-6.27	-0.11	0.37	-0.45
NLL	0.05	0.66	1.14	-0.02	0.93	-0.04	0.06	0.61	0.85	0.11	0.38	0.99

Table 5. Annual mean of maximum and minimum temperature, standard deviation and coefficient of variation over the period 1980–2015

Region	Maximum temperature			Minimum temperature		
	Mean	σ	CoV	Mean	σ	CoV
EAP	25.6	0.5	2.02	13.8	0.8	5.6
ELL	28.8	0.6	2.04	15.3	0.5	3.0
NLL	27.5	0.5	1.73	15.8	0.7	4.4

Table 6. Trend analysis of annual minimum and maximum temperature (1980–2015)

Region	Annual maximum temperature			Annual minimum temperature		
	MK's tau	p-value	Slope	MK's tau	p-value	Slope
EAP	0.5143	< 0.0001	0.0314	0.0159	0.9032	0.0048
ELL	0.5905	< 0.0001	0.0425	0.5492	< 0.0001	0.0301
NLL	0.4790	< 0.0001	0.0320	0.5714	< 0.0001	0.0381

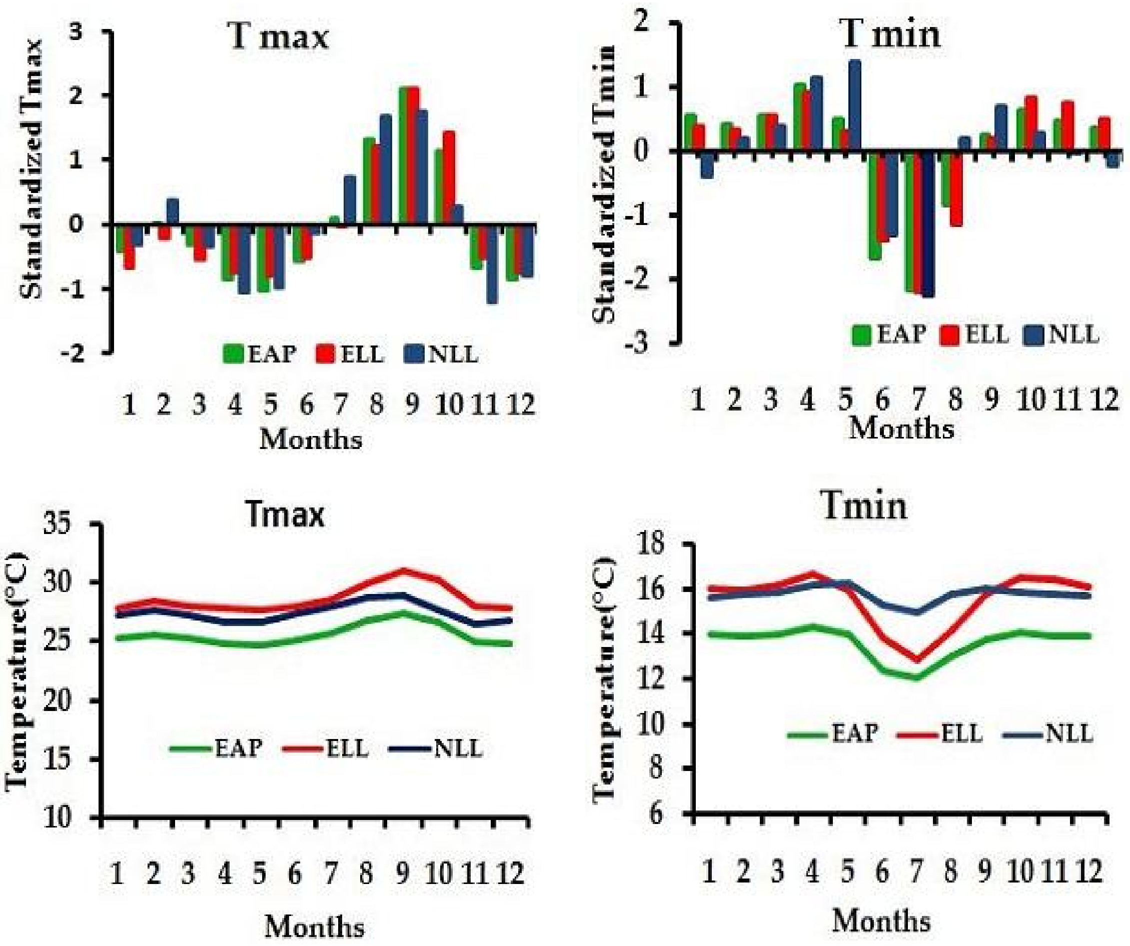


Fig. 4. Monthly variability and pattern of maximum and minimum temperature at EAP. ELL and NLL

T max: maximum temperature, T min: Minimum Temperature

whereas the Kendall's tau for ELL and NLL are respectively 0.55 and 0.57. Then Mann Kendall test and Sen's slope method revealed upward trend of minimum temperature at ELL and NLL while no significant trend was observed at EAP over the period 1980-2015.

3.3 Spatial Distribution of Rainfall and Temperature

Fig. 6 shows a spatial distribution of annual mean rainfall, annual mean of maximum and minimum temperature in the study region whereas Fig. 7 displays a spatial distribution of seasonal mean rainfall. The annual mean rainfall distribution ranges from 1,073 mm observed in NLL to 1,168 mm occurred in EAP. Extremes temperatures in the study region highlight that low land regions are hotter than plateaus location. This is observed by low values of extreme temperatures in EAP (25.5°C and 12.4°C for maximum and minimum temperature respectively) whereas high values are observed in ELL and NLL (28.9°C and 15.8°C for maximum and minimum temperature respectively).

The results of annual rainfall distribution show a general increase precipitation from lowlands (ELL and NLL) to plateaus (EAP). On the other hand, extreme temperatures display a spatial variation which depends mainly on topography and increase from high altitude to lowlands. These results agree with other studies conducted in west of Burundi [20] which find that temperature is very low and rainfall very high in highland regions while high temperature and low precipitation are observed in lowland regions.

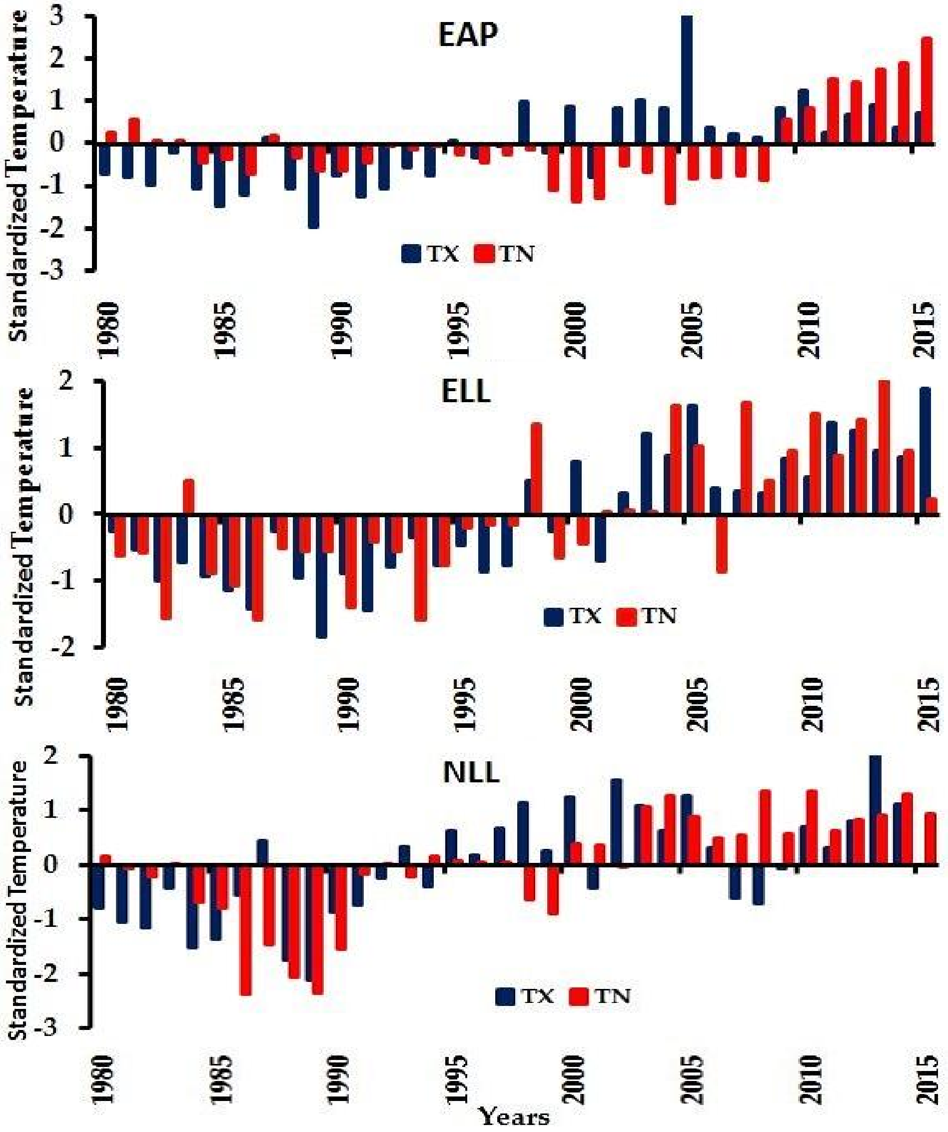
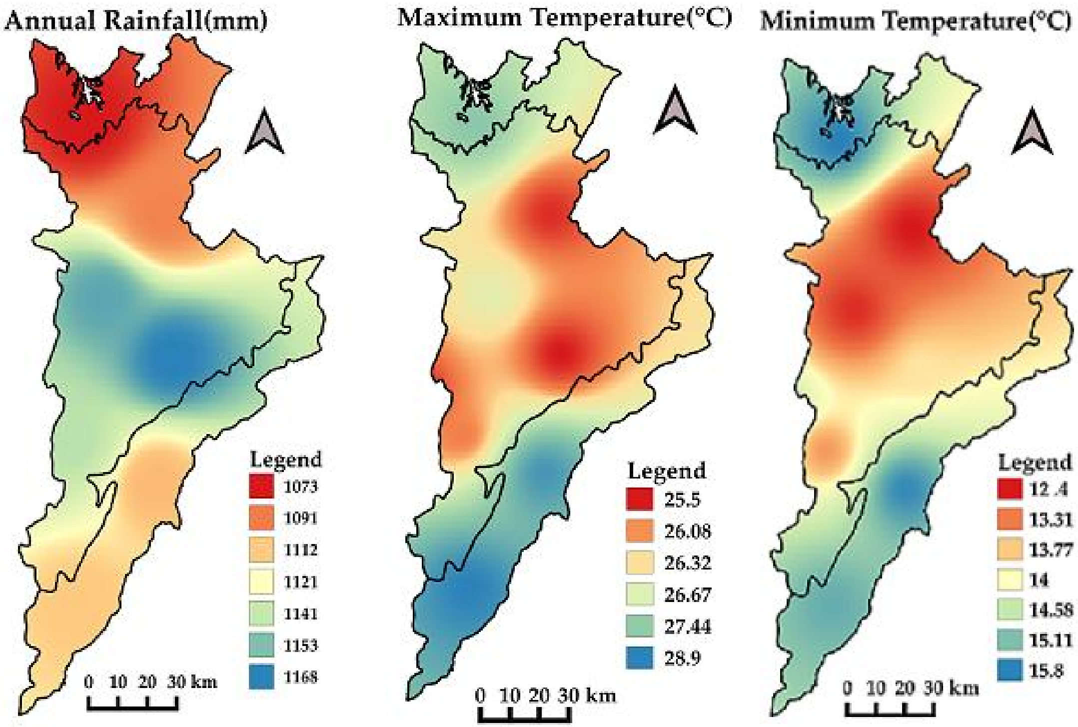


Fig. 5. Inter-annual variability of maximum and minimum temperature at EAP, ELL and NLL
TX: maximum temperature, TN: minimum temperature

The seasonal distribution of rainfall presents also a spatial variation of precipitation. Low amount of rainfall are observed in north and northeastern region and there are increasing of rainfall towards the south region for two rain seasons. However an inverse pattern of dry season distribution displays high amount of rainfall in north region (at NLL) which is decreasing to south region.

We remark also that the two rain seasons contribute almost equally to the annual rainfall but the season FMAM has a higher amount of rainfall. The contribution of dry season to annual rainfall is very small compared with others rain seasons. This is normal because there is no rainfall in dry season and the low amount is observed generally in the second half of September with the beginning of precipitation. Indeed the rain season ONDJ shows lowest amount of rainfall at NLL region which may explain the drought observed in this region for a longtime in October and generally caused by the delay of precipitation. This situation may imply the starvation which usually hits the population of the north provinces of Burundi.

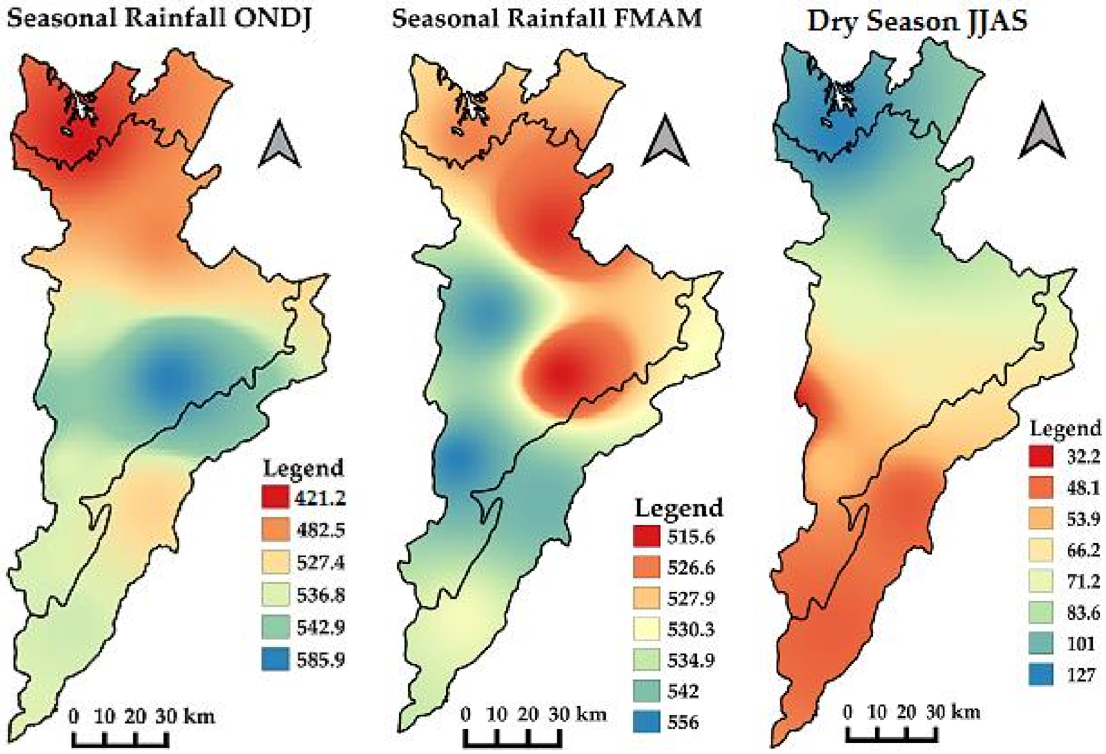


Annual Rainfall(mm)

Maximum Temperature(°C)

Minimum Temperature(°C)

Fig. 6. Spatial distribution of annual mean rainfall, annual mean maximum and minimum temperature



Seasonal Rainfall ONDJ

Seasonal Rainfall FMAM

Dry Season JJAS

Fig. 7. Spatial distribution of seasonal mean rainfall in the study region

4. CONCLUSION

The study investigated the variability and trend of rainfall and extreme temperatures over three eastern and northeastern regions of Burundi during the period 1980-2015. Seven stations located in the study area were considered to collect monthly mean data used in assessing and representing the fluctuation and trend of those climatic parameters. Our study area is threatened and susceptible to climate variability and climatic disasters, then such studies are very important to highlight the attitudes adopted facing climate change.

Annual and seasonal variability of rainfall and extreme temperatures have been analyzed using standardized variable anomaly, coefficient of variation. Particularly, the precipitation concentration index has been used for rainfall to study the distribution concentration pattern. Using non parametric tests Mann-Kendall and Sen's slope method, the trend of climate parameters has been analyzed for the historical period over the study region. Furthermore a spatial distribution of annual and seasonal mean of climate parameters was performed using inverse weighted distance (IWD) interpolation method in QGIS software.

The findings of the study indicate that there are significant monthly and annual rainfall fluctuations in the long time series with different rainfall variability. However the analysis does not demonstrate consistent significant trend of rainfall in the study area at annual and seasonal scale. Mann Kendall test results revealed no trend in annual and seasonal rainfall with a p-values greater than a significant level $\alpha=0.05$ except season FMAM. In this season a significant downward trend is detected with 0.03 and 0.01 of p-values and -2.93 and -6.27 of Sen's slope values respectively for EAP and ELL. The rain season ONDJ presents the lowest amount of rainfall for northern region NLL where drought is frequently observed. The results confirm that high variability of monthly rainfall is experienced in NLL region. This may explain the drought usually observed in this region at the starting of the first rainfall season and causes the delay of cultural season.

The temperature analysis indicates that the maximum and minimum temperature trends have increased in the past 36 years in almost all regions and the variability does not show strong fluctuations at monthly or annual scale over the period 1980-2015. The Mann Kendall test results indicate significant annual maximum and minimum trends in the long time series over all regions with a p-value very small, less than 0.0001. The coefficient of variation shows small values which means that the region does not experience very high variation of extreme temperatures.

The spatial distribution of rainfall and extreme temperatures displays also a wide variation across the region depending on topography of the study area. Thereby, the small annual and seasonal mean values of rainfall were observed in NLL and ELL with a high variation found in season ONDJ and there are increasing of rainfall towards the south region. Conversely the high values of maximum and minimum temperatures were found in lowland regions and they decrease with altitude. EAP presents small values of annual mean maximum and minimum temperatures.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the German Federal Ministry for Education through the German Academic Exchange Service (DAAD) for the financial support to this research work. The authors also gratefully acknowledge the Geographical Institute of Burundi for providing rainfall and temperature data for the selected stations in the study area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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