Investigating Drought Frequency in the Eastern Region of Rwanda during the Last Two Decades

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Investigating Drought Frequency in the Eastern Region of Rwanda during the Last Two Decades

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Declaration

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

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DEDICATION

This dissertation is dedicated to my family and friends for their resilient prayers.

Abstract

Climate has an influence on socio-economic development. Agriculture is a vital socio-economic sector in the Eastern region of Rwanda. Climate variability, thermodynamic processes, small and large scale weather patterns, land and atmosphere feedbacks influence droughts significantly. In this study, the trend of past rainfall characteristics and severity of drought conditions over Eastern Region of Rwanda were assessed. Monthly rainfall data of ENACTS dataset which combines ground data observations (Station data) and satellite data, which make blended dataset over four stations spread in Eastern region of Rwanda districties Nyagatare, Kawangire, Kibungo and Bugesera and obtained from Rwanda Meteorological Agency were used. The spatial and temporal characteristics of rainfall were investigated based on time series analysis bringing to an end the trend and seasonality components of the time series. This study investigated annual and seasonal drought characteristic for the period spanning from 1981 to 2016 for Eastern region of Rwanda. The component of drought investigated in this study includes severity, Frequency and probability of occurrence. Precipitation deficit was quantified by the use of The Standardized Precipitation Index (SPI) computed over run 3 for March-April-May (MAM) season, October-November-December (OND) season and annual(12 months). Frequencies of diverse drought categories were computed and used to determine the probability of occurrence of diverse drought episodes. Time series analysis for the parameters was done to determine the trend and the temporal variability of drought characteristic. The SPI analysis done on the two rainy seasons returned four categories of drought namely the mild drought with values ranging between -0.01 to –0.99, moderate drought ranging from -1 to -1.49, severe drought with values ranging between -1.5 to -1.99 and extreme drought condition with SPI values less or equal to -2. There is high probability of mild drought in both seasons in all stations that were studied with Bugesera recording the highest probability during MAM season while Kawangire record the highest probability in OND season. Droughts of varying intensity were noted to last for several seasons and individual drought category had low probability for higher drought intensity.

Key Words

The key words for this research are: Drought frequency; SPI; Eastern Region of Rwanda; MAM; OND.

LIST OF ACRONYMS

CDI: Combined Drought Index

CV: Coefficient of Variability

ENACTS: Enhancing National Climate Services

ET: Evapo-transpiration

GDP: Gross Domestic Product

IPCC: Intergovernmental Panel on Climate Change

IRI: International Research Institute

MAM: March-April-May

MIDIMAR: Ministry of Disaster Management and Refugees

NISR: National Institute of Statistics of Rwanda

OND: October- November- December

PDI: Precipitation Drought Index

PDSI: Palmer Drought Severity Index

SPI: Standardized Precipitation Index

TDI: Temperature Drought Index

VDI: Vegetation Drought Index

WMO: World Meteorological Organization

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CHAPTER ONE: INTRODUCTION

1.1. Background of the study

Social and economic development of countries especially in the developing countries is influenced by the climate. [1]. Climate variability, thermodynamic processes, small and large scale weather patterns, land and atmosphere feedbacks influence droughts significantly. [2]. Invariable disruptive conditions and intrinsically unusual conditions of climate extremes are the challenges that exist in assessing changes in climate extremes. [1] [3]

In Rwanda the agricultural sector which is more challenged by change in climate extremes contributed to 29%,29%,28%,28%,31% in 2012,2013,2014,2015,2016 and 2017 respectively of gross domestic product(GDP) [4] . Further, the Rwandan labor market is predominated by agriculture with 73% of Rwandan population classified as farmers [5]. Drought is one of the challenges that they face. Low access to basic social services and lack of sufficient information on the characteristics of the climate extreme events, as long as the higher extreme poverty rate in Rwanda 16.3% [6], contribute more to the vulnerabilities to impacts of climate change.

It has become hard for the agricultural sector in eastern province of Rwanda to sustain production to cope with increased demand for products due to the climate variability and prolonged dry and drought in that region. Indirectly or directly climate can affect livestock with its shocks leading poor to devastating effects [7]. In Rwanda 1750 cows died in Nyagatare district due to lack of fodder and water in 2015 [8]. Furthermore, vulnerability can often be increased by land use changes, hence raising the potential for catastrophic influence from climate extremes, like drought and flood. These could be attributable to factors such as insufficient research funding, inappropriate technology, inefficient infrastructure, and lack of farm credit [9].

Droughts have notable socio-economic impacts because rain fed agriculture is the backbone to the economy of Rwanda. Drought assessment techniques commonly used based on water supply indices derived from rainfall data. In our days, the planning for drought mitigation has changed from disaster management to drought risk management as the characteristics, action and anticipated losses due to droughts remains highly unpredictable.

Therefore **investigating drought frequency in eastern province of Rwanda in the last two decades** will help the country in the decision making as well as an early warning system for the future drought events.

1.2. Problem statement

Millions of people in Africa continue to be affected by Droughts through their socio economic impacts on the affected area.

Drought is distinguished when it turns into natural disaster [10]. In Rwanda, agriculture is a vital socio-economic sector as it is the second contributor on GDP and the Eastern province occupies a big part of agricultural productivity. Drought is different from the other natural disasters mainly due to its wide spatial coverage and it inevitable recurrence in areas after every few years. Rwanda is currently highly vulnerable to climate change as it depends strongly on rain fed agriculture both for rural livelihoods and exports of coffee and tea; it is also reliant on hydropower for half of its electricity generation, a driver of economic growth. The water scarcity is often the most limiting factor for electricity generation, crop production and livestock. Rwanda's energy may be at risk as hydropower contributes 50% of electricity, making it vulnerable to variation in rainfall and evaporation. Generating capacity of hydroelectric dams is reduced by drought, and this was happened in Rwanda in 2004 which forced the government to rent diesel power plants to satisfy the demand [11].

Recently, between September 2015 and June 2016, drought affected crops on 16,119 hectares of land in Kayonza District, 11,012 hectares in Nyagatare District and 750 hectares in Kirehe District, more than 47,300 households have been affected [8].

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1.3. Objectives of the study

The main aim of the study is to investigate **Drought Frequency in the Eastern Region of Rwanda during the Last Two Decades.**

The following are the specific objectives:

i. To determine the spatial-temporal variability of rainfall in Eastern region of Rwanda.
ii. To determine the past drought characteristics in Eastern province of Rwanda

1.4. Justification of the study

Droughts have socio-economic significant impacts because rain fed agriculture is the backbone to the economy of Rwanda, furthermore Rwanda's energy security may be at risk as hydropower contributes 50% of electricity, making it vulnerable to variation in rainfall and evaporation as droughts reduce generating capacity of hydroelectric dams. For that reason investigating drought frequency in the Eastern Region of Rwanda will be importance in both policy planning and implementation of early warning systems as well as development and management of agricultural, water resources and other drought vulnerable sectors of the economy.

CHAPTER TWO: LITERATURE REVIEW

2.1. Overview of Drought

Drought initiates from an inadequacy of precipitation(less than normal) over a wide range period of time. It may happen in all climate zones and is caused by large scale characteristics of atmospheric circulation, like high temperature, winds transporting continental rather than oceanic air masses, or high pressure. Though, due to local effects drought characteristics change from one region to another and its effects on local water resources accessibility compared to the demand. [12]. The causes for droughts occurrence are complex since they can depend on hydrologic processes and not only on atmosphere [13] . Drought impacts in various ways. The effect of drought may be direct or indirect, singular or cumulative, immediate or delayed. Droughts lead directly to poor crop yield, famine, deterioration of pasture, dead of live stock etc. There are many and complex direct losses caused by drought. Some of them lead to changes of land use practices, abandonment of fertile lands, migration of rural population, heavy pressure on urban areas and so on. These put serious strain on the economic development of a nation, either immediately or with a time interval [14] .Drought severity, too, is difficult to determine. And apart of duration, intensity and geographical space of a drought event, it is also dependent on human made activities and vegetation on a region's water supplies. Drought's wide reaching impacts make its effects on economy, society, and environment difficult, even if it is possible to identify and quantify. The meaning of drought should not be separated from its societal environment. Drought impacts on society may remain for many years even if it may happen in a season or in a period of years. In addition, the impacts of a drought rely largely on society's susceptibility to drought at that specific instant. Succession drought in the same region will likely have different effects, even if they are identical in, duration, intensity, and spatial characteristics. Ordinary to all kinds of drought is the fact that they initiate from precipitation deficiency that result in water scarcity for some activity or for some group. Obviously there are many human and natural factors that eventually affect the availability of water to society. Occasionally this shortage concurs with periods of high wind speed, low humidity, and high temperature.

2.2. The Definition of Drought

The term "drought" and its features have been defined differently in numerous applications [15].

Drought definitions might be categorized as either conceptual or operational, with conceptual referring to those definitions formulated in general terms to identify the boundaries of the concept of drought. [16] . For example, the American Heritage Dictionary [17] defines drought as “a long period with no rain, especially during a planting season.” As another example, Random House Dictionary [18] defines it as “an extended period of dry weather, especially one injurious to crops.”

Conceptual definitions provide little guidance to those who wish to apply them to current (i.e., real-time) drought assessments. Operational definitions attempt to identify the onset, severity, and termination of drought episodes. Estimations of potential impacts are included in some operational definitions. An operational definition, for example, would be one that compares daily precipitation values to evapotranspiration (ET) rates to determine the rate of soil moisture depletion, and expresses these relationships in terms of drought effects on plant behavior at various stages of crop development. The effects of these meteorological conditions on plant growth would be reevaluated continuously by agricultural specialists as the growing season progresses. Operational definitions can also be used to analyze drought frequency, severity, and duration for a given historical period. Such definitions, however, require data on hourly, daily, monthly, or seasonal moisture deficiency or yield departures from “normal” (i.e., expected) in order to identify when drought occurred. These definitions can be used to calculate the probabilities of droughts of varying intensity, duration, and spatial characteristics.

2.3. Types of drought

2.3.1. Meteorological drought

Meteorological drought is usually defined by a precipitation deficiency threshold over a predetermined period of time [19] . Some meteorological drought definitions developed for application in various countries of the world include: 1) less than 2.5 mm of rainfall in forty-eight hours(United States) [15]; 2) fifteen days, none of which received as much as 0.25 mm (Britain) [16]; 3) when annual rainfall is less than 180 mm (Libya) [17]; 4) actual seasonal rainfall is deficient by more than twice the mean deviation (India) [18]; and 5) a period of six days without rain (Bali) [17].

Definitions constructed for application to one region but applied to another often create problems since the meteorological conditions that result in drought are highly variable around the world. Perceptions of these conditions are equally variable. Both of these points must be taken into account in order to identify the characteristics of drought and make comparisons between regions

2.3.2. Agricultural drought

Agricultural drought is referred as soil moisture deficiencies relative to water demands of plant life, usually crops. Agricultural drought definitions link various characteristics of meteorological drought to agricultural impacts, focusing, for example, on precipitation shortages, departures from normal, or numerous meteorological factors such as evapotranspiration [16].The deficit of rainfall influences the plant or crop in its different stage of development and leads to the decrease of yields [20] .

2.3.3. Hydrological drought

Hydrological drought occurs when the precipitation period effects does not meet a quota on ground water, lakes and streamflow reservoir [21]. This type of drought late the meteorological and agricultural drought and is associated to them. Although the deficity of precipitation is the main cause of all types of drought the impact is different and the hydrologists consider its influence on the hydrologic system. As the hydrological drought leads to the reduction of streamflow,lakes and ground water level and volume, this may cause water shortage for public water supply, lack of hydroelectric power production and impacts other sectors which rely on electricity in daily activities.

2.3.4. Socio-economic Drought

This kind of drought combines meteorological, hydrological and agricultural drought and associate their elements to the supply and demands of some economic goods [22].

Some economic goods such as food grains, forage, fish, water, and hydroelectric power depends on weather, due to climate variability and climate change as a results of that weather related conditions the demands for economic goods exceeds the supply which cause this type of drought.

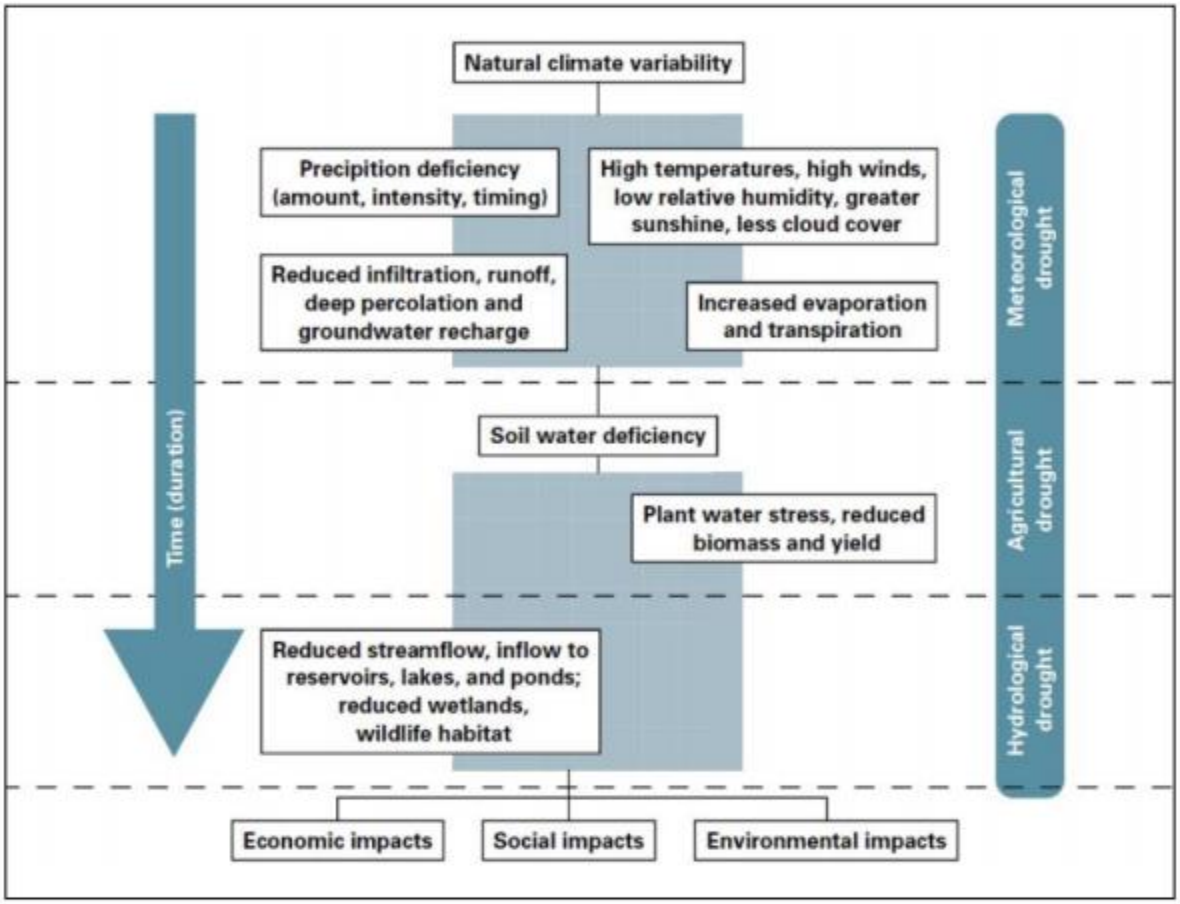

Figure2. 1: The Connections and Impacts of the Types of Drought [23]

2.4. Drought Monitoring

Drought is an intricate hazard so that it can not seen as deficity of precipitation only. The extent of drought impacts is closely related to the timing of the onset of the precipitation scarcity, its intensity and the duration of the event [24]. Monitoring drought is providing timely, accurate information for drought risk reduction. Tools that provide drought indices have been designed to identify drought characteristics. The preference is due to the type of drought, the hydro climatology, the available data, the purpose of the study and the vulnerability of the society.

2.4.1. Precipitation deciles

This drought index was developed and introduced by Gibbs and Maher (1967), where the precipitation totals for preceding three months are ranked against climatologically records

[25]. The monthly precipitation data are arranged into deciles in other to avoid the weakness of normal percent-approach.

Table2- 1: Precipitation deciles index scale [25]

Decile value	Decile classification
Deciles 1-2 Lowest 20%	Much below normal
Deciles 3-4 Next lowest 20%	Below normal
Deciles 5-6 Middle 20%	Near normal
Deciles 7-8 Next highest 20%	Above normal
Deciles 1-10 Highest 20%	Much above normal

2.4.2 Standardized Precipitation Index (SPI)

The standardized Precipitation Index (SPI) was developed by McKee in 1993, and this is probabilistic based, for any time series. This index is the standardized precipitation difference from the mean for a time specific divided by the standard deviation which is determined from past records [26]. This is calculated using monthly precipitation data which is the only input used in this software and need for at least continuous period of 30years [27]. SPI can provide early warning of drought and in assessment of drought severity and can compute for multiple timescales like 3, 6, 12, 24 and 48months. SPI has been recommended by World Meteorological Organization for drought monitoring [27]. For normal situation this index is zero, the more negative value, the more severe the drought will be and non-drought conditions where SPI become positive. The shorter the timescales used like -1, -2,-3 months, the highest probability to monitor and assessing drought severity and able to issuer drought early warning.

Table2- 2: SPI drought classification scale [27]

SPI Value	**Drought category**	**Time in category**
0 to -0.99	Mild drought	~24%
-1.00 to -1.49	Moderate drought	9.2%
-1.50 to -1.99	Severe drought	4.4%
< -2.00	Extreme drought	2.3%
		~40%

2.4.3 Palmer Drought Severity Index (PDSI)

Palmer Drought Severity Index was first developed by Palmer in 1965. This software aim to measure the departure of the moisture supply and to provide the moisture condition which is standardized [28]. PDSI is a meteorological index which is mostly used in USA Governmental agencies and states in other to trigger drought relied. PDSI is based on water supply and one of the most complicated drought index to be used [29]. PDSI allow the comparison of different climatic zone, and its algorithm is relatively use, precipitation, temperature data, and soil water content data.

Table2- 3: PDSI classification scale [28]

PSDI value	Drought category
4 or more	Very wet
2.0 to 2.99	Moderate wet
1.0 to 1.99	Slight wet
0.5 to 0.99	Incipient wet spell
0.49 to -0.99	Near normal
-0.5 to -0.99	Incipient dry spell
-1.0 to -1.99	Mild drought
-2.0 to -2.99	-2.0 to -2.99
-3.0 to -3.99	Severe drought
-4.0 or less	Extreme drought

2.4.4 Combined drought Index

Combined drought index was developed by **Balint et al., 2011.** It is statistical index, which comparing the long term hydrometeorological conditions with the long term average characteristics in the same interest period within the year [30]. This CDI combine precipitation drought index (PDI), temperature drought index (TDI) and Vegetation drought index (VDI)

Table2- 4: Combined drought index scale [30]

CDI value	Drought severity
>1.0	No drought
1.0 to 0.8	Mild drought
0.8 to 0.6	Moderate drought
0.6 to 0.4	Severe drought
<0.4	Extreme drought

CHAPTER THREE: DATA AND METHODOLOGY

3.0. Introduction

This section describes the data and methodology used in the study

3.1. Area of the Study

Eastern Province is the largest with 9,813Km^2, the most populous with 2,660,814 peoples and the least densely populated with 275/Km^2 of Rwanda's five province. It has seven districts: Bugesera, Gatsibo, Kayonza, Kirehe, Ngoma, Nyagatare and Rwamagana. The capital city of the Eastern Province is Rwamagana. Eastern Province is located between Latitude 1˚45'00" S and Longitude 30˚30'00" E.

Table3- 1: Selected stations in Eastern Region of Rwanda

Station Name	Latitude	Longitude
Nyagatare	-1.294722	30.33139
Kawangire	-1.824167	30.44778
Kibungo	-2.16	30.5
Bugesera	-2.239633	30.150126

3.2. Data

The dataset used in this study included monthly total precipitation over the 4 stations which are Nyagatare, Kibungo, Kawangire, and Bugesera. These datasets are ENACTS dataset from Rwanda Meteorology Agency Headquarter, Kigali spanning the period 1981 to 2016.

3.3. Data Quality Control

3.3.1. ENACTS dataset

Enhanced National Climate Services (ENACTS), was developed by International Research Institute (IRI) Colombia, for climate and society with aim of improving the availability, enhancing climate data access and enhancing utilization information [31]. That dataset contain daily, decadal and monthly rainfall and temperature data, which obtained by combining, ground data observations (Station data) and satellite data, which make blended dataset. This is hosted in Rwanda by Rwanda Meteorology Agency (MeteoRwanda) under which ENACTS project operate. ENACTS dataset are quality controlled with a spatial resolution of 4km [32] .

3.4. Methodology

The following methodology will be used to achieve this research objectives and specific objectives.

3.4.1. Trend Analysis

Trend in rainfall at a particular station can be examined by applying the regression analysis with time as the independent variable and annual rainfall as the dependent variable [33]. A linear equation, y = mx + c 3.1

Defined by c (the intercept) and trend m (the slope), which represents the rate of increase or decrease of the variable, can be fitted by regression and x is time in years.

3.4.2. Seasonality Analysis

To indicate temporal variability of rainfall and measure the dispersion of the data in a series around the mean, the coefficient of variability (CV) will be used; A higher value of CV is the indicator of larger variability, and vice versa and will be computed as shown in Equation 3.1.

$$CV=\frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i-\overline{x})^2}}{\overline{x}} \qquad 3.2$$

Where the selected variable is x_i , $\overline{x}$ is the mean and N is the sample size. CV is used to classify the degree of variability of rainfall events as less (CV < 20), moderate (20 < CV < 30), and high (CV > 30) [34] .

3.4.3. Drought Characteristics

3.4.3.1. Drought Severity and Duration

Drought severity will be analysed using SPI for the period of 1982-2017. Standardized precipitation series will be calculated using the arithmetic average and the standard deviation of precipitation series. As shown in the Equation 3.2.

$$SPI=\frac{X_i-\overline{X}}{\sigma} \qquad 3.3$$

Where $X_i$the precipitation of ith month or season is, $\overline{X}$ is the mean and σ represents the standard deviation. From this formula, Positive values represent wet events while drought events are represented by negative values. It will be assumed that drought occurrence of any intensity in a given year implies the occurrence of drought across the region for that specific year.

3.4.3.2 Frequency and Probability of Drought Occurrence

The probability of drought occurrence (P (L,i)) will be used in prediction of drought occurrence and will be computed as shown in Equation 3.3.

$$P\,(L,i)=\frac{F_l I}{n} \qquad 3.4$$

Where n represents number of observation while $F_l I$ represents the frequency of drought of L category and I month. Each drought category of m run length month is defined as the succession of m months of that drought category preceded and followed by a different drought category. If the frequency of L drought category m run period is F_{Lm} and the maximum run length is mm for L drought category, then F_L frequency of at least one month of category L is shown in the Equation 3.5

$$F_L=\sum_{m=1}^{mm} F_{Lm} \qquad 3.5$$

The frequency F_{Lm1} of at least m_1 runs is given by the Equation 3.6.

$$F_{Lm1}= F_L-\sum_{m=1}^{m_1-1} F_L \text{ given } 1\leq m_1 \leq mm \qquad 3.6$$

Without refereeing to a particular drought category taking the interest of the occurrence of a sequence of drought. The frequency F_{dm} describes the frequency of a run of m months of drought; then the frequency of at least one month run of drought F_d is expressed as

$$F_d =\sum_{m=1}^{mm} F_{dm} \qquad 3.7$$

The frequency of at least m_1 months of drought F_{dm1}

$$F_{dm1}= F_d -\sum_{m=1}^{m_1-1} F_{dm} \qquad 3.8$$

Frequency provides useful information about how frequent drought of various categories and lengths occurs.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. Spatial-temporal Characteristics of Rainfall in Eastern Region of Rwanda

4.1.1. Rainfall Characteristics in Eastern Region of Rwanda

The rainfall characteristics were analyzed to examine the behavior of long term annual and seasonal rainfall distribution in the Region under study and presented in Figures 4-1 to Figure 4-6.

4.1.1.1. Result from Spatial Rainfall Distribution over Eastern Region of Rwanda

Figures 4.1 and figure4.2 shows the spatial distribution of the seasonal and annual rainfall in Eastern Region of Rwanda.

For MAM, (Figure4.2) the rainfall amount ranges from 239 mm to 319mm. The minimum is in Nyagatare which is the north of the region, while the maximum is located in Kibungo.

During the OND season (Figure4.1), the rainfall amount range from 264 to 293mm. This shows a slight decrease in rainfall compared to MAM rainfall. The minimum is located in Bugesera which is the south west of the region while the maximum is in Kibungo. Moreover annual rainfall distribution figutre4.1 shows that high rainfall amount were observed in Kibungo and Kawangire respectively while low annual rainfall amount is located in Nyagatare and Bugesera respectively, the rainfall amount varies from 722mm to 838mm.

4.1.1.2. Temporal Distribution of Mean Monthly Rainfall

The temporal distribution of rainfall over Eastern region was investigated. The Figure 4.3 to Figure 4.6 shows that rainfall received in all stations was found to be bimodal the pattern commonly referred to as ‘short rain’ and ‘long rain’ seasons. In figure4.3 to figure4.6 the long rain starts from March to May (MAM) season while the short rains last from October to December (OND). It is also noted that the June to August period forms the driest season in Rwanda.

4.1.2. Trend Analysis

Trend of 1981-2016 rainfall in Eastern Region of Rwanda were computed and the results shown in the Table4-2 and figure4.7 to figure4.10.

Regression analysis carried for the annual rainfall is showed in the fig4.7, 8, 9, and 10 respectively. The developed functional relationships for the variables are also showed in the figures. Table4.2 shows the regression analysis values of the slope for all the four stations.

The slope coefficient indicates the rate of change in the rainfall characteristic. The sign of the slope defines the direction of the trend of the variable, if sign is positive then it has increasing trend and if sign is negative then it has decreasing trend [33]. The value of slope (m) for Bugesera was -2.72 and that for Kibungo it was - 4.52, which indicates there was decreasing trend of rainfall for these two stations. For the stations Kawangire and Nyagatare the values of slope (m) were 2.26 and 0.63 which indicated there was increasing trend in the rainfall of these two stations. The results showed that there is a non statistical significance trend for Nyagatare station as it has a small slope magnitude.

4.1.3. Coefficient of Variability

Spatial variability of rainfall was analysed based on coefficient of variability and the results presented in the table4-3 and figure4.7

The coefficient of variability values in Table 4-3 and figure4.11 indicate that seasonal precipitation is highly variable in space and time than annual rainfall. Notably, annual and seasonal coefficient of variability values ranged from 0.14 to 0.36. The results from annual and seasonal rainfall variability showed that seasonal precipitation have high coefficient of variability of about 0.4(40%) while annual precipitation presented the low coefficient of variability less than 0.2(20%). Precipitation variability was noted to be higher in MAM season, compared to OND season over most of the region indicating that the OND season is more dependable than MAM. Annual coefficient of variability indicated the value of variability in Bugesera (0.14) while high values of variability of 0.19, 0.18 and 0.17 were observed in Kawangire, Nyagatare and Kibungo respectively. During MAM, seasonal coefficient of variability indicates that the largest value of variability was observed at Nyagatare and Kawangire, 0.36 and 0.32 respectively while the lowest value of variability was found at Bugesera 0.27. Results from OND season showed that coefficient of variability is high at Nyagatare and Kawangire, 0.29 and 0.27 respectively and the lowest value of variability was found to be 0.24 with Bugesera and Kibungo presenting an equal coefficient of variability.

4.2. Drought Characteristics Eastern Region

4.2.1. Analysis of Standardized Precipitation Index

The results of applied SPI method on annual and seasonal precipitation are presented in the figure4.12 to figure4.15.

Analysis done turned into four droughts categories which included the mild drought, moderate drought, severe drought and extremely drought condition as shown in Figure 4-12 to Figure 4-15. The results of the applied SPI method on annual and seasonal precipitation totals showed out higher runs of the drought of varying intensity in the last decades with remarkably expressed drought intensity.

4.2.2 Frequency of Drought Occurrence

The frequency of drought occurrence was analysed based on its probability of recurrence. The Table 4-4 presents results of probability values of drought occurrence in Eastern Region of Rwanda. Table4.4 shows that there was a high probability of mild drought in MAM and OND seasons in the four selected stations in the Eastern Region compared to other three drought categories with Bugesera and Kawangire recording the highest probability in MAM and OND season respectively. During MAM season the probability of occurrence of the moderate drought was noted to be high in Kibungo (0.19) and Nyagatare (0.17) while Bugesera presented a least probability of occurrence (0.03). The results shows that OND seasonal probability of occurrence of moderate drought is high in Bugesera that other station considered with Nyagatare and Kawangire recording an equal probability of occurrence while Kibungo presented the least probability of occurrence of moderate drought in OND. The probability of occurrence of the severe drought is low for all four stations, with zero in Kawangire and Kibungo for OND season and for MAM season zero probability of occurrence of severe drought was noted in Nyagatare and Bugesera; evidence that severe drought condition rarely happens during those seasons and their respective stations. The probability of occurrence of extreme drought range from 0.03 to 0.06 for all most stations with Bugesera recording extreme drought in both season with 0.06 and 0.03 in MAM and OND respectively. During MAM season the highest probability of occurrence of extreme drought was founded in Bugesera, the other considered stations had an equal probability of occurrence of zero. The results showed that for all stations there was extreme drought in OND season with the probability of occurrence of 0.06 in Kibungo and an equal probability of 0.03 for three remaining stations; this shows that short rain season in the Eastern Region of Rwanda is frequently affected by extreme drought category than long rain season.

The results of the applied SPI method on seasonal rainfall pointed out higher runs of the drought of varying intensity in the last decade with remarkably expressed drought intensity as shown in the table4-5 to table4-12.

The longest drought period is considered to have occurred between 1993-1996, 1998-2001 and 2013-2016 for the MAM season while for the OND season it is 1986-1996 and 2002-2005. Extreme drought longest period was observed in 2004-2005 over Kibungo in OND season while extreme followed by severe drought was noted in 2004-2005 in Bugesera during OND season; the longest period of moderate drought category was found in 1994-1996 over Kibungo and Nyagatare during MAM season. Therefore years of high intensity drought (extreme and severe) during OND was noted to be, 2004, 2005 and 2010 while in MAM season the years was noted to be, 2000, 2004 and 2014 for extreme drought, and severe drought was observed in 1984, 2005 and 2010 during OND season while severe drought in MAM season was noted in 2006, 2014 and 2014 in the region under study.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1: Conclusion

Drought analysis based on SPI index indicated that Eastern Region of Rwanda were susceptible to intense drought conditions. The droughts analysis over the area of study noted all drought categories from mild drought to extreme drought with mild drought observed to have a high frequency. The findings have established that in the last decade (1986-1996) there has been an increase in drought runs in OND season with Kawangire recording the highest run of 10; Severe and extreme events was noted to have a small run except in Bugesera and Kibungo which record seasonal increase in severe and extreme drought runs in 2004-2005 during OND . Given that these are rainfall seasons, it implies that the conditions might be worse in other dry seasons; therefore reducing risks and impacts of drought is of greatest importance and requires that greater emphasis be placed on preparedness and mitigation. Increase in drought conditions can be likely associated to climate change.

5.2: Recommendations

5.2.1: Research Community

More research is needed in understanding different types of drought in the Eastern region and the whole Rwanda. Future research can look into different spatial and temporal scale in Rwanda. SPI have limitations that it cannot account for water deficit caused by evapotranspiration, soil moisture, deep percolation, and recharge, in order to improve indices one has to consider such factors that influence water to compare performance of different drought indices.

5.2.2: Society and Policy Makers

Enhanced management and preservation of available water resources, water harvesting and recycling of waste water could also produce more water not only for livestock production but also irrigation. Credit provision and improved household welfare policies are also a priority for both short-term and long-term adaptation measures. Critical interventions would be monitoring climate change and disseminating information to farmers through agricultural extension, to encourage both short- and long-term adaptations.

ADDENDUM ONE: TABLES

Table4- 1: Summary of Mean Annual Rainfall in Eastern Region

Months	Kawangire	Nyagatare	Bugesera	Kibungo
January	51.0	43.9	62.0	68.3
February	64.3	47.8	69.4	72.8
March	106.2	94.4	102.9	120.3
April	124.0	98.9	117.1	136.0
May	53.4	45.7	44.0	62.8
June	10.7	11.1	8.5	9.4
July	4.1	6.8	2.4	4.6
August	22.3	29.3	18.2	21.7
September	54.6	67.6	49.6	49.8
October	96.4	108.5	82.4	92.5
November	109.7	98.5	107.3	119.8
December	78.6	70.0	75.1	80.2

Table4- 2: Trend Analysis Based regression analysis for Rainfall

Station	Slope(m)
Bugesera	-2.72
Nyagatare	0.63
Kawangire	2.26
Kibungo	-4.52

Table4- 3: Coefficient of Variability of 1981-2016 Rainfall

Station	CV		
	Annual	MAM	OND
Bugesera	0.14	0.27	0.24
Nyagatare	0.18	0.36	0.29
Kawangire	0.19	0.32	0.27
Kibungo	0.17	0.28	0.24

Table4- 4: Probability values of Drought Occurrence in Eastern Region of Rwanda

Drought Categories	Kawangire		Nyagatare		Kibungo		Bugesera	
	MAM	OND	MAM	OND	MAM	OND	MAM	OND
Mild drought	0.31	0.44	0.36	0.25	0.22	0.31	0.47	0.28
Moderate drought	0.14	0.11	0.17	0.11	0.19	0.08	0.03	0.14
Severe drought	0.03	0.0	0.0	0.06	0.06	0.00	0.00	0.06
Extreme drought	0.0	0.03	0.0	0.03	0.00	0.06	0.06	0.03

Table4- 5: Result of Drought Years during OND over Bugesera

Years	Drought Categories	SPI Index
1981	Moderate	-1.09
1985	Mild	-0.27
1988	Mild	-0.25
1990	Mild	-0.46
1991	Mild	-0.36
1993	Moderate	-1.23
1995	Mild	-0.01
1996	Moderate	-1.05
1998	Moderate	-1.06
1999	Moderate	-1.05
2002	Mild	-0.16
2004	Extreme	-2.17
2005	Severe	-1.82
2007	Mild	-0.48
2010	Severe	-1.63
2013	Mild	-0.48
2015	Mild	-0.31
2016	Mild	-0.41

Table4- 6: Result of Drought Years during MAM over Bugesera

Years	Drought Categories	SPI Index
1983	Mild	-0.14
1984	Mild	-0.86
1993	Mild	-0.34
1994	Moderate	-1.47
1995	Mild	-0.92
1996	Mild	-0.82
1998	Mild	-0.23
1999	Mild	-0.57
2000	Extreme	-2.19
2001	Mild	-0.06
2003	Mild	-0.09
2004	Mild	-0.09
2007	Mild	-0.73
2008	Mild	-0.79
2009	Mild	-0.91
2011	Mild	-0.24
2013	Mild	-0.07
2014	Extreme	-2.38
2015	Mild	-0.27
2016	Mild	-0.55

Table4- 7: Result of Drought Years during OND over Nyagatare

Years	**Drought Categories**	**SPI Index**
1981	Mild	-0.19
1984	Severe	-1.53
1985	Mild	-0.20
1987	Mild	-0.98
1988	Moderate	-1.21
1989	Mild	-0.14
1993	Mild	-0.88
1998	Mild	-0.58
1999	Moderate	-1.12
2002	Mild	-0.47
2003	Moderate	-1.00
2004	Moderate	-1.22
2005	Severe	-1.52
2010	Extreme	-2.13
2015	Moderate	-1.29

Table4- 8: Result of Drought Years during MAM over Nyagatare

Years	Drought Categories	SPI Index
1983	Moderate	-1.46
1984	Mild	-0.47
1987	Mild	-0.56
1989	Mild	-0.07
1992	Mild	-0.12
1994	Moderate	-1.37
1995	Moderate	-1.42
1996	Moderate	-1.17
1998	Mild	-0.61
1999	Mild	-0.06
2000	Moderate	-1.45
2001	Mild	-0.19
2008	Mild	-0.81
2009	Mild	-0.57
2010	Mild	-0.97
2013	Mild	-0.32
2014	Mild	-0.90
2015	Mild	-0.02
2016	Moderate	-1.28

Table4- 9: Result of Drought Years during OND over Kibungo

Years	Drought Categories	SPI Index
1981	Mild	-0.76
1982	Mild	-0.50
1987	Mild	-0.25
1990	Mild	-0.69
1991	Mild	-0.11
1993	Moderate	-1.38
1995	Mild	-0.70
1996	Moderate	-1.43
1998	Moderate	-1.18
1999	Mild	-0.47
2004	Extreme	-2.08
2005	Extreme	-2.09
2010	Mild	-0.56
2011	Mild	-0.08
2013	Mild	-0.83
2016	Mild	-0.62

Table4- 10: Result of Drought Years during MAM over Kibungo

Years	**Drought Categories**	**SPI Index**
1984	Mild	-0.49
1987	Mild	-0.05
1992	Mild	-0.03
1994	Moderate	-1.03
1995	Moderate	-1.16
1996	Moderate	-1.01
1998	Moderate	-1.03
1999	Mild	-0.61
2000	Moderate	-1.45
2004	Mild	-0.65
2006	Severe	-1.65
2007	Moderate	-1.43
2008	Moderate	-1.40
2012	Mild	-0.19
2013	Mild	-0.32
2014	Severe	-1.94
2016	Mild	-053

Table4- 11: Result of Drought Years during OND over Kawangire

Years	Drought Categories	SPI Index
1981	Mild	-0.06
1984	Mild	-0.70
1986	Mild	-0.14
1987	Moderate	-1.02
1988	Mild	-0.01
1990	Mild	-0.28
1991	Mild	-0.71
1992	Moderate	-1.33
1993	Moderate	-1.01
1994	Mild	-0.73
1995	Mild	-0.06
1996	Mild	-0.82
1998	Mild	-0.43
1999	Mild	-0.74
2001	Mild	-0.02
2003	Mild	-0.42
2004	Extreme	-2.25
2005	Moderate	-1.41
2008	Mild	-0.52
2010	Mild	-0.75
2015	Mild	-0.01

Table4- 12: Result of Drought Years during MAM over Kawangire

Years	Drought Categories	SPI Index
1983	Mild	-0.85
1984	Mild	-0.74
1990	Mild	-0.24
1992	Moderate	-1.14
1993	Mild	-0.21
1994	Mild	-0.61
1995	Moderate	-1.12
1996	Mild	-0.37
1998	Mild	-0.58
1999	Moderate	-1.41
2000	Moderate	-1.07
2001	Mild	-0.91
2007	Mild	-0.76
2008	Mild	-0.54
2009	Moderate	-1.42
2014	Mild	-0.84
2016	Severe	-1.54

ADDENDUM TWO: FIGURES

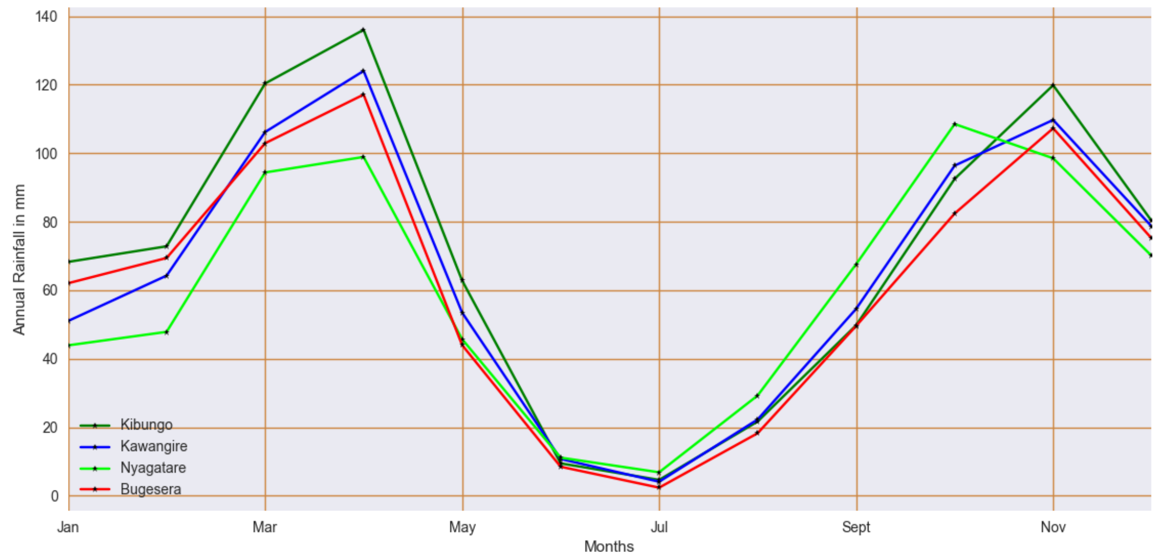

Figure4. 1Annual Rainfall Distribution over Eastern Region

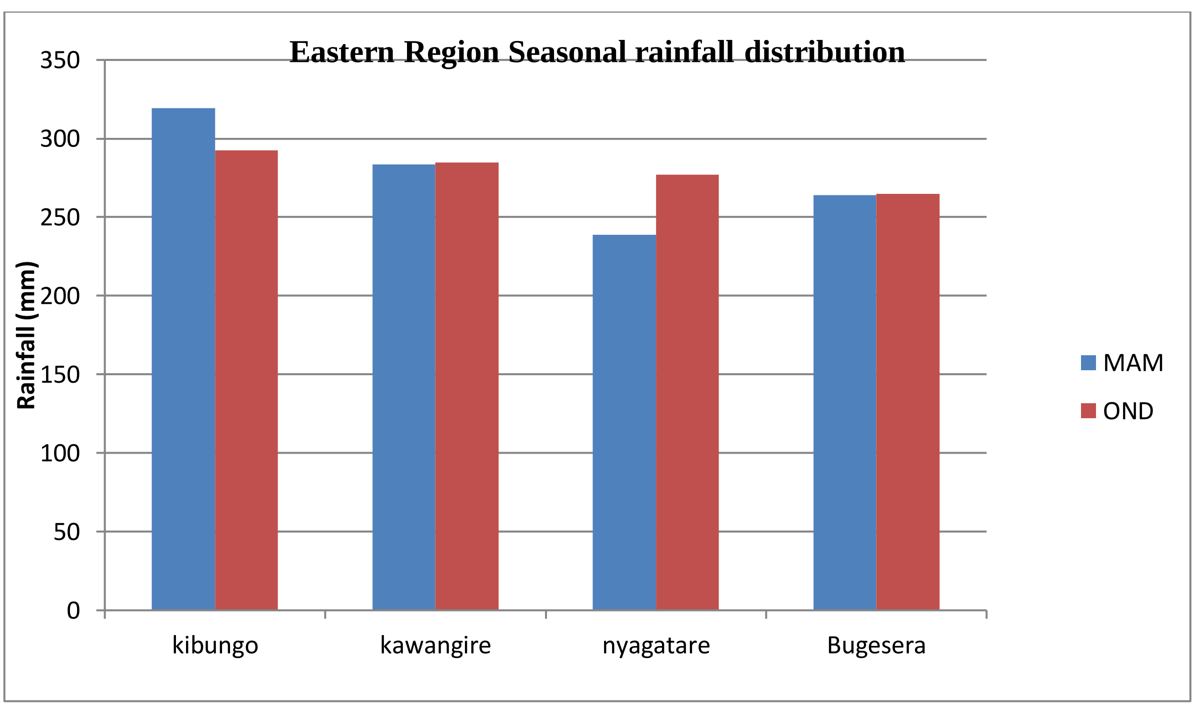

Figure4. 2 Spatial distribution of mean total rainfall over Eastern Region during MAM and OND over the period of 1981-2016

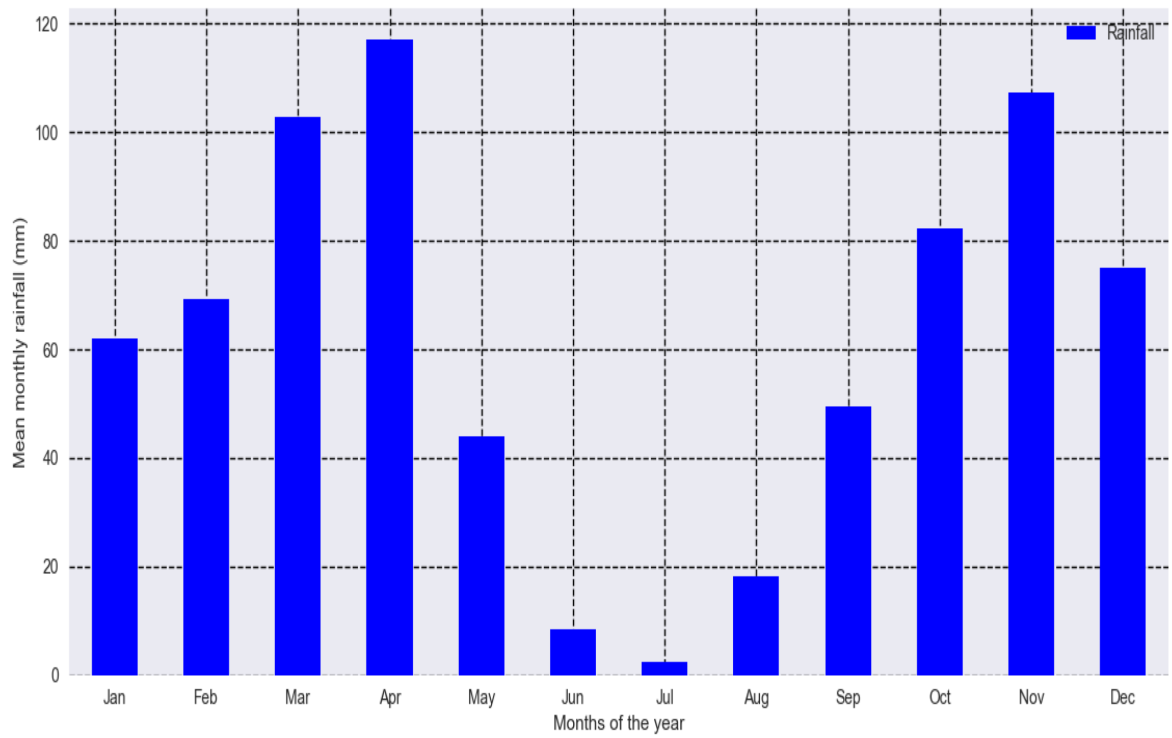

Figure4. 3:Annual rainfall distribution over Bugesera

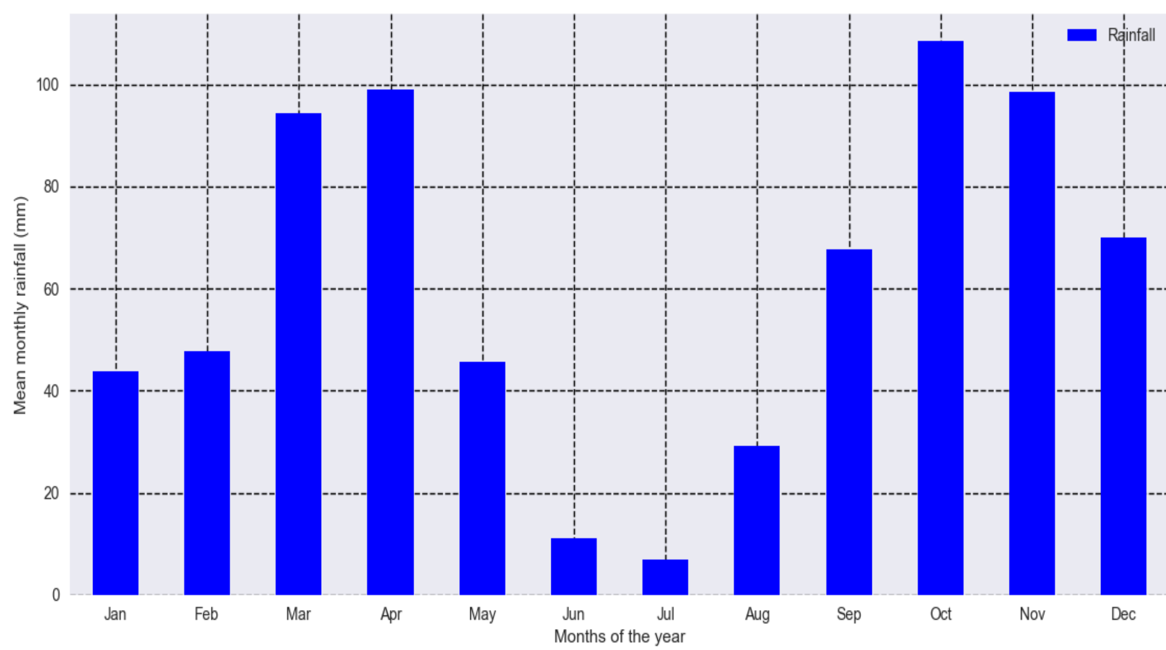

Figure4. 4: Annual rainfall distribution over Nyagatare

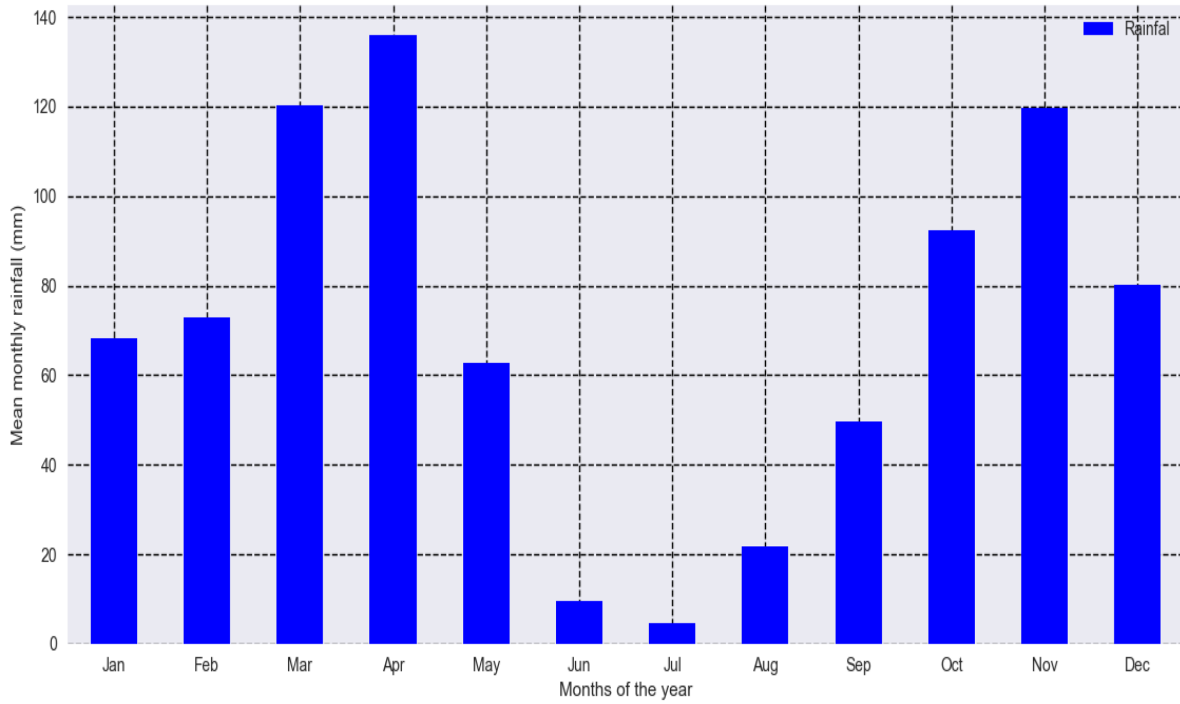

Figure4. 5: Annual rainfall distribution over Kibungo

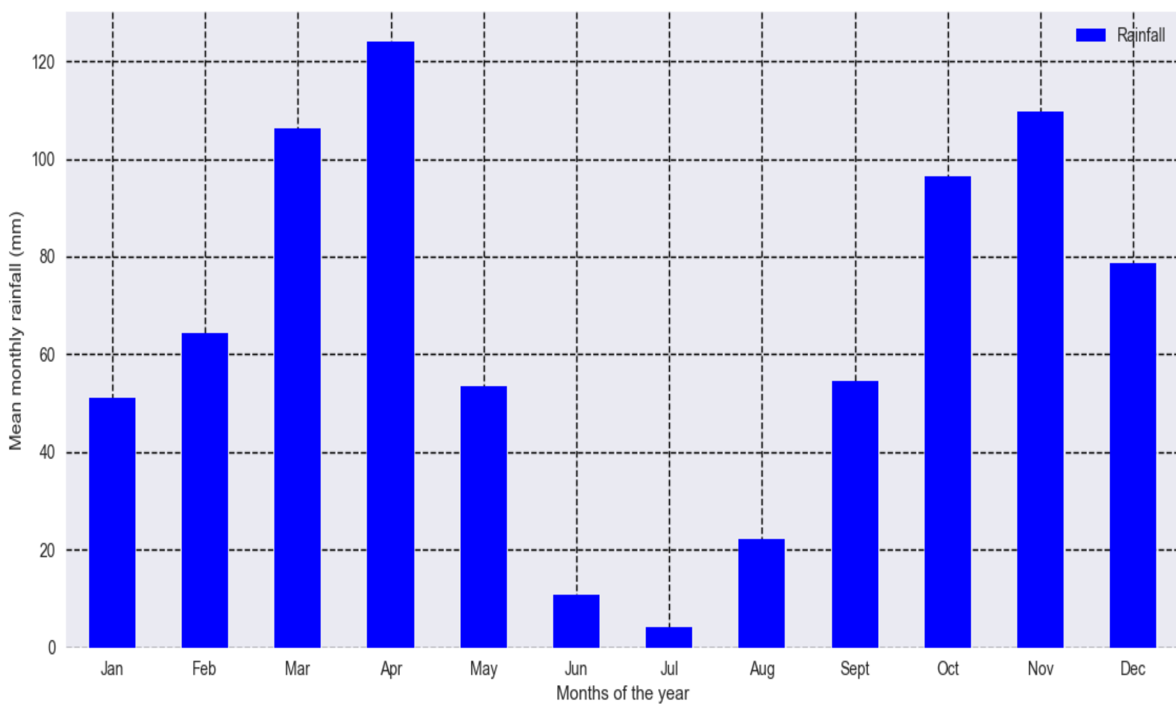

Figure4. 6: Annual rainfall distribution over Kawangire

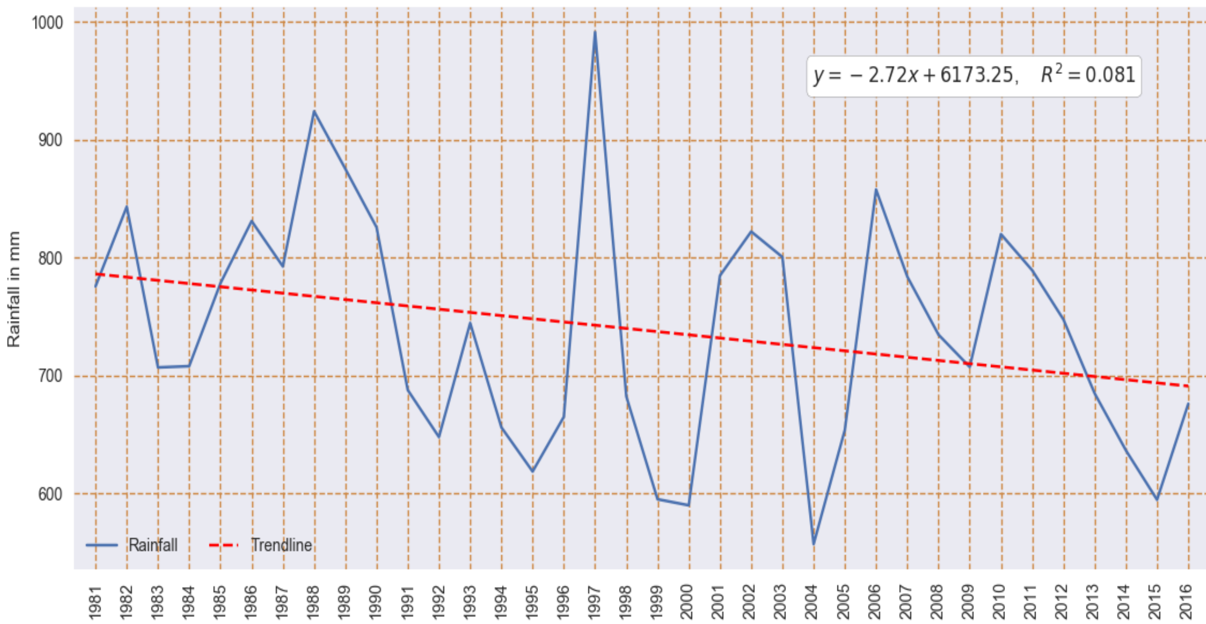

Figure4. 7: Bugesera annual rainfall trend from 1981 to 2016

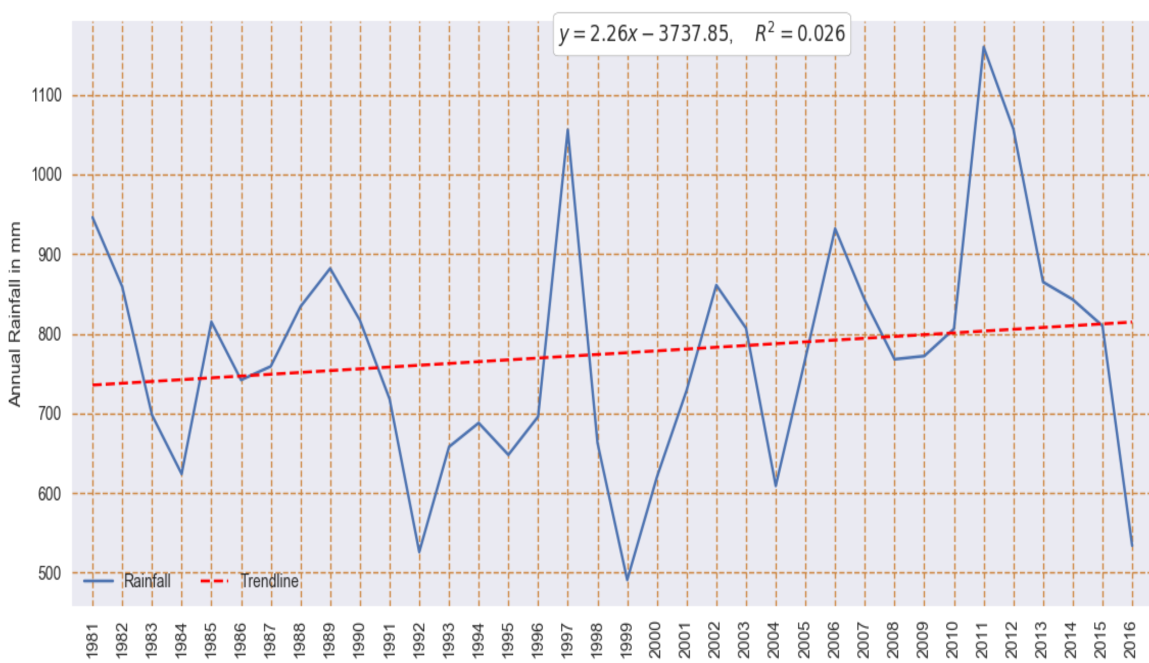

Figure4. 8: Kawangire annual rainfall trend from 1981 to 2016

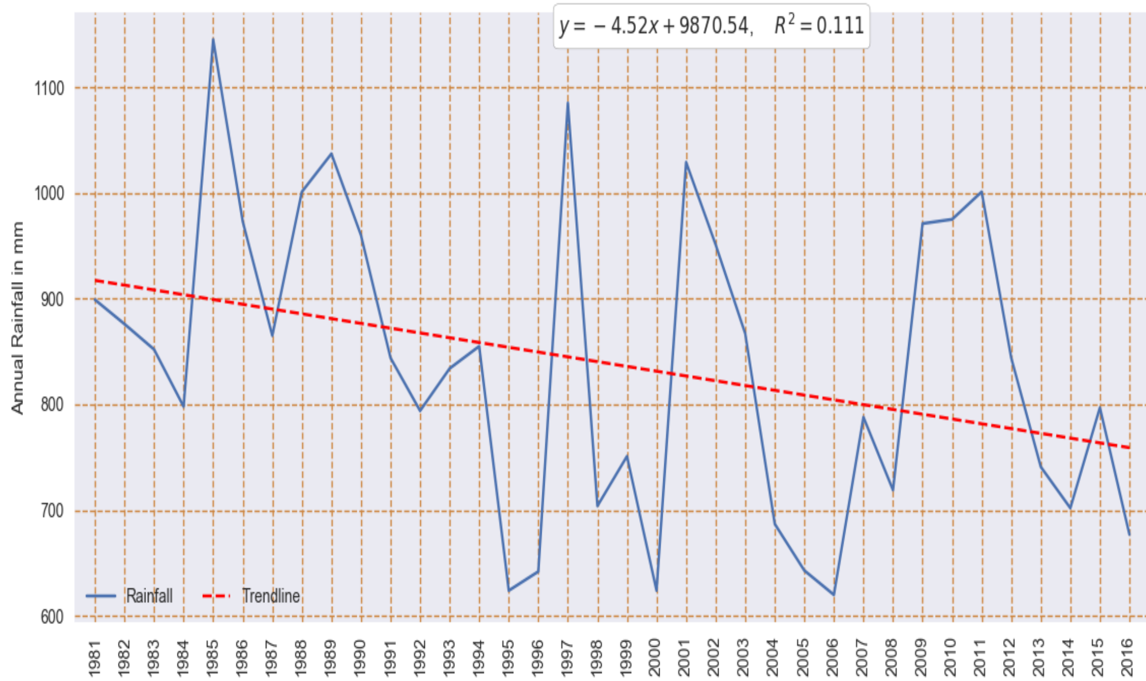

Figure4. 9: Kibungo annual rainfall trend from 1981 to 2016

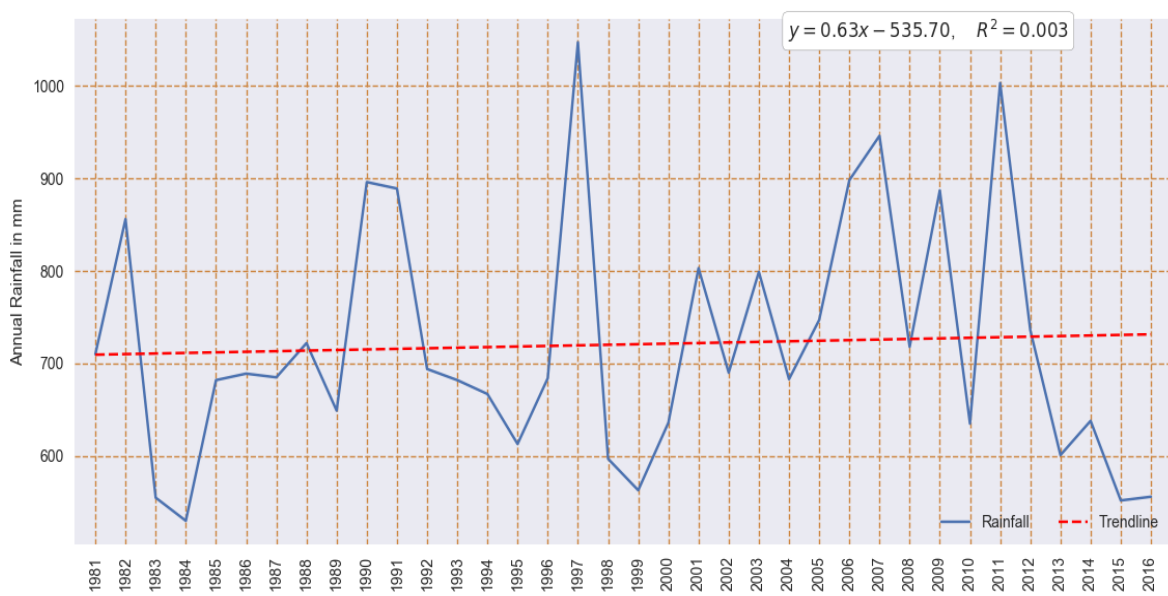

Figure4. 10: Nyagatare annual rainfall trend from 1981 to 2016

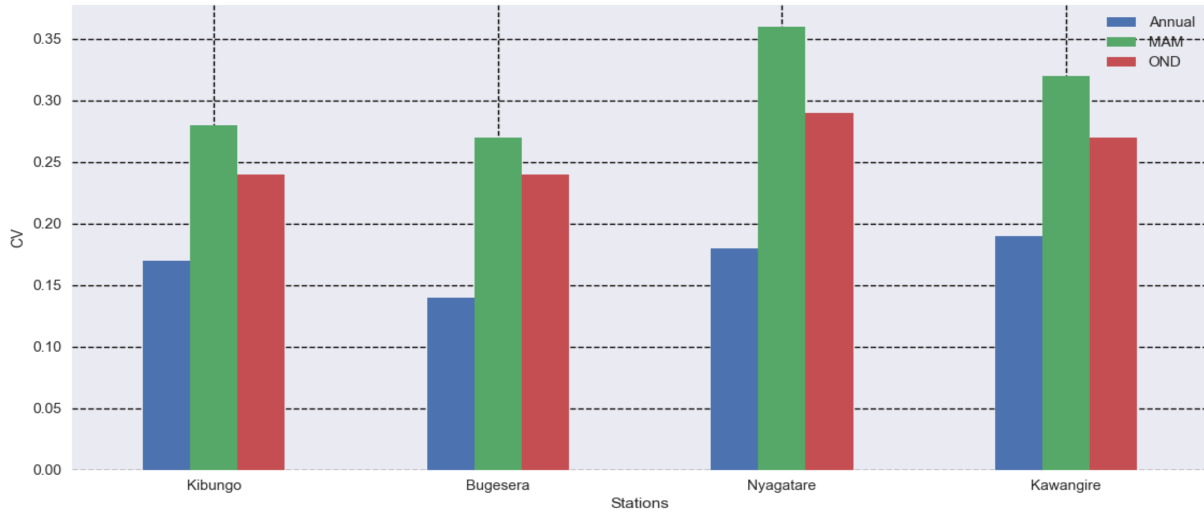

Figure4. 11: Spatial annual and seasonal rainfall variability in Eastern Region over the period of 1981-2016

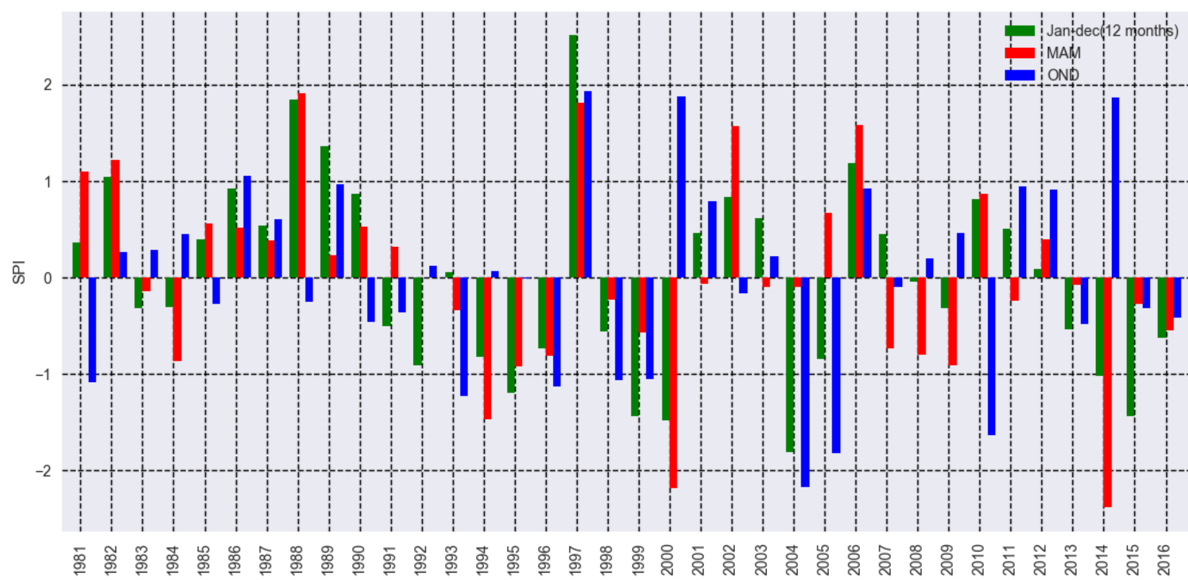

Figure4. 12: Variation of SPI over 1981-2016 for Bugesera

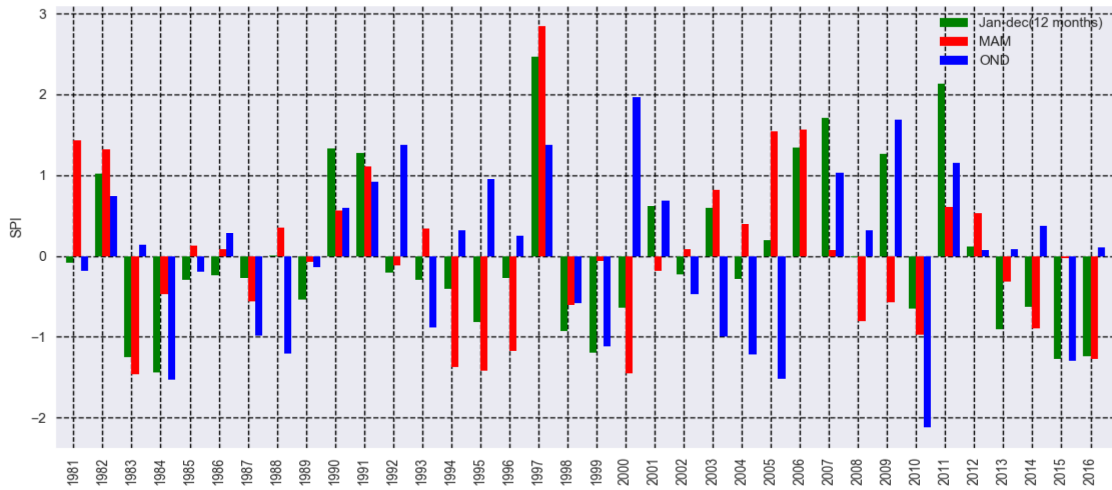

Figure4. 13: Variation of SPI over 1981-2016 for Nyagatare

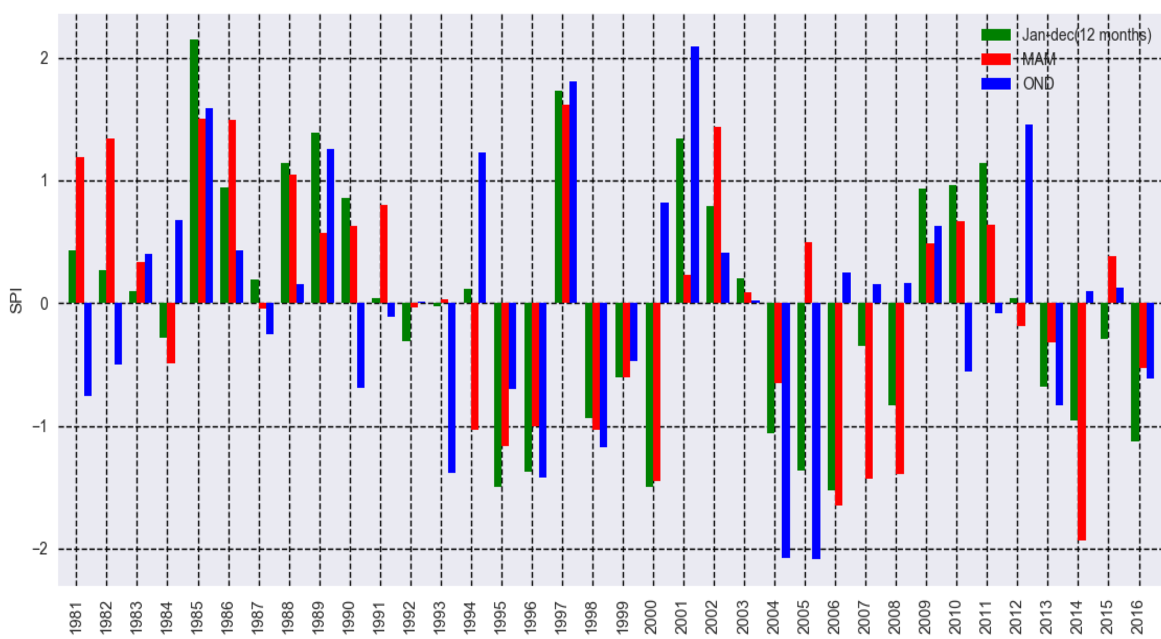

Figure4. 14: Variation of SPI over 1981-2016 for Kibungo

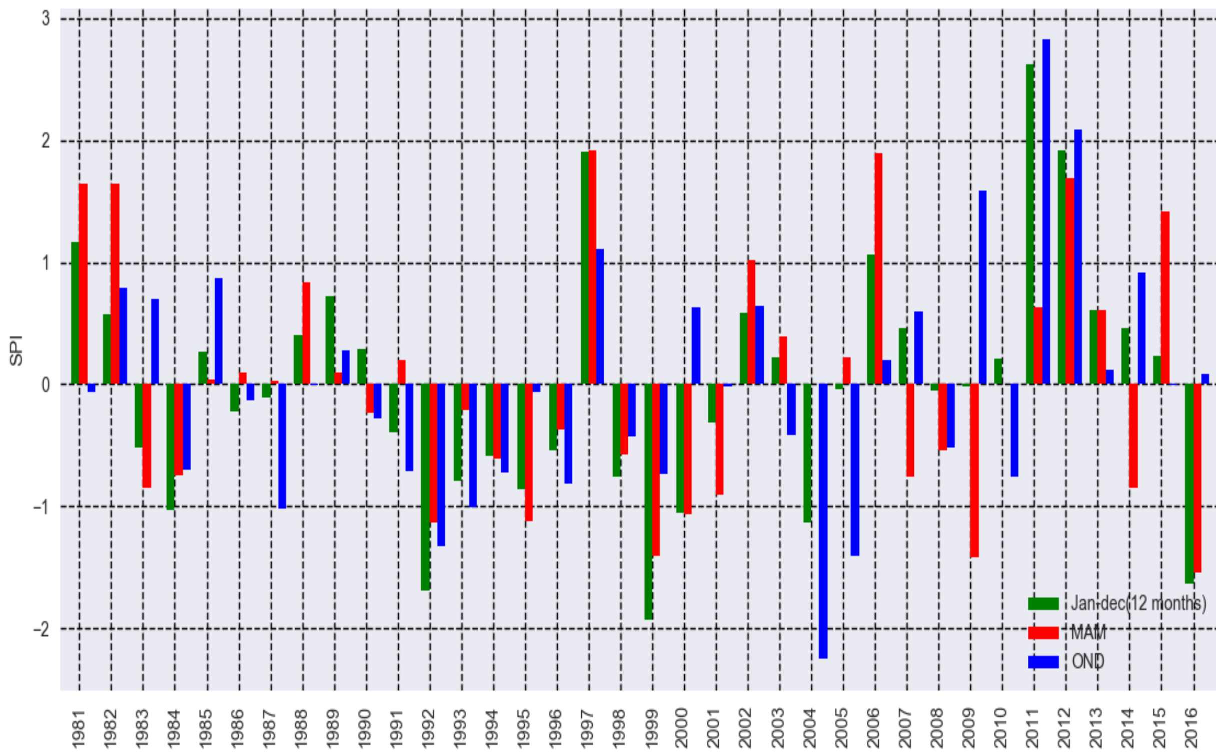

Figure4. 15: Variation of SPI over 1981-2016 for Kawangire

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