INVESTIGATING THE EFFECT OF CLIMATE VARIABILITY AND CHANGE ON MAIZE YIELD IN RWANDA

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DECLARATION

I declare that this dissertation is my original work and has not been submitted elsewhere for examination, the award of a degree or publication.

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DEDICATION

I dedicate this work to my lovely Mother, family and friends. Thank you for believing in me and being by my side.

ABSTRACT

The knowledge of climate variability is essential for successful agriculture, especial by rain fed crops. The goal of this research was to investigate the effect of climate variability and change on maize yield in Rwanda. Fifteen weather stations across the country were used and with regard to rainfall and temperature, the intra-seasonal climate variability were determined through analysis of various characteristics, including start and end dates of the season, length of the season, rain days, total seasonal rainfall, maximum temperature, minimum temperature, temperature range and growing degree days. The procedure of determining rainfall characteristics was carried out in Instat Plus statistical package Version 3.36 at station level.

Early onset was identified in the Southwestern region during MAM season and northwestern regional during SOND. Cessation occurred over northeastern region during MAM season and northwestern region during SOND. More rainfall was received during MAM season. Eastern province and Central region of the country were very dry compared to other locations in the country. Highest temperatures were recorded in Nyagatare (Eastern Province) and Mageragere (Central region) with 27.0^{0}C and 26.4^{0}C respectively. Lowest temperatures were recorded at Busogo (Northern Province) with 20.5^{0}C and 22.9^{0}C at Gikongoro (Southern region).

Temperature characteristics (maximum temperature, minimum temperature, temperature range and Growing Degree Days) showed negative relationships with maize yield, which implied that an increment in temperature resulted in a reduction in maize yield and a reduction in temperature resulted in increasing maize yields. Whereas, rainfall characteristics (Cessation, season length, rainy days, total seasonal rainfall), showed a positive relationships with maize yield, implying that an increase in rainfall improved maize yield and a decrease in rainfall lead to poor maize yield.

The results revealed that there is an increase in climate variability (rainfall, maximum and minimum temperature) in RCP8.5 compared to RCP4.5. Rainfall is projected to increase by 4.3% (98 mm) at Busogo, 2.8% (50 mm) at Gikongoro, 3.3% (36 mm) at Kawangire and 3.1% (41 mm) at Rubengera, while maximum temperature will increase by 1.7% (0.4 ^{0}C), 1.6% (0.4

^{0}C), 1.5% (0.4 ^{0}C) and 1.2% (0.3 ^{0}C) at Busogo, Gikongoro, Kawangire and Rubengera respectively. The minimum temperature also, will increase by 1.4% (0.2 ^{0}C) at Busogo, 1.4% (0.2 ^{0}C) at Gikongoro, 1.9% (0.3 ^{0}C) at Kawangire and 2.0% (0.3 ^{0}C) at Rubengera. From the future climate data, AqauaCrop model was used to simulate maize yield from 2021 to 2049. The results revealed that Rwanda's agriculture, season A (September – January), maize yield will decrease by 8.1% (205kg/ha) at Busogo, 1.6% (28kg/ha) at Kawangire and 1.2% (23kg/ha) at Rubengera, and an increase in maize yield was projected at Gikongoro of 0.3% (5kg/ha) under RCP8.5.

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LIST OF ACRONYMS

^0C	Degree Celsius
CIAT	International Center for Tropical Agriculture
CIP	Crop Intensification Program
ENACTS	Enhancing National Climate Services
FAO	Food and Agriculture Organization of the United Nations
GDD	Growing Degree Day
GCM	Global Circulation Model
GDP	Gross Domestic Product
IRI	International Research Institute
ITCZ	Inter -Tropical Convergence Zone
JJA	June- July- August
Kcal/ g	kilocalorie per gram
LUCP	Land Use Consolidation Program
MAM	March- April- May
MINAGRI	Ministry of Agriculture and Animal Resources
MLR	Multiple Linear Regression
NDVI	Normalized difference vegetation index
NISR	National Institute of Statistics of Rwanda
NMHS	National Meteorological and Hydrological Services
NPK	Nitrogen-Potassium-Calcium
RAB	Rwanda Agriculture Board
RCP	Representative Concentration Pathways
RCA4	Rossby Center Regional Atmospheric Model
REMA	Rwanda Environment Management Autorty
RMA	Rwanda Meteorology Agency
SOND	September- October- November- December

CHAPTER ONE

1.0 Introduction

This chapter presents the background information, including problem statement, objectives, hypothesis tested, significance and area of the study.

1.1 Background Information

The farming system in the developing countries is the most main source of income for many people. Rain-fed agriculture is the most important in Sub-Saharan Africa and occupies 97% of the land cultivated (FAO, 2005). The agriculture in this region have been affected by climate variability and change and causes high impacts on agriculture production *(*Rockström *et al*., 2004). As started by Mohammed and Tarpley, (2007), the increase in temperature will reduce final yields. Similarly, the variability of rainfall patterns affect the final yield, in the case of high amount of rainfall received in a period of time has a negative result on crop production (Seo *et al*., 2005). Suitable understanding of temperature and rainfall variability as the main parameters of climate and accurate forecasting helps in agriculture activities through decisions making. The experts and analysts in climate change and food security have developed different models showing how the future weather events will have adverse impacts on crop production (Ringler *et al*., 2010).

Agriculture in Rwanda is extremely vital for nutrition and food security, poverty reduction and it is important in economic development. The sector contributes 31% of the national (GDP) Gross Domestic Product and 70% of the labor force in the country is employed by this sector (NISR, 2018). The sector has a great potential to spur national growth. However, the growth sector has been marked with a lot of fluctuation. In the 1980's, agriculture growth was 0.5% while in the 1990's its growth declined by -3.9% leading to low performance of financial system. This was occasioned by constraints in farmers' income, poor soil fertility, low use of farm inputs and non-use of current agriculture technologies (Muhinda, 2013).

Farming of food crops in the country has been the major activity of smallholder farmers purely for subsistence purposes. The production level of these crops has been extremely low due to the inadequate use of farm inputs and adverse impacts of climate change and variability. Therefore, to increase agriculture production and ensure food security, the smallholder farmers should adopt new climate smart agriculture production technology practices including use of up to date farm inputs (MINAGRI, 2011) and mainstreaming climate information in planning and decision making processes.

After the genocide of 1994 in Rwanda , agriculture sector has experienced a quick speed of growth ensuing from enhanced investments in the Crop Intensification Program (CIP), growth of food production, the input subsidies on fertilizers and seeds and Land Use Consolidation Program (LUCP) (World Bank, 2014). The impending threats from climate variability and change present challenges to the sustainability of these gains.

Nowadays, day by day the world's population is ever-increasing considerably. In order of satisfying this rising demand for food and reduce spiraling poverty, the agriculture sector has to increase the productivity per unit cropped area of their land. The fluctuations in crop yield in Rwanda is influenced by many factors, one of them is climate variability. Reddy and Pachepsky, (2000) noted that climate variability still remains the key determinant of crop yields in the countries with advanced agriculture technology. Currently, the risks related to climate variability and change impacts on food security and food production have been give attention.

Food crops are very important to Rwandan agriculture (Mupenzi *et al*., 2011) with maize crop being amongst the major stable food crops in the country. This crop has given priority under one of the program of MINAGRI which is Crop Intensification Program(CIP) for taking away and eradicate food insecurity in the country (MINAGRI, 2011). In general maize crop is grown and widely traded in both international and local markets. However, the productivity of this crop presents high variability across countries. Water deficit and water availability influence the variability of maize yield, like they influence the variability of yield in other cereal crop (Aylward *et al.*, 2015).

The study of long term daily data of weather is a way of understanding and learning about the chance of occurrence of weather events connected with agriculture production with a view to identifying dangerous times of no rain or little amount of rainfall which follows planting and can cause the death of seedlings, high intensity rainfall can badly damage crop plants and can also cause diseases, and high temperature or less rainfall at the time of growth of flowers that result in poor formation of the final yield. Such analysis would also be crucial in assisting in the assessment of how the risk could be managed through application of numerical and statistical models to long term datasets of the weather in order to point out the impact of climate change and variability (Cooper *et al., 200*9).

Crop production is influenced by both climatic and non-climatic parameters. Thornton *et al*., (2010) said that maize grains are decreasing in Rwanda, and by 2030 the decline in maize will be 11% and 15% was predicted in 2050. Adhikari *et al*., (2015) stated that the decrease in maize yield in maize yield will maintain and at the end of this century the decrease will goes up to 45% resulting from climate change, but they did not point out the reason behind this decline on maize yields.

1.2 Problem Statement

Several phenomena such as increased frequency and intensity in drought and floods, and increase in air temperature resulting from climate variability and change have affected the East African countries, including Rwanda. These phenomena, in the region result in food insecurity and malnutrition owing to the associated declining agriculture productivity (FAO, 2017). Rwanda is characterized by a rapidly increasing population in an environment characterized by highly unpredictable and variable weather patterns which pose a risk to agriculture production. With the projected increase in temperature and decrease in rainfall under climate change, crop production would be faced with a much bigger challenge.

Agriculture in Rwanda is under danger from the highly by unpredictable and variable climate with the eastern province of the country already being affected by the change in climate manifestation in long severe droughts. The northern province of the country is prone to high intensity rainfall which causes extreme flooding events. With this increasing climate variability and change, agriculture production in the country will be much more at risk of failure.

The information on intra-seasonal variability of climate in Rwanda is still inadequate despite its critical role in influencing final crop yields. Characterizing climate variability in the country will be the is the first step towards formulating strategies and approaches for fighting the effects of the unpredictable and variable weather patterns, which make it difficult for farmers to plan and manage their farming activities, thereby leading to losses in agriculture. This research will therefore, investigate the effects of climate variability and change on maize yields, with the aim of recommending proper planning and management for agricultural activities and adaptation strategies that could improve maize yields and cushion maize production against the adverse impacts of climate variability and change in Rwanda.

1.3. Objectives of the study

The overall objective of this study was to investigate the influence of climate variability and change on maize yields in Rwanda. To achieve this objective, the following specific objectives were undertaken:

a) Determine the intra-seasonal climate variability with respect to rainfall and temperature characteristics for short-rainy and long- rainy seasons in Rwanda.
b) Characterize the variability in the observed maize yields across producing regions of Rwanda
c) Determine the influence of climate variability parameters in (a) above on maize yields in Rwanda.
d) Assess the impact of future climate variability and change on maize yields using AquaCrop model in Rwanda.

In order to achieve the above specific objectives, the study was guided by the following research questions:

i. What are the intra-seasonal characteristics of climate in Rwanda?
ii. To what extend are the maize yields variable in Rwanda?

iii. Do the intra-seasonal climate characteristics influence the variability in maize yields?

iv. Can maize yields in Rwanda be accurately predicted using AquaCrop model?

1.4. Hypothesis

The hypothesis tested in this study was that:

Climate variability is the major determinant of maize yield fluctuation in Rwanda.

1.5. Significance of the study

The most of the studies on climate variability and change impacts on agriculture in Rwanda were focusing on the effects of rainfall. In climate variability researches, less attention was given to temperature. Noting that these two climate variables are often interrelated, the consideration of just one variable would lead to omission and hence bias. It is in response to this gap that this study was analyzing climate variability in the context of both rainfall and temperature characteristics and their effect on maize productivity.

Understanding the intra-seasonal characteristics of climate variability will form the basis for informed planning and, decision making for agriculture.

Results from this study would inform government, agricultural extension staff and researchers on planning and developing strategies which can help farmers in maximizing and sustain maize yield, encourage the advance use of historical weather information, forecasting and early warning message. The results will also provide a scientific basis for future research associated to climate change impacts on maize and other crops in order to minimize the negative effects of climate variability and change on agriculture.

1.6. Study Area

The section below briefly presents the area of study, its climate, soils and socioeconomic activities.

1.6.1. Area of the study

Rwanda is a small country, landlocked, located in East Africa and because of presences of hills and mounts this county is known as a thousand hills country. It covers an estimated surface area of 26,338 km^2. It's located between latitude 1°4′ and 2°51′ South, and longitudes 28°53′and 30°53′ East. The neighbours of Rwanda are: Uganda in the northern, Tanzania to the east, Burundi on the border of south and to the Democratic Republic of Congo to the west border. Figure 1 shows the administrative map of Rwanda.

Figure 1: Administrative map of Rwanda

Source :(http://ontheworldmap.com/rwanda/rwanda-political-map.htm)

Rwanda is close to the equator, with its climate being tropical and moderated by hilly terrain varying between 900m and 4507m above the mean seal level from the eastern part to the western part of the country (REMA, 2015).

1.6.2. Topography and Climate of Rwanda

Approximately all of Rwanda is at least 1,000 m above sea level; in the northwest part of the country where, Rwanda share boundary with Democratic Republic of Congo (DRC) are elevated and dominated by the volcanoes includes Virunga Mountains, the highest mountain is Karisimbi with 4,519 m of height and Lake Kivu is at 1,460 m above sea level, in the continuity of the Albertine Rift Valley (McSweeney Robert *et al*., 2011). River Ruzizi drains Lake Kivu to Lake Tanganyika. The elevation in the central part of Rwanda, it elevation is ranging between 1,500 and 2,000 m and the eastern plateau of the country where, Rwanda share border with Tanzania by the Akagera River, the elevation is less than 1500m. Generally, the northern and western provinces of Rwanda, are the regions of the highest altitudes of the country and low latitudes are found in southern and eastern provinces of Rwanda (Ntwali *et al*., 2016). Because of this high elevation the climate is a tropical temperate climate.

The eastern parts and central parts of Rwanda are generally characterised by climate of semi-arid type owing to their position in the rainy shadow of the western highlands. Because of the water bodies existing near the country and due to topography, the rainfall is characterised by much variation in spatial and temporal. Inter -Tropical Convergence Zone (ITCZ) influences the seasonal rainfall which makes Rwanda experiencing two rainfall seasons. The long rains season (MAM) starting from March to May, while the short rains season (SOND) occurs over the period of September to December. The long rain season and short rain season are alternated with dry seasons; where long dry season (JJA) starts in June and ends in August and short dry season takes the period of January to February. The mach rainfall is received in MAM season.

Temperature in Rwanda varies very little all through the year. The warmest part of the country is the eastern part where the annual average of temperature varies from 20 to 21^0C and the temperature in the low valley of Bugarama is between 23 and 24^0C. The cooler temperature is experienced by the higher elevation in central plateau where the temperature is ranging from 17.5 to 19^0C and the highlands parts of the country have the lowest temperatures which is less than 17^0C (RMA, 2018).

1.6.3. Soils of Rwanda

Soils in Rwanda are generally fragile in nature. The northwest region of the country is a highland region, the soils are rich and fertile due to volcanic soils, and these soils are conductive for cultivation of different varieties of food crops including wheat, banana, maize, sorghum, beans, green peas and potato. the Congo –Nile Crest where the elevation is between 1,500 and 1,700m their soil are acidic soils and are very suite for tea cultivation. There are also river valleys and wetlands with generally fertile soils. Volcanoes part in the northern region has very fertile soils and rich in nitrogen content from natural forests like Gishwati and volcano National park (Nzeyimana *et al.*, 2013). Soils of the lowlands in the eastern side of the country are moderately fertile. The main problem in this area is the long dry season which requires much supply of water for crops. The soils in the northern part have a Ph which is less than 5.0 because of the nutrient leaching in highlands. Generally, in Rwanda one can say that the soils are acidic with the pH below 5.5 (Nzeyimana *et al*., 2013).

1.6.4. Agriculture activities.

The economy of Rwanda is predominantly driven by the agriculture sector, where the livestock and crop production are occupied by the majority of population. Is the reason why, agriculture is measured as the major source of income for national growth and poverty reduction among the citizens (REMA, 2015).

A big number of farmers put their focus in the production and growing of staple food crops including rice, maize, banana, cassava, beans, sweet potatoes, sorghum, wheat, Irish potatoes and soybean. Others specialize in growing, different varieties of fruits and vegetables. Cash crops including sugar cane, coffee and tea are grown and more income is earned from their exportation. The most known cash crop in Northern Province is Pyrethrum. Some farmers grow forage and under agroforest system indigenous plant and medicinal plant are also grown (RAB, 2013).

CHAPTER TWO
LITERATURE REVIEW

2.0 Introduction

This chapter presents a review of past studies, including methodology related to this study. At the beginning, the chapter examines the interaction between climate and agriculture, globally, regionally and country level. Also an extensive view of the influence of climatic conditions on maize growth and development, as well as the interaction between climate and agronomic practices associated with maize production have been presented in this chapter.

2.1 Climate and its impact on agriculture production

Spatial-temporal distributions of rainfall determines the productivity of agriculture and therefore can directly contribute to the fight against hunger and extreme poverty through agriculture improvement (IPCC, 2007). This is particularly true in Sub-Saharan African where agriculture production is highly dependent on rainfall availability and its distribution (Jury, 2002).
The success or failure of an agricultural season is influenced by the timing of onset of the rainfall season and its cessation and, the length of rainfall season as well, which determines the amount of water availability to crops (Ati *et al*., 2002). Crop growth requires adequate soil water from planting to maturity (Rashid and Rasul, 2011). Generally, besides the phenological stages, crop water requirement influenced by different crops depends on different climatic factors like wind speed, relative humidity and solar radiation (Naheed and Mahmood, 2006). These factors often manifest in extremes and are unpredictable and very highly variable, particularly in semi-arid areas (Akponikpe *et al*., 2008).

Under the Pakistan semi-arid farming conditions, rainfall received during various phenological stages of maize correlated highly with the final crop yields. For a growing season of total rainfall in the range 135 mm to 530 mm, rainfall during the vegetative stage strongly correlated with the final maize yield ($r = 0.61$) and total rainfall received during the reproduction stage had equally a strong correlation coefficient ($r = 0.6$) with final maize grain yield (Rashid and Rasul, 2011).

Poor distribution of rainfall within a season may leads to water stress which is harmful to leaf development, stem development and elongation in crop. Consequently, this would affect the final crop yield (Muchow, 1989). Temperature and rainfall distribution have different impacts on yield depending on the phenological stage involved (Chen *et al*., 2004). An understanding of the occurrence of their extremes is critical in helping to choose cultivars with early maturation (Mati, 2000). Control of agriculture operations, growing of climate resilience cultivars and good timing of planting time according to the onset of the season could reduce the effects of weather patterns to crop yield (Anderson and Hazell, 1987).

2.2 Geographical Distribution and Origin of Maize

Corn commonly known as Maize (*Zea mays.L)*, was originated from Mesoamerican perhaps in highlands of Mexico. From there, the crop was extended to the entire world. Phylogenetic analysis and archaeological records suggest that the domestication of the maize plant begun six thousand years ago. In the 15th century, the America was discovered by Europeans and this was marked as the beginning of observation of spreading maize crop to the rest of the world. The temperate zone was the main part of the world where maize crop were spread (Office of the Gene Technology Regulator, 2008). However, none knows with certainty the source of maize because it is impossible to test and explain experimentally the origin of maize. That is why science has given less focus on determination of the origin of maize and more attention was given in understanding of important variation found within the species (Brown *et al*., 1985).

In last the decade, maize production in Africa has been greatly increasing even in the driest and wettest area of Africa where, it's replacing other grain cereals including millet, sorghum and rice. In south and east Africa, maize has become very vital staple food and in local diets, more than 50% of calories are attributed to maize crop.

Maize is important in east Africa where it serves as a staple crop even if its value varies depending on the purposes of the countries. Tanzania, Malawi, Ethiopia and Kenya grow maize as a main cereal and as a major subsistence crop, though maize is less vital compared to other crops like tubers and roots in Uganda, and Rwanda produce a little amount tons of maize compared to other cereals (Aylward *et al*., 2015).

Maize was introduced in Rwanda in 1960 (Fortine of Africa, 2018). Since 2006, under the implementation of the Crop Intensification Program, maize has been prioritized alongside other stable crops of main concern by the Government of Rwanda. Different districts produce maize for domestic as well for export. The main producers of maize consist of Gicumbi, Gatsibo, Ngoma, Rutsiro, Nyagatare, Musanze, Gisagara, Rukomo and Nyaruguru. The maize production potential in Rwanda ranges from 167000 to 258505 metric tons. This productivity is necessary for income generation, food security, poverty reduction and contributes to fish feed, and in the making of poultry and animals feed. Different varieties of maize are grown in the country include M104, KH500-46A, RHM102, M081, Z607, RHM103, M104 and M102.

In this planet, maize can be cultivated in a large array of environments planet, from 58^{o} North (Canada) to 40^{o} South (Chile). Subtropical, temperate and tropical maize also are suitable for growing maize beyond 34^{0} between 30^{0} N -34^{0} S and less than 30^{0}N respectively. Usually, maize is grown at different altitudes, ranging from sea level to 3,800m above sea level (Pamela *et al*., 2003). The maize is mainly produced in the temperate regions maize in the world with regard to the area cultivated and yields, where some countries include Brazil, Europe and China supply the highest. Five countries dominate the production of maize worldwide, where they produce about 75 % of world total production. These countries include USA, Argentina, Brazil Mexico and China) (Nafziger, 2008).

2.3 Use and Importance of Maize

Globally among other cereals, maize crop ranks third place after rice and wheat with regard to totat production and total area planted. Maize is the most essential staple crop grown world-wide. Serves as livestock feed human food and also as row material in industries (Gwirtz and Garcia-Casal, 2014). Maize is high in content of starch, where it contains about 72%, 10% of protein and 4 % fat. Maize supplies 365 kilo-calories of energy per 100grams of grain consumed. Various types of food products including glues, beverage, cakes, starch, oil, industrial alcohol and sweeteners are processed from maize in industries. Maize also is used for manufacturing acetone and lactic acid which are very important for fermentation in industries, textile, foundry and food production (Ranum *et al*., 2014).

With the expansion of livestock and poultry production as well as the increased use as food to humans, its demand has tremendously increased. Among cereal grains, the trading in maize has expanded greatly (Cornindia, 2008).

2.4 Maize Growth, Development and Morphology

Maize *(Zea. mays L)* grows to a height ranging from 1 to 4 m. It is a annual grass and maize is a monoecious crop which has overlapping and large sheaths (Leszek and Vincent, 2012). It combines both inflorescence; male (tassel) and female. The female inflorescence is always developed in the leaf axis and the male at the top of the stem is there where it is formed (Series, 2017). Maize develops a normal root that supports the vertical and rigid shoot, which is ended with nodes and internodes. The cultivars that grow in temperate zones are shorter compared to those grown in tropical and subtropical zones. The leaves of maize are wide, opposed in position and are developed at each node. Depending on maize varieties, the number, size and orientation of the leaves are different and some varieties can have more than 30 leaves at the full growth .

Maize growth cycle undergoes several crop development stages. Belfield and Brown (2011), stated that the maize development stages are initial, vegetative, flowering (silking and tasseling) and the final stage of formation of yield and ripening. These phases can be broadly summarized into two major stages, namely the reproductive phase and vegetative phase (Table 1).

Table 1: Vegetative and reproductive stages of maize

Vegetative phases	**Reproductive phases**
Emergence is represented by **VE**	Silking is represented by **R1**
Appearance of the first leaf: **V1**	Blister is represented by **R2**
Appearance of the second leaf: **V2**	Milk is represented by **R3**
Appearance of the third leaf: **V3**	Dough is represented by **R4**
The n^{th} leaf is represented by **V(n)**	Dent is represented by **R5**
Tasseling is represented by **VT**	Physiological maturity is represented by **R6**

The emergence of the maize seedling requires suitability of conditions, when the conditions are favorable the emergence will take 4 to 5 days but when there is unfavorable conditions the seedling may require between 5 and 21days to emerge (Alford and Bangs, 1948). Planting depth, soil temperature and soil moisture are the factors that influence the emergence of the seedling. In the second and the third week after the emergence, maize crop is able to resist to environmental stresses including hail. At the third leaf stage is the determination stage of a number of leaves and ear shoots to be produced, besides the plant is still growing or young. Table 2 below gives the summary of maize growth stages following the seedling emergence, their approximate period in days, and environmental impact on final yield.

Table 2: Maize growth stages and their approximate days after emergence

Growth stage	Approximate time following seedling emergence (days)	Environmental impact
V3	From 8 to 10 days	The leaves and ear shoots are determined. At this stage maize plant can be destroyed by the persistence of flooding.
V6-V8	From 21 to 36 days	Maize is developing above the soil. Corn is at risks of wind and hail. The plant requires adequate moisture and nutrients.
V12-V17	From 36 to 60 days	Number per ear and rows' size are determined at this stage and. The stress in kernel at this stage is due to moisture and nutrients.
VT-R1	From 54 to 62days	This stage is represented by the visibility of tassel and Ears shoots. Final yield is affected by water stress.
R2	From 66 to 74 days	This stage is known as swelling phase. Kernels contain almost 85% of moisture.
R3	From 76 to 86 days	This is the milking stage. Moisture stress is the main cause to reduce yield. The Kernel contains 80% of moisture.
R4	From 84 to 88 days	This is the Dough stage. Dry weight is formed and kernel contain 70% of moisture.
R5	From 90 to 100 days	This is the Dent stage. Moisture stress can reduce the kernel weight and 55% of moisture is in the Kernel
R6	Between 105days and 120 days	The kernel is fully developed. Dry weight accumulation is at the maximum. This stage is known as Physiological maturity.

2.5 Climatic Conditions and Soil Conditions for growing Maize

Maize grows well in deep, fertile and well-drained soil, and in areas where the total seasonal rainfall is above 500 mm. The crop is tolerant to soil acidity. However, the crop fails to grow in highly acidic soils (Plessis, 2003). Such soils, require the application of lime order to diminish

the acidity in soil and increase yield (Goulding, 2016). Drought and waterlogging have high negative effect on the growth and development of the maize crop. In waterlogged areas, they need to drain their agriculture fields and also use ridge tillage.
The high loss of maize yield is due to drought. The drought is very severe in flowering stage that the reason why in dry areas water conservation necessary and other important methods like tied-ridges and mulching are needed in these areas (Plessis, 2003).

Temperature also has a negative effect on maize crop. Temperature above 32^{o}C affects the viability of the pollen and the growth and germination are affected by the temperature less than 10^{o}C. This means that the lowest temperature for the germination of the seed is 10^{o}C.

In an environment of 20^{o}C, the germination will takes 5 to 6 days (Plessis, 2003, Haji, 2013). Germination of the seed is faster and less variable in the soil with 16^{o}C to 18^{o}C. High temperature above 32^{0}C lowers the variability of pollen, while low temperature, below 10^{o}C retards maize growth.
The amount of fertilizer required for better growth and development of maize depends on the fertility of the soil fertility and crop yield one wishes to produce. Extra nourishment is need in the soil with poor fertility since the main objective is high yield and major nutrients are phosphorous and Nitrogen. Manure is most preferred because of its excellence as a source of nutrients and improvement of soil structure (Smale *et al.*, 2011).

2.6 Maize water requirements

The amount of water required by a crop depends on variety grown (Doorenbos and Kassam, 1986). For varieties with medium maturation period, 500mm to 800mm of water is needed. They found that the productive stages from flowering to yield formation require large quantities of water and are highly affected by shortage of water which in turn depresses the final crop yield (Doorenbos and Kassam, 1986). Pollination, tasseling and silking are very sensitive to water deficit and therefore, water shortage at these stages leads to reduce number of grain per cob. When water deficit is severe during pollination and silking stage, either, there would be no grain yield formation or a little grain would be form resulting into the death of the silks.

2.7 Climatic and Agronomic Operations for Maize

The section below presents the climatic influences on the key agronomic practices maize production.

2.7.1 Planting and Fertilizer application

Maize seed germination is very sensitive to availability of soil moisture. Consequently, planting should be undertaken when the soil is wet, preferably two days after onset of rainfall with cumulative rainfall amounting to at least 25mm (Adu *et al*., 2014). Too little as well as excessive soil moisture are both detrimental to seed germination and seedling survival respectively. Soil moisture deficit leads to non-germination or seed rot while waterlogging condition deprives the soil of air that is necessary for the biochemical processes that result into germination and seedling emergence (Shaban, 2013) In addiction the field for planting maize should not contain any residue, deposit or contamination of harmful materials and pesticides (Thai Agriculture Standard, 2010). Routine monitoring of the soil chemistry and scheduled soil tests should be carried out before setting up agriculture systems, where farmlands are surrounded by sources of pollutants such industry (Thai Agriculture Standard, 2010).

Planting depth in maize farming is very important in influencing the rate of germination and seedling emergence. A planting depth of 5cm is recommended(Pioneer Hi-Bred, 2009). For uniformity and ease of routine management of the crop, planting of the maize for the entire field should be accomplished in a single day (FAO, 2005).

In the initial stages of development of the maize crop, the rate of nutrient uptake is pretty slow due to the underdeveloped root system as well as limited root extent within the soil. The crop will therefore require adequate supply of phosphorus that supports root development (Costa *et al*., 2009). However, sufficient supply of nutrients (N, P, and K) at every stage of development of the crop is necessary for optimizing growth. Potassium uptake by the maize crop ends shortly after the silking stage, while that of nitrogen and phosphorus continues until close to maturity (Amali and Namo, 2015). This calls for continued supply of these essential nutrients to the crop.

Nitrogen is very important source of amino acids for the synthesis of proteins, and as a building block of all living matter (Adamczyk *et al*., 2010). Its deficiency in maize crop manifests in yellowing of the leaves, signifying loss of chlorophyll that is essential in primary production (Thai Agriculture Standard, 2010).

Shehu *et al*., (2018) noted that more than 70% of the cases studied showed a high response of maize yield to Nitrogen use leading to increase yields. The yield of maize was reduced when nitrogen was missing in the package of fertilizer (NPK). Generally, new hybrids and high yielding varieties require more nutrients depending on the status of fertility in the soil of the farm (Guy Sela, 2018). After harvesting, integration of maize crop residues into the farm land is a suitable form of nutrients recycling in maize production. Plant residue, leaves and stalks help potassium to be returned into the soil (Ritchie *et al*., 1989).

2.7.2 Weed control

The completion between weed and maize for space, soil water, nutrients and light cause the augmentation of production costs, loss of grain quality and loss of final yield (Mhlanga *et al*., 2016). Maize crop respond quickly to weed completion in the vegetative stage (Adu *et al*., 2014). Consequently, to enhance grain production is better to control the weed initial 2-4 after planting (Mashingaidze *et al*., 2012). Maize seed has been noted to be one important source of weed seeds in density dependent (Westerman *et al*., 2008).

The pressure of the weed is minimized when the aboveground and belowground herbicides are applied by seed producers. Effective weed management practices demands for maize planting immediately after land preparation, row planting, in the case of manual practices two hand weeding at 3 and 6 weeks after planting, and through judicious use of herbicides (Ghosheh *et al*., 1996). The herbicides use is less tedious, less laborious, cheaper and faster which makes it more important than manual use in weed control (Adu *et al*., 2014).

2.7.3 Pest and Disease Control

The major field and storage pests of maize consist of cutworms, stem borers, grasshoppers, larger grain borer, weevils and termites (Hirai, 1991). After harvesting the loss of yield is cause by storage insects. It is very essential to control insect pests, diseases and weeds when you are a seed producer. Some companies use the scouting and the principles of integrated pest management to determine when the use of pesticides is needed with regards to the environment (Akowuah *et al*., 2012). Pesticides are harmful to the environment and to human health for that reason proper skills and knowledge are required and application parameters, use of equipments human protection and use of spraying equipment are very important (Damalas and Koutroubas, 2017).

Bacteria blight, rust, smuts and streak are the main diseases of maize. The vulnerability of maize to the disease differ from cultivars to cultivars, but some disease like root rots, maize streak virus, grey, ear rot, cob, stem rot, leaf rot, tassel smut and rust are very dangerous to maize plant. It is recommended to farmers to cultivate the resistant and tolerant varieties depending on disease (Plessis, 2003).

2.7.4 Harvesting and Storage

In order to avoid losses due to rotting and soiling, harvesting of maize should be done during weather conditions, after the maize grain has attained maximum maturity of kernel and when the maize leaves are dry at 80- 90% (Gaile, 2008).

The storage of pesticides and fertilizers and other dangerous materials shall not be in different place with maize storage. The storage of maize must be, free from animals for preventing the contamination from these animals, also the ventilated building must be not poor and not wet. The floor must have the supporting materials which are very dry to avoid mold of the grain which is caused by moisture. During dry season, in the store temperature range must be from 25 to 30^0C and 65% of relative humidity (Thai Agriculture Standard, 2010)

2.8. Climate and Crop Growth Model

To be able to predict average of the atmospheric weather phenomena at large-scale, the Global Circulation Models (GCMs) have been developed (Dixson *et al*., 2013). GCMs are able to simulate global climate data at continental scales; on the other hand, in the simulation of local dynamic and features at sub-grid scale, the capacity of these GCMs is limited (Wilby and Wigley, 1997). The spatial resolution divergence between GCMs and regional models is the main constraint in using directly the outputs from climate models data in climate studies at local level (Giorgi, 1990). Even if future GCMs runs on high resolution, there will still be a need to downscale the outputs so that they match the local sites before being further use in climate change studies (Srinivas, 2013).

Downscaling therefore converts the coarse spatial resolution of any GCM outputs to a fine spatial resolution by generating local data from GCM outputs. This is done by linking global scales predictions to regional dynamics in order to generate climate variables specific to a particular region (Dixson *et al*., 2013). Currently, downscaling is used in climate simulation by many projects, and one of those projects used is Coordinated Regional Climate Downscaling Experiment (CORDEX), this project is able to produce dynamical downscaled simulation at high resolution climate models (Mutayoba and Kashaigili, 2017). Hence, the predicted climate can be used in prediction of crop growth.

Several studies have been conducted to assess the impacts of climate change on crop production using the models that are able to simulate crop yield (Kropff, 2016). Some of them showed that AquaCrop model is important to simulate the relation between crop, climate and water (Droogers and Aerts, 2005). This model which has been developed by the Food and Agriculture Organization (Hsiao *et al*., 2009) is used to estimate corn production in the study area under different climate scenarios. Various advantages of this model includes its requirement of less climatic data than most of crop models, the user friendly interface, and strong emphasis on relationship between crop yield, climate change, carbon dioxide and water, make this model to be recommend by the FAO a large number of users in this globe (Hsiao *et al*., 2009). When yield is predicted under variable water supply and the information on input is limited the AquaCrop model is preferred, encouraged and recommended over other models as a simple model. It is a model that simulates yield response to water as a driven-water crop model for numerous herbaceous crops. It is planned to balance robustness, simplicity and accuracy and mostly suitable for addressing the conditions of water as key factor to determine the production of the crop. In agriculture the accuracy of the model for a crop to respond to water is very significant for optimizing crop water productivity (Geerts et al. 2009). The validation and parameterization have been done for AquaCrop model in order to simulate maize yield response to water (Hsiao et al. 2009; Heng et al. 2009). The foundation of the AquaCrop model is the crop growth engine where the growth and the production of the crop are determined by the consumptive quantity of water used by the plant. FAO Irrigation & Drainage Paper no. 33 has developed many helpful empirical functions (Doorenbos and Kassam, 1979) and this stand for determination of yield response field water, tree crops and vegetable. This model requires common available input includes of climate, soil, crop and field management. Climate data; rainfall, temperatures and evapotranspiration, can be daily, 10 days interval or monthly. Through the water productivity, the transpiration of the plant is converted into biomass for this reason AquaCrop model is completely water- driven growth model. Figure 2 shows the flowchart of the AquaCrop model with its different components and their relationship.

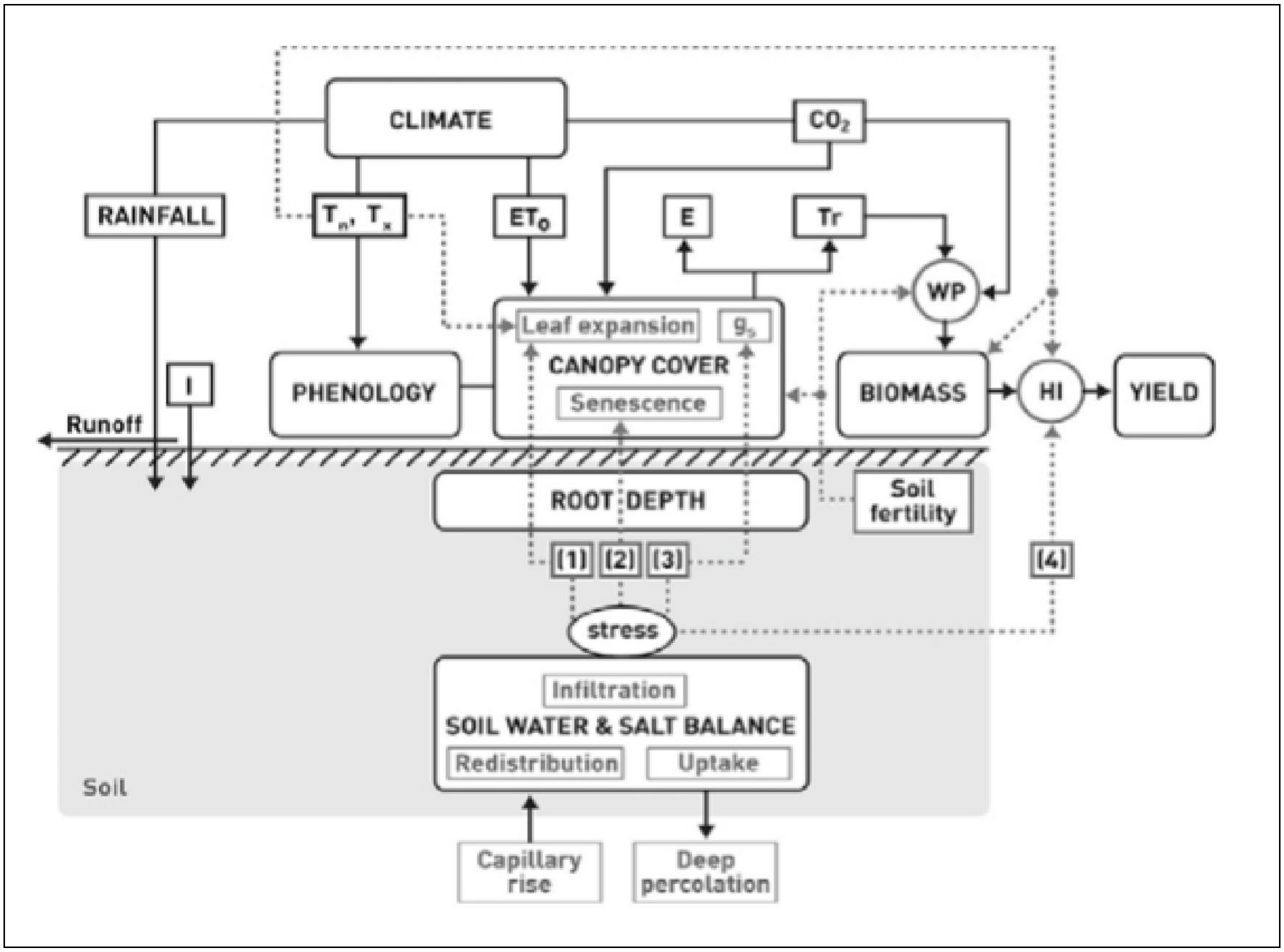

Figure 2: AquaCrop model flow chart and the interaction between different components

(Steduto *et al*.,2009).

2.9 Conceptual framework

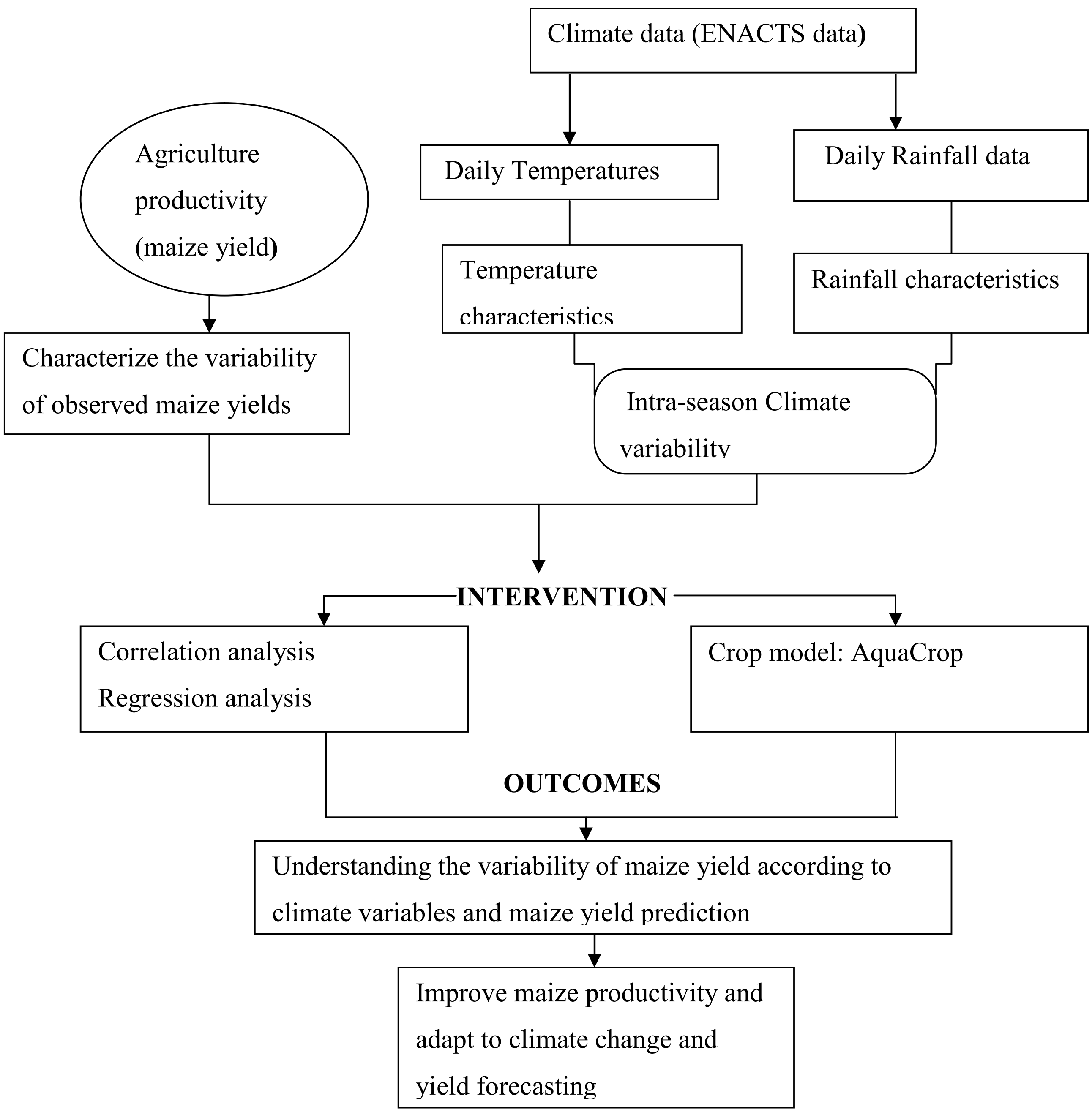

Figure 3: Conceptual framework representing the relationship between different components of the study.

CHAPTER THREE
DATA AND METHODOLOGY

3.0 Introduction

This chapter discusses in details the various types of data and their sources, methodology and tools used to achieve the specific objectives of this study.

3.1. Data types and Sources

This section gives the types of data used in this study and their sources.

3.1.1 Observed Data

This study used the observed daily data of rainfall, maximum temperature and minimum temperature, and seasonal maize yields. Meteorological data were obtained from various stations distributed across Rwanda (Table 3) and locations of the stations across the country are shown in Figure 4. Rainfall data are for the period of 1981 to 2017 and temperature data are for the period of 1983 to 2016. Maize yields expressed in kilograms per hectare (kg/ha) for both seasons (season A and season B) for the period 2007-2017 were collected from National Institute of Statistics of Rwanda (NISR), Ministry of Agriculture and Animal resources, and Rwanda Agriculture Board (RAB).

Table 3 : Location of meteorological stations used in this study

Number	Province	District	Names of station	Longitude	Latitude	Elevation (m)
1.	Kigali	Nyarugenge	Mageragere	30.03	-2.01	1400
2.		Kicukiro	Rubirizi	30.11	-1.98	1450
3.		Gasabo	Masaka	30.21	-2	1550
4.	South	Huye	Butare Aero	29.71	-2.6	1760
5.		Nyamagabe	Gikongoro Met	29.56	-2.46	1910
6		Ruhango	Byimana	29.71	-2.16	1750
7	West	Rubavu	Gisenyi Aero	29.25	-1.66	1554
8		Rusizi	Kamembe Aero	28.91	-2.46	1591
9		Karongi	Rubengera Met	29.42	-2.05	1700
10	North	Gicumbi	Byumba Met	30.05	-1.6	2235
11		Gakenke	Rushashi	29.89	-1.73	1650
12		Musanze	Busogo-Isae	29.55	-1.56	2100
13	East	Nyagatare	Nyagatare	30.31	-1.28	1377
14		Kayonza	Kawangire	30.43	-1.81	1473
15		Ngoma	Kibungo-Kazo	30.5	-2.15	1604

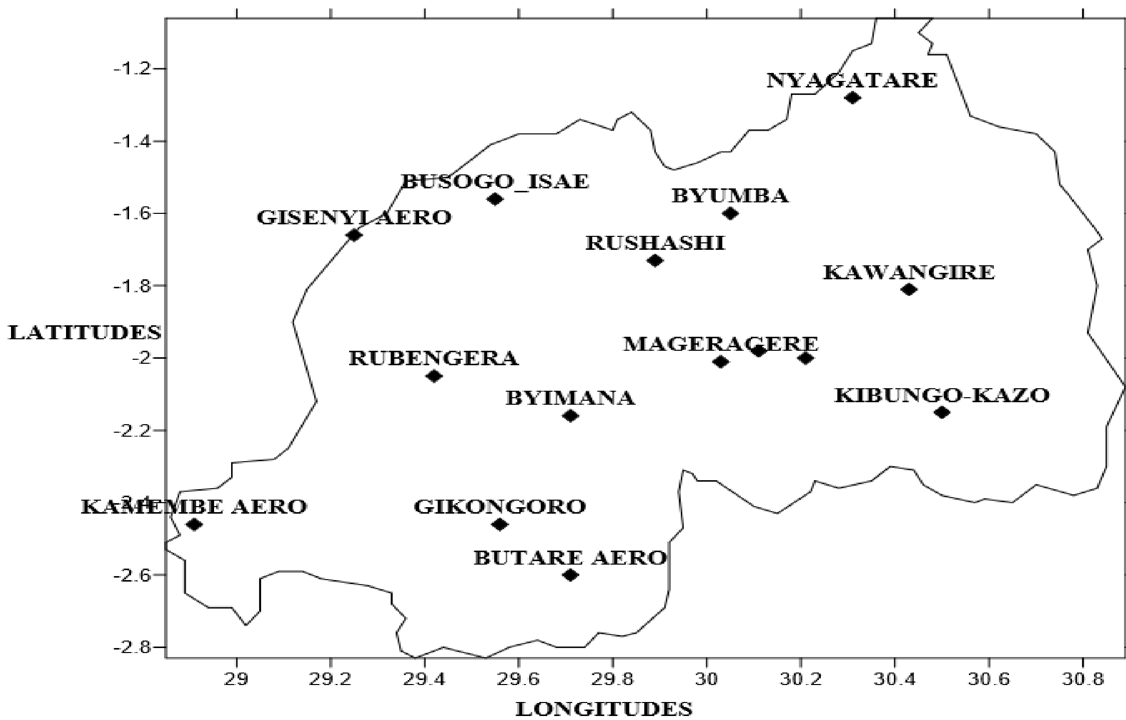

Figure 4: Map of Rwanda showing location of stations used in the study

Rainfall data were collected from the observed ground stations as well as from the International Research Institute (IRI) developed approach, known as Enhancing National Climate Services (ENACTS) for humanity and climate dataset hosted by Rwanda Meteorology Agency. ENACTS data are at spatial resolution of 5km and is the outcome of satellite based and ground station observations (Dinku *et al*., 2017). Temperature data were collected from the ground observations and satellite based data provided by the ENACTS dataset hosted by Rwanda Meteorology Agency.

3.1.2 Model Data

Model data used in this study are daily data of rainfall and temperature from RCA4, Coordinated Regional Climate Downscaling Experiment (CORDEX), and Regional Climate Model (RCM). The downscaled data are available for the period 1971-2005 and 2 GCMs over Africa, for RCP4.5 and RCP 8.5 and running in the transient mode for the period 1951-2100 at 50km (0.448) resolution over Rwanda. As the terms of use of CORDEX were given by developers, the quality control was done according to the terms (http://wcrp-cordex.ipsl.jussieu.fr/). Downscaled GCM under RCA4 used ICHEC-EC-EARTH (ICHEC) of institute of ICHEC (Europe) and MPI-MPI-ESM-LR (MPI) of Institute of MPI-M (Germany).

3.2. Methodology

This section presents the methods that were used to address all the specific objective of this study in order to achieve the overall objective.

3.2.1 Data Quality Control

The consistency of the rainfall and temperature data was tested by using the pettit's test. This test is commonly used to detect a single change point in climate series with continuous data. It tests the hypothesis, *Ho*: the variables follow one or more distributions that have the same location parameters means no change against the alternative hypothesis, *Ha:* that there is an existence of change point. Pettitt's test is defined by equation (1) and (2)

$$K_T = \max|U_{t,T}| \quad (1)$$

The change point of the series is located at K_T, provided that the statistic is significant. The significance probability of K_T is approximated for $p \leq 0.05$

$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} \text{Sign}\left(X_i - X_j\right) \quad (2)$$

Where, X_i,X_j Are the sequential data values, T is the number of the recorded data.

3.2.2. Determination of the intra-season climate variability

This section represents the tools and methods that were used in the determination of variability in rainfall and temperature.

3.2.2.1 Rainfall characteristics

With regard to rainfall, the intra-seasonal climate variability were determined through analysis of various characteristics, including the start and end dates of seasonal rainfall, length of the season, rain days, total seasonal rainfall. Daily data were organized in a format required by Instat plus statistics package Version 3.36, developed by University of Reading for processing climate data. The software was used to determine the rainfall characteristics in MAM season and SOND season at station level, the year which was not meeting the criteria given in Onset and Cessation was marked as miss value.

These characteristics were determined using the following approach:

i. Onset date of the rainy season considered, was the a day later than 1st March for the March- May rainy season, and 1st September for the September- December season when the accumulated rainfall in three consecutive days is at least 20 mm and which is not followed by more than 7 days of dry spell with a threshold value of 0.85 mm in next 30 days (Laux *et al*., 2008) , (Marteau *et al*., 2009), (Sivakumar, 1988).

ii. Cessation date or end date of the rainy season considered, was the earliest probable day after 1st May for the MAM rainy season and 1st December for the SOND rainy season when the soil water balance reaches zero with a fixed average of 5 mm of Evapo-transpiration per day, and 100 mm/meter of the maximum soil water holding capacity

iii. Duration or length of the rainy season was the number of days between the onset and cessation dates.

iv. Season number of rain days (in days) were considered to be the days in a season with at least 0.85mm of rainfall recorded in 24hours from 6:00 am to 6:00 am of the following day (08:00 am to 8:00 am of the following day in local time).

v. Total seasonal rainfall amounts were obtained by summing all the rainfall collected within the season.

3.2.2.2 Temperature

The temperature characteristics that were determined from the observed daily data include the trends in maximum temperature, minimum temperature, temperature range and the growing degree days. These parameters were computed using the methodologies presented herein below:

i. Seasonal trend of maximum and minimum temperature were determined from time series plots of these data. A trend line was fitted to the data, and its regression is of the form given as equation (3) determined.

$$\boldsymbol{Y = aX + b} \qquad (3)$$

Where, $\boldsymbol{y}$ represents temperature, amount in ^{0}C, $\boldsymbol{a}$ represents slope, hence the rate of change of temperature over the time, and $\boldsymbol{b}$ represents the intercept on $\boldsymbol{Y}$-Axis.

ii. Growing degree day

The Growing Degree Days (GDD), also known as the Thermal Heat Units (THU) were computed on daily time steps and then accumulated over the time period of the respective maize phenological stages.

The GDD was computed using equation (4):

$$\boldsymbol{GDD} = \left(\frac{\boldsymbol{T_{max}} + \boldsymbol{T_{min}}}{\mathbf{2}}\right) - \boldsymbol{T_b} \qquad (4)$$

Where $\boldsymbol{T_{max}}$, represents maximum temperature, $\boldsymbol{T_{min}}$ Represents minimum temperature, and $\boldsymbol{T_b}$ Represent the base temperature also known as the threshold temperature of the crop. The value of the maize crop was considered as 10^{o}C.

Since the equation 2 calculates GDD for one day, the accumulated GDD over the phenological stage or, entire growing season were computed using equation (5).

$$\boldsymbol{GDD} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{n}} \left(\frac{\boldsymbol{T_{max}} + \boldsymbol{T_{min}}}{\mathbf{2}}\right) - \boldsymbol{T_b} \qquad (5)$$

Where n represents the number of days over which summation is done.

3.2.2.3 Variability and trend analysis of climate characteristics.

The regression equation and trend line analysis were used to test the distribution of data. The regression analysis was applied to test for the linear relationship between time and the variable of interest. The regression analysis can be carried out straight off on the time series. The trend in climatic variables in a particular field can be studied by using the regression analysis with time as the independent variable and climatic variables as the dependent variable. A linear equation (3) of the section 3.2.2.2, defined by b (the intercept) and trend A (the slope), which stands for the rate of increment or lessening of the variable, can be fitted by regression and x is time in years.

3.2.3. Variability of the observed maize yield

Variability of maize yield was analyzed using the coefficient of variation. This coefficient of variation showed how individual maize yield data points vary about their long term mean value. This was determined by dividing the standard deviation by the mean and expressing the ratio as a percentage.
General formula of coefficient of variation that was used in this study is given in equation (6):

$$CV = \frac{S}{M} * 100 \qquad (6)$$

Where, CV is the coefficient of variability, S represents standard deviation and M represents the mean values of the maize yield data.

3.2.4 Relationship between maize yields and climate characteristics

Correlation and regression were used as the tools for determining the relationship between climate variability parameters and maize yield.

3.2.4.1 Correlation Analysis

In this study correlation analysis was carried out in order to understand the relationship between individual climate characteristic and maize yield in different areas of Rwanda. Student t and tabulated values were used to test the significance of the correlation. The degree of relationship between maize yield and climatic characteristics was analyzed using the Pearson's correlation coefficient. The Pearson's correlation coefficient, r, also known as Pearson Product-Moment was computed as the ratio of the covariance of maize yields and the corresponding climatic characteristics being studied as given in equation (7).

$$r_{xy} = \frac{\frac{1}{n}\sum_{i=1}^{n}(xi-\overline{x})(yi-\overline{y})}{\sqrt{\left[\frac{1}{n}\sum_{i=i}^{n}(xi-\overline{x})^2\right]\left[\frac{1}{n}\sum_{i=1}^{n}(yi-\overline{y})^2\right]}}$$

$$r_{xy} = \frac{Cov(x,y)}{SD_x * SD_y} \quad (7)$$

Where $\overline{x}$ The mean of independent observation and represents climate characteristics xi; $\overline{y}$ Is the mean of the dependent variable and represents maize yield, yi, $Cov(x,y?)$ Is the covariance of x and y, SD_x is the standard deviation of x and SD_y is the standard deviation of y.

The null hypothesis H_0 that will be tested in this study is that there is no significant correlation between climatic characteristics and maize yields, while the alternative hypothesis H_1, is that there is a significant correlation between climatic characteristics and maize yields.

To test these hypotheses, this study employed the student t-test, wherein the computed t- statistic was compared with the tabulated t values. Equation (8) gives the equation that was used to compute the t-statistic.

$$t_{(n-2)} = r * \sqrt{\frac{(n-2)}{(1-r^2)}}$$

$$t_{(n-2)} = \sqrt{\frac{r^2(n-2)}{(1-r^2)}} \quad (8)$$

Where, r is the correlation coefficient obtained; n is the sample size; n-2, is the degree of freedom. The correlation coefficient was considered to be statistically significant if the computed t-statistic was greater than the tabulated t-values.

3.2.4.2 Regression Analysis

The relationship linking the statistical significant climatic parameters identified in section 3.2.3.1 above with the observed maize yields was determined using Multiple Linear Regression (MLR) equation of the form given in equation (9).

$$\mathbf{Y} = \boldsymbol{b_0} + \boldsymbol{b_1 X_1} + \boldsymbol{b_2 X_2} + \cdots + \boldsymbol{b_n X_n} + \in \tag{9}$$

Where, Y is the dependent variable (predictant) represents maize yield, $\in$, is the error term,$\boldsymbol{b_0}$ Y intercept (constant independent) of $\boldsymbol{x_i}$ and $\boldsymbol{b_i}$ are the regression coefficients independent of climatic characteristics (rainfall, maximum temperature and minimum temperature).

3.2.5 Assessing the impact of climate variability on maize yields

In the assessment of the impact of climate variability and change on maize yield, the AquaCrop model was used. The inputs in this model were climate variables; rainfall, temperature and evapotranspiration. AquaCrop needs future climate data for simulating maize yields under future climate and CORDEX model were applied in simulation of climate information. In calibration of the AquaCrop, climate parameters of 33 years from 1983 to 2016 were used as a base period, but in comparison of simulated yield and observed yield this study used 10 years because the observed maize yield, were from 2007 to 2017.

In the evaluation of the CORDEX-RCMs model performance to simulate temperature and rainfall, root mean square error (RMSE) and BIAS were used. The simulated climate data of the temperature for the period of 1983 to 2005 and rainfall for the period of 1981 to 2005 from CORDEX-RCMs were compared to the observed climate data of temperature and rainfall of the same period. For the future climate data are for the period of 2021 to 2050 and this period was used to predict maize yield.

The smaller RMSE value, the more respectable and the gross performance of the model is represented by the value closer to zero. RMSE and Bias formulas are given in equation (10) and (11).

$$\boldsymbol{RMSE} = \sqrt{\frac{\mathbf{1}}{\boldsymbol{N}}\sum_{\boldsymbol{I}=\mathbf{1}}^{\boldsymbol{n}}(\boldsymbol{P}_{\boldsymbol{i}} - \boldsymbol{O}_{\boldsymbol{i}})^{\mathbf{2}}} \tag{10}$$

$$\boldsymbol{BIAS} = \frac{\mathbf{1}}{\boldsymbol{N}}\sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{n}}(\boldsymbol{P}_{\boldsymbol{i}} - \boldsymbol{O}_{\boldsymbol{i}}) \tag{11}$$

Where P and O of the equation (10) and (11) represent the simulated and observed values, respectively, N is the number of pairs and “i” represents the pairs being simulated and observed. RMSE and Bias used to determine which RCA4 is good for the projection of future climate variable of rainfall and temperatures in Rwanda.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.0 Introduction

This chapter provides the results obtained from the analyses carried out to meet the specific objectives of this study. The results are presented sequentially according to the specific objectives.

4.1 Data Quality Control

This section represents the method used to estimate the missing data and test for homogeneity of the data.

4.1.1 Data Availability and Estimation of the Missing Data

Rainfall data were available from 1981 to 2017 and temperature (maximum and minimum) data were available from 1983 to 2016. While the maize yield data were available for 10 years only starting from 2007 to 2017.the future climate data for the period of 2021 to 2050 were also available. This study used the available dataset because there was no missing data.

4.1.2 Test for Homogeneity of the Data

The homogeneity test was carried out and Figures (5 to 7) represent the results for Busogo station. The Pettitt test was used to test the homogeneity of rainfall data, maximum temperature and minimum temperature for fifteen stations across the country. The climatic variables were plotted against the time. The pettitt's test is a nonparametric test that requires no assumption about the distribution of the data. When the calculated p-value is greater than the significance level with 0.05 of alpha, the null hypothesis should be rejected. The null hypothesis Ho means that the data are homogeneous and the alternative hypothesis; Ha means that there is a date at which there is a change in the data. The plotted time series of rainfall and temperature were found to be homogeneous with the p- value of 0.124 for rainfall, 0.186 for maximum temperature and 0.754 for minimum temperature, which implies that the data used in this study, were homogeneous from 1981 to 2017 for rainfall and from 1983 to 2016 for temperature.

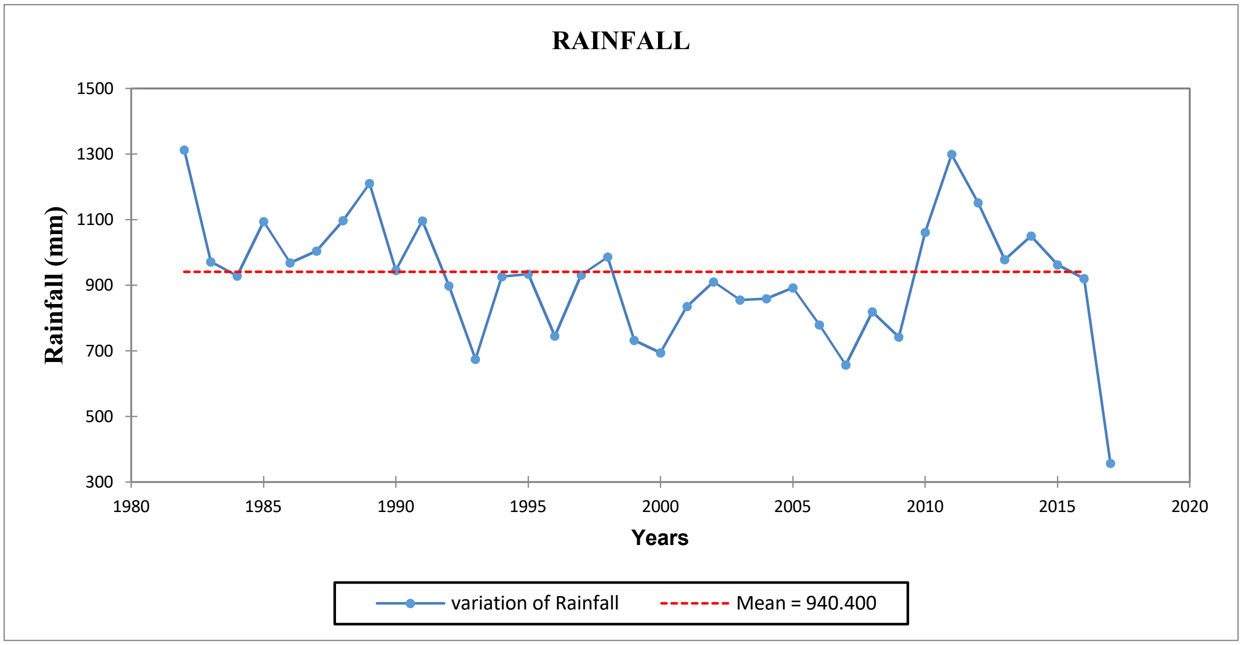

Figure 5: Pettitt's test result for homogeneity of Rainfall for Busogo from 1981 to 2017.

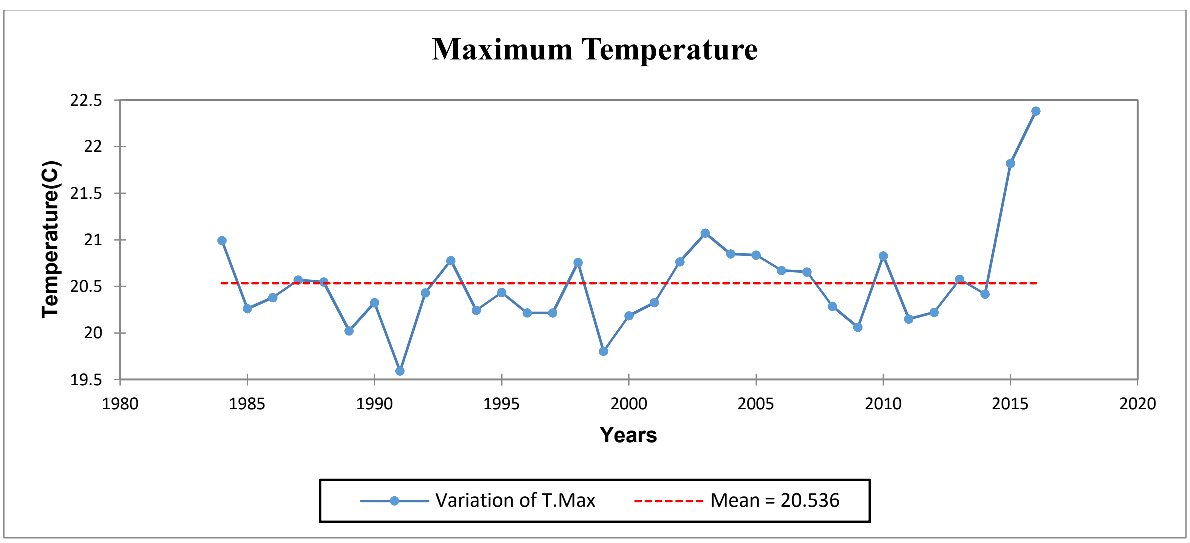

Figure 6: Pettitt's test result for homogeneity of average of maximum temperature for Busogo from 1983 to 2016.

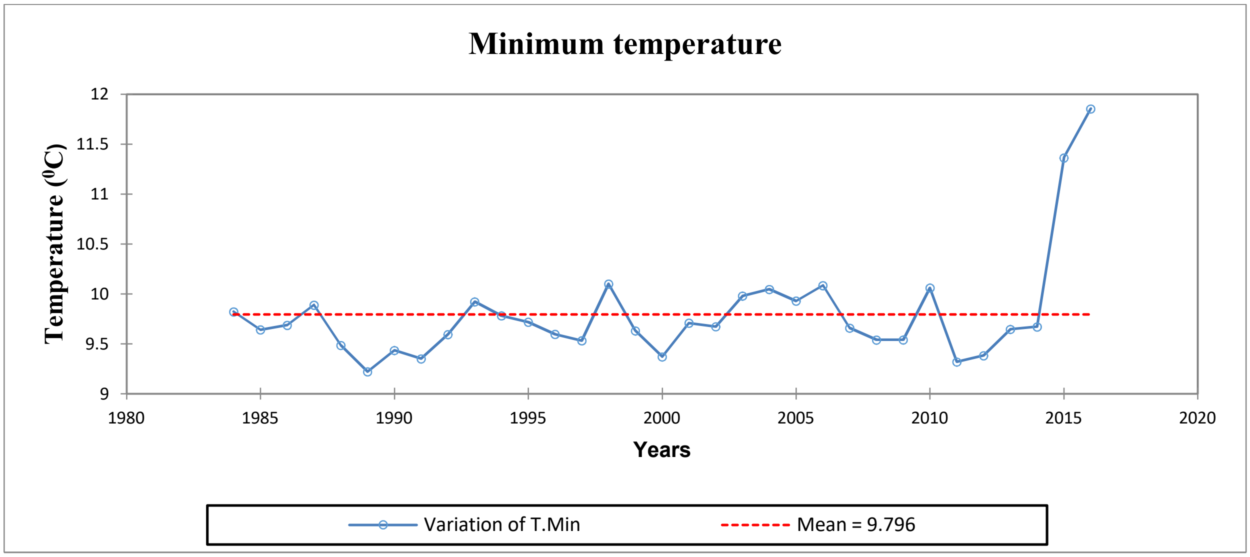

Figure 7: Pettitt's test for homogeneity of average of Minimum temperature for Busogo from 1983 to 2016.

4.2. Rainfall Characteristics

Different characteristics determined are: Onset and Cessation of rainfall during the seasons, which are presented in Table 4, while Table 5 represents the values of Rainy days, Season length and Seasonal Total Rainfall for MAM and SOND Seasons.

For the MAM season, onset ranges from early March to middle March in the region (Table 4). The onset over Rwanda shows a gradual progression from the Southwest part of the country towards the Northern-East of the country. While for SOND season, onset in the region starts from end of September to the early October from the northeast region of the country towards the southwest region of the country.

Results indicated that cessation of MAM season began in the early May in the east, center and west region, but in the northern part and southern region of the country, it starts in middle May. On the other hand, for SOND season, the cessation was identified in the beginning of December from the east to the west region of the country.

Table 4: Start and End of MAM and SOND seasons for all stations (1981-2017)

Province	Names	Start of the Season (mean date)		End of the season (Mean date)	
		MAM	SOND	MAM	SOND
KIGALI	Mageragere	13 March	19 October	10 May	03 December
	Rubirizi	16 March	21 October	05 may	05 December
	Masaka	17 March	25 October	06 May	07 December
SOUTH	Butare Aero	08 March	06 October	17 May	06 December
	Gikongoro Met	09 March	08 October	17 May	04 December
	Byimana	14 March	12 October	11 May	04 December
WEST	Gisenyi Aero	06 March	28 September	06 May	06 December
	Kamembe Aero	04 March	22 September	08 May	10 December
	Rubengera Met	08 March	06 October	07 May	07 December
NORTH	Byumba Met	07 March	25 September	16 May	05 December
	Rushashi	11 March	27 September	19 May	06 December
	Busogo-Isae	10 March	26 September	15 May	08 December
EAST	Nyagatare	12 March	18 October	04 May	01 December
	Kawangire	15 March	11 October	07 May	04 December
	Kibungo-Kazo	18 March	22 October	10 May	06 December

From the results in Table 4 below, it was observed that the South, West and North provinces had a long seasonal length in both seasons, with days between 71-51, 61-59 and 69-65 respectively, compared to Kigali and East province with seasonal length of 51-58 and 53-54 days respectively. From Kigali to the eastern part of the country the amount of rainfall observed in both seasons were less compared to amount received in northern, southern and western parts of Rwanda. This decrease in rainfall amount was attributed to reduction of number of rainy days, which lead to decrease of the growing season and put moisture stress to the crop due to water deficit.

Table 5: Seasonal length, seasonal rainy days and mean seasonal total rainfall for fifteen stations

Province	Names	Seasonal length (Mean Days)		Seasonal Rain days (Mean days)		Mean Seasonal total rainfall (mm)	
		MAM	SOND	MAM	SOND	MAM	SOND
KIGALI	Mageragere	58	56	38	43	312	276
	Rubirizi	55	46	29	34	296	233
	Masaka	51	44	28	33	265	290
SOUTH	Byimana	59	54	37	40	311	325
	Butare Aero	71	61	44	50	397	390
	Gikongoro Met	69	59	41	48	395	398
WEST	Gisenyi Aero	61	69	44	62	301	413
	Kamembe Aero	65	77	48	73	348	389
	Rubengera Met	59	62	38	48	327	380
NORTH	Byumba Met	69	71	54	56	391	375
	Rushashi	69	69	32	41	284	336
	Busogo-Isae	66	77	31	33	374	445
EAST	Nyagatare	54	53	54	63	222	261
	Kawangire	54	63	30	34	271	297
	Kibungo-Kazo	53	64	34	37	301	316

4.2.1 Trend analysis of variability in rainfall characteristics

Figure 8 and Figure 9 shows the trend results of rainfall characteristics (Onset and cessation of the season, Length of the season, Rain days and Total seasonal rainfall) for Busogo station. Rainfall characteristics are plotted against time and other results for selected stations are given in Appendix I.

In Figure 8 below, it can be observed that from the regression line there was an insignificant shift of Onset and Cessation in MAM season and SOND in Busogo which lead to increase or decrease of the seasonal length. The shift in the onset and cessation also happened in other parts of the country and caused a change in season length depending on the area. The results also show an increasing trend in season length in this station.

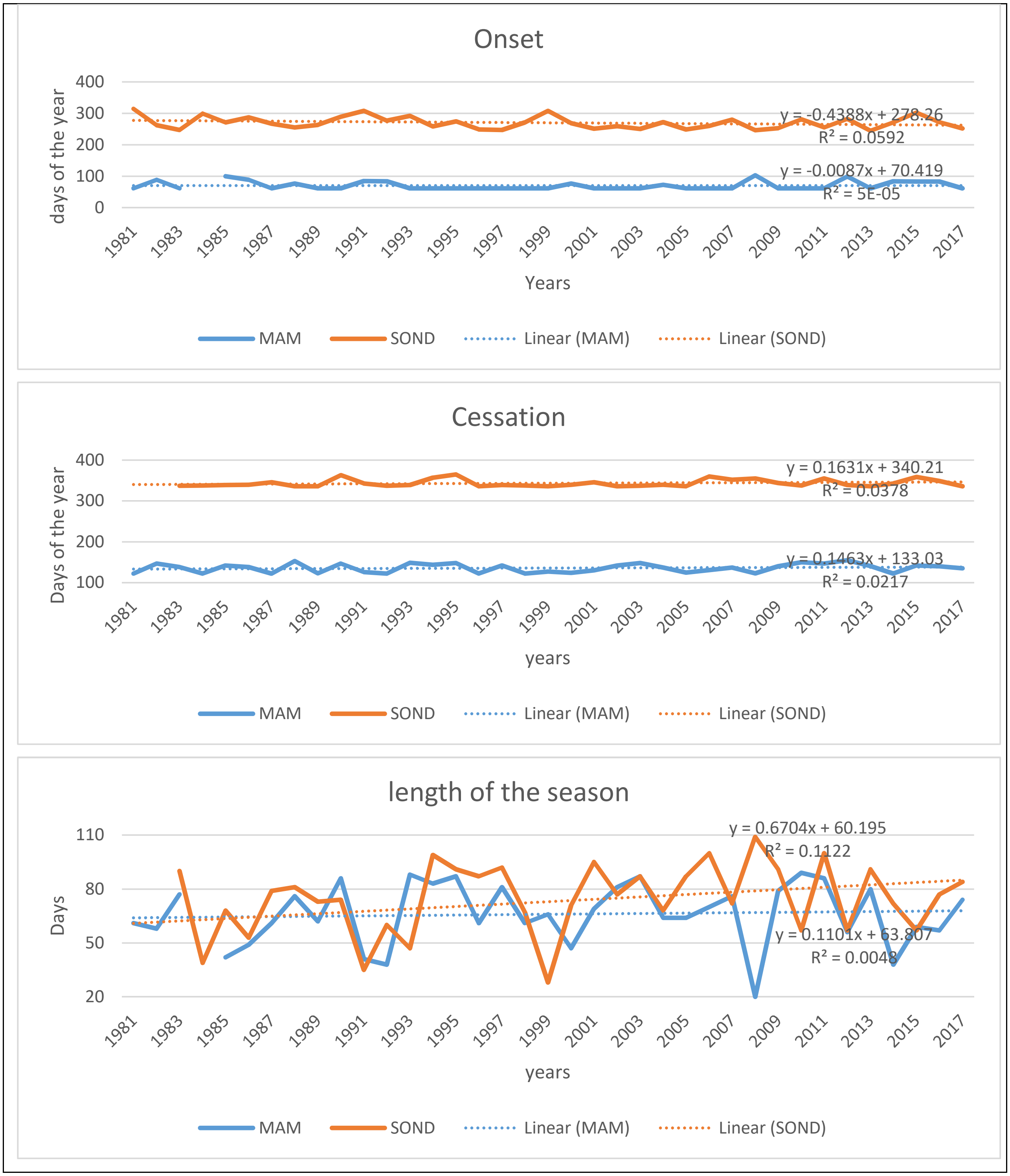

Figure 8: Trend analysis of Seasonal rainfall characteristics (Onset, Cessation and seasonal length) for Busogo from 1981 to 2017

From Figure 9, it can be observed that trend line show an increasing in seasonal rainy days for both short and long rainy season. Also, it was showed a continuous increasing in seasonal rainfall in this area. This increase in seasonal rainfall can be interpreted as evidence of the severe floods that affecting this part of the Northern Province.

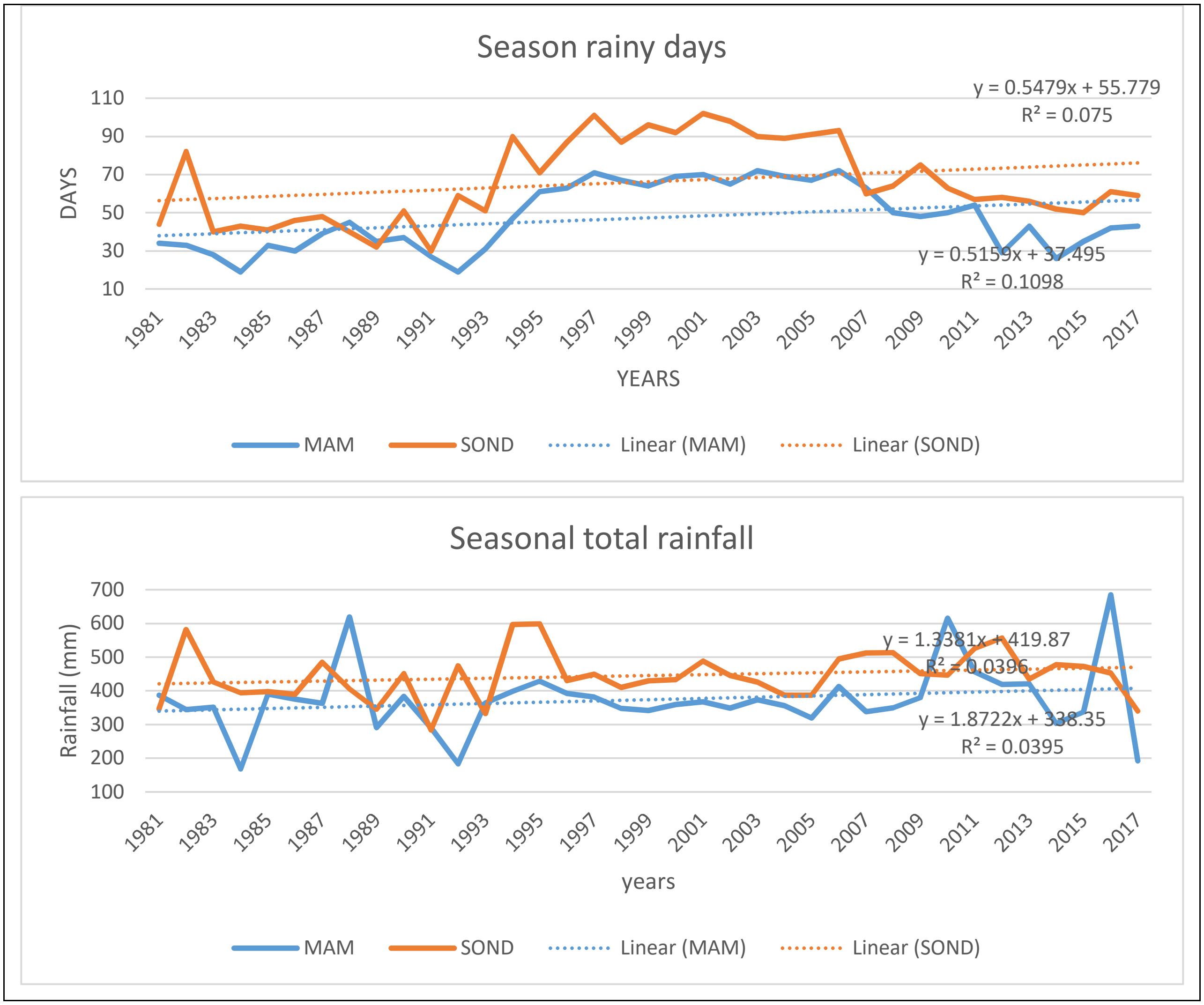

Figure 9: Trend analysis of Seasonal rainfall characteristics (Seasonal Rainy days and seasonal total rainfall) for Busogo from 1981 to 2017

4.3 Temperature Characteristics

Temperature characteristics, including mean maximum temperature, mean minimum temperature, seasonal temperature range and GDD, were derived from daily temperature data. Table 6 shows the summary values of temperature characteristics.

Table 6: Mean temperature (Maximum, Minimum and Temperature range and GDD)

Province	Name	Mean Tmax (°C)		Mean Tmin (^{0}C)		T. range (°C)		GDD	
		MAM	SOND	MAM	SOND	MAM	SOND	MAM	SOND
KIGALI	Mageragere	26.4	27.2	15.9	15.8	10.5	11.4	1019.4	1406.4
	Rubirizi	26.3	27.1	15.7	15.5	10.6	11.6	1013.6	1379.7
	Masaka	26.9	27.4	15.8	15.7	11.6	11.7	1046.3	1407.1
SOUTH	Byimana	24.7	25.1	14.7	14.1	10.0	11.1	885.9	1189.6
	Butare Aero	24.6	25.3	14.6	14.1	10.0	11.1	882.2	1182.3
	Gikongoro	22.9	23.3	13.8	13.1	09.1	10.1	768.1	999.3
WEST	Gisenyi Aero	25.1	25.3	15.5	14.9	09.6	10.3	950.5	1228.9
	Kamembe Aero	26.0	25.9	15.5	15.3	10.5	10.7	990.8	1287.4
	Rubengera Met	24.4	25.1	15.1	15.2	09.4	09.8	897.7	1235.8
NORTH	Byumba Met	21.2	21.7	13.0	12.8	08.3	08.9	651.4	879.8
	Rushashi	24.2	24.6	12.6	12.6	11.6	12.0	777.4	1052.3
	Busogo-Isae	20.5	20.7	10.2	09.8	10.3	10.9	493.6	645.2
EAST	Nyagatare	27.0	27.6	14.4	15.3	12.6	12.3	986.2	1393.5
	Kawangire	26.5	27.4	15	15.2	11.5	12.2	988.1	1377.4
	Kibungo-Kazo	26.3	26.8	15.2	15.4	11.1	11.4	986.5	1357.1

The results from Table 6 show that Eastern province and Kigali had the highest maximum temperatures. In both seasons the recoded highest temperature was 27^0 C for MAM season and 27.6 for SOND season in Nyagatare station, and 26.9^{0}C for MAM and 27.4^{0}C for SOND in Masaka station one of Kigali stations. The lowest temperature was found in the northern part of the country with 20.5^{0}C for MAM and 20.7 for SOND season in Busogo. The eastern part and central part of Rwanda were drier compared to other part of Rwanda including North, South and West provinces. As it can be seen from the results of this Table 6, SOND season is hotter than MAM season, where the temperature range is between 08.9^{0}C and 12.3^{0}C for SOND compared MAMA season which is ranging from t 08.3^{0}C to 12.6.

4.3.1 Trend analysis of variability in temperature characteristics

Trend analysis was carried out for rainfall characteristics (maximum temperature, minimum temperature, temperature range and growing degree days) for all stations. Figure 10 and Figure 11 show the trend results of temperature characteristics for Busogo they are plotted against time and other results for remaining stations are given in Appendix II.

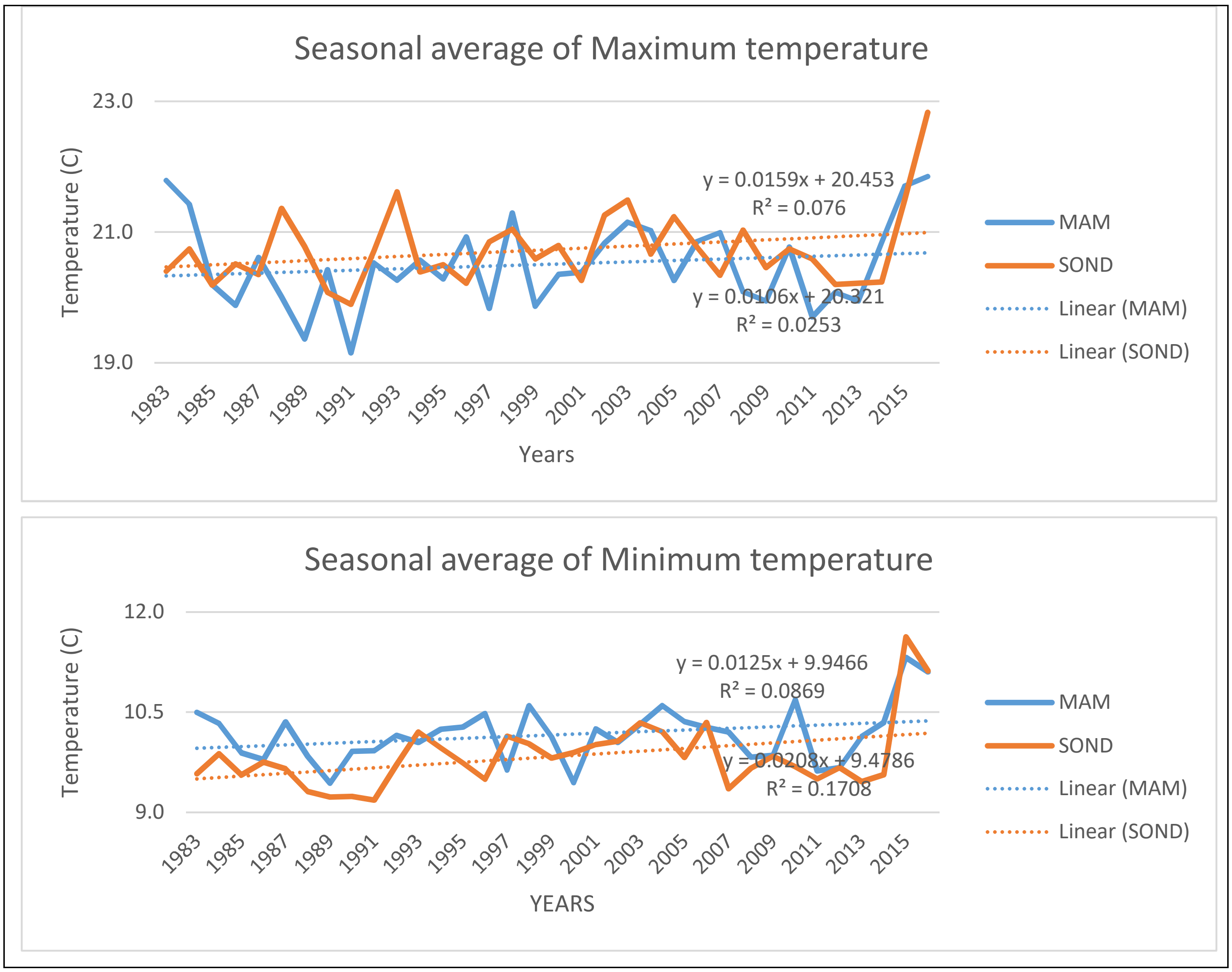

Figure 10: Trend analysis of Maximum and Minimum temperature for Busogo from 1983 to 2016

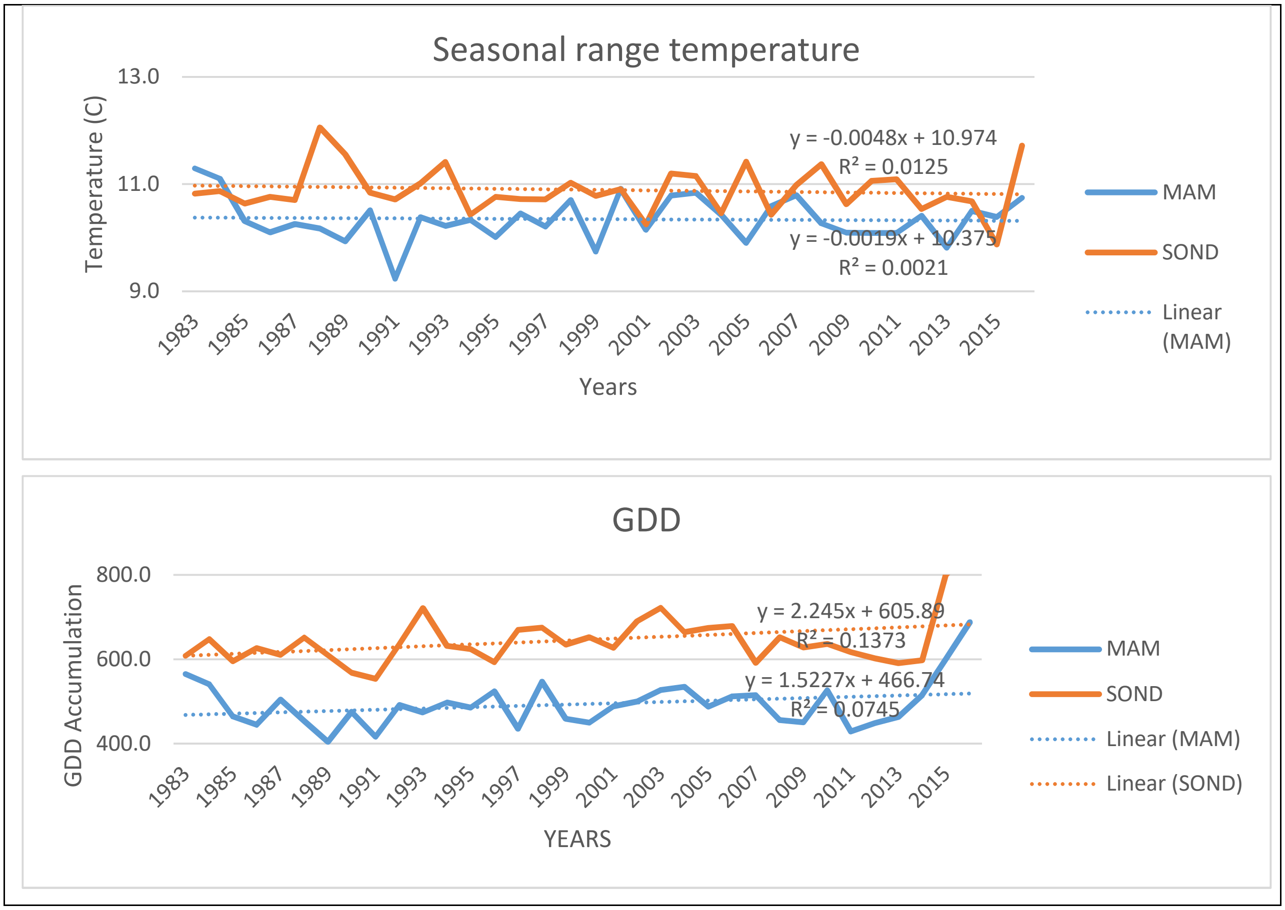

Figure 11: Trend analysis of seasonal range temperature and GDD for Busogo from 1983 to 2016

From the results above from Figure 10 and Figure 11, the trend analysis of variation of temperatures characteristics for Busogo station, had shown a continuous increase in maximum, minimum, temperature range and GDD over this area. The increase in maximum temperature and minimum temperature can be a good reason to give a proof of rising in temperature in most parts of our country and even many parts of the world as a result of climate change.

The Southern province; trend analysis shows an increasing trend of maximum temperature, minimum temperature in both season and increasing trend of GDD for MAM season, but decreasing trend were found in the temperature range of both seasons and in GDD of SOND season. In the western province the trend analysis shows an increasing trend of maximum temperature in MAM season and a decreasing trend in SOND season; a decreasing trend of minimum temperature during MAM season and an increasing trend of minimum temperature during SOND season; for the temperature ranges the trend analysis shows an increasing trend in MAM and a decreasing trend in SOND.

4.4. Analysis of coefficient of variation in observed maize yields

Coefficient of variation (CV) was used to explain the variability in observed maize yields in Rwanda for the period of 2007 to 2017. The high percentage value of CV, indicate a high degree of variability of maize yields. Regional variability of maize yields in both seasons (Season A and B) is shown in Table 7, Figure 12 and Figure 13 show the trend analysis in maize yield in Season A and Season B respectively.

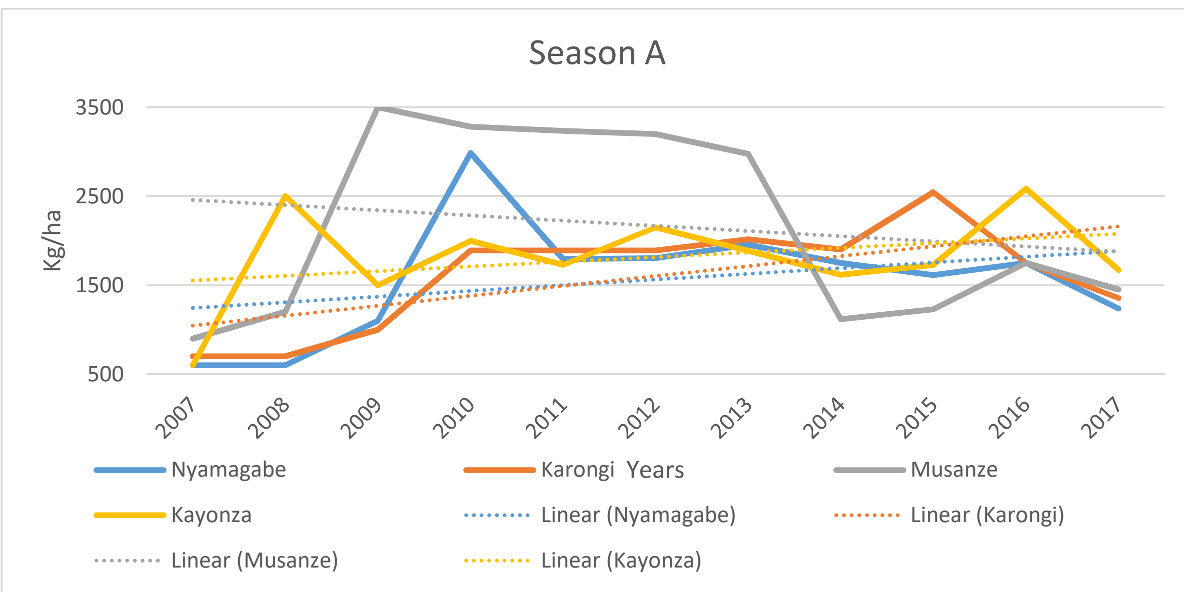

Figure 12: Variation of maize yield in season A for Gikongoro, Rubengera, Busogo and Kawangire from 2007 to 2017.

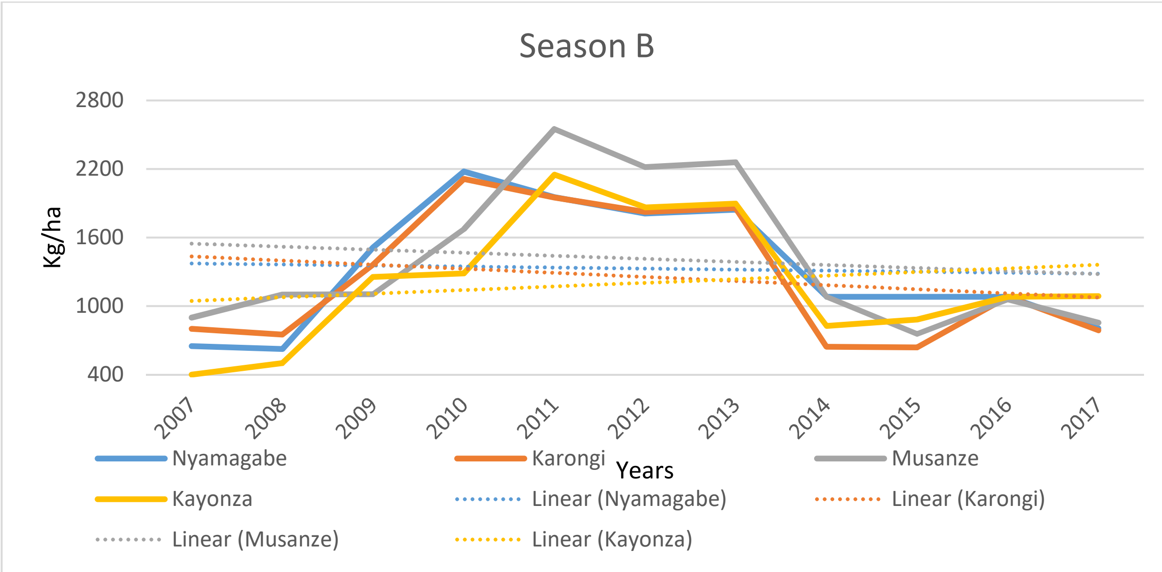

Figure 13: Variation of maize yield in season B for Gikongoro, Rubengera, Busogo and Kawangire from 2007 to 2017.

From the results in Figure 12 above, it can be observed that in season A there has a negative trend in maize yield in Musanze district in the Northern Province, on the other hand a positive trend was observed in Nyamagabe, Karongi and Kayonza. The highest maize yield was observed in Musanze from 2008 to 2014. Figure 13, shows the results of trend analysis and variation variation in Season B where there was a negative trend in maize yield in Nyagabe, Karongi and Musanze, but Kayonza showed a positive trend in maize yield. The highest values were recorded in Musanze and Nyamagabe. The records show an increasing in maize yield for the period of 2009 to 2013 and a decrease started from 2014, this decrease can be attributed to the decrease in rainfall amount and an increasing in temperature all over the country.

Table 7: Coefficient of variation of maize yields in selected areas across the country

Province	Names	Coefficient of variation in %	
		Season A	Season B
KIGALI	Kigali	40	37
SOUTH	Ruhango	45	42
	Huye	35	43
	Nyamagabe	43	42
WEST	Rusizi	37	44
	Karongi	37	46
	Rubavu	45	53
NORTH	Musanze	49	46
	Gakenke	35	35
	Gicumbi	39	41
EAST	Kayonza	29	47
	Ngoma	40	60
	Nyagatare	31	40

From the result given in the Table 7 above, it can be observed that there is much variability in maize yield in different regions of the country. Both seasons (season A which starts in September to January and season B which starts from March and ending in June) have shown much variation in maize yield, especially in season B, where the high CV is 60% in Ngoma district located in the Eastern province and less CV of 35 is found in Gakenke located in the Northern Province of the country. For season A which starts in September, the variability is much lower in comparison with season B. Coefficient of variation of the season A is lowest in Kayonza which is part of the eastern province and the highest was observed in Musanze part of the Northern Province.

4.5 Relationship between maize yields and climate characteristics

In order to assess the relationship between maize yields and climate characteristics, correlation and regression methods were adopted in both seasons (MAM and SOND).

4.5.1 Correlation Analysis

Correlation analysis between maize yield and climate characteristics in short rainy season (SOND) and long rainy season (MAM) for Gikongoro (Nyamagabe) in southern province is shown in Table 8. The results for other selected stations are given in Appendix III.

Table 8: Correlation analysis between maize yield and climate characteristics for Gikongoro.

Climate characteristics	MAM season				SOND season			
	Correlation coefficient	T cal	T tab	Interpretation	Correlation coefficient	T cal	T tab	Interpretation
Onset Date	-0.84	4.310	1.812	Sign	-0.76	3.267	1.812	Sign
Cessation Date	0.54	1.814	1.812	Sign	0.65	2.412	1.812	Sign
Season Length	0.76	3.267	1.812	Sign	0.80	3.852	1.812	Sign
Rainy Days	-0.31	0.901	1.812	No Sign	-0.30	0.897	1.812	No Sign
Seasonal Rainfall	0.76	3.267	1.812	Sign	0.79	3.425	1.812	Sign
T Max	-0.17	0.492	1.812	No Sign	-0.82	4.006	1.812	Sign
T Min	0.57	1.962	1.812	Sign	-0.49	1.589	1.812	No Sign
T Range	-0.51	1.676	1.812	No Sign	-0.46	1.645	1.812	No Sign
GDD	0.54	1.814	1.812	Sign	-0.88	5.240	1.812	Sign

The results given in Table 8, shows a positive correlation in rainfall characteristics except Onset date and Rainy days which showed a negative correlation. Temperature characteristics showed a negative correlation except minimum temperature and growing degree days which showed a positive correlation. In season A, the correlation is significant for some climate characteristics includes Onset date, Cessation, Season length, Total season rainfall, Minimum temperature and growing degree days. On the other hand, Onset date, Cessation, Season length, Total season rainfall, Maximum temperature and growing degree days their correlation is significant for season B. Even if the correlation is significant in both seasons in this case of Gikongoro station, but some stations include Butare Aero, Kamembe Aero and Kawangire have shown non-significant correlation between maize yield and climatic characteristics.

In conclusion it was found that, the correlation analysis showed a positive relationship between rainfall characteristics and maize yield, this means an increase in rainfall will improve maize yield and a decrease in rainfall will lead to poor maize yields. On the other hand temperature characteristics showed a negative correlation with maize yields, which means that an increase in temperature results in a decrease in maize yield and a decrease in temperature results in increasing maize yields.

4.5.2 Multiple Regression Analysis

In order to determine how the climate characteristics affect the maize yield in Rwanda, multiple regression analysis was carried out with parameters that are significantly correlated with maize yield and Table 9 gives the regression models and the coefficient of determination (R^2) for season A and season B for the selected stations across the country.

Table 9: Multiple Regression analysis between maize yield and climate characteristics

Stations	Regression model for MAM	R^2	Regression models for SOND	R^2
Mageragere	Y=-106.21+15.43*Seasonal Length+ 0.47*GDD	0.51	Y=126.47-8.49*GDD+454.84*Tmax	0.24
Rubirizi	Y= -1340.55+13.31*Onset+27.05*Seasonal Length	0.50	Y=10156.70+51*Rainy Days -220.40*Tmax-3.36*GDD	0.77
Masaka	Y=3344.32+7.40*Seasonal Length-2.33*GDD	0.45	Y=14797.54+21.91*Rainy Days+163.91*Tmin-614.28*Tmax	0.63
Byimana	Y=1385.55-2.63*Seasonal Length+3.23*Total Rainfall -1.21*GDD	0.26	Y=58899.98-11.14*Seasonal Length+0.41*Total Rainfall -2015.77*Tmin-1124.70*Tmax	0.80
Butare Aero	-	-	Y=30475.19-1142.99*Tmax	0.53
Gikongoro Met	Y=418.04-0.26*GDD-3.90*Season Length +3.70*Seasonal Rainfall	0.29	Y=162.89+4.66*Seasonal Rainfall +8.48*Tmax	0.13
Gisenyi Aero	Y=13326.50+3.55*Total Rainfall-515.53*Tmax	0.41	Y=-1282.27+6.57*Total Rainfall	0.34
Kamembe Aero	-	-	Y= 31238.12-1119.47*Tmax	0.29
Rubengera Met	Y=1388.92+10.21*Cessation+1717.72*Season Length +19.57*Trange	0.57	Y=162.89+4.66*Seasonal Rainfall+18.77*Tmin-13.87*Tmax	0.52
Byumba Met	Y=22098.71+1.41*Total Rainfall–1199.33*Tmax +6.60*GDD	0.54	Y=24539.16-2.959*Seasonal Length+31.52*Rainy Days -1105.03*Tmax	0.67
Rushashi	Y= 9092.92+18.40*Cessation-420.26*Tmax	0.57	Y=32100.44-1221.05*Tmax-63.19*Trange+7.02*Rainy Days	0.63
Busogo-Isae	Y=4180.04-0.26*GDD-1176.27*Tmax	0.51	Y=20272-52.32*Season Length+1.47*Seasonal Rainfall+8.48*Tmax	0.13
Nyagatare	Y= 9558.27+40.40*Cessation-601.98*Tmax+3.04*GDD	0.45	Y=18962.95-577.11*Tmax-82.70*Trange	0.32
Kawangire	-	-	-	-
Kibungo-Kazo	Y=26349.10-1312.30*Tmax+9.44*GDD-12.60*Rainy Days + 2.73*2.73*Total Rainfall	0.45	Y=15751.23+333.73*Tmin-628.62*Tmax-7.07*Total Rainfall	0.70

Coefficient of determination (R^2) is identifying the relationship between maize yield and characteristics of rainfall or temperature, which shows a significant correlation, except at stations where the correlation analysis shown no signs, including, Kawangire (season A and B), Butare (season A) and Kamembe (season A). In Table 9 above, the results from the observed stations show a strong relationship, the coefficient of determination is more than 50% in more than a half of the selected stations, and this can explain the variability of maize yield according to different climate characteristics of rainfall and temperature in different areas across the country. Since there are other factors that affect crop yield other than climatic characteristics, and the large area covered by the station, the performance of the models in different areas is not expected to have exact features which other despite being in the some homogeneous climate zone. Some of the other factors that may affect maize yield apart from climate characteristics include pests and disease control, soil characteristics, utilization and availability of resources including fertilizers and farming practices.

4.6 Assessing the Impact of Climate Variability and Change on Maize Yield

In the assessment of the effect of future climate variability and change on maize yield, the AquaCrop model was used. The climate variation refers to the inter-annual variation of rainfall and temperature in representative stations, where each province is represented by one station. The representative stations include the Busogo, Kawangire, Gikongoro and Rubengera, representing northern, Eastern, southern and western province respectively. The AquaCrop model uses different input, including climate input (rainfall, maximum temperature, minimum temperature, reference evaporation and carbon dioxide concentration), Crop characteristics and Soil characteristics.

4.6.1 CORDEX Model Performance Evaluation

This study used two methods to evaluate the performance of Rossyby Center Regional Atmospheric Model (RCA4) driven Global circulation model (GCMs) to simulate the observed rainfall and temperature. The methods included root mean square error calculated using equation (8) and Bias which is given by equation (9). Different meteorological stations given in Table 3 were used to assess the performance of this model in simulating temperature (maximum and minimum temperature) for the period of 1983- 2005 and the period of 1981- 2005 for rainfall simulation and the results are shown in Table 10 for temperature and Table 11 for rainfall.

Table 10: Validation of RCA4 driven GCMs temperature

Station Name	Maximum Temperature				Minimum Temperature			
	ICHEC		MPI		ICHEC		MPI	
	RMSE	Bias	RMSE	Bias	RMSE	Bias	RMSE	Bias
Mageragere	2.6	-2.0	1.7	-0.9	3.3	-3.2	2.3	-2.2
Butare Aero	3.4	-2.9	2.3	-1.8	2.9	-2.6	2.0	-1.8
Gikongoro	1.9	-1.1	1.4	0.1	2.2	-1.7	1.3	-0.9
Byimana	3.3	-2.9	2.2	-1.7	2.8	-2.3	1.8	-1.3
Gisenyi	3.8	-3.4	2.4	-1.9	2.5	-2.1	1.4	-0.9
Kamembe	2.8	-2.2	1.8	-0.9	2.9	-2.7	1.7	-1.5
Rubengera	3.3	-2.8	2.2	-1.5	3.3	-3.0	2.3	-2.0
Byumba	1.6	0.8	2.5	2.1	1.7	-0.9	1.0	0.1
Rushashi	2.7	-2.2	1.7	-0.9	1.7	-0.5	1.2	0.4
Busogo	1.8	0.2	2.3	1.5	2.6	1.9	3.2	2.9
Nyagatare	3.1	-2.3	2.2	-0.9	3.4	-2.7	2.3	-1.7
Kawangire	2.9	-2.3	1.9	-1.0	2.6	-2.2	1.7	-1.3
Ngoma-Kazo	1.8	-0.9	1.5	0.3	2.1	-2.0	1.3	-1.1

The results above in Table 10, shows that RCA4 driven by MPI Model was performing well in simulating future temperature (maximum and minimum) in Rwanda. Among thirteen stations under the study, it is performing well for simulating Maximum temperature with RMSE ranging from 1.4 to 2.5 and most of the stations have Bias values closer to zero except Byumba station with 2.1 of Bias value whereas the RMSE values of ICHECH were ranging from 1.8 to 3.8 . Also for simulating Minimum temperature, MPI Model was performing well with RMSE ranging from 1.0 to 3.2. On the other hand 1.7 to 3.4 is the range for ICHECH Model.

Table 11: Validation of RCA4 driven GCMs rainfall

Station Name	Rainfall			
	ICHEC		MPI	
	RMSE	Bias	RMSE	Bias
Mageragere	1.6	-0.6	1.7	-0.6
Huye	4.0	1.9	4.6	2.1
Nyamagabe	4.1	1.6	4.7	1.8
Ruhango	3.0	1.1	3.3	1.2
Rubavu	3.3	1.1	3.7	1.5
Rusizi	2.4	-1.8	2.5	-1.7
Karongi	2.9	0.9	3.1	1.0
Gicumbi	2.3	0.6	2.5	0.8
Gakenke	2.3	0.3	2.5	0.5
Busogo	5.6	3.2	6.0	3.6
Nyagatare	1.5	0.6	1.5	0.7
Kayonza	2.1	0.9	2.3	1.0
Ngoma-Kazo	1.4	-0.5	1.5	-0.4

From the results above in Table 11, it can be observed that RCA4 driven by ICHECH Model was performing well in simulating future rainfall compared to MPI. In all stations under the study, it is performing well for simulating rainfall with RMSE ranging from 1.5 to 5.6 with lowest value in Nyagatare and the highest value in Busogo. Whereas the RMSE values of MPI were ranging from 1.5 to 6.0. The Bias values were ranging from -1.8 to 3.2 for ICHECH and from -1.7 to 3.6 for MPI Model.

Generally, MPI model performed better compared to ICHEC model in simulating daily temperature and ICHECH performed better than MPI in simulating daily rainfall. Therefore, the study used temperature projection datasets from the MPI model and rainfall projection datasets from the ICHECH model to evaluate the impacts of future climate change and variability on maize yields over Rwanda.

4.6.2 Aquacrop validation

In calibration of the AquaCrop, climate parameters of 33 years from 1983 to 2016 were used as a base period, but in comparison of simulated yield and observed yield this study used 10 years because the observed maize yield, were from 2007 to 2017. The comparison between simulated yield from AquaCrop and observed yield are shown in Table 12.

Table 12: comparison between observed and simulated maize yield for evaluation of AquaCrop

Years	Busogo (North)		Gikongoro (South)		Kawangire (East)		Rubengera (West)	
	Observed Maize Yield	Simulated Maize Yield	Observed Maize Yield	Simulated Maize Yield	Observed Maize Yield	Simulated Maize Yield	Observed Maize Yield	Simulated Maize Yield
2007	900	1685	600	1559	600	1529	700	1534
2008	1200	2100	1100	1611	2500	1878	700	1566
2009	3500	2805	2987	1574	1500	2170	1000	1625
2010	3281	2733	1794	2325	2000	2054	1892	2527
2011	3233	2892	1803	2384	1730	2066	1892	2563
2012	3200	2738	1956	2351	2150	2068	1892	2539
2013	2977	2668	1752	2300	1887	2165	2106	2521
2014	1118	1726	1615	2365	1619	2077	1901	2358
2015	1231	2189	1750	2456	1729	2121	2543	2521
2016	1750	2548	1230	2147	1985	2037	1750	2541

The results above show the comparison between the observed maize yield in Busogo, Nyamagabe, Kawangire and Rubengera. It can be observed that the maize yields simulated by AquaCrop model are higher than the maize observed in Gikongoro, Kawangire and Rubengera, on the other hand the observed maize yield in Busogo are higher compared to the simulated maize yield in that area.

Correlation and regression analysis were carried out to show the relationship between observed maize yield and simulated maize yield from AquaCrop; results are given in Table 13.

Table 13: Correlation and regression analysis between observed maize yield and simulated maize yield from AquaCrop

Study Area	Correlation Coefficient	R^2 (Coefficient of Determination)
Busogo	0.92	0.85
Gikongoro	0.15	0.02
Kawangire	0.54	0.29
Rubengera	0.93	0.86

The analysis shows a high positive correlation between observed maize yield and simulated maize yield in season A (September to January) in Busogo, Rubengera and Kawangire with a correlation coefficient of 0.92, 0.93 and 0.54 respectively. The lowest correlation was observed in Gikongoro with 0.15 of correlation coefficients. The regression analysis also shows that the model is able to predict maize yield in Busogo up to 85%, 86% in Rubengera, 29% in Kawangire and 2% in Gikongoro. The values of Coefficient of determination (Table 13) showed that the variability in simulated maize yield by Aquacrop model is explained by the relationship between observed maize yield and simulated maize yield values. For that reason, Aquacrop model is 86% fit in prediction of maize yield in Rubengera, 85% fit for predicting maize yield in Busogo, 29% fit for predicting maize yield in Kawangire and 2% fit for predicting maize yield in Gikongoro.

This study performed the Mean Error for maize yield. The Mean Error which is the difference between simulated values and the true/observed values were negative in Busogo and positive in Gikongoro, Kawangire and Rubengera. The negative values of the Mean Error indicate that the AquaCrop model has under predicted maize yield and the values must be added to each simulated yield for adjustment. The positive values of the Mean Error indicate that the AquaCrop model has over predicted maize yield and the values must be subtracted from simulated maize yield. The observational error obtained in evaluation and calibration of the model was -169 kg/ha in Busogo, 448kg/ha, 246 kg/ha and 601kg/ha for Gikongoro, Kawangire and Rubengera respectively. Table 14 gives the true values of simulated maize yield in the study area.

Table 14: Simulated maize yield by AquaCrop model under future climate under RCP4.5 and RCP8.5 for Busogo, Gikongoro, Kawangire and Rubengera from 2021 to 2049

YEARS	BUSOGO		GIKONGORO		KAWANGIRE		RUBENGERA	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
2021	2406	2221	1982	1950	1780	1736	1976	1914
2022	2275	2078	1865	1896	1715	1721	1856	1854
2023	2281	1936	1838	1813	1753	1668	1870	1758
2024	2334	2039	1918	1864	1757	1697	1899	1812
2025	2260	2185	1982	1949	1746	1735	1861	1899
2026	2336	2128	1928	1958	1758	1735	1919	1907
2027	2092	2128	1785	1930	1691	1733	1728	1872
2028	2326	2021	1948	1896	1774	1696	1931	1802
2029	2857	1979	2008	1823	1796	1681	1997	1760
2030	2303	2183	1877	1967	1762	1749	1876	1916
2031	2286	2094	1900	1923	1778	1728	1896	1879
2032	2254	2181	1908	1970	1752	1761	1894	1923
2033	2506	2265	2075	2011	1836	1775	2053	1974
2034	2415	2147	2015	1943	1805	1749	2000	1893
2035	2376	2122	1983	1958	1780	1748	1959	1893
2036	2364	2152	1962	1956	1783	1731	1950	1907
2037	2460	2222	2044	1998	1829	1777	2040	1941
2038	2342	2312	1953	2055	1778	1802	1934	2018
2039	2428	2294	2031	2048	1809	1805	2011	2011
2040	2471	2263	2054	2011	1835	1795	2035	1978
2041	2300	2365	1945	2079	1784	1814	1935	2051
2042	2364	2296	2003	2072	1798	1816	1965	2026
2043	2414	2285	2036	2010	1831	1789	2020	1982
2044	2495	2153	2035	1961	1831	1748	2027	1906
2045	2368	2260	1983	2021	1796	1797	1948	1974
2046	2440	2232	2026	2026	1812	1802	2016	1986
2047	2394	2308	1996	2042	1803	1820	1975	2006
2048	2393	2355	2022	2115	1821	1817	1995	2073
2049	2908	2317	2089	2083	1850	1828	2076	2045
Average	2395	2190	1972	1977	1788	1760	1953	1930

The simulated future maize yield was in season September- January (2021-2049). The results of the average maize yield comparison between RCP4.5 and RCP8.5 showed that, the maize yield will reduced under RCP8.5 over Busogo by 8.6% (205kg/ha), while 1.6% (28kg/ha) will reduce over Kawangire and 1.2% (23kg/ha) at Rubengere. On the other hand, at Gikongoro, will be an increase in maize yield by 0.3% (5kg/ ha). Generally there will be a decrease in maize yield over the area of study due to climate change and variability.

4.6.3 Variation in climate parameter as an effect of climate change

The annual variation of future climatic parameters (rainfall, maximum temperature and minimum temperature) due to the effect of climate change for Busogo, Gikongoro, Kawangire and Rubengera are shown in Table 15 and Figures 12, 13 and 14 show the annual variation of future climate data mentioned above. The comparison between the annual average of RCP4.5 and RCP8.5 for the period of 2021 to 2050 revealed that there is an increase in climate variability (rainfall, maximum and minimum temperature) in RCP8.5 compared to RCP8.5. The rainfall will be increased by 4.3% (98 mm) at Busogo, 2.8% (50 mm) at Gikongoro, 3.3% (36 mm) at Kawangire and 3.1% (41 mm) at Rubengera, while maximum temperature will increase by 1.7% (0.4 ^{0}C), 1.6% (0.4 ^{0}C), 1.5% (0.4 ^{0}C) and 1.2% (0.3 ^{0}C) at Busogo, Gikongoro, Kawangire and Rubengera respectively. The minimum temperature also, will be increased by 1.4% (0.2 ^{0}C) at Busogo, 1.4% (0.2 ^{0}C) at Gikongoro, 1.9% (0.3 ^{0}C) at Kawangire and 2.0% (0.3 ^{0}C) at Rubengera.

Table 15: Comparison between the Averages of future climate as result of climate change

Station name	RCP4.5	RCP8.5	Difference	Percentage (%)
Average of Rainfall (mm)				
Busogo	2279	2377	98	4.3
Gikongoro	1782	1832	50	2.8
Kawangire	1089	1125	36	3.3
Rubengera	1290	1331	41	3.1
Average of Maximum Temperature (^{0}C)				
Busogo	23.1	23.5	0.4	1.7
Gikongoro	24.4	24.8	0.4	1.6
Kawangire	27.2	27.6	0.4	1.5
Rubengera	24.5	24.8	0.3	1.2
Average of Minimum Temperature (^{0}C)				
Busogo	14.3	14.5	0.2	1.4
Gikongoro	14.1	14.3	0.2	1.4
Kawangire	15.4	15.7	0.3	1.9
Rubengera	14.5	14.8	0.3	2.0

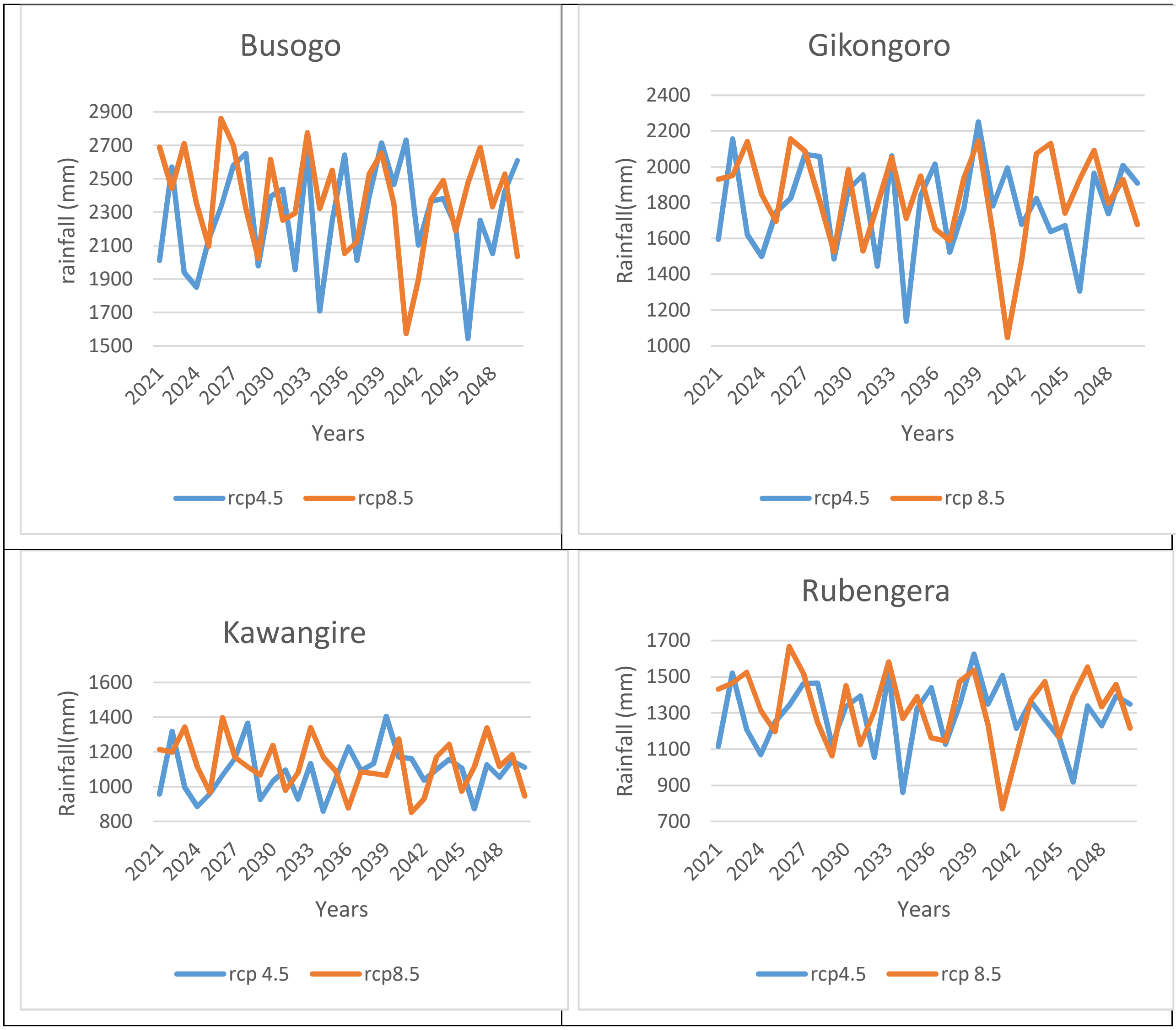

Figure 14: Annual variation of future rainfall in Busogo, Gikongoro, Kawangire and Rubengera for period of 2021 to 2050

Annual rainfall variation analysis shown in Figure 14 for Busogo, Nyamagabe, Kawangire and Rubegrera showed that there is much accumulation of arainfall in Busogo (North) compared to other selected sitations and less rainfall will be received in Kawangire (East). The variation in rainfall also shown that the difference between RCPs is not too much, but RCP8.5 has higher values compared to RCP4.5

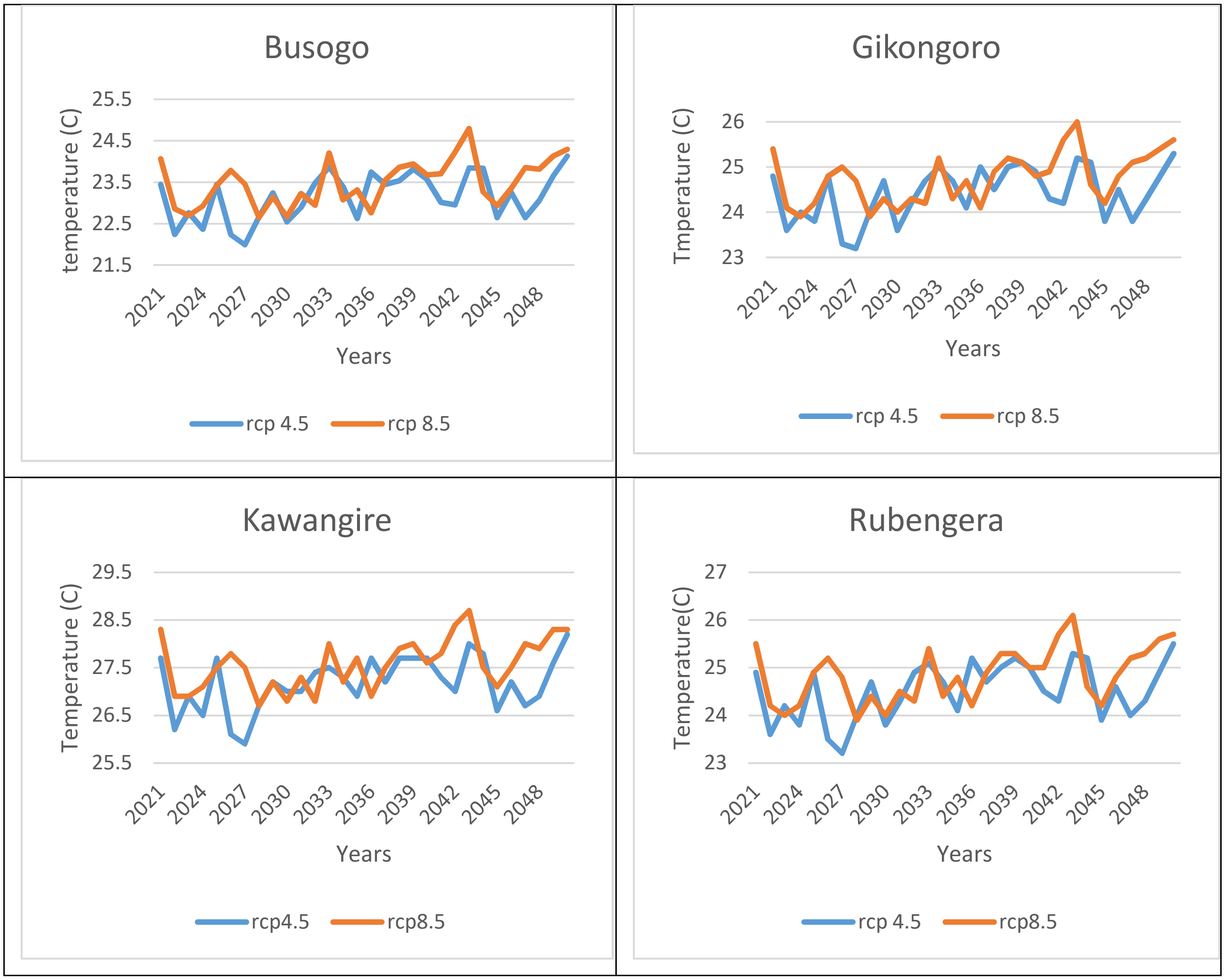

Figure 15: Annual variation of future maximum temperature in Busogo, Gikongoro, Kawangire and Rubengera for period of 2021 to 2050.

From Figure 15, it can be observed that the values of RCP8.5 are higher than the values of RCP4.5. Projected maximum temperature in RCP8.5 and RCP4.5 are increasing especial for the period of 2039 to 2050.

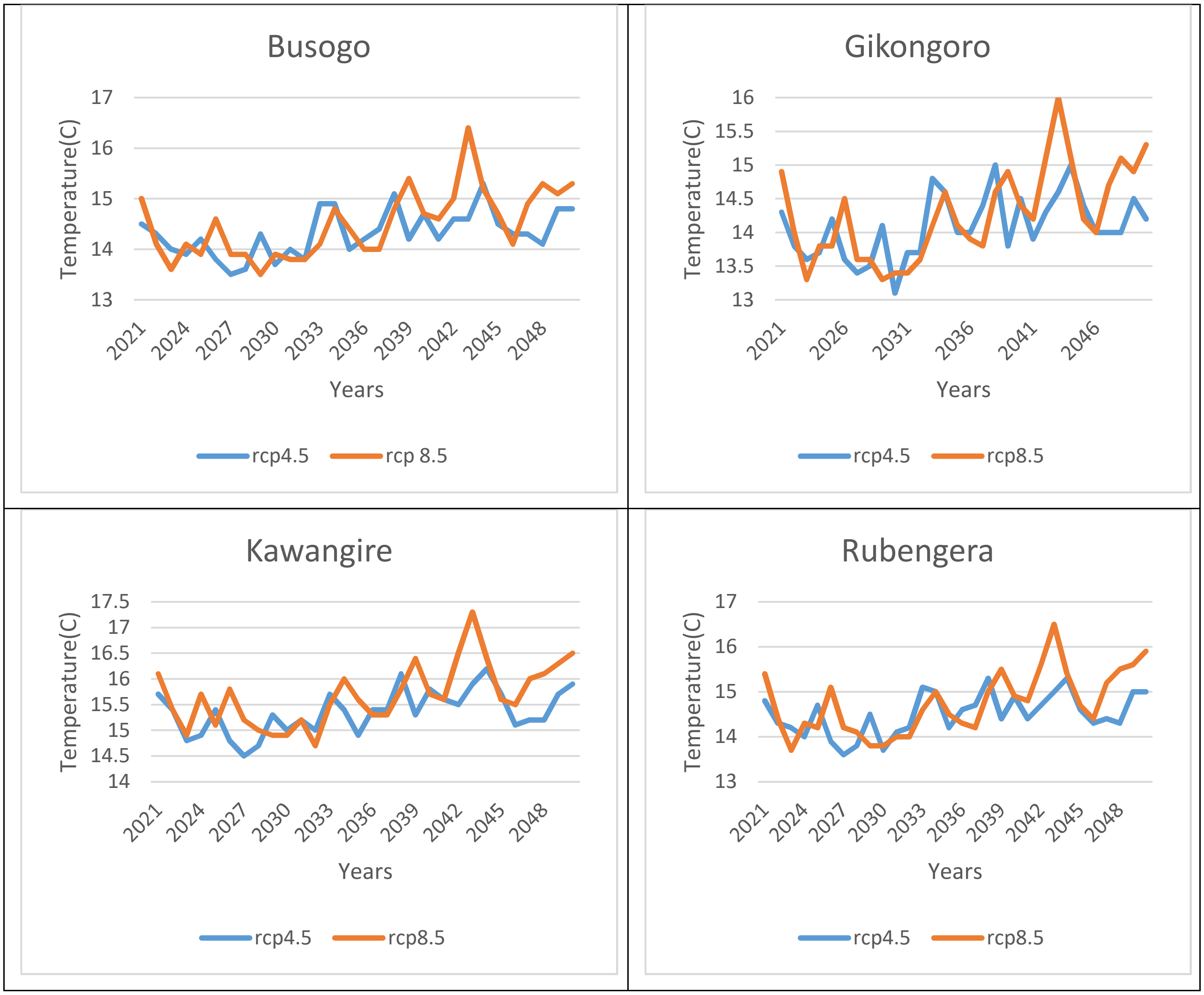

Figure 16: Annual variation of future minimum temperature in Busogo, Gikongoro, Kawangire and Rubengera for period of 2021 to 2050

From the results given in Figure 16 above, it can be observed that in Busogo, Gikongoro, Kawangire and Rubengera station, the projected minimum temperature is higher in RCP8.5 compared to RCP4.5 and the minimum temperature is increasing from the period of 2033 to 2050.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.0 Introduction

This chapter gives summary of all results, conclusions which come from different results found in the study and recommendations that can help farmers to mitigate the climate variability and change and recommendation to future research.

5.1 Conclusions

Based on the results of the research on this study, it can be concluded climate variability and change affected and will continue to affect the maize yield in the future. As temperature and rainfall have notably increased year by year and still is increasing and the variability in onset and cessation of the season, they may lead to pollen viability and water stress which direct to poor final maize yield and there were amounts of maize yield and area of production at a deceleration which could have been induced by climate variability and change. This can be the indicator of the importance of climate on crop production and agriculture sector in general.

Even if the output from AquaCrop model shows that this model over predicted maize yield in Gikongoro, Kawangire and Rubengera, the combination of climate model (CORDEX) and crop model (AquaCrop) for the future maize yield production revealed that climate change will greatly have negative impact on maize yield.

5.2 Recommendations

Bearing in mind the result of the study, the following recommendations were made:

1. This study showed that, there is increase of future climate parameters, there is a need of government policies and plans from in the direction of mitigation strategies and measures, such as campaigning on reducing the emission of green house gas in atmosphere, the use of

resources and their conservation in order to reduce the risks which could be resulted in climate variability and change.

2. This research focused on maize, meanwhile maize crop is not the only crop, contributing to agriculture production in the country. Scientists and researchers should carry out further research to other plant crops in order to mitigate with climate variability and change and increasing agriculture productivity. The models skills are not adequate to simulate the climate data over Rwanda, there is a need of studies on different models for simulating the climate data. The impacts of future climate variability and change would not be evaluated without climatic information, so the consistent projections of weather data from climate models are desirable. To combine both climate and crop models is a strong approach for producing information concerning different components. This holistic approach should be encouraged in the country.

3. Farmers could adapt a number of adaptation options including planting dates after onset of the rain season, introduction of varieties that are tolerant to high heat (climate resilience varieties) and the irrigation control system in dry areas where season length is short and rainfall amount is critical in order to avoid the effect of future climate on maize production.

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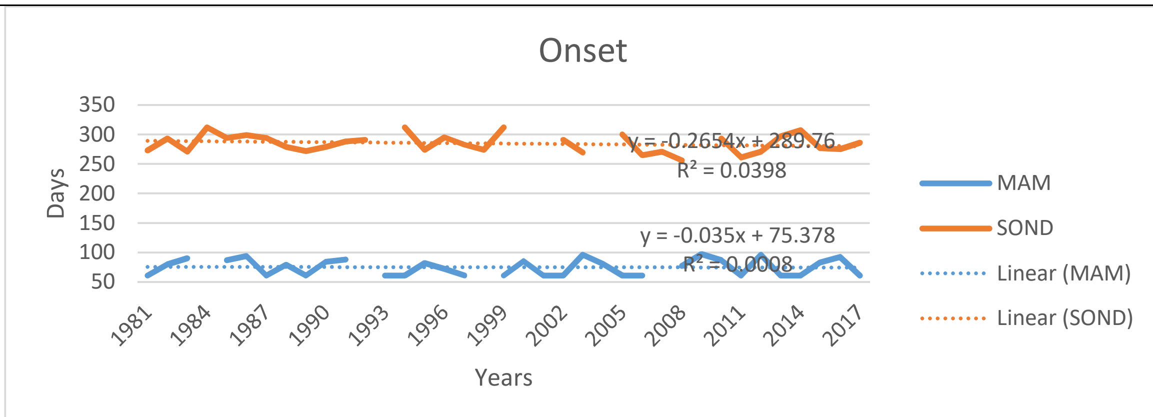
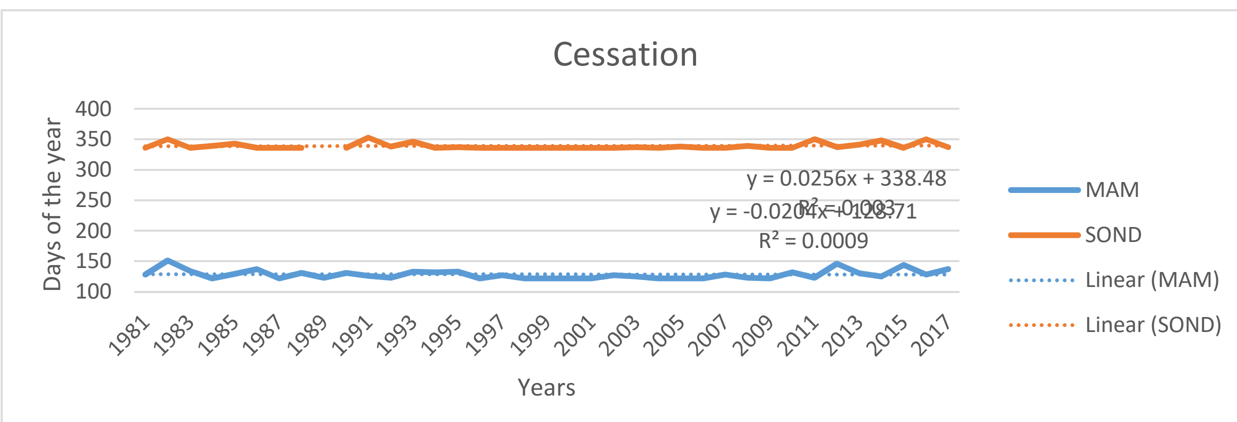
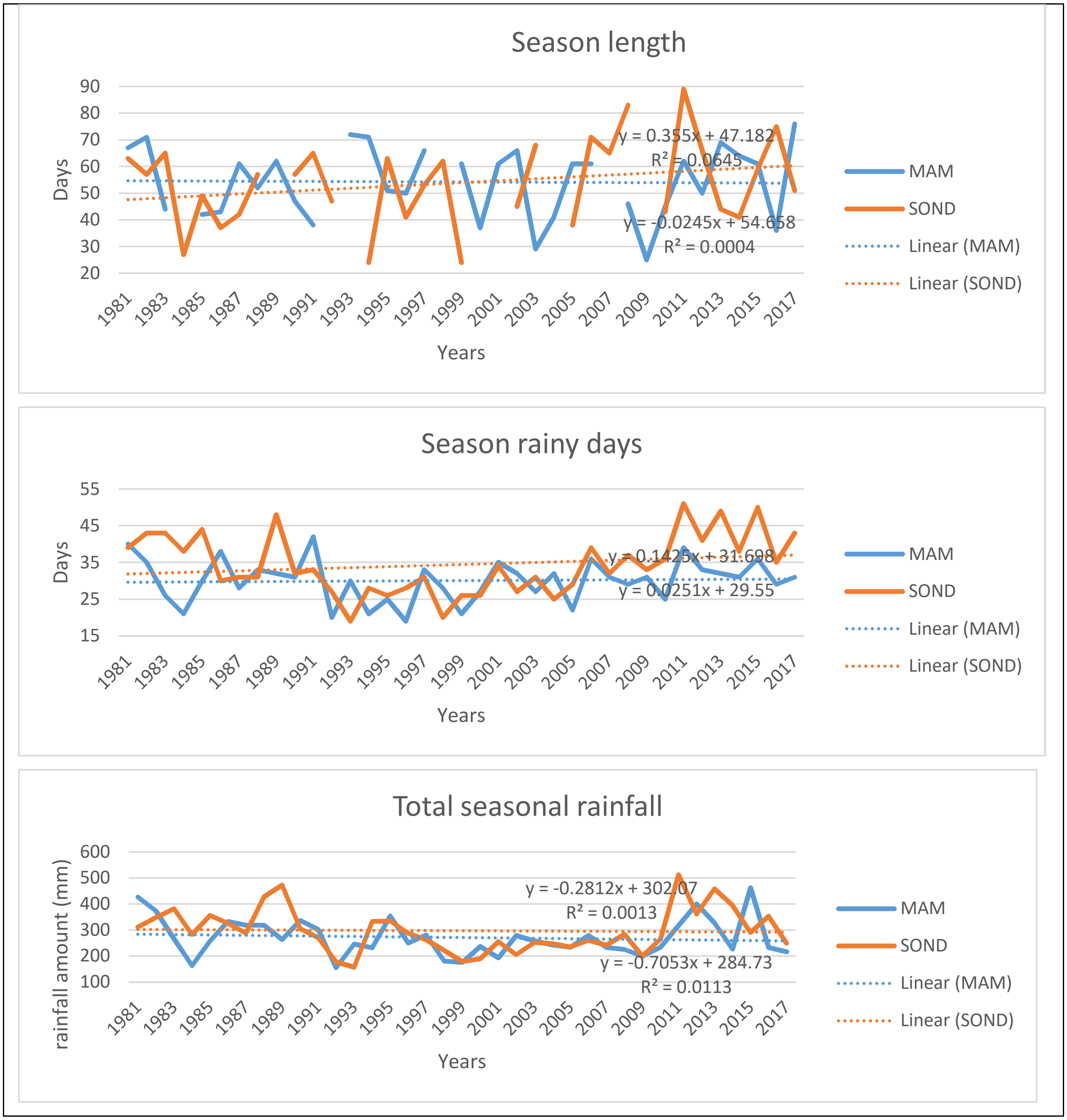
APPENDICES

AppendixI

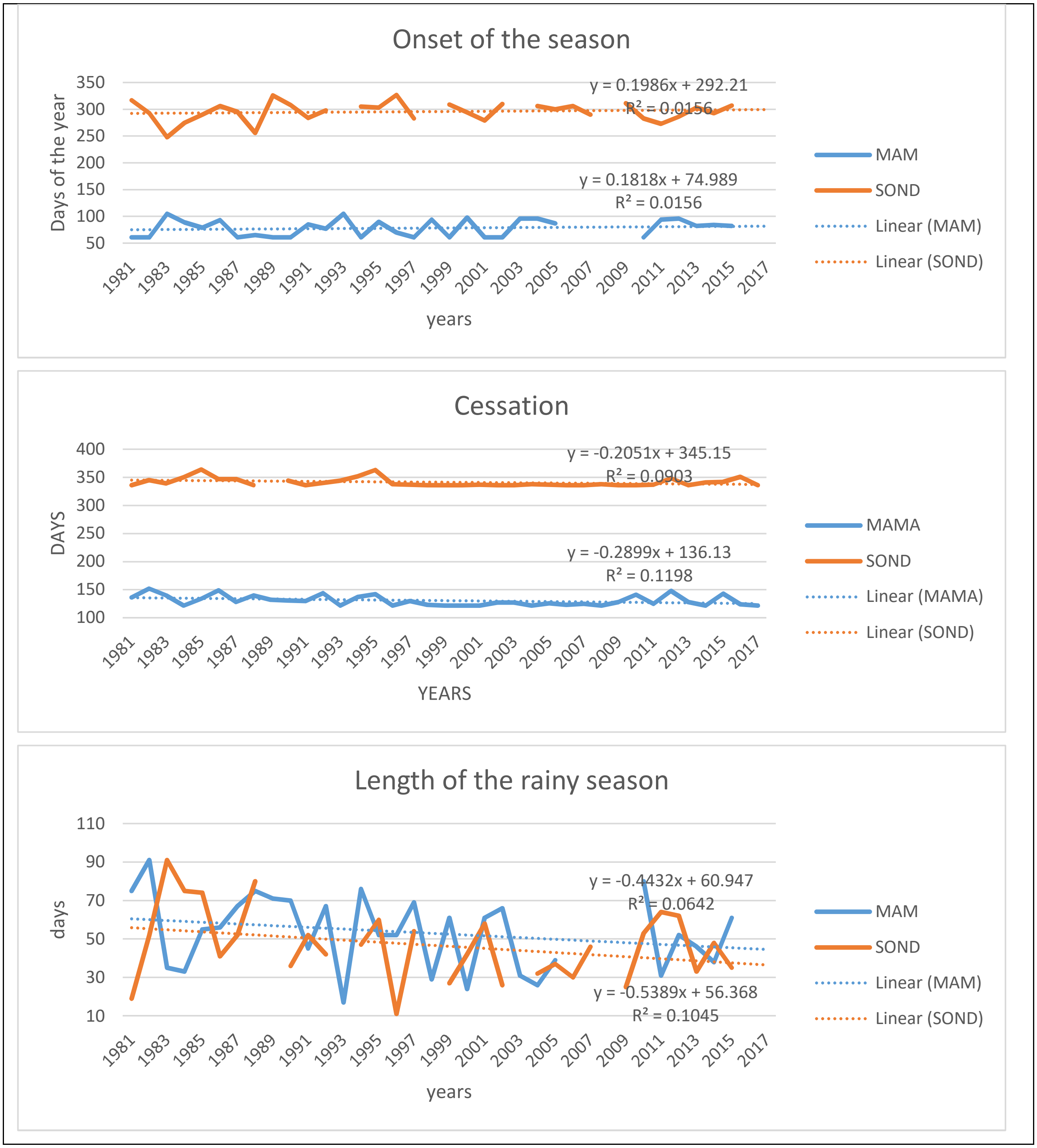
Seasonal trend analysis of rainfall characteristics (Onset, Cessation, Length of the season, rainy days and total seasonal rainfall) for Mageregere, Rubirizi, Masaka, Butare Aero, Gikongoro Met, Byimana, Gisenyi Aero, Kamembe Aero, Rubengera Met, Rushashi, Byumba Met, Nyagatare, Kawangire and Kibungo- Kazo.

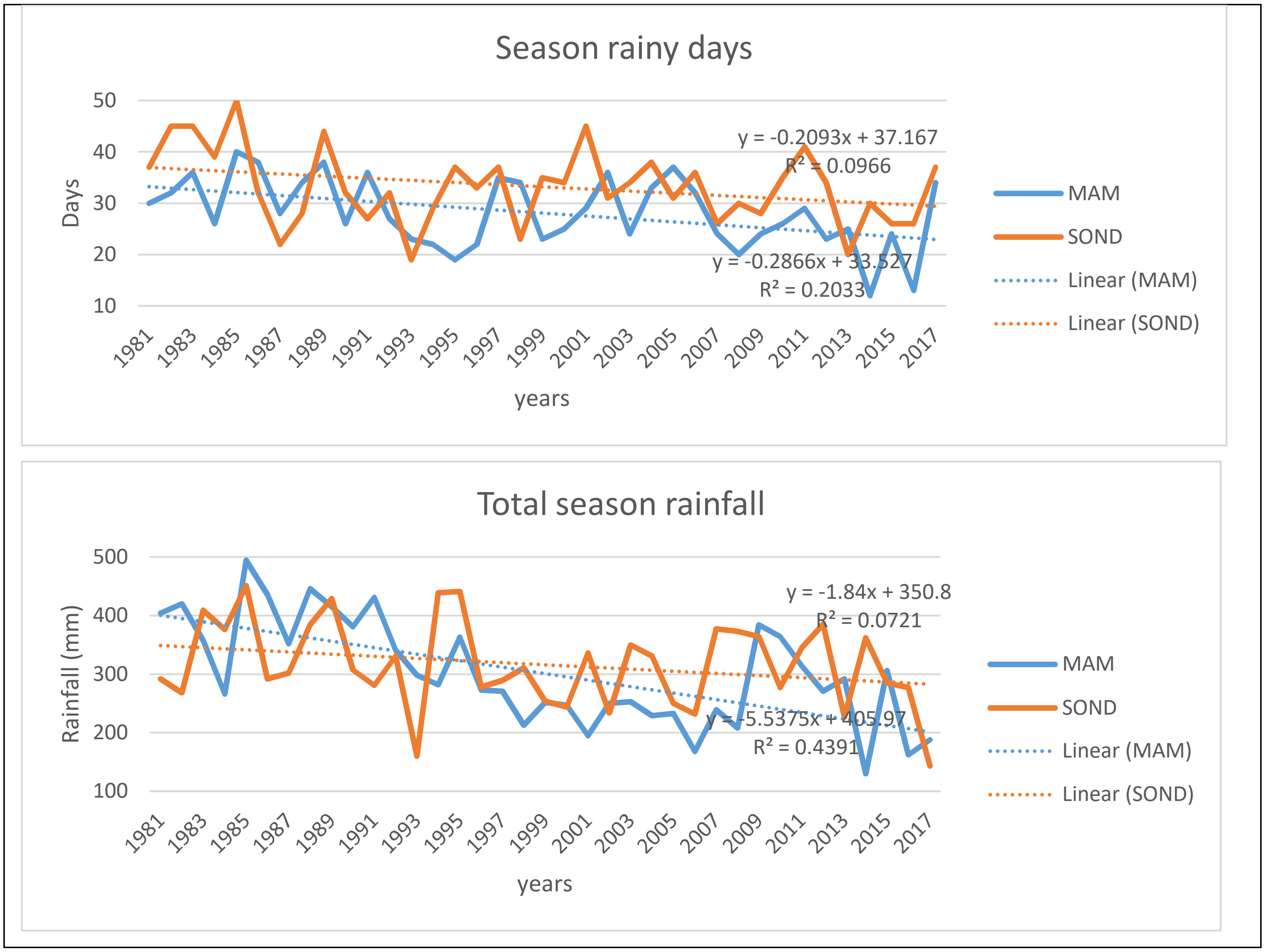




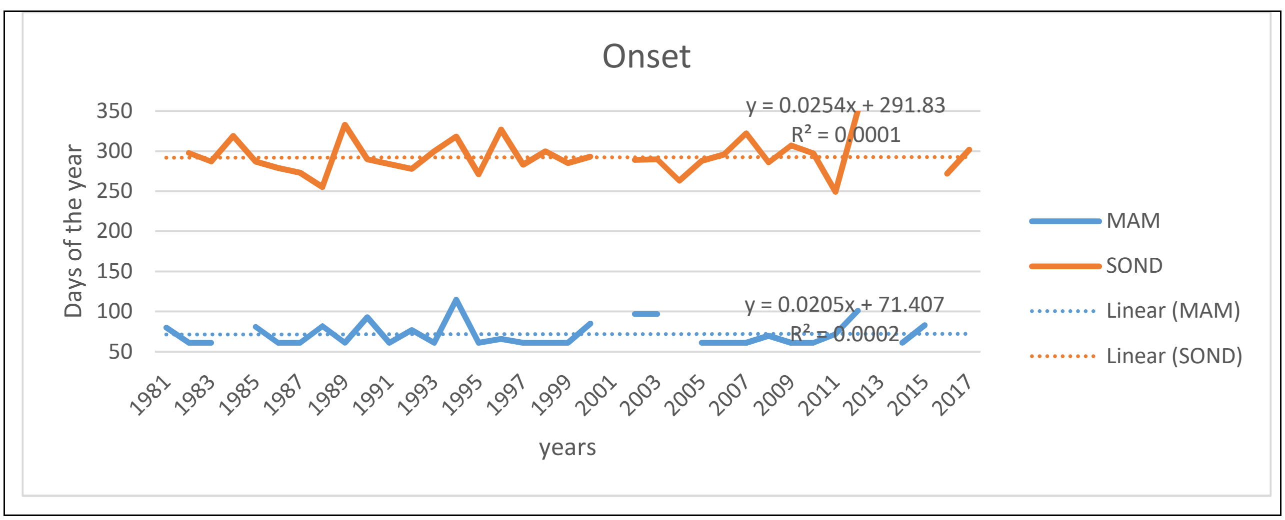


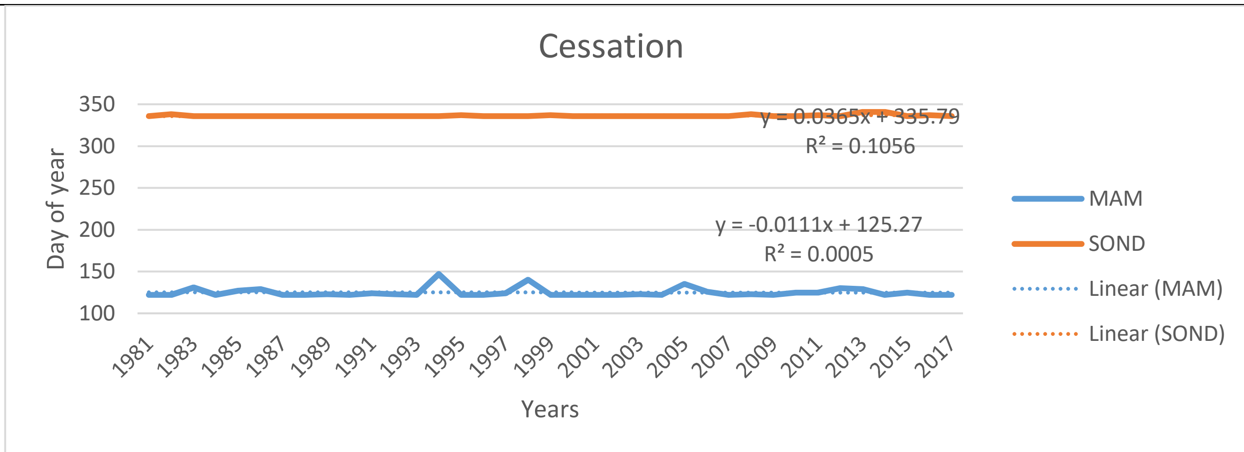
Seasonal trend analysis of Rainfall characteristics for Kawangire

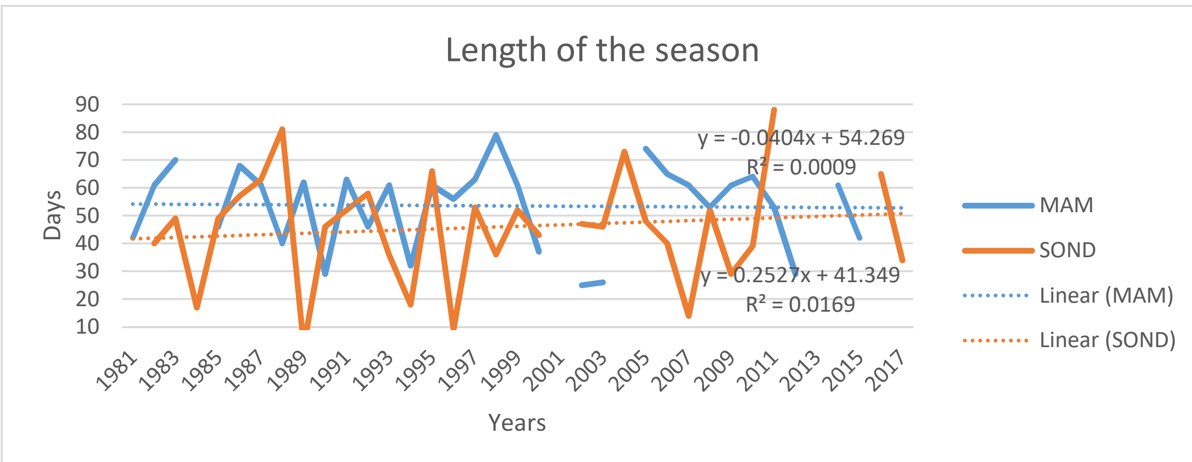

Onset of the season
Days of the year
350
300
250
200
150
100
50
y = 0.1986x + 292.21
R² = 0.0156
y = 0.1818x + 74.989
R² = 0.0156
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
years
MAM
SOND
Linear (MAM)
Linear (SOND)
Cessation
DAYS
400
350
300
250
200
150
100
y = -0.2051x + 345.15
R² = 0.0903
y = -0.2899x + 136.13
R² = 0.1198
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
YEARS
MAMA
SOND
Linear (MAMA)
Linear (SOND)
Length of the rainy season
days
110
90
70
50
30
10
y = -0.4432x + 60.947
R² = 0.0642
y = -0.5389x + 56.368
R² = 0.1045
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
years
MAM
SOND
Linear (MAM)
Linear (SOND)

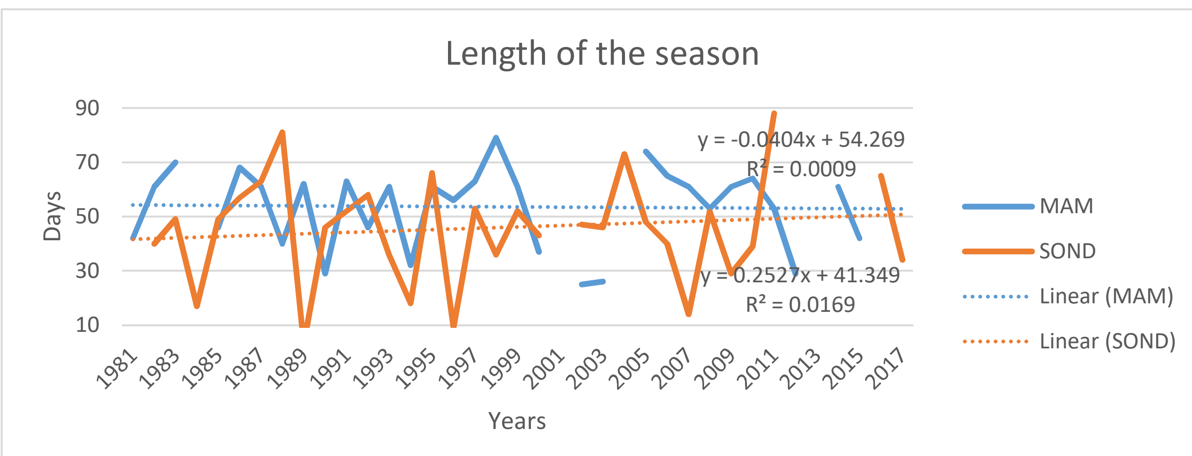


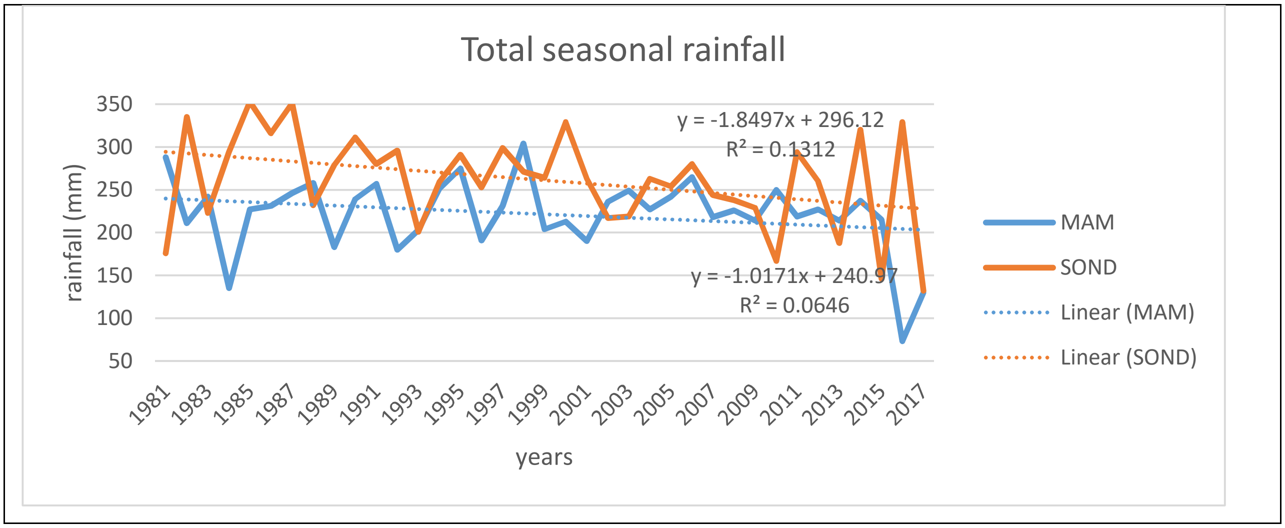
Seasonal trend analysis of Rainfall characteristics for Kibungo-Kazo



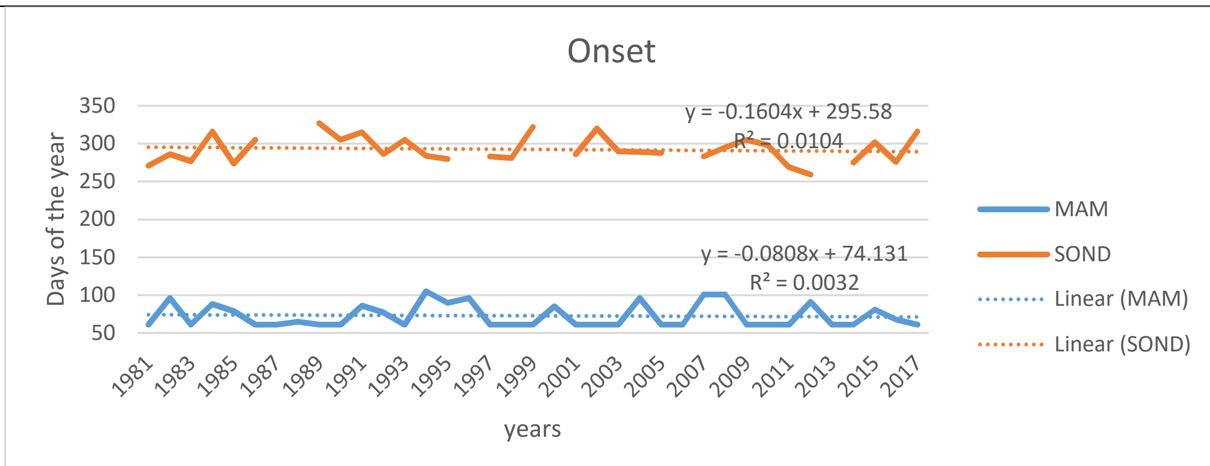

Cessation
350
300
250
200
150
100
Day of year
y = 0.0365x + 335.79
R² = 0.1056
y = -0.0111x + 125.27
R² = 0.0005
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
Years
MAM
SOND
Linear (MAM)
Linear (SOND)

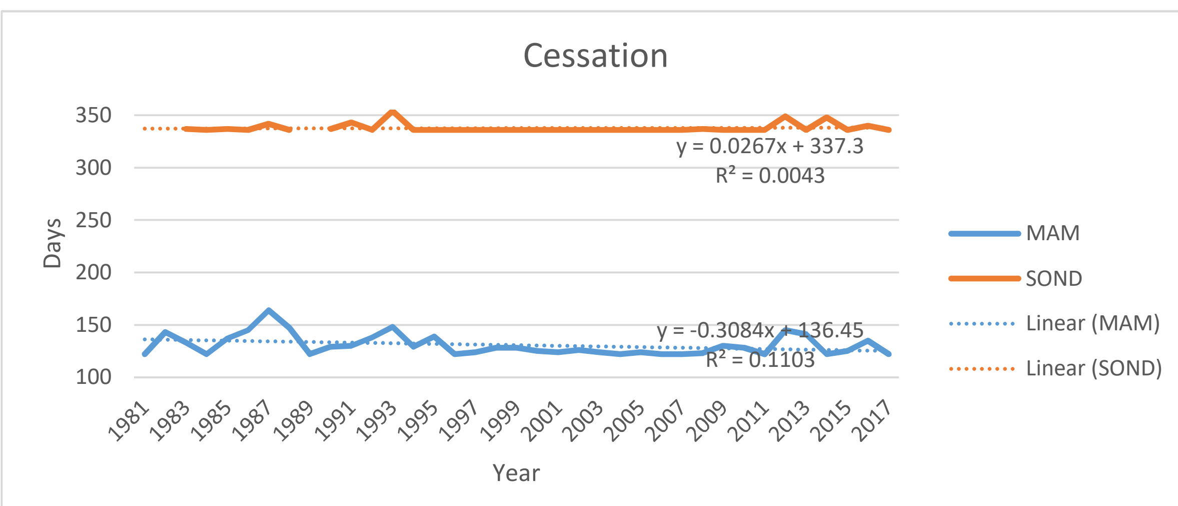

Length of the season
90
80
70
60
50
40
30
20
10
Days
y = -0.0404x + 54.269
R² = 0.0009
y = 0.2527x + 41.349
R² = 0.0169
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
Years
MAM
SOND
Linear (MAM)
Linear (SOND)

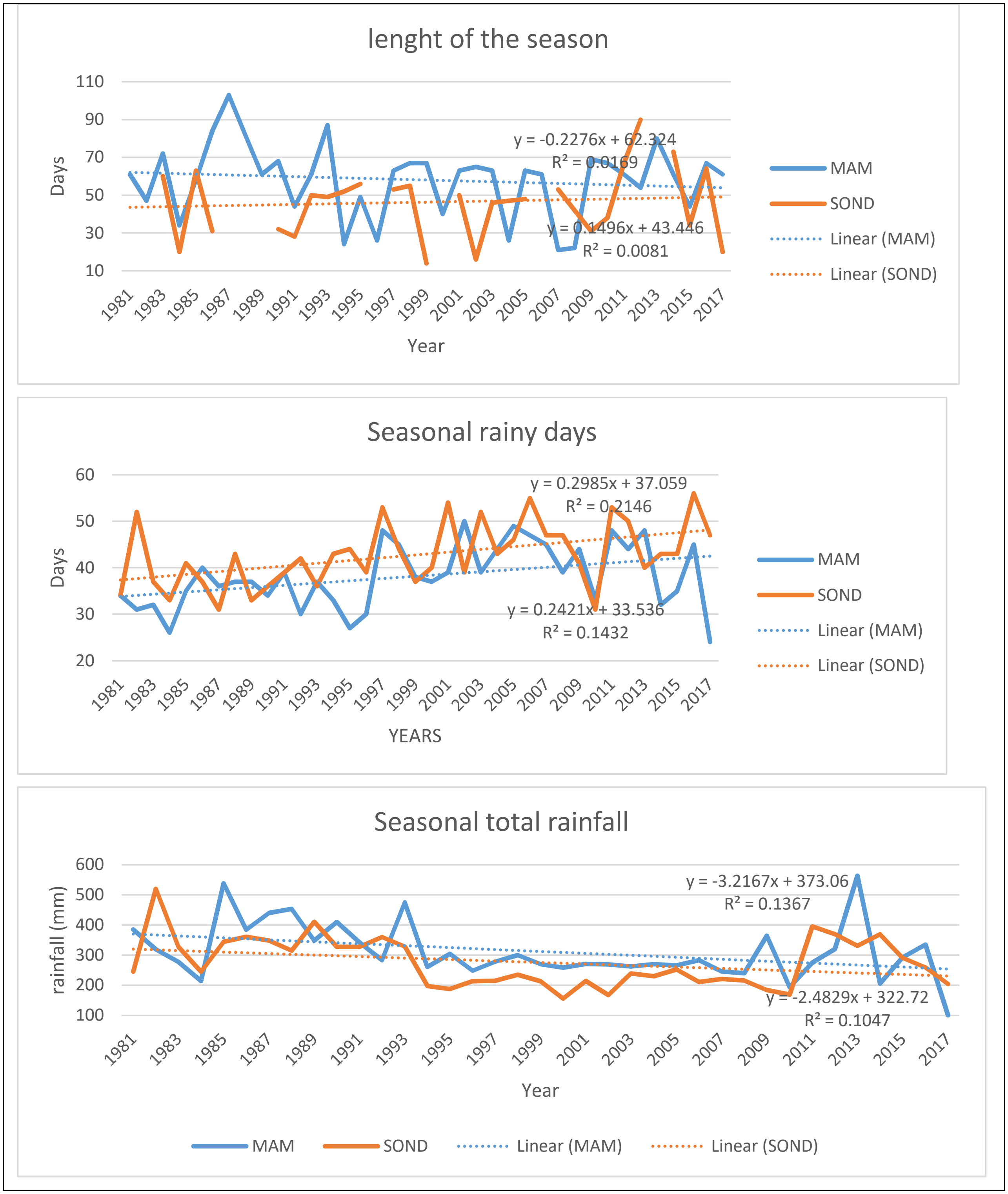

Length of the season
90
70
50
30
10
Days
y = -0.0404x + 54.269
R² = 0.0009
y = 0.2527x + 41.349
R² = 0.0169
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
Years
MAM
SOND
Linear (MAM)
Linear (SOND)



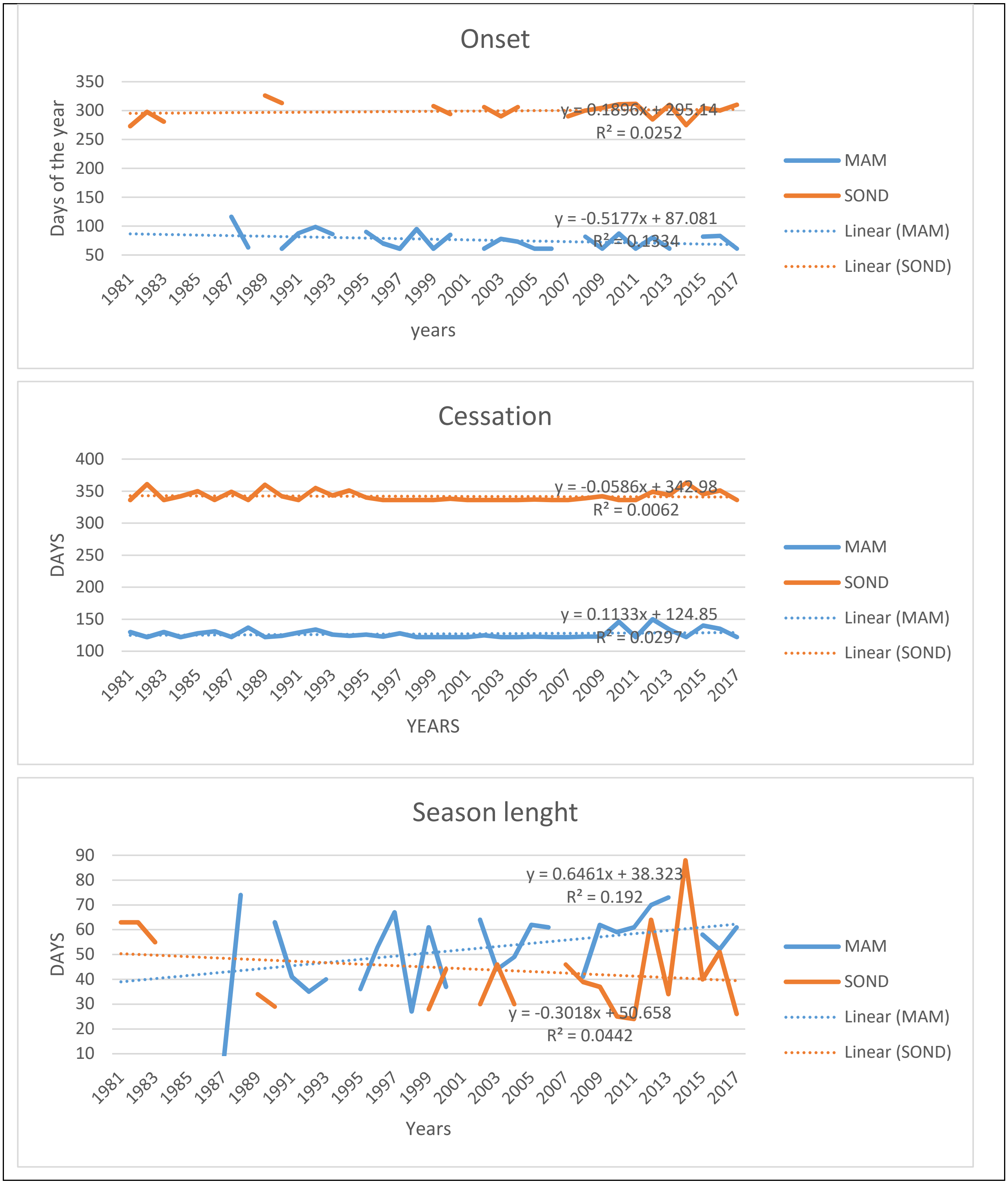
Seasonal trend analysis of Rainfall characteristics for Nyagatare

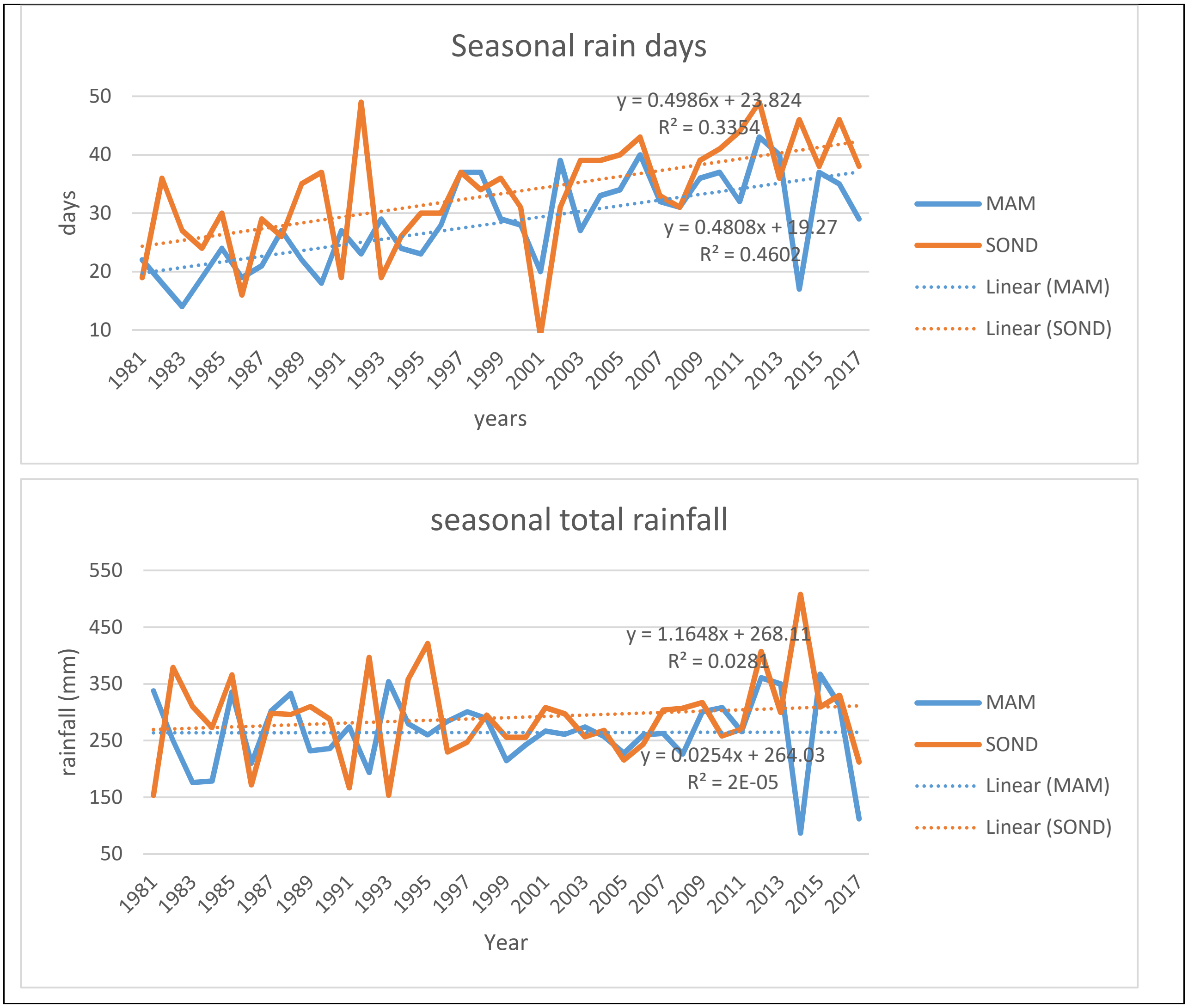




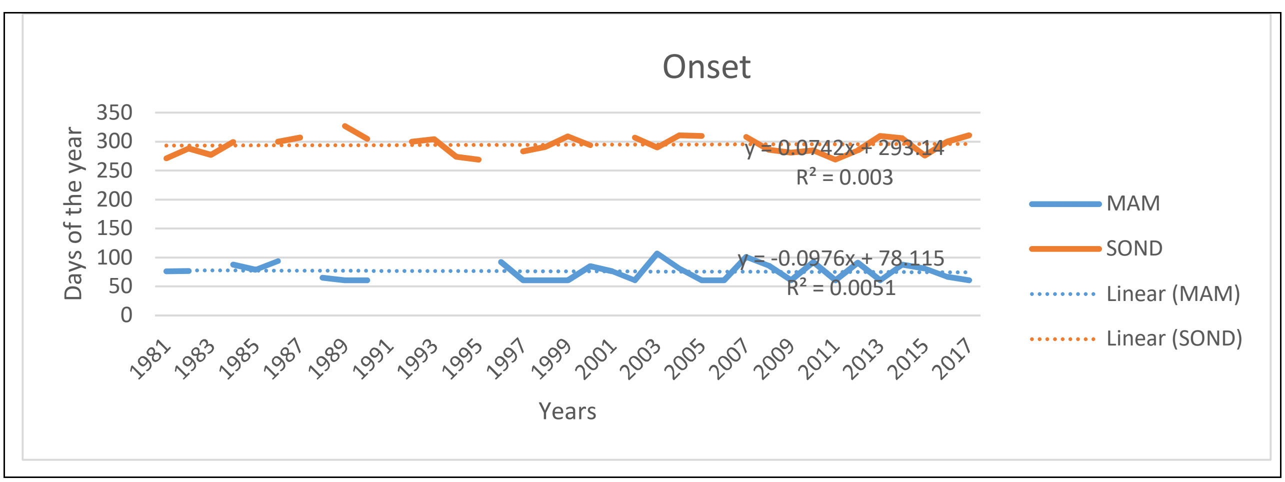


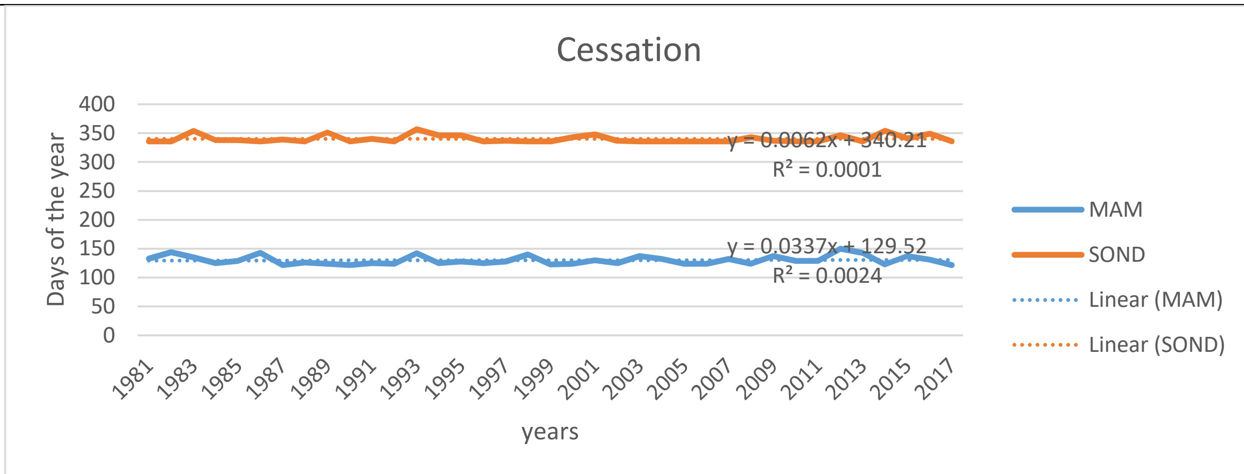
Seasonal trend analysis of Rainfall characteristics for Mageragere

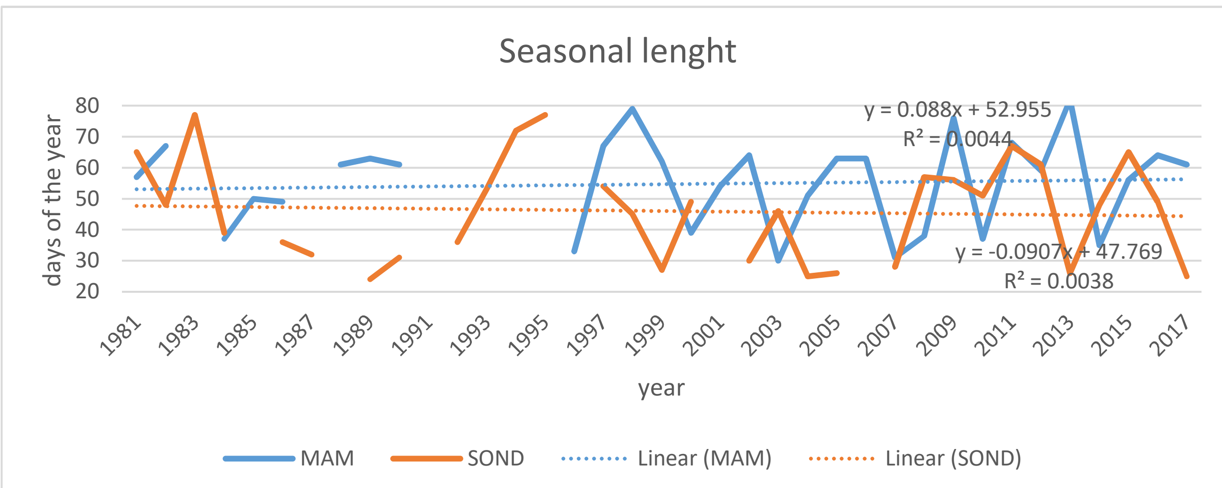

Onset
Days of the year
350
300
250
200
150
100
50
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
years
y = 0.1896x + 295.14
R² = 0.0252
y = -0.5177x + 87.081
R² = 0.1334
MAM
SOND
Linear (MAM)
Linear (SOND)
Cessation
DAYS
400
350
300
250
200
150
100
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
YEARS
y = -0.0586x + 342.98
R² = 0.0062
y = 0.1133x + 124.85
R² = 0.0297
MAM
SOND
Linear (MAM)
Linear (SOND)
Season lenght
DAYS
90
80
70
60
50
40
30
20
10
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
Years
y = 0.6461x + 38.323
R² = 0.192
y = -0.3018x + 50.658
R² = 0.0442
MAM
SOND
Linear (MAM)
Linear (SOND)

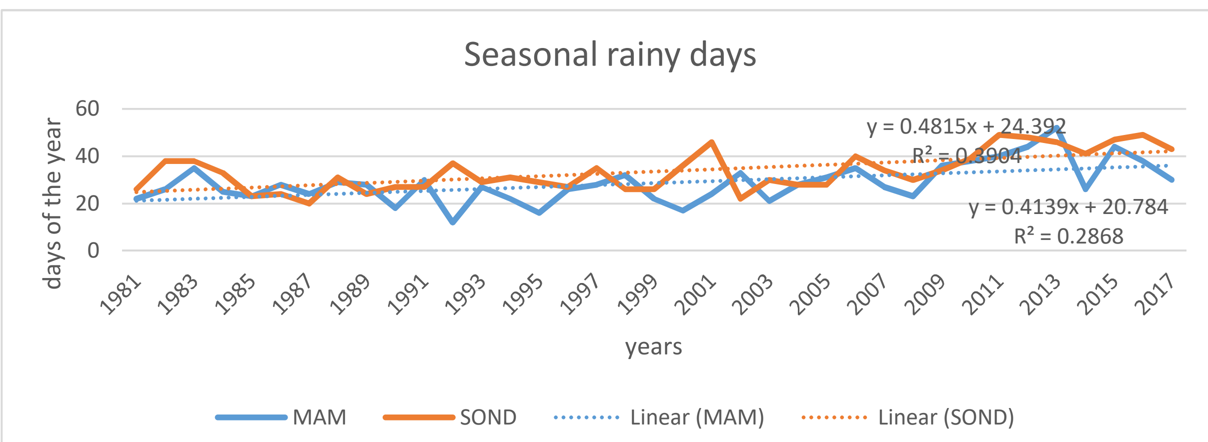


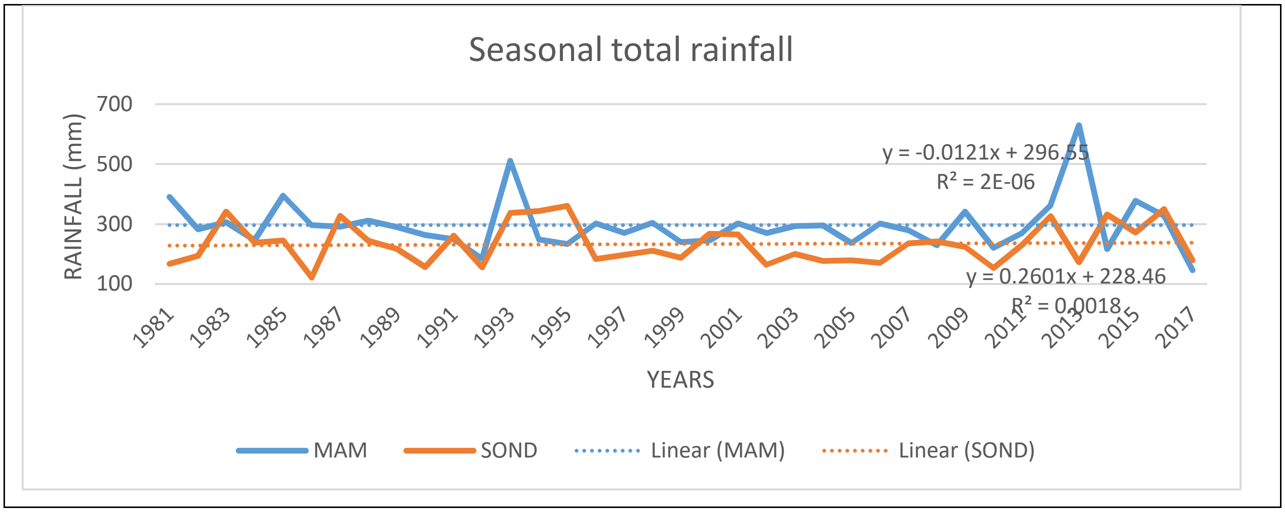
Seasonal trend analysis of Rainfall characteristics for Masaka



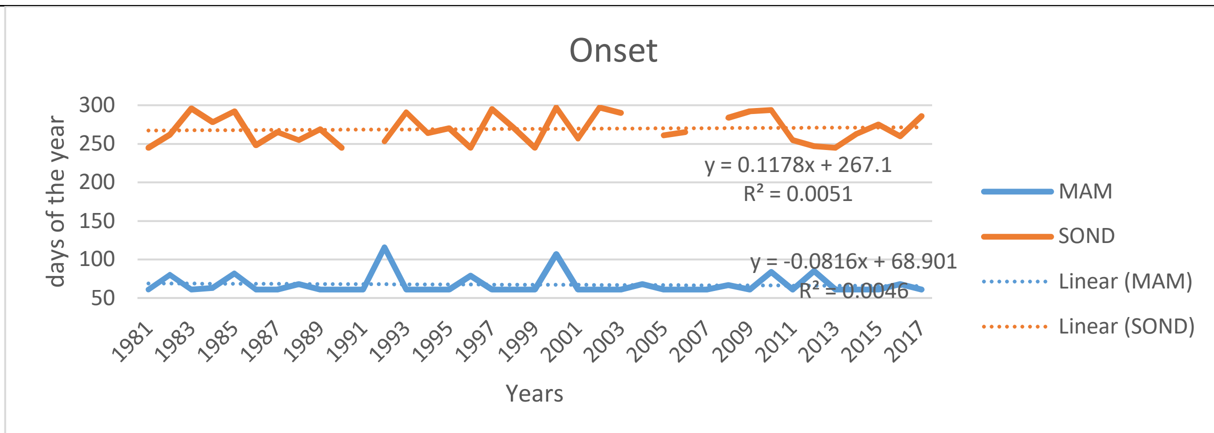

Cessation
Days of the year
400
350
300
250
200
150
100
50
0
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
years
y = 0.0062x + 340.21
R² = 0.0001
y = 0.0337x + 129.52
R² = 0.0024
MAM
SOND
Linear (MAM)
Linear (SOND)

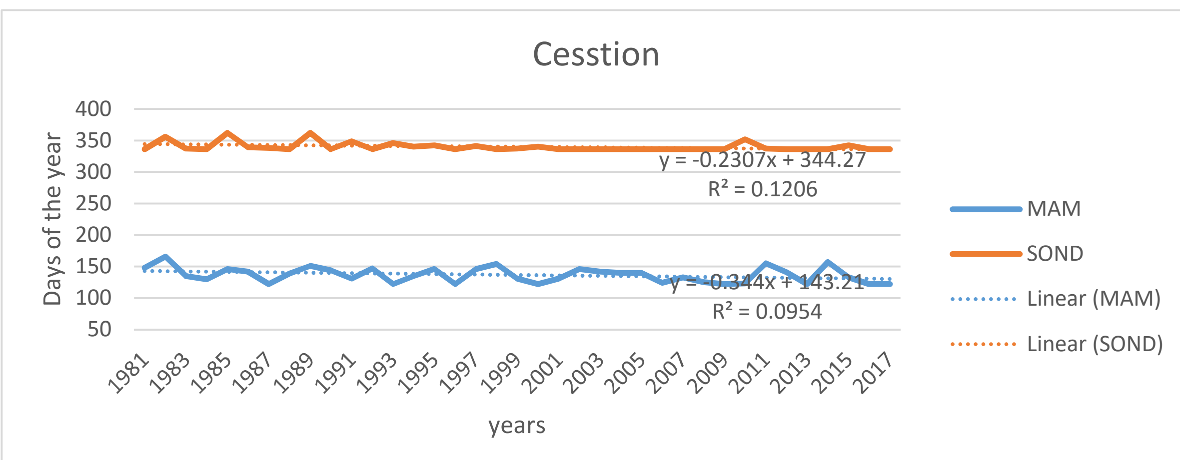

Seasonal lenght
days of the year
80
70
60
50
40
30
20
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
year
y = 0.088x + 52.955
R² = 0.0044
y = -0.0907x + 47.769
R² = 0.0038
MAM
SOND
Linear (MAM)
Linear (SOND)

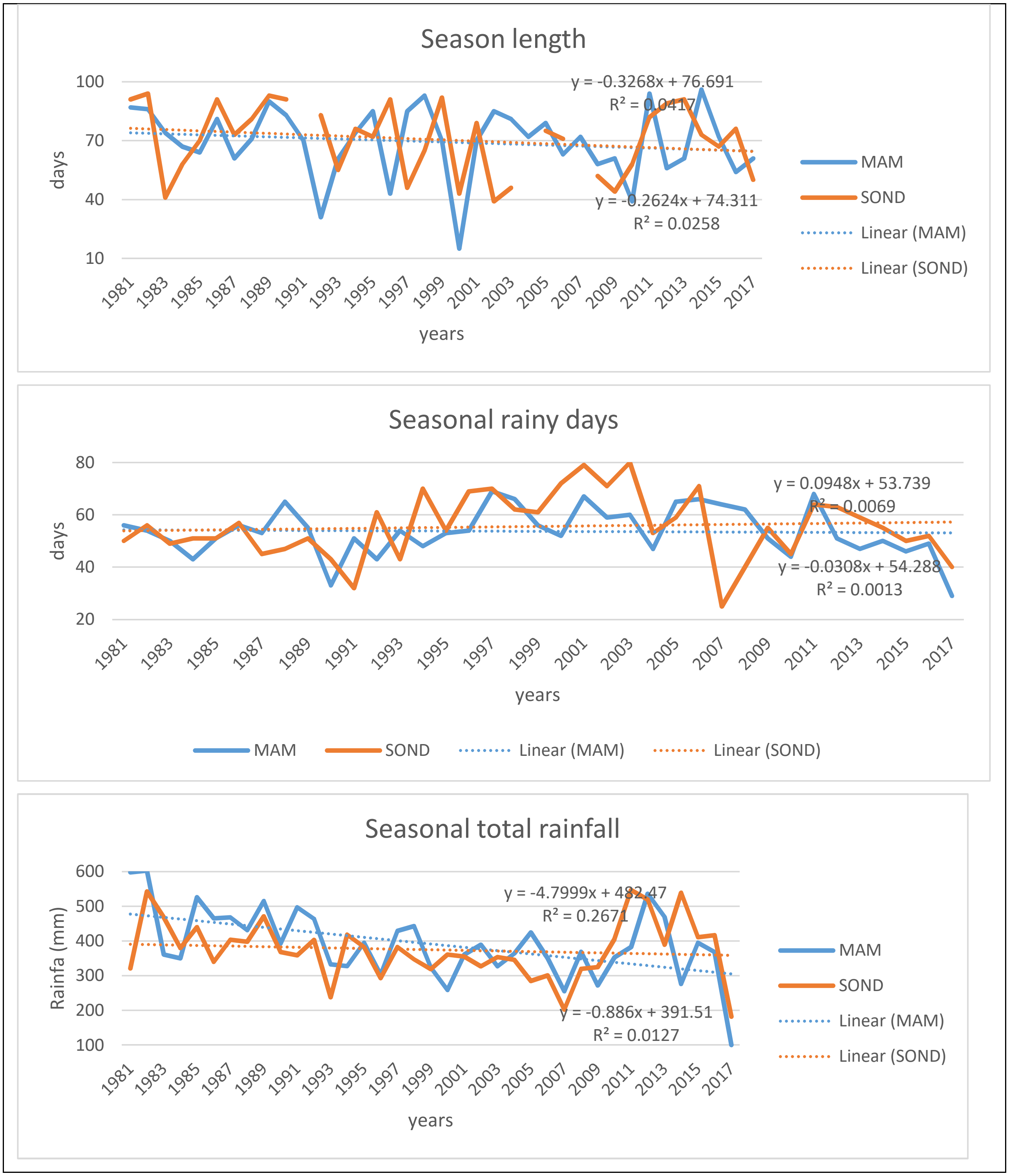

Seasonal rainy days
days of the year
60
40
20
0
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
years
y = 0.4815x + 24.392
R² = 0.3904
y = 0.4139x + 20.784
R² = 0.2868
MAM
SOND
Linear (MAM)
Linear (SOND)



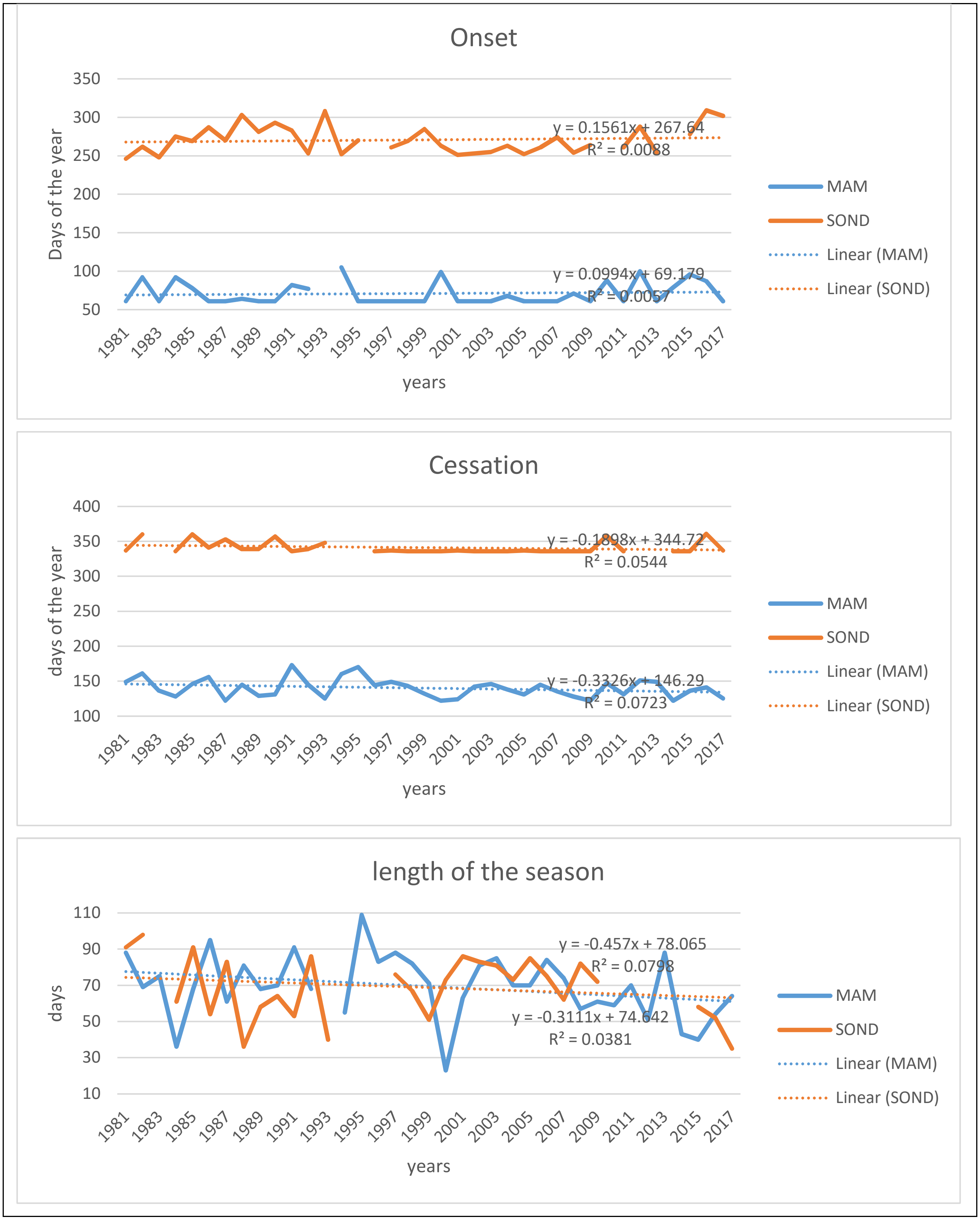
Seasonal trend analysis of Rainfall characteristics for Rubirizi

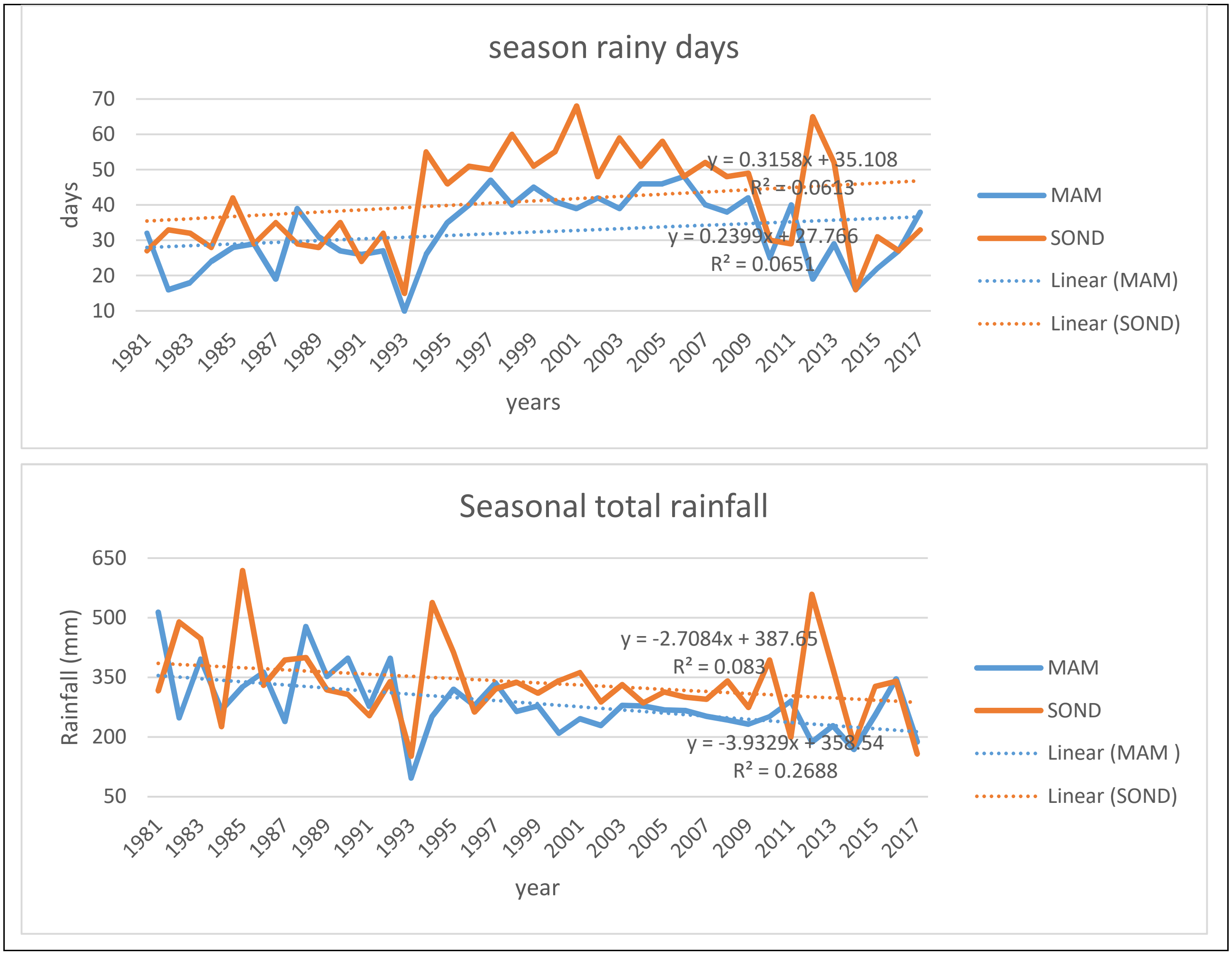




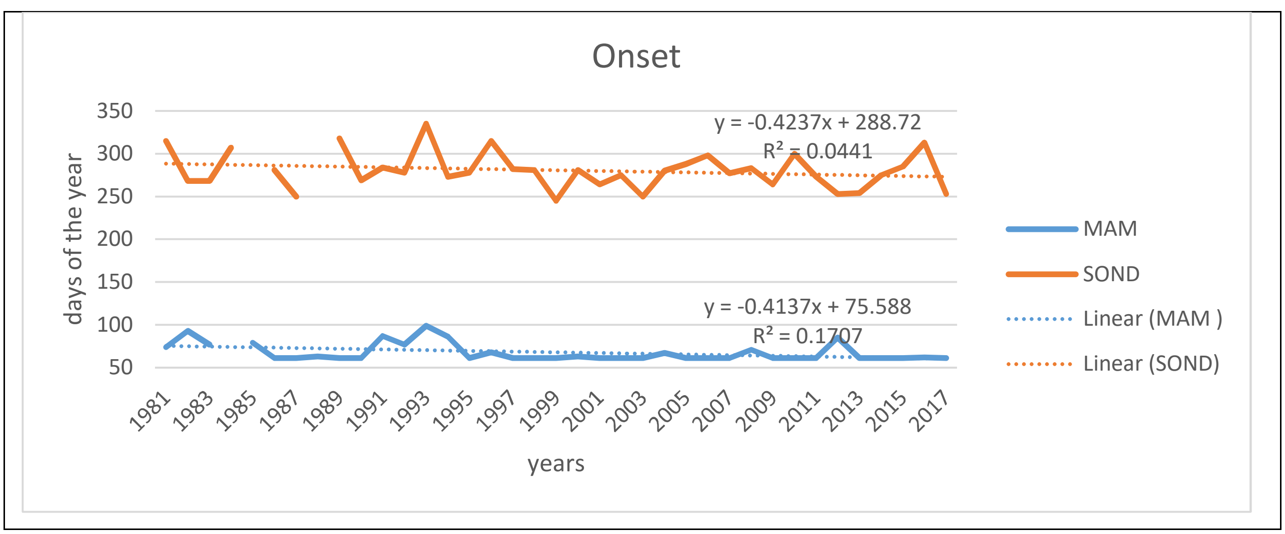


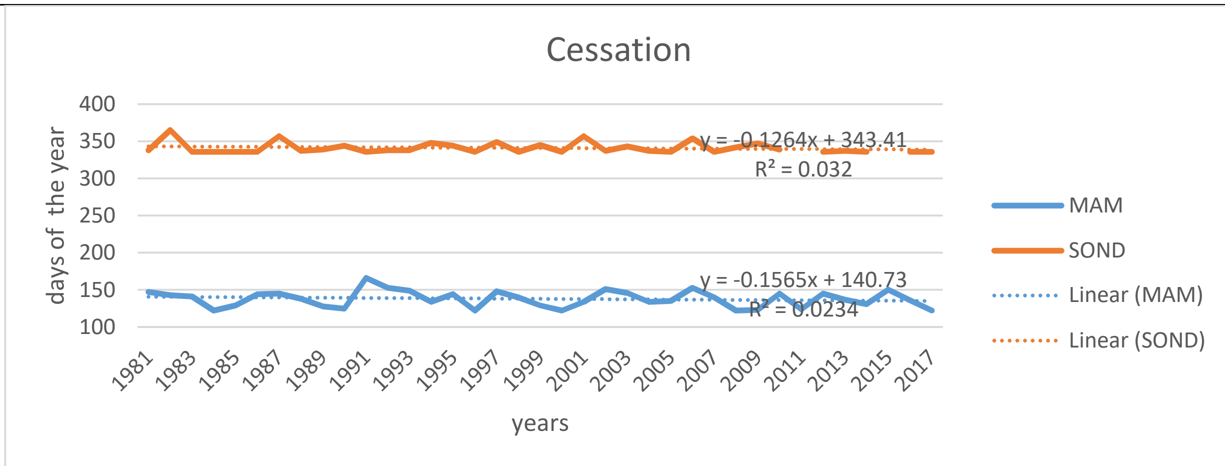
Seasonal trend analysis of Rainfall characteristics for Byumba

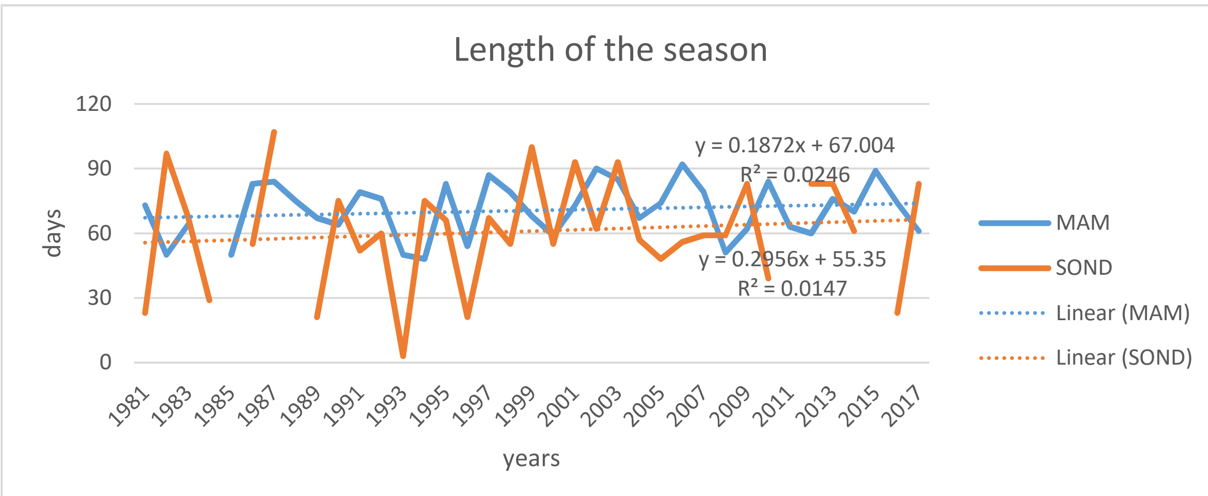

Onset
Days of the year
350
300
250
200
150
100
50
y = 0.1561x + 267.64
R² = 0.0088
y = 0.0994x + 69.179
R² = 0.0057
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
years
MAM
SOND
Linear (MAM)
Linear (SOND)
Cessation
days of the year
400
350
300
250
200
150
100
y = -0.1898x + 344.72
R² = 0.0544
y = -0.3326x + 146.29
R² = 0.0723
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
years
MAM
SOND
Linear (MAM)
Linear (SOND)
length of the season
days
110
90
70
50
30
10
y = -0.457x + 78.065
R² = 0.0798
y = -0.3111x + 74.642
R² = 0.0381
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
years
MAM
SOND
Linear (MAM)
Linear (SOND)

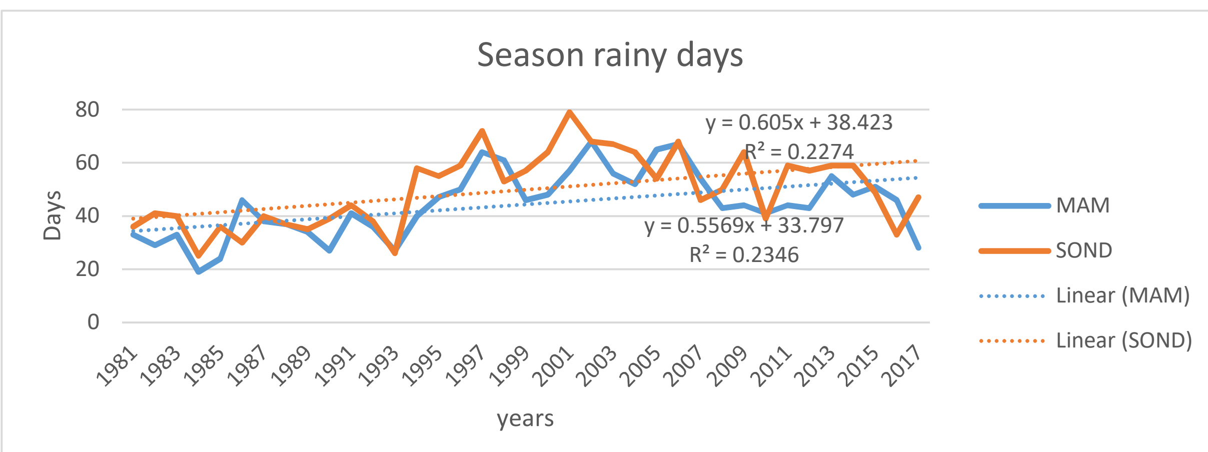


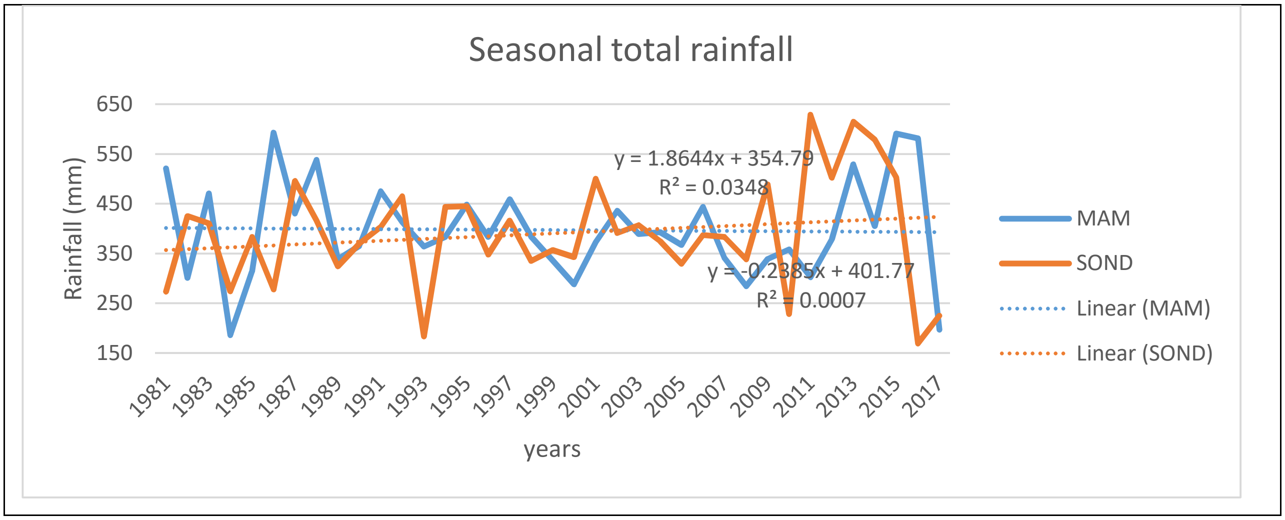
Seasonal trend analysis of Rainfall characteristics for Rushashi



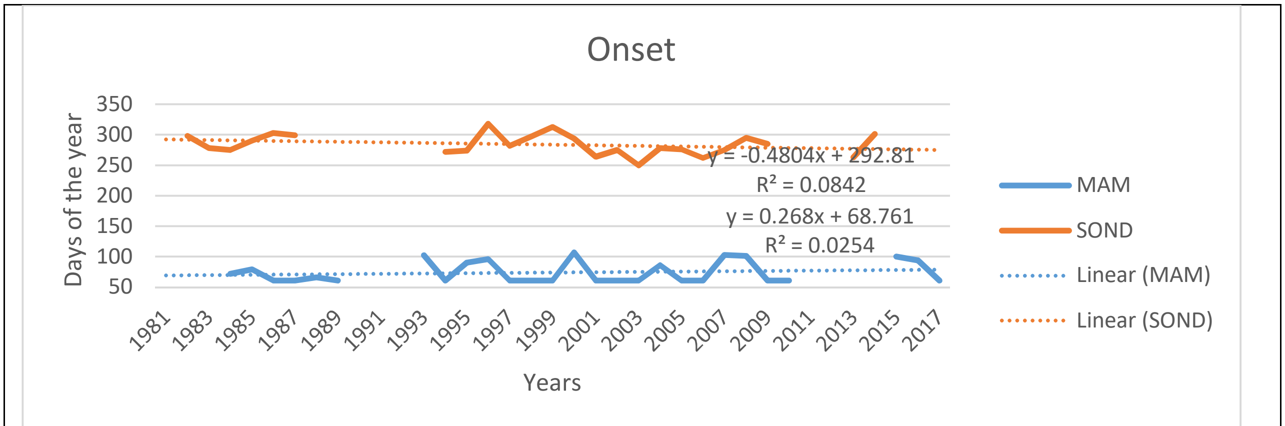

Cessation
days of the year
400
350
300
250
200
150
100
y = -0.1264x + 343.41
R² = 0.032
y = -0.1565x + 140.73
R² = 0.0234
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
years
MAM
SOND
Linear (MAM)
Linear (SOND)

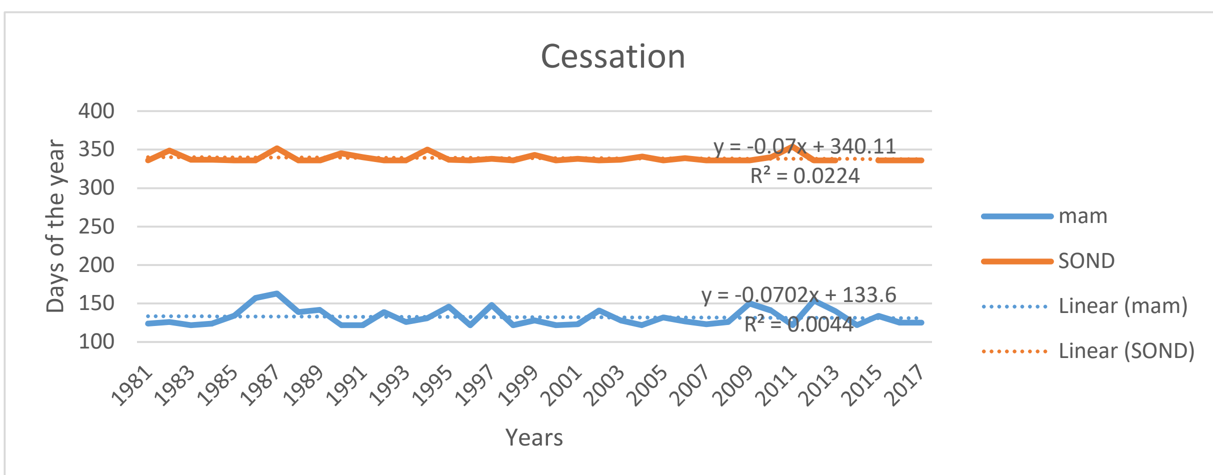

Length of the season
days
120
90
60
30
0
y = 0.1872x + 67.004
R² = 0.0246
y = 0.2956x + 55.35
R² = 0.0147
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
years
MAM
SOND
Linear (MAM)
Linear (SOND)

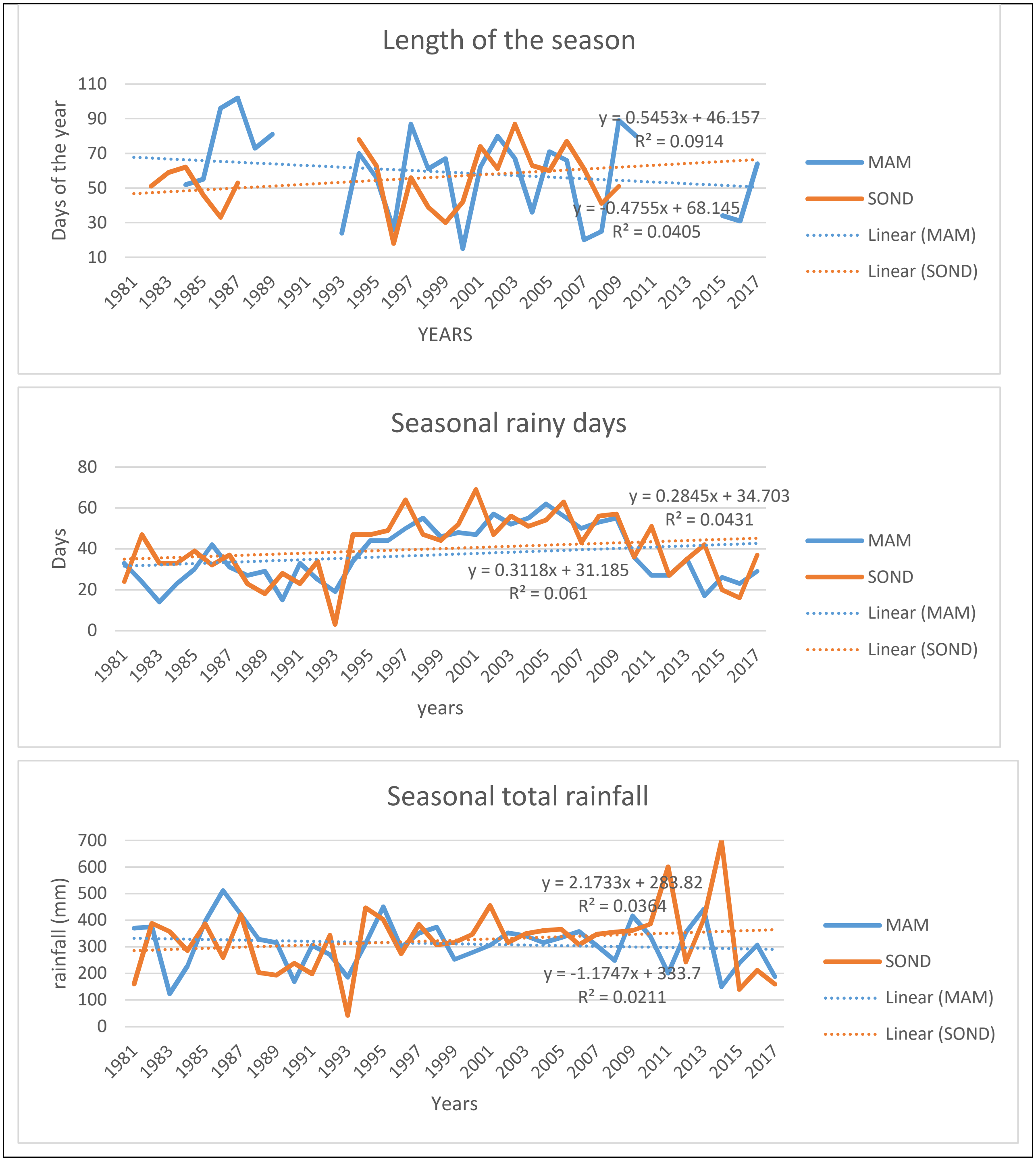

Season rainy days
Days
80
60
40
20
0
y = 0.605x + 38.423
R² = 0.2274
y = 0.5569x + 33.797
R² = 0.2346
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
years
MAM
SOND
Linear (MAM)
Linear (SOND)



Seasonal trend analysis of Rainfall characteristics for Butare

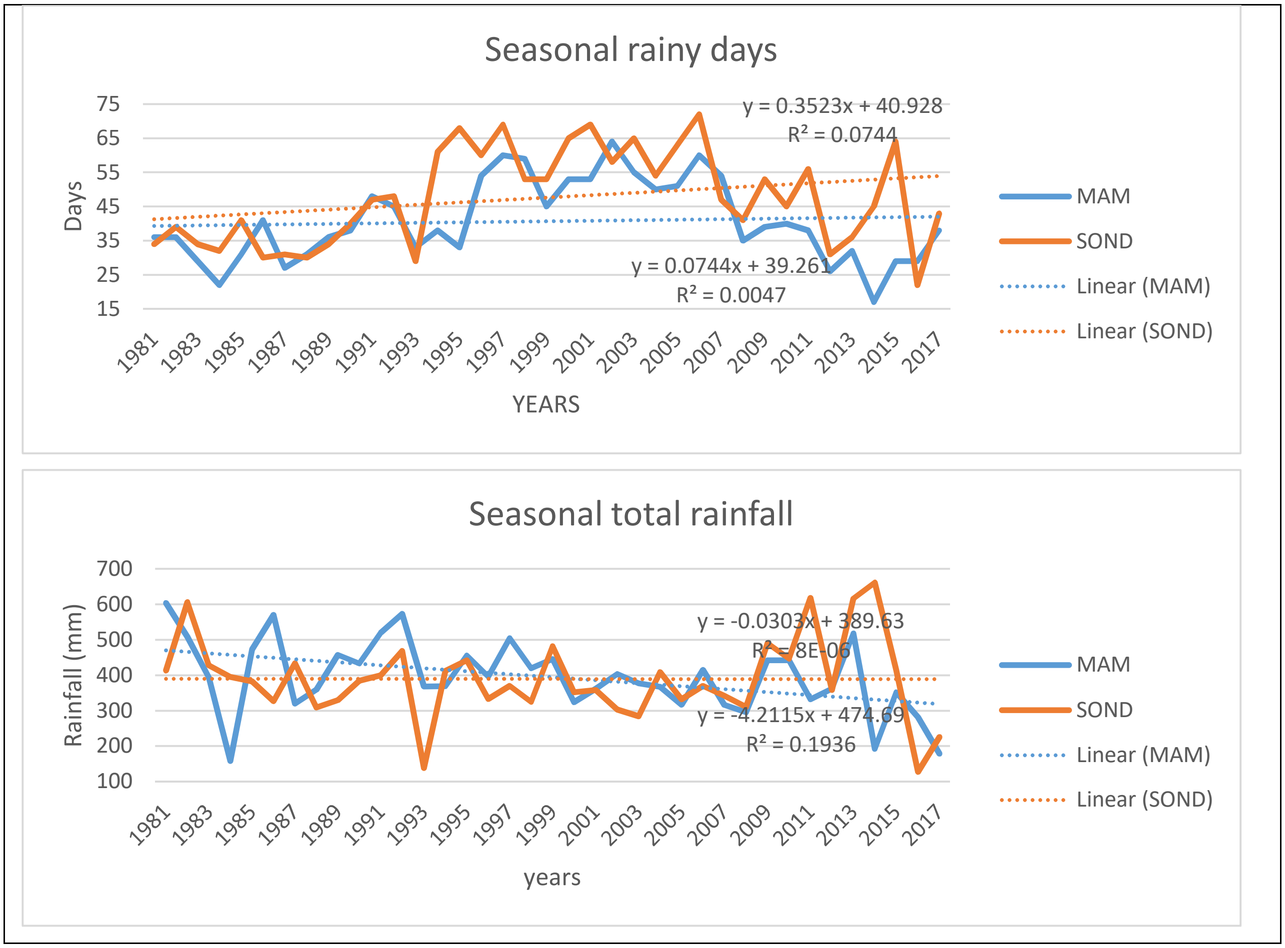




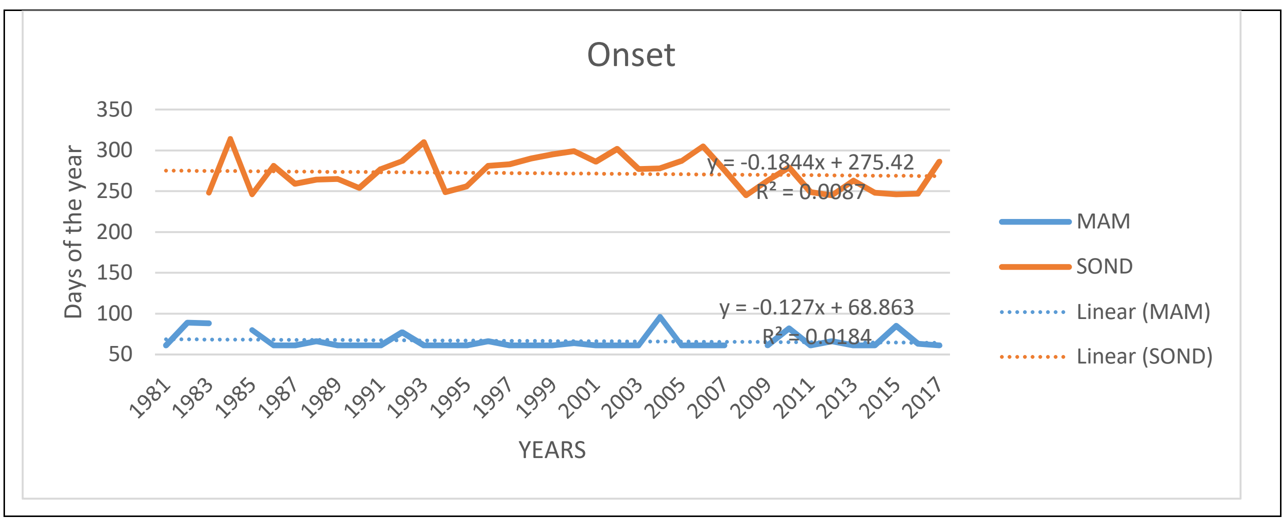


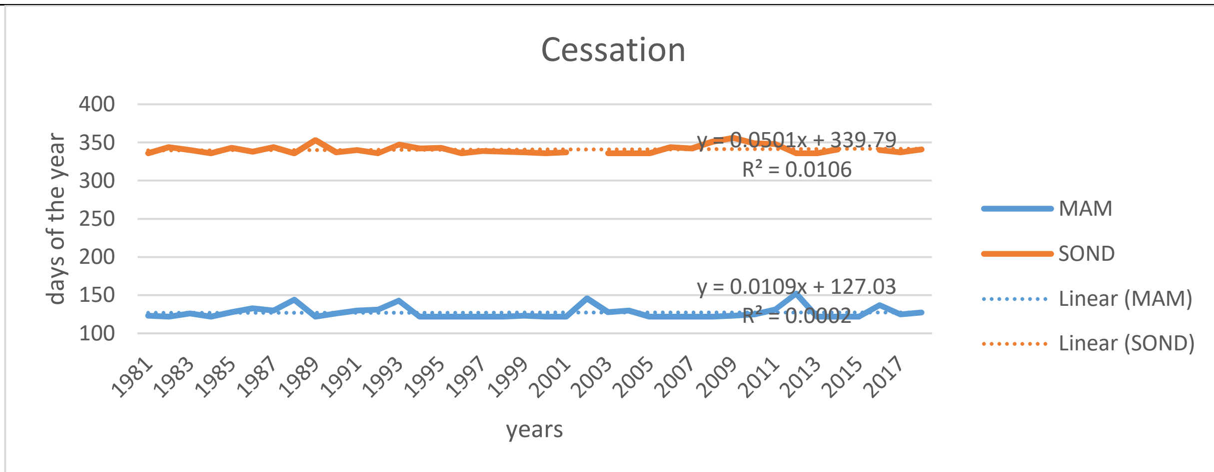
Seasonal trend analysis of Rainfall characteristics for Byimana

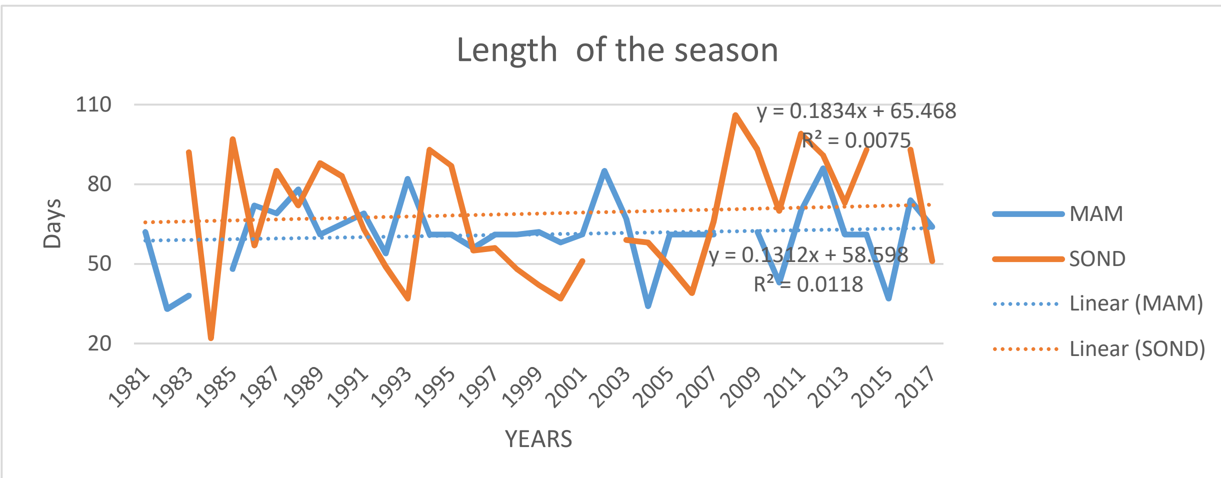

Onset
days of the year
350
300
250
200
150
100
50
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
years
y = 0.1274x + 279.9
R² = 0.0034
y = -0.2397x + 73.5
R² = 0.0459
MAM
SOND
Linear (MAM)
Linear (SOND)
Cessation
days of the year
400
350
300
250
200
150
100
y = 0.0897x + 337.7
R² = 0.0206
y = -0.137x + 140.41
R² = 0.0157
years
MAM
SOND
Linear (MAM)
Linear (SOND)
Length of the season
days
100
80
60
40
20
0
y = 0.1027x + 66.914
R² = 0.0038
y = 0.2722x + 53.923
R² = 0.0139
years
MAM
SOND
Linear (MAM)
Linear (SOND)

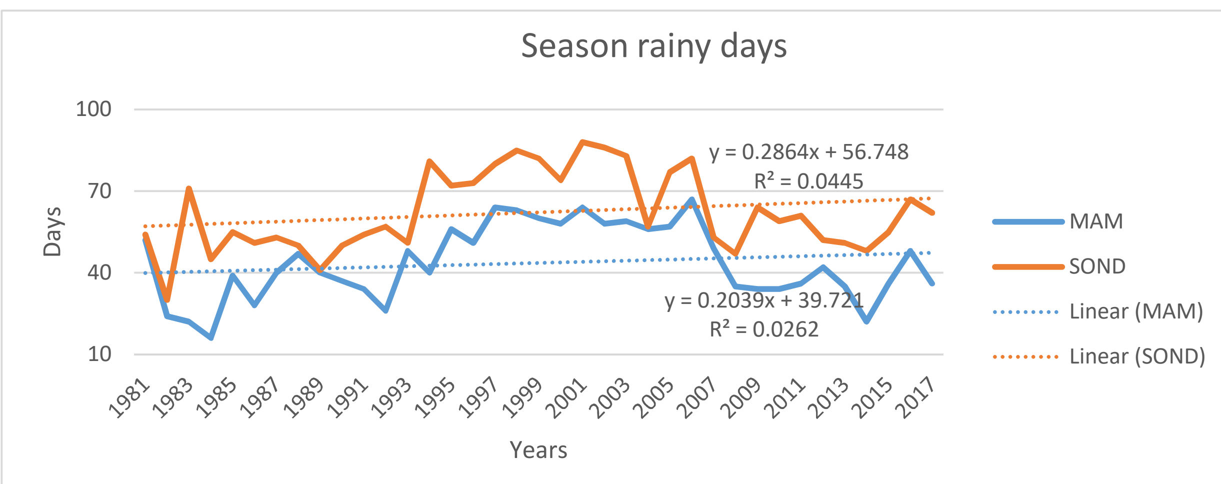


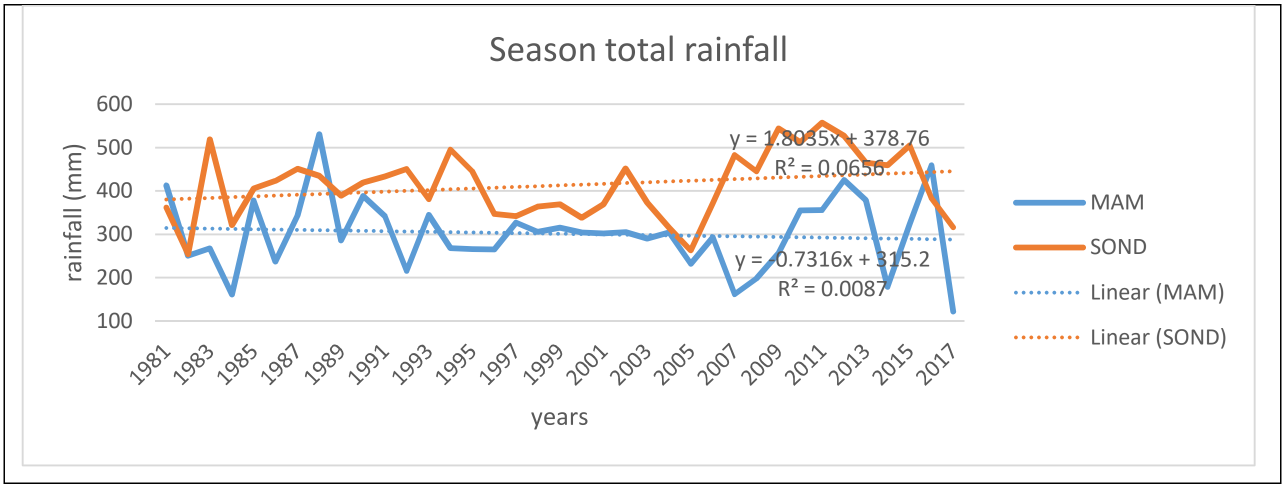
Seasonal trend analysis of Rainfall characteristics for Gikongoro



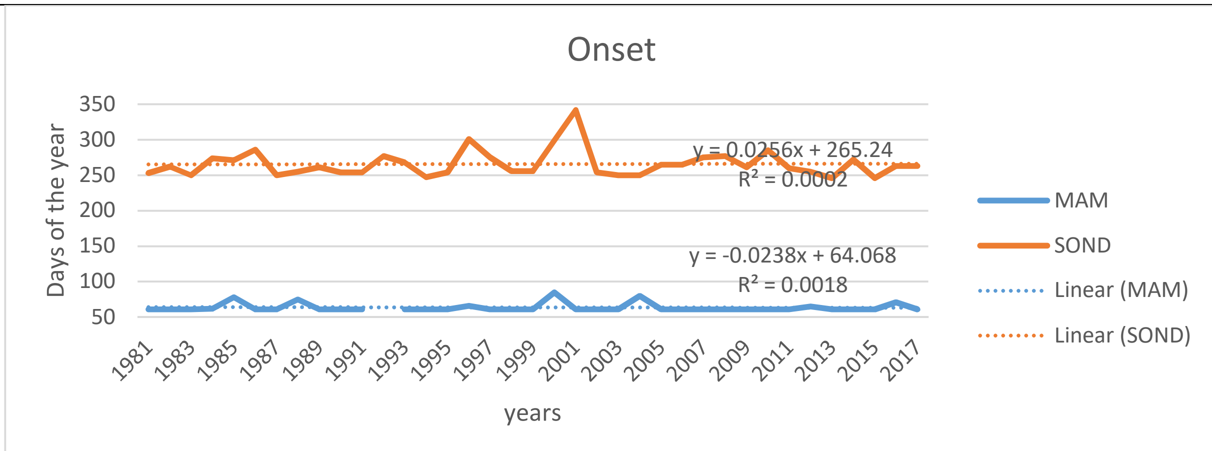

Cessation
days of the year
400
350
300
250
200
150
100
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
years
y = 0.0501x + 339.79
R² = 0.0106
y = 0.0109x + 127.03
R² = 0.0002
MAM
SOND
Linear (MAM)
Linear (SOND)

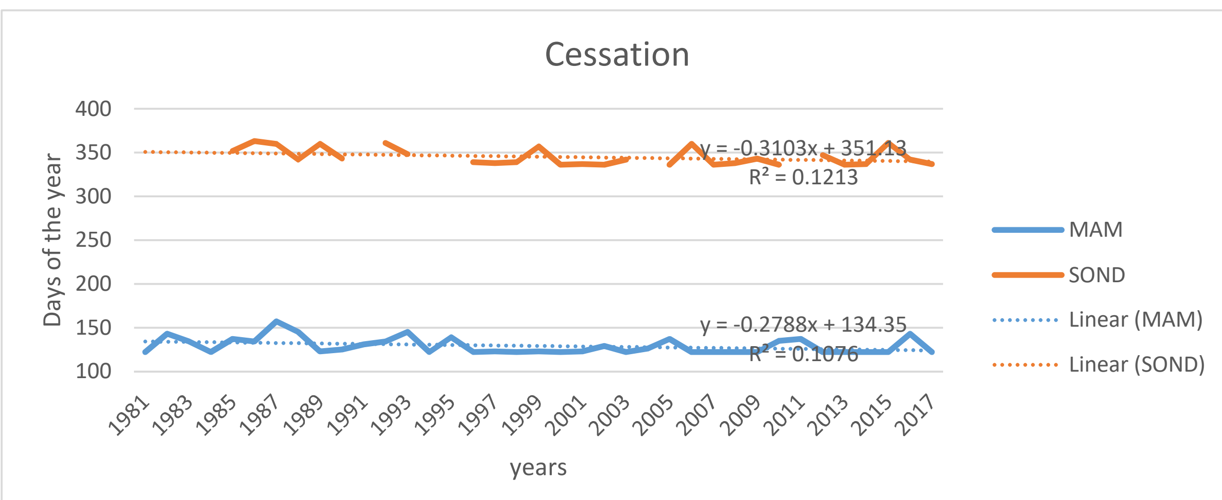

Length of the season
Days
110
80
50
20
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
YEARS
y = 0.1834x + 65.468
R² = 0.0075
y = 0.1312x + 58.598
R² = 0.0118
MAM
SOND
Linear (MAM)
Linear (SOND)

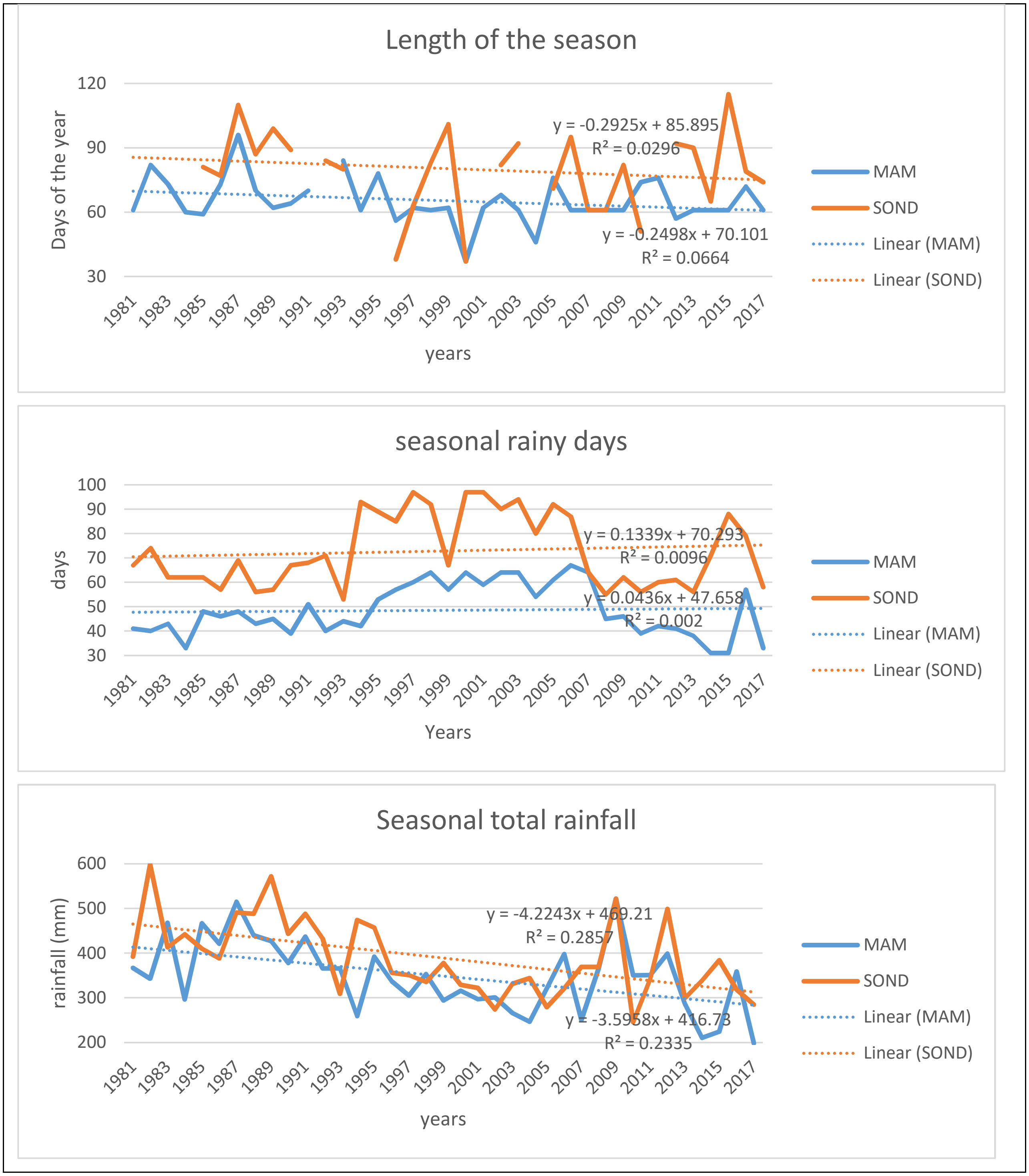

Season rainy days
Days
100
70
40
10
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
Years
y = 0.2864x + 56.748
R² = 0.0445
y = 0.2039x + 39.721
R² = 0.0262
MAM
SOND
Linear (MAM)
Linear (SOND)



Seasonal trend analysis of Rainfall characteristics for Gisenyi

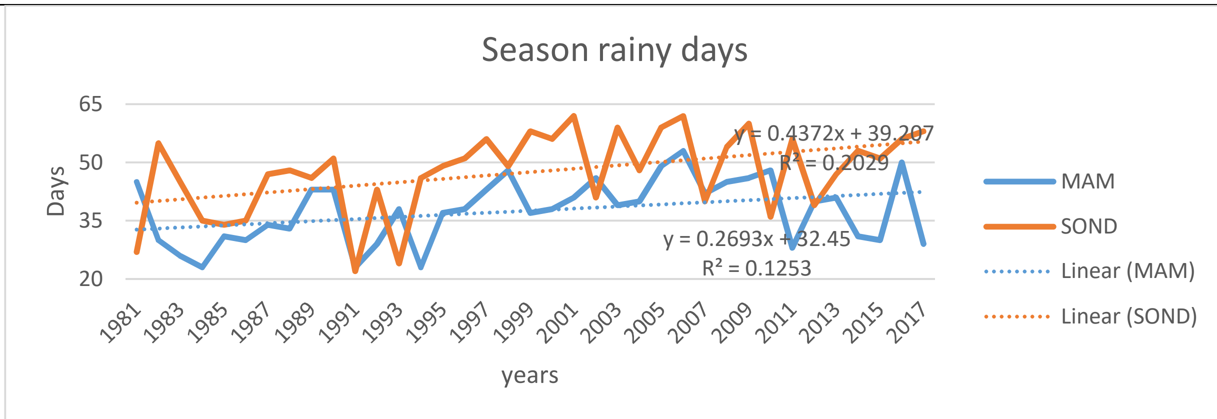


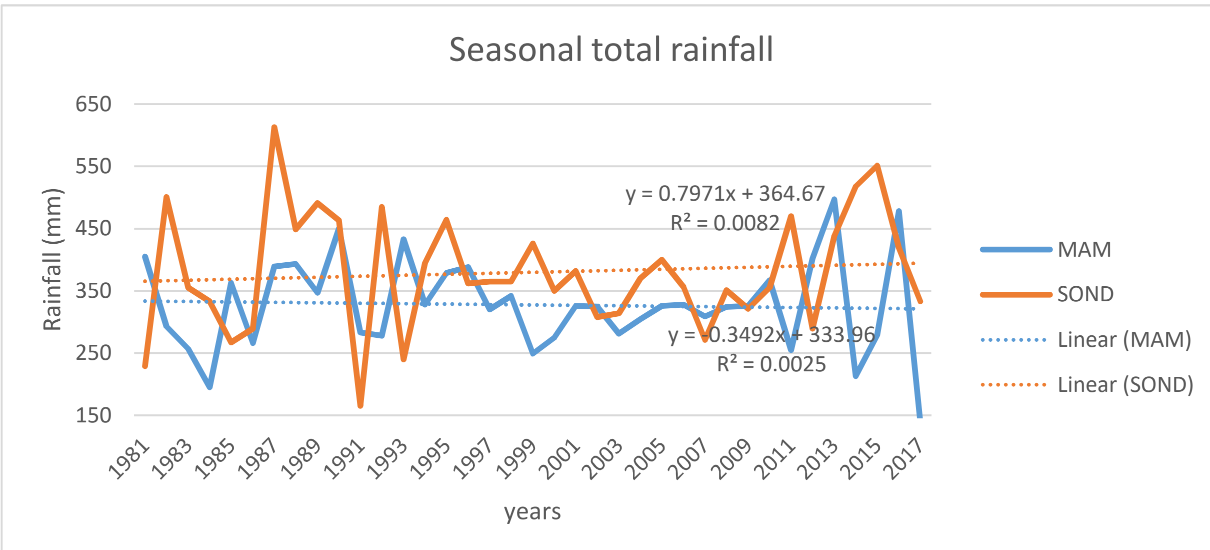




Seasonal trend analysis of Rainfall characteristics for Kamembe


Onset
days of the year
years
y = -0.7311x + 294.29
R² = 0.1757
y = -0.356x + 75.542
R² = 0.0807
MAM
SOND
Linear (MAM)
Linear (SOND)
Cessation
days of the year
Years
y = -0.1896x + 345.19
R² = 0.0445
y = 0.0477x + 127.45
R² = 0.0031
MAM
SOND
Linear (MAM)
Linear (SOND)
Length of the season
Days
Years
y = 0.4633x + 52.624
R² = 0.0908
y = 0.5001x + 49.195
R² = 0.0972
MAM
SOND
Linear (MAM)
Linear (SOND)

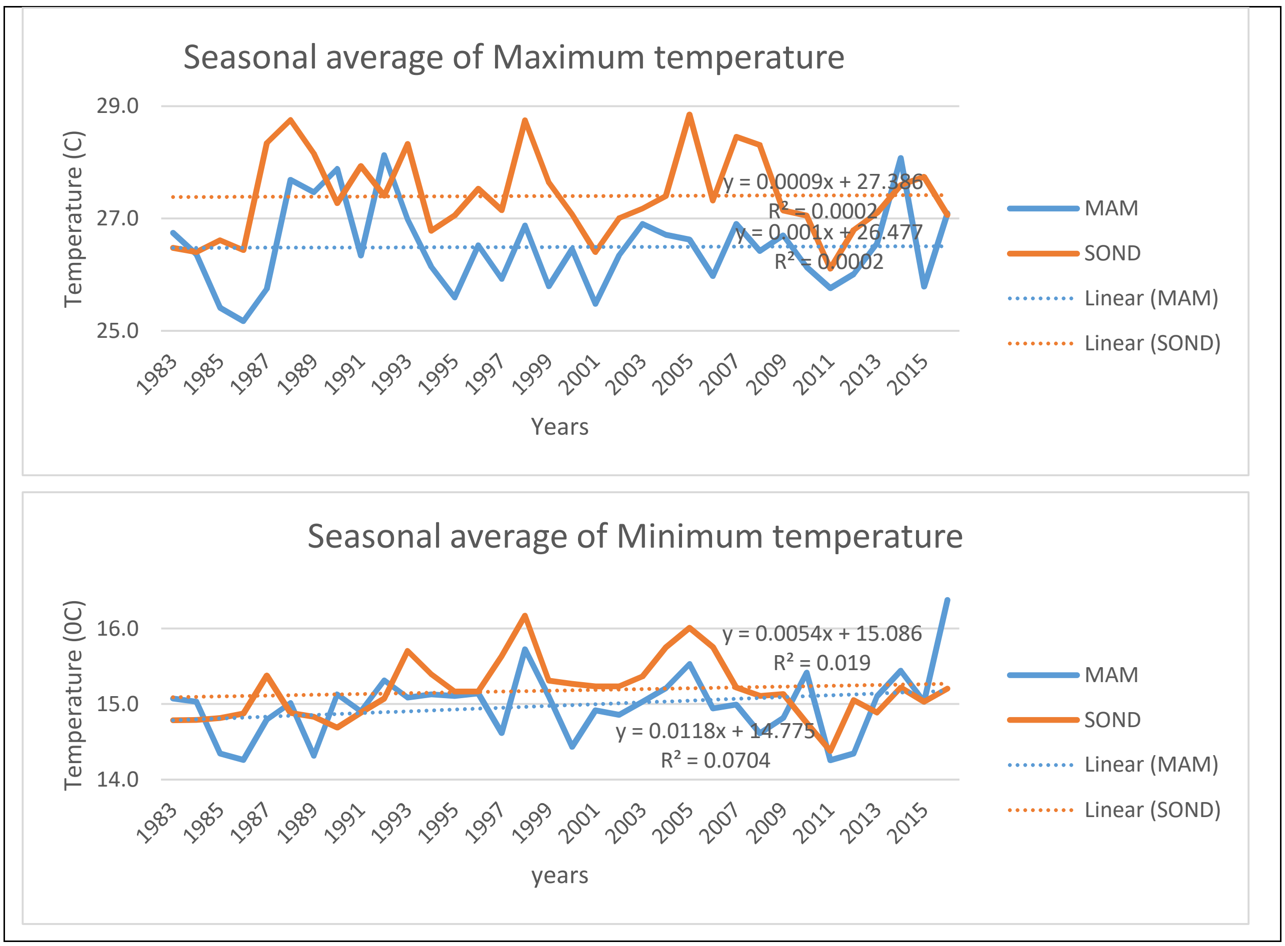


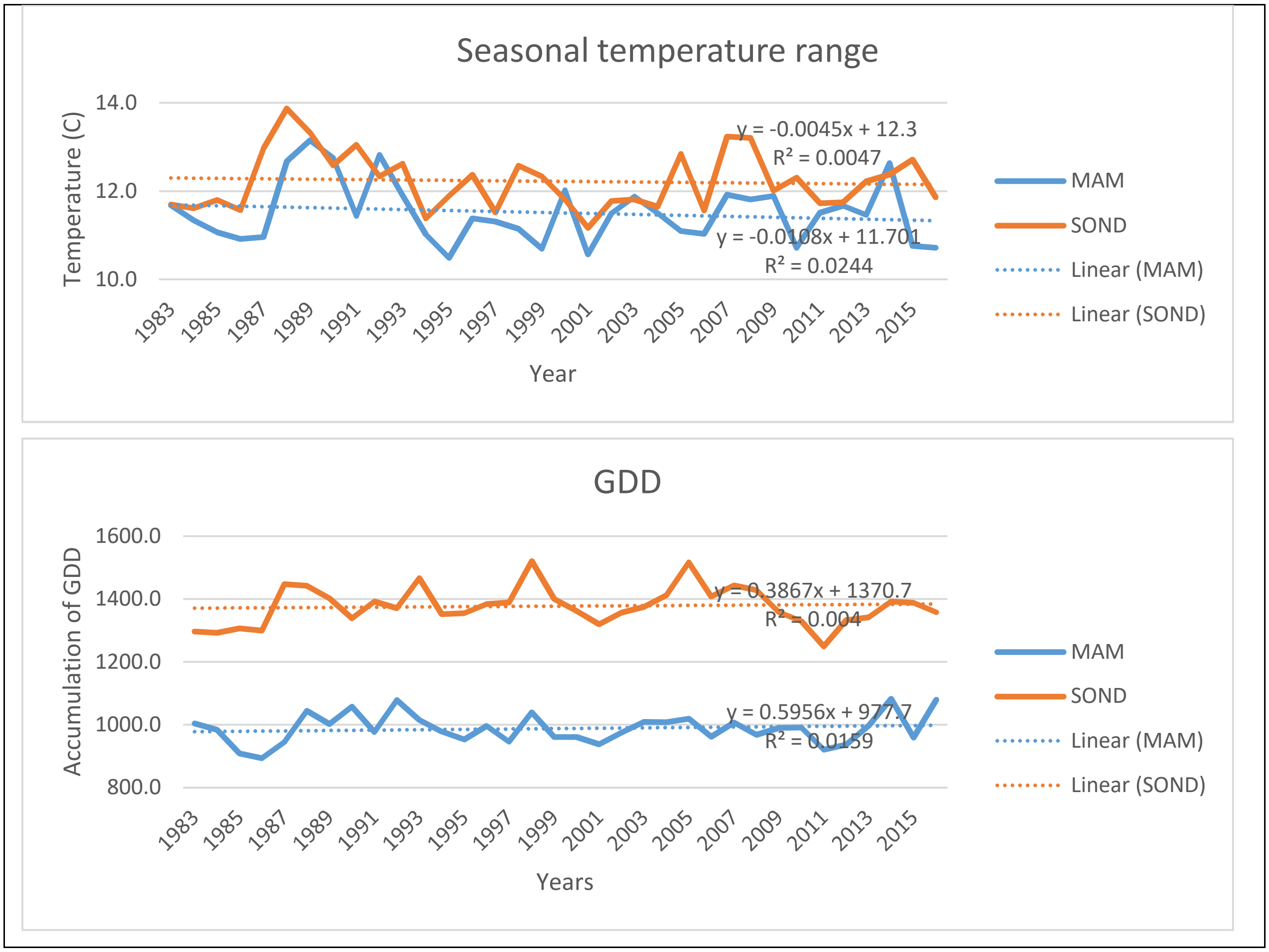


Seasonal trend analysis of Rainfall characteristics for Rubengera

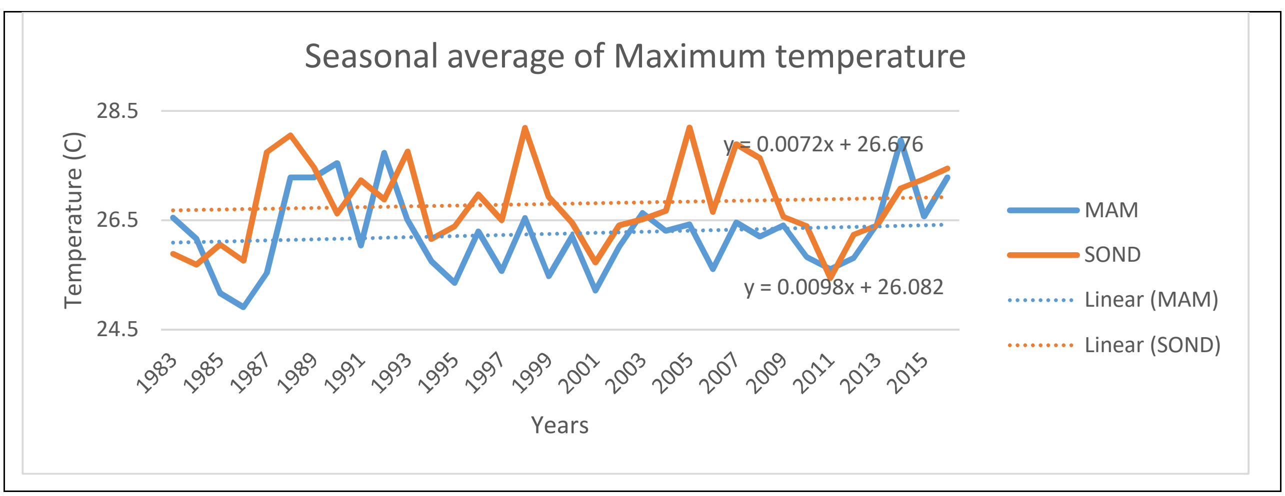
AppendixII

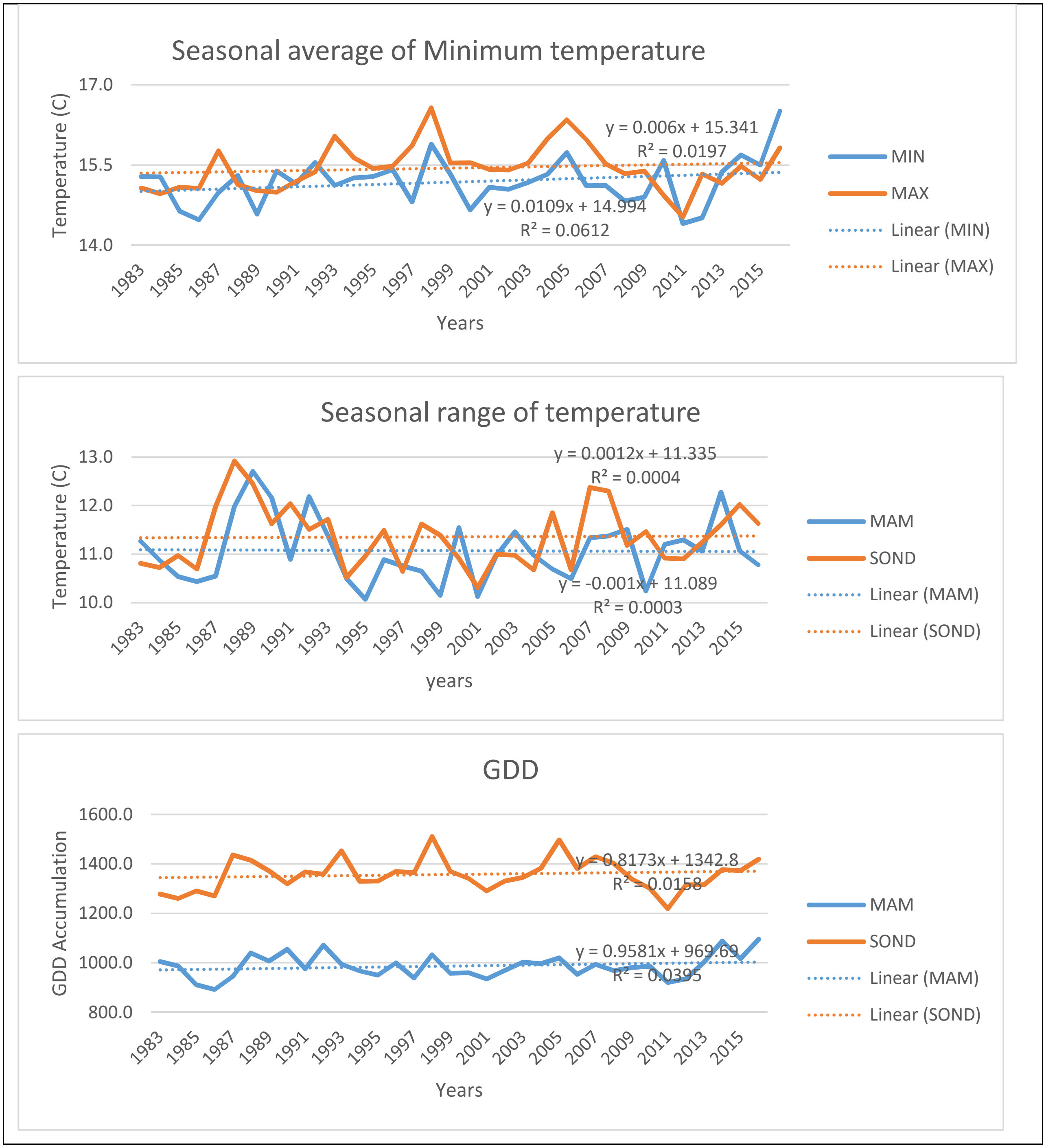
Seasonal trend analysis of temperature characteristics (Maximum temperature, Minimum temperature, temperature range and GDD) for Mageregere, Rubirizi, Masaka, Butare Aero, Gikongoro Met, Byimana, Gisenyi Aero, Kamembe Aero, Rubengera Met, Rushashi, Byumba Met, Nyagatare, Kawangire and Kibungo- Kazo.



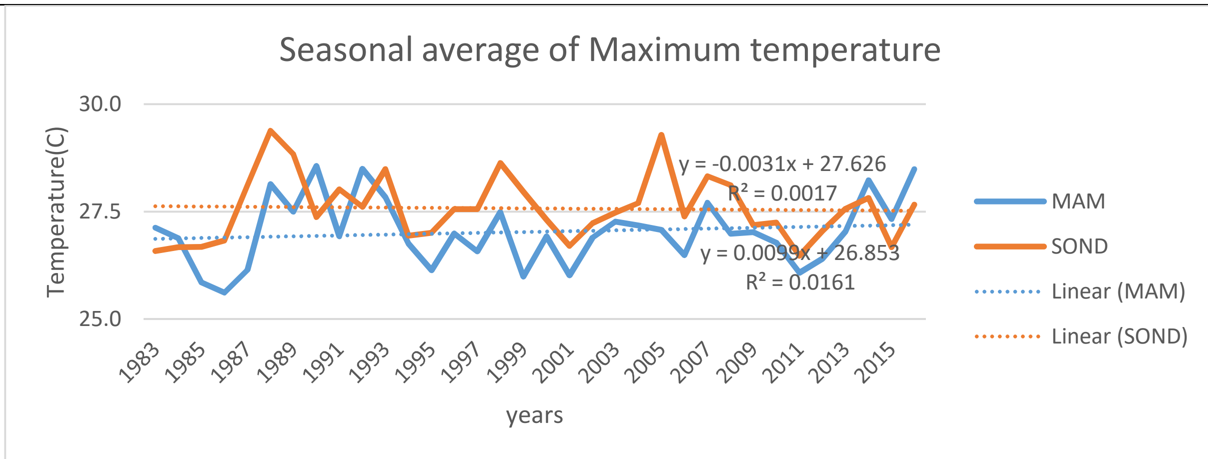


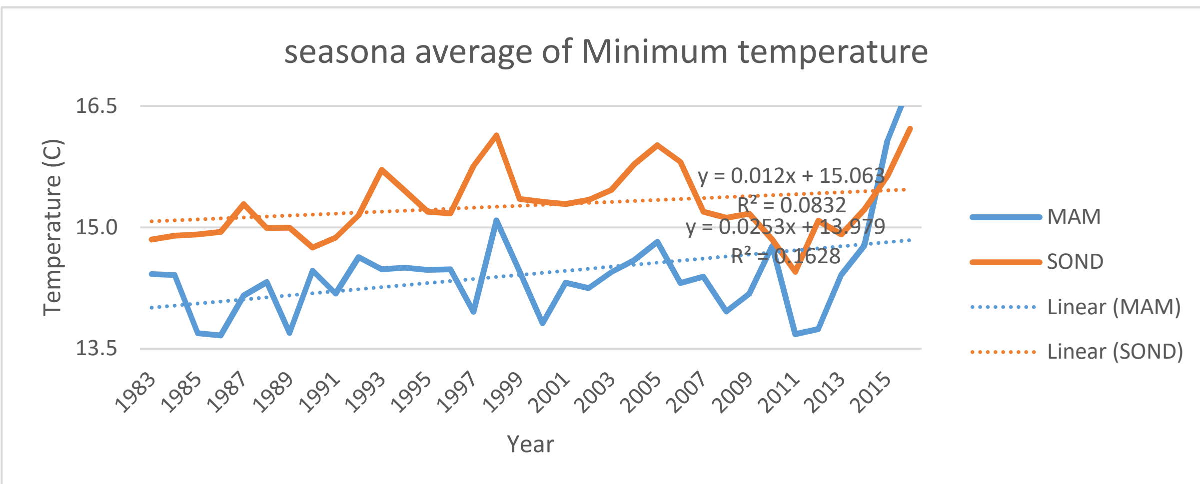
Seasonal trend analysis of temperature characteristics for Kawangire

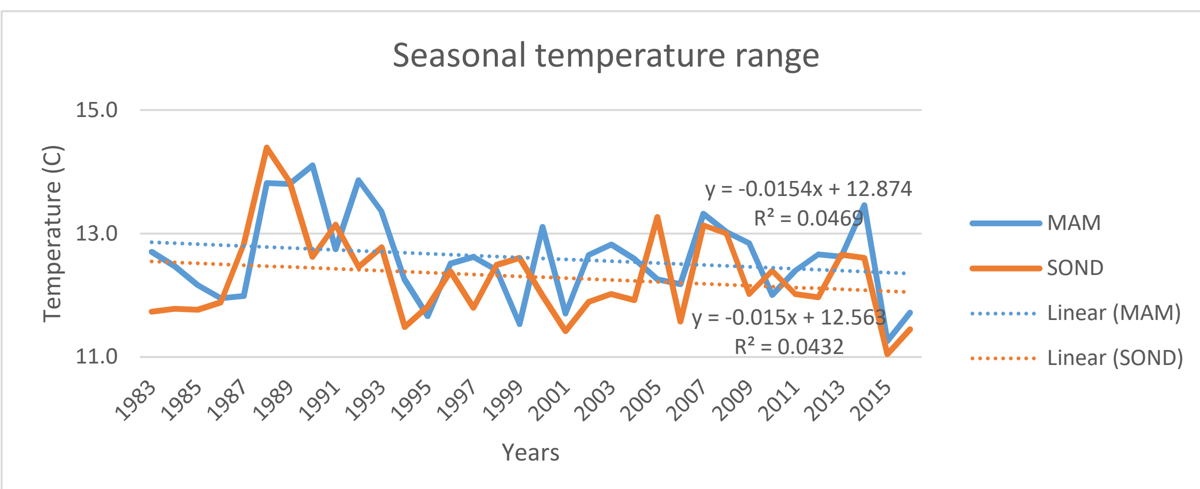


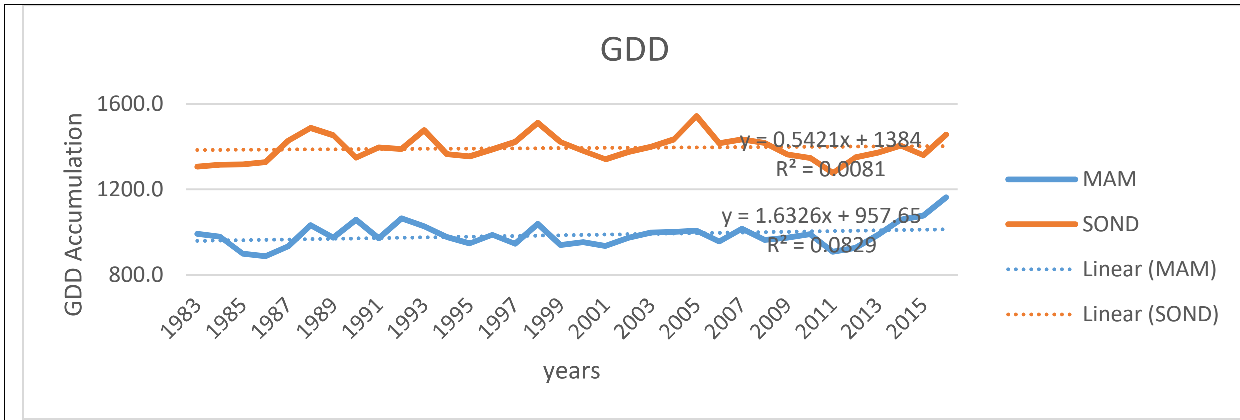


Seasonal trend analysis of temperature characteristics for Kibungo-Kazo

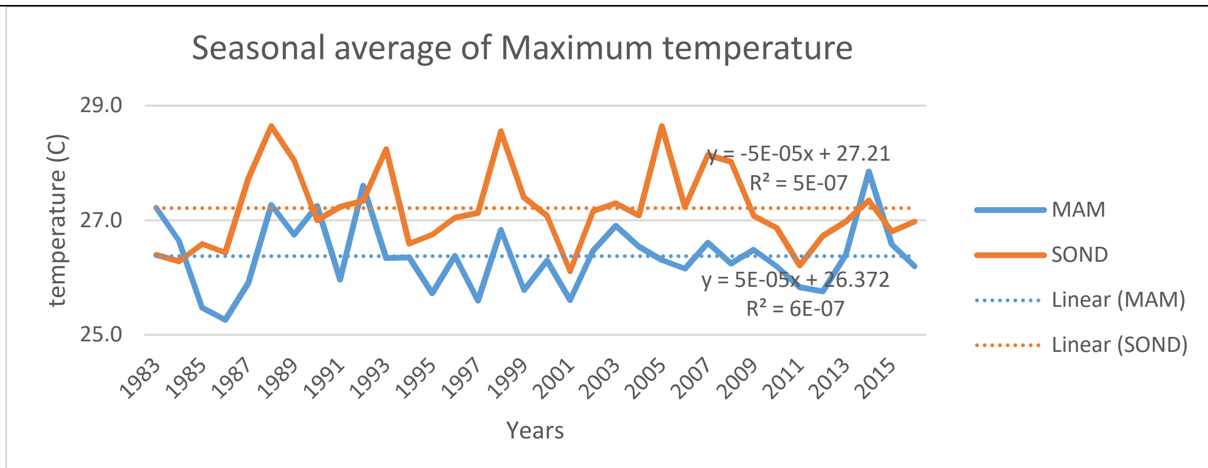

Seasonal average of Maximum temperature
30.0
27.5
25.0
Temperature(C)
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
years
y = -0.0031x + 27.626
R² = 0.0017
y = 0.0099x + 26.853
R² = 0.0161
MAM
SOND
Linear (MAM)
Linear (SOND)

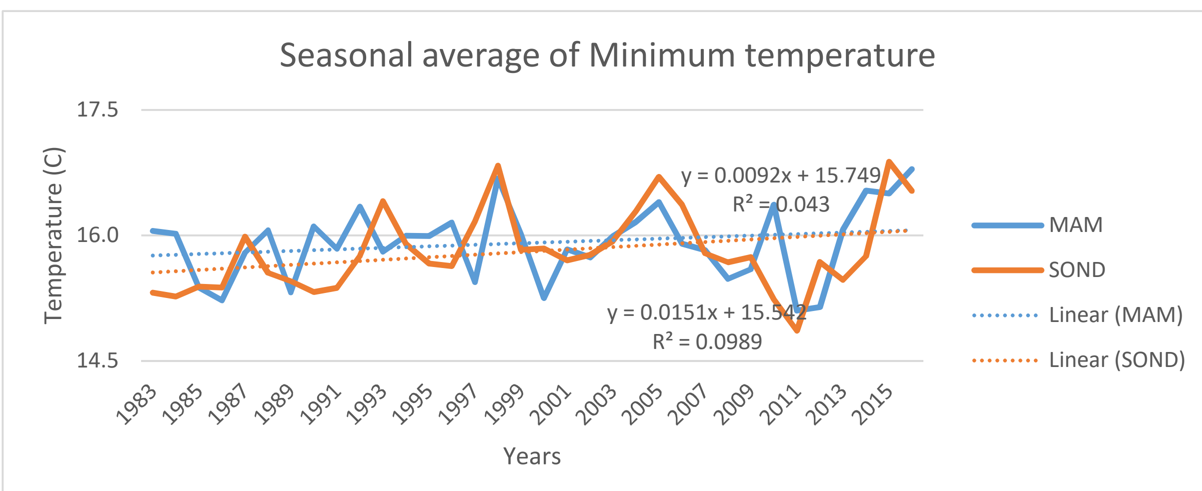

seasona average of Minimum temperature
16.5
15.0
13.5
Temperature (C)
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Year
y = 0.012x + 15.063
R² = 0.0832
y = 0.0253x + 13.979
R² = 0.1628
MAM
SOND
Linear (MAM)
Linear (SOND)

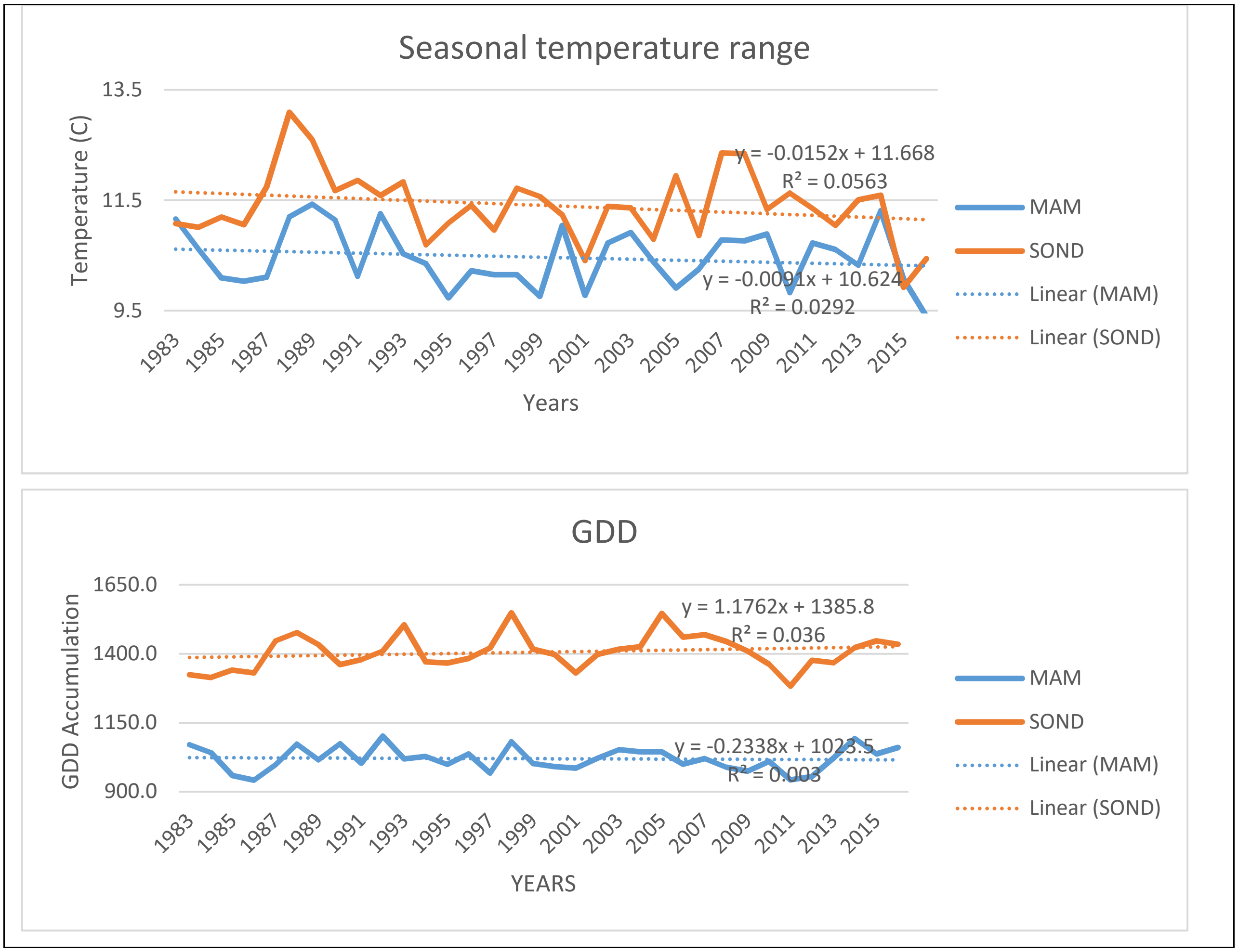

Seasonal temperature range
15.0
13.0
11.0
Temperature (C)
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Years
y = -0.0154x + 12.874
R² = 0.0469
y = -0.015x + 12.563
R² = 0.0432
MAM
SOND
Linear (MAM)
Linear (SOND)



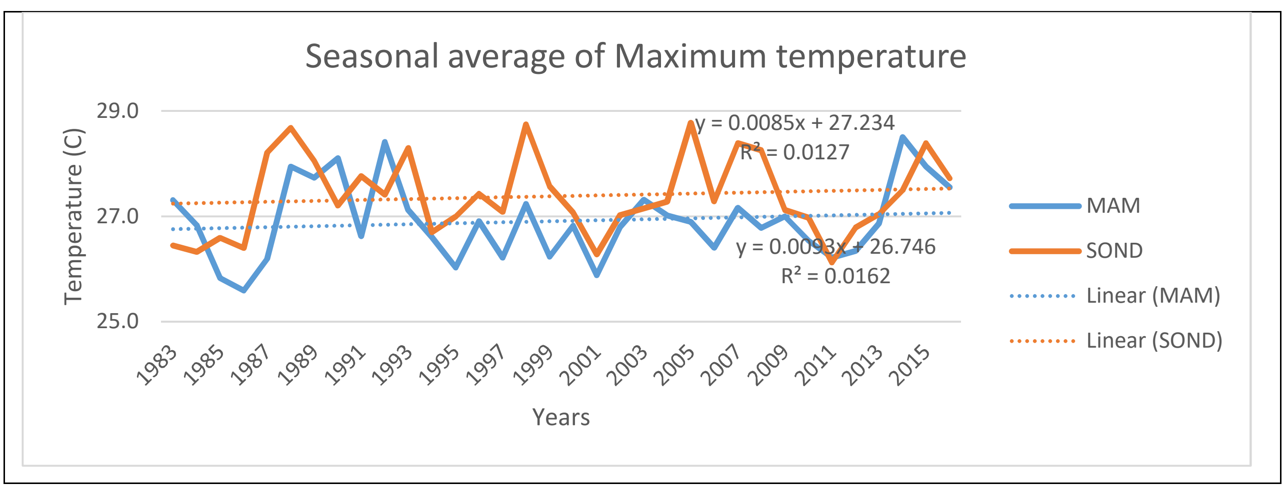
Seasonal trend analysis of temperature characteristics for Nyagatare

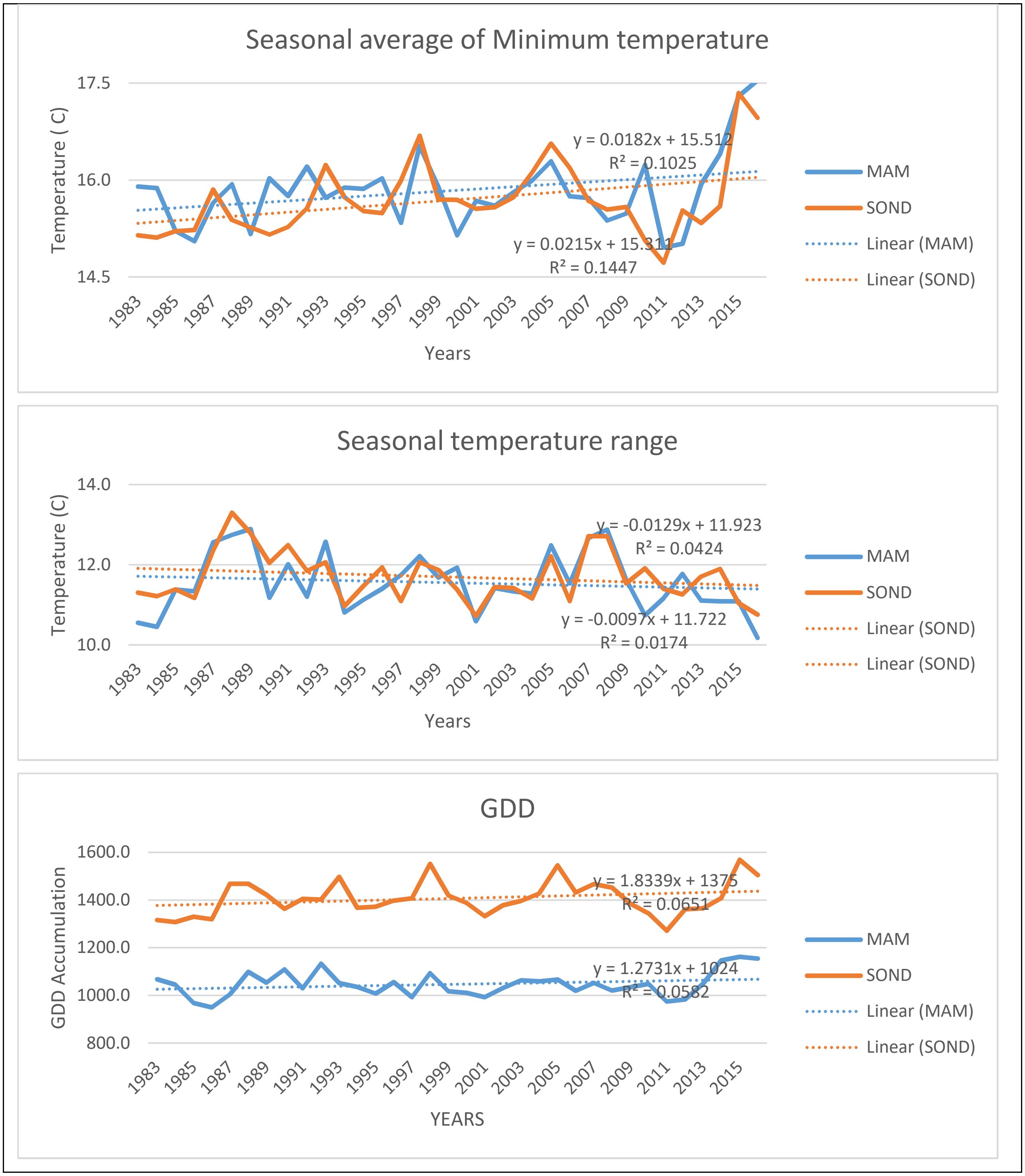




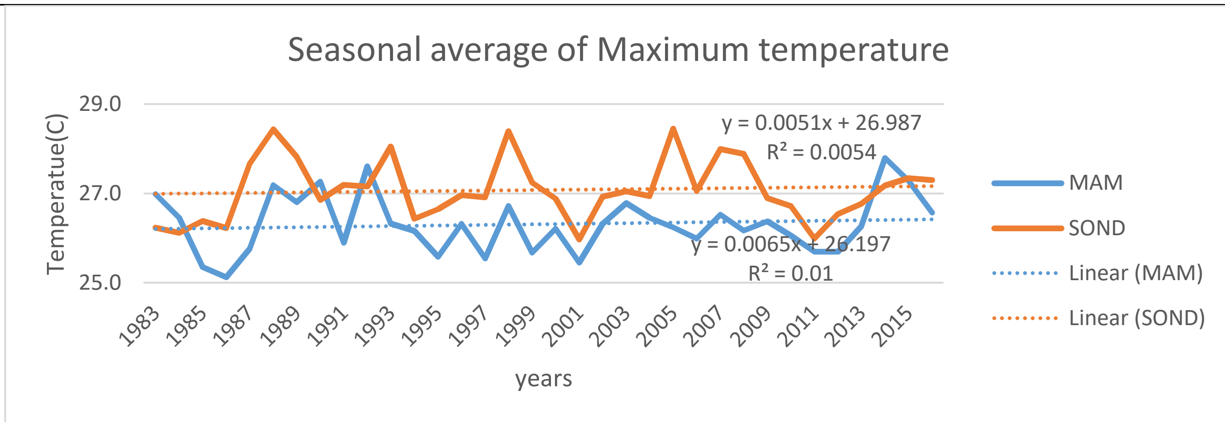


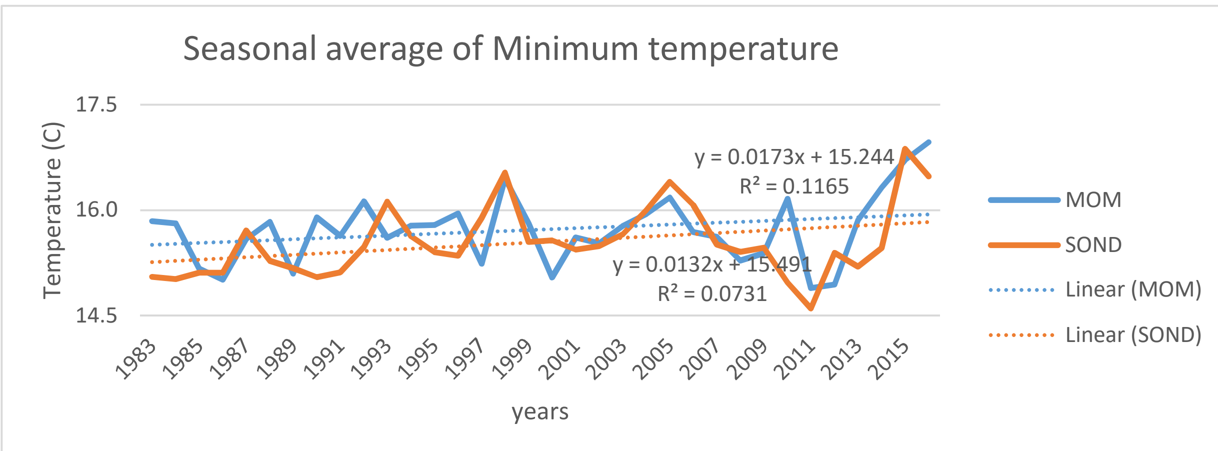
Seasonal trend analysis of temperature characteristics for Mageragere

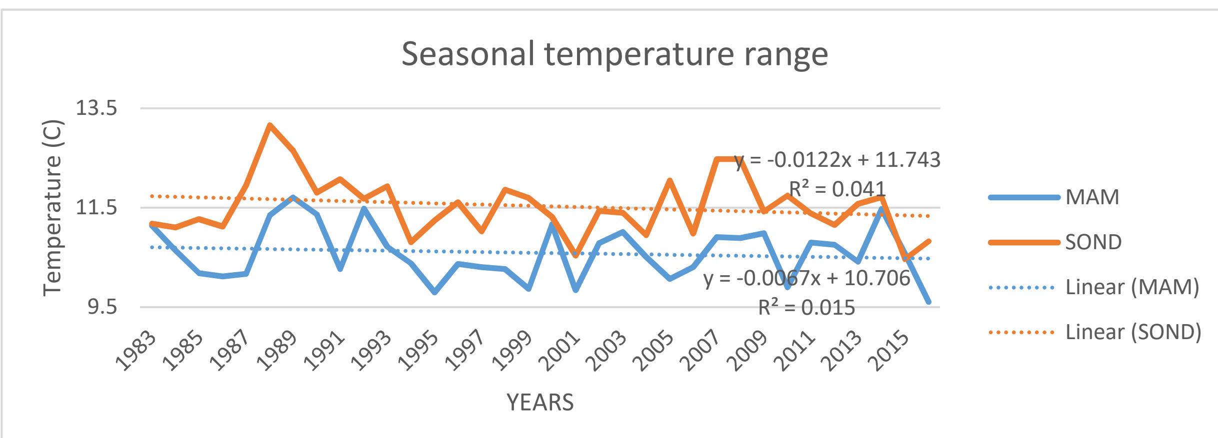


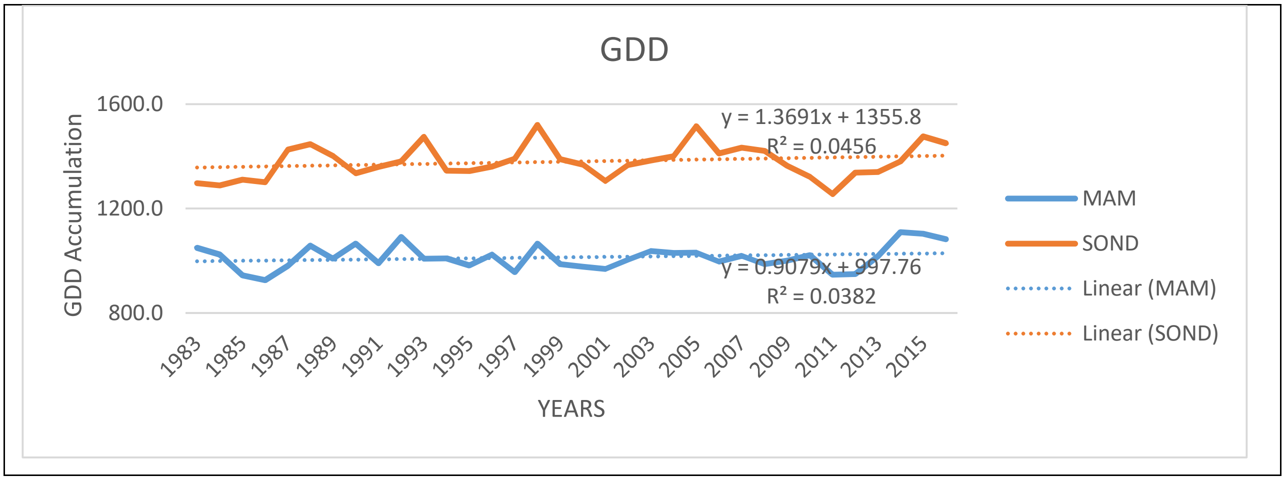


Seasonal trend analysis of temperature characteristics for Masaka

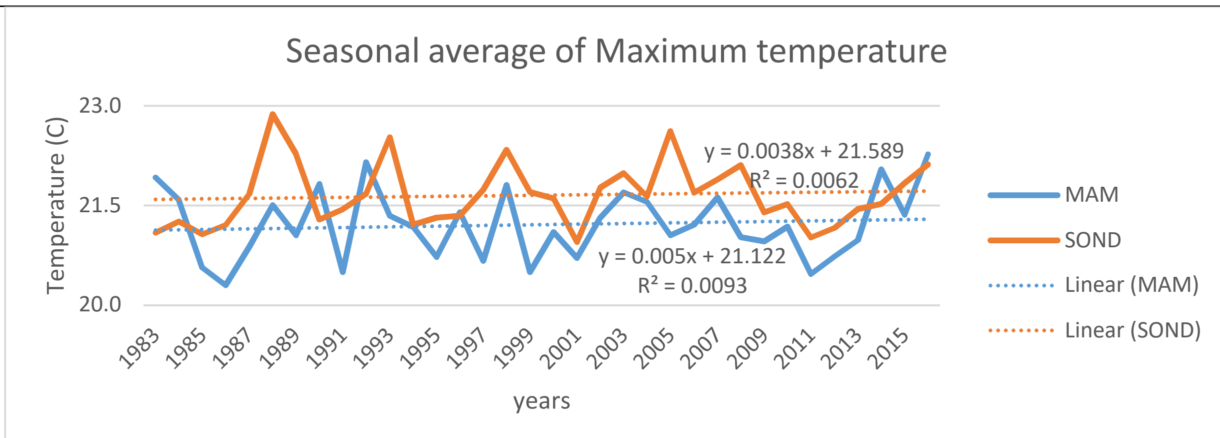

Seasonal average of Maximum temperature
Temperatue(C)
29.0
27.0
25.0
y = 0.0051x + 26.987
R² = 0.0054
y = 0.0065x + 26.197
R² = 0.01
1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
years
MAM
SOND
Linear (MAM)
Linear (SOND)

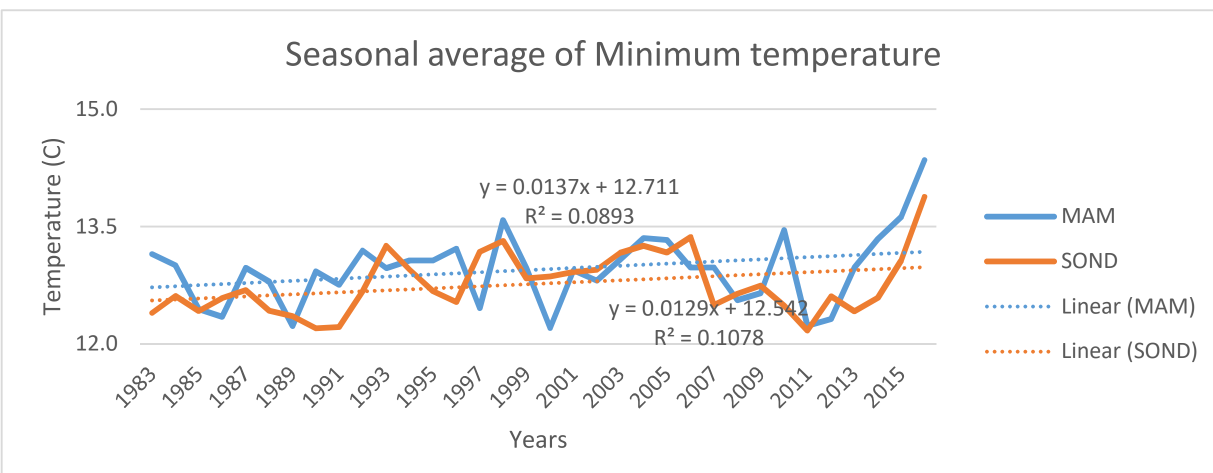

Seasonal average of Minimum temperature
Temperature (C)
17.5
16.0
14.5
y = 0.0173x + 15.244
R² = 0.1165
y = 0.0132x + 15.491
R² = 0.0731
1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
years
MOM
SOND
Linear (MOM)
Linear (SOND)

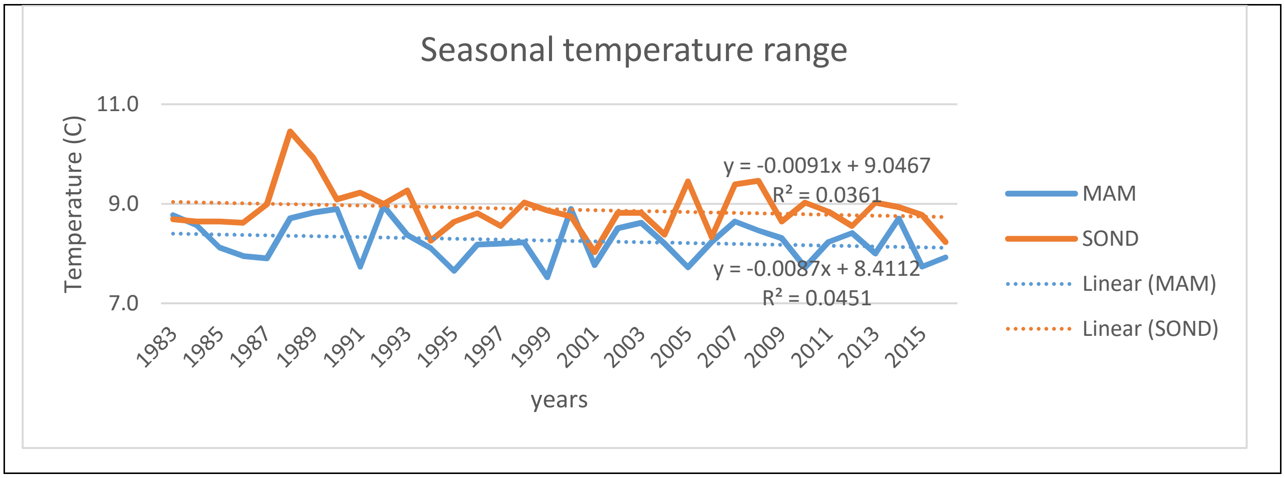

Seasonal temperature range
Temperature (C)
13.5
11.5
9.5
y = -0.0122x + 11.743
R² = 0.041
y = -0.0067x + 10.706
R² = 0.015
1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
YEARS
MAM
SOND
Linear (MAM)
Linear (SOND)



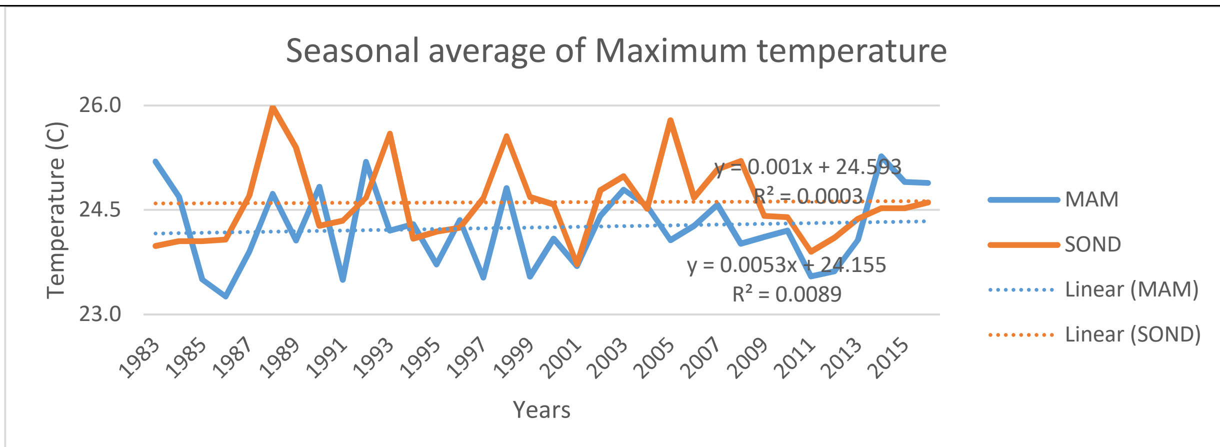
Seasonal trend analysis of temperature characteristics for Rubirizi

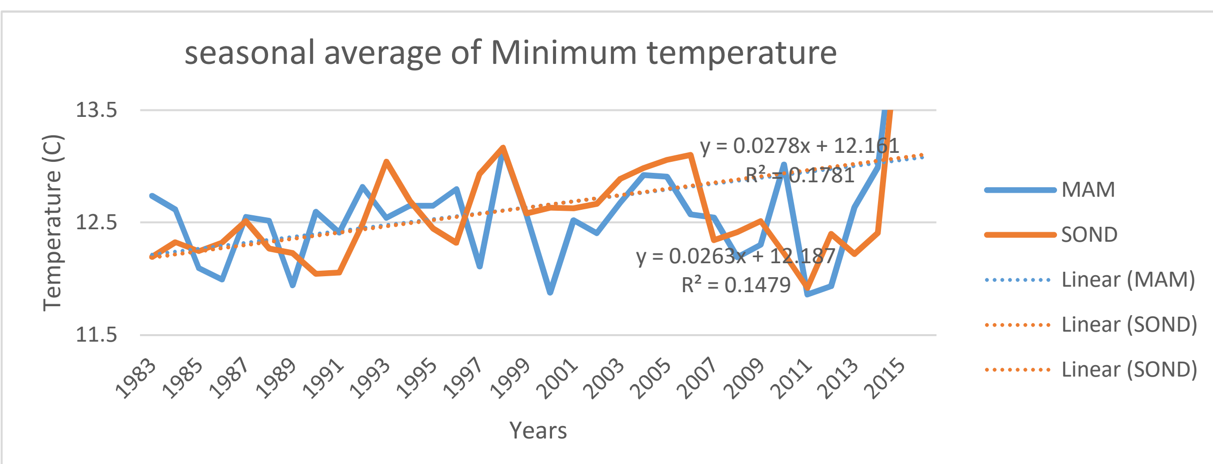


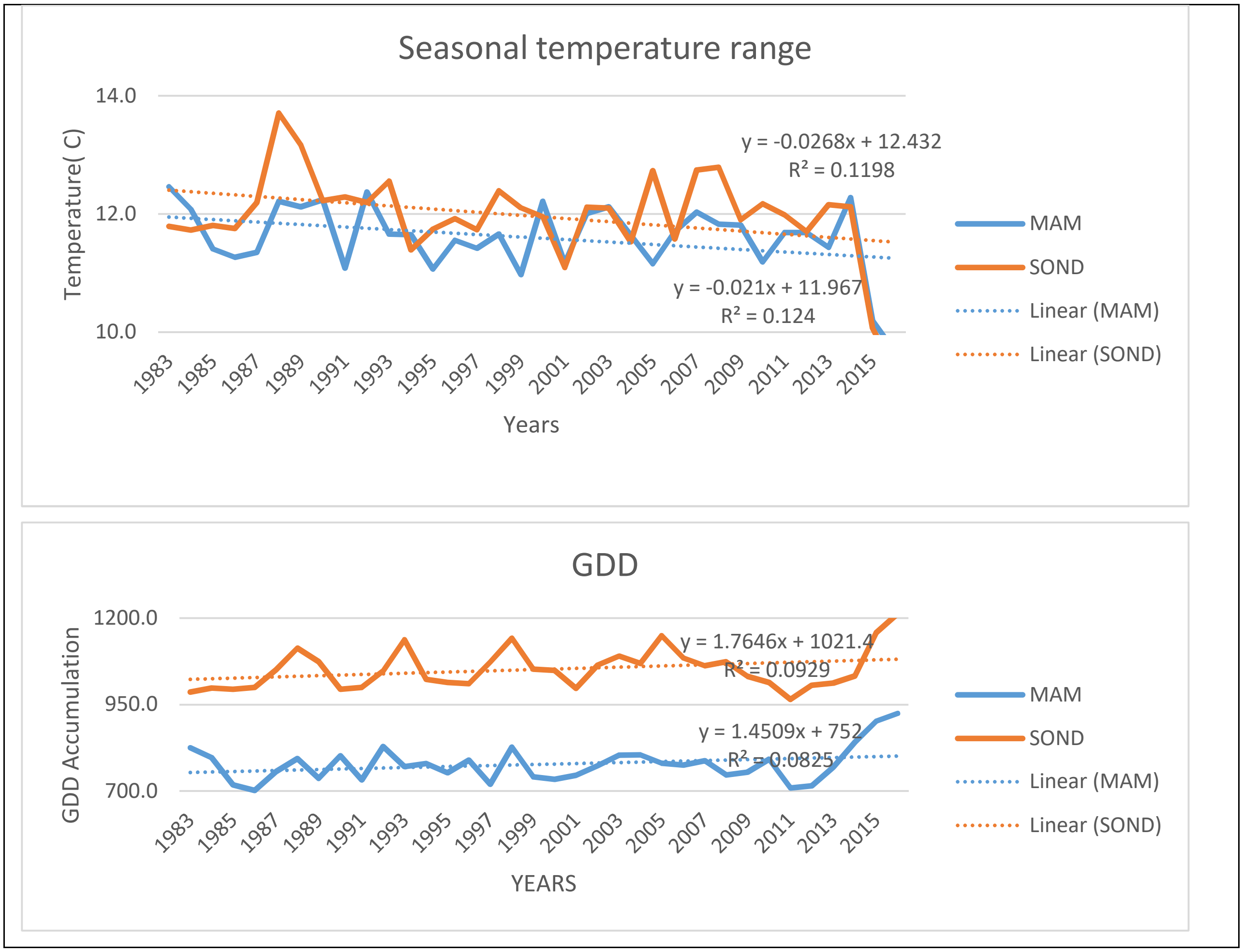




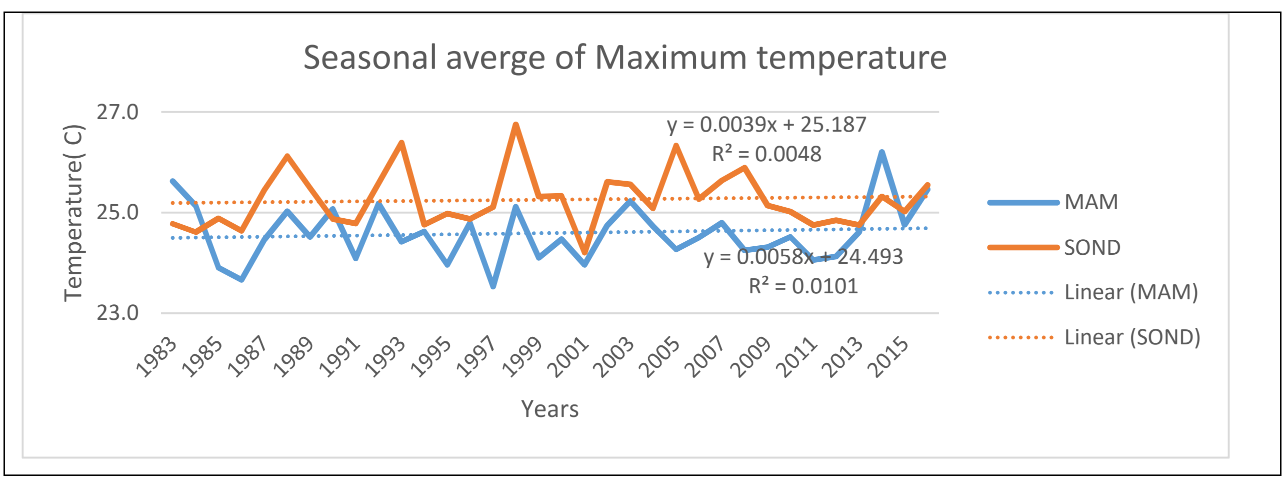
Seasonal trend analysis of temperature characteristics for Byumba

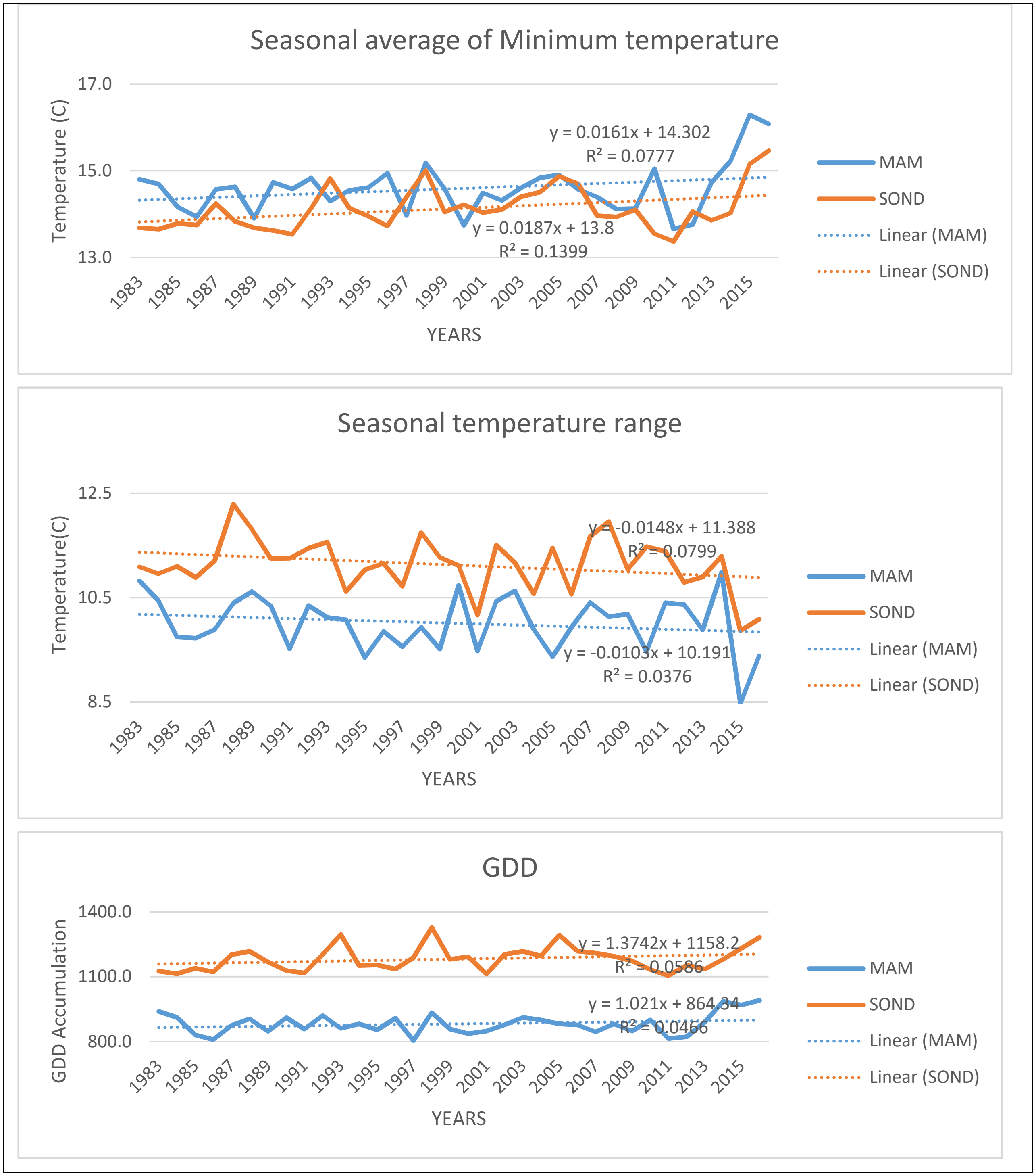




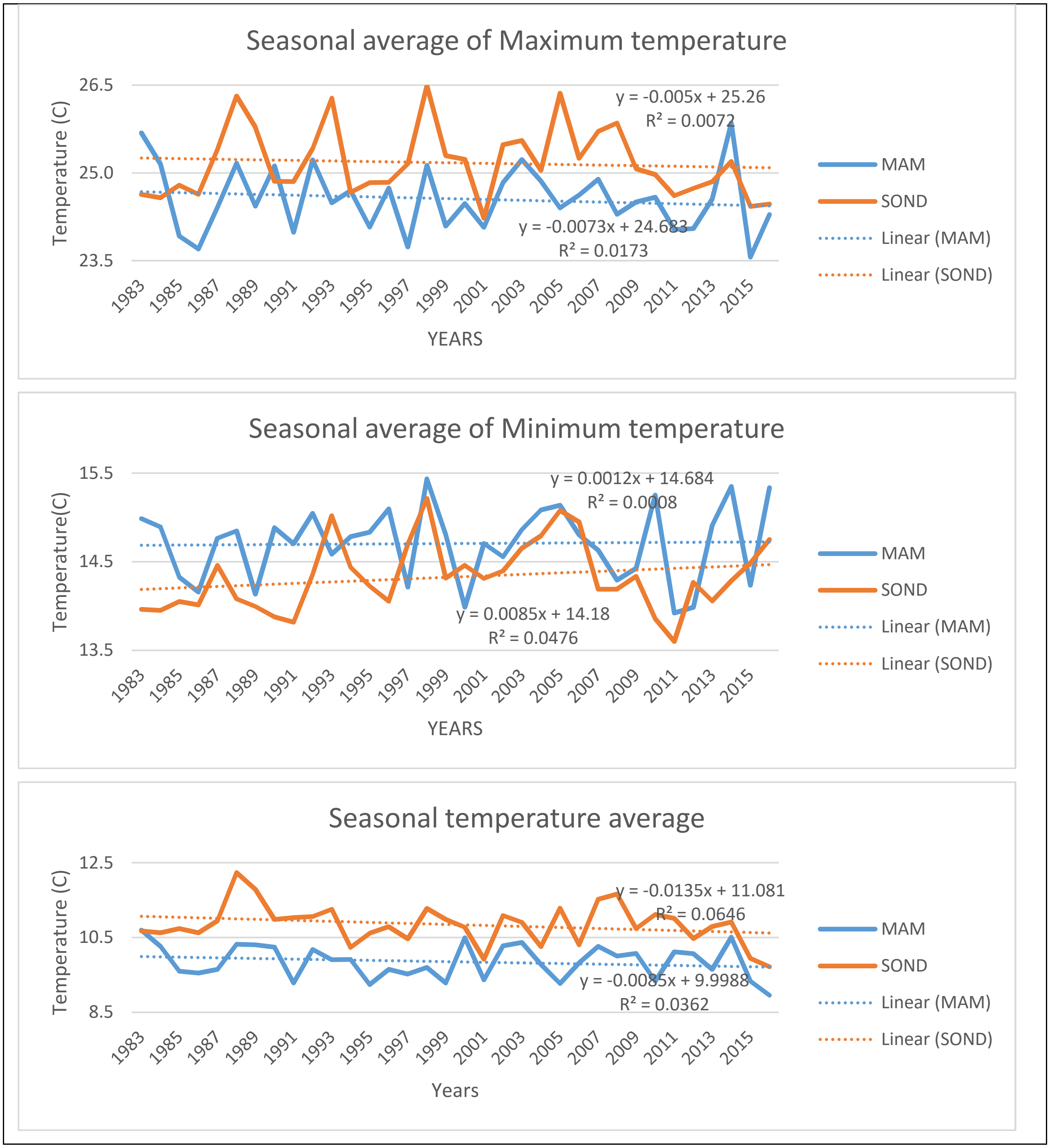


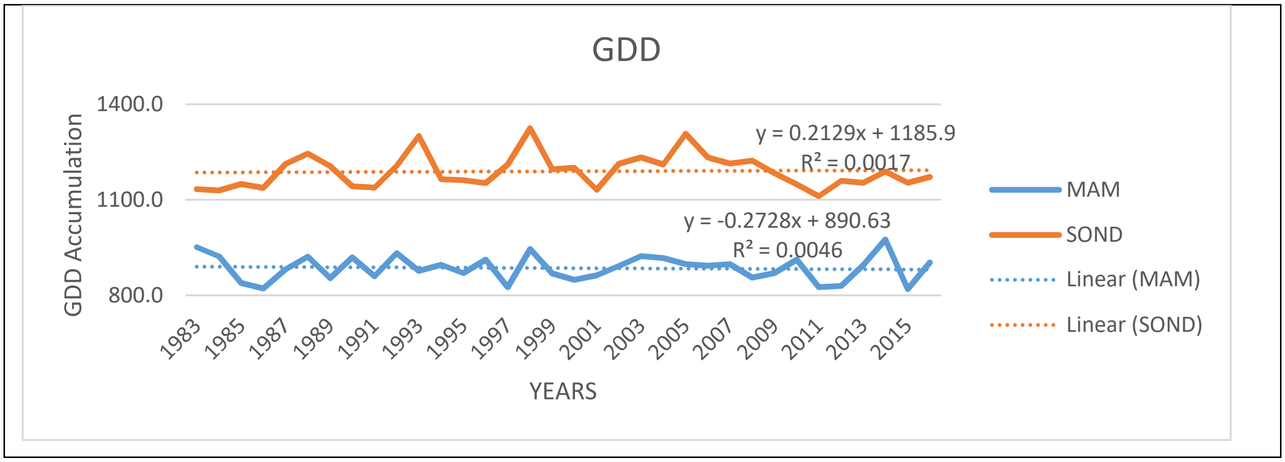
Seasonal trend analysis of temperature characteristics for Rushashi



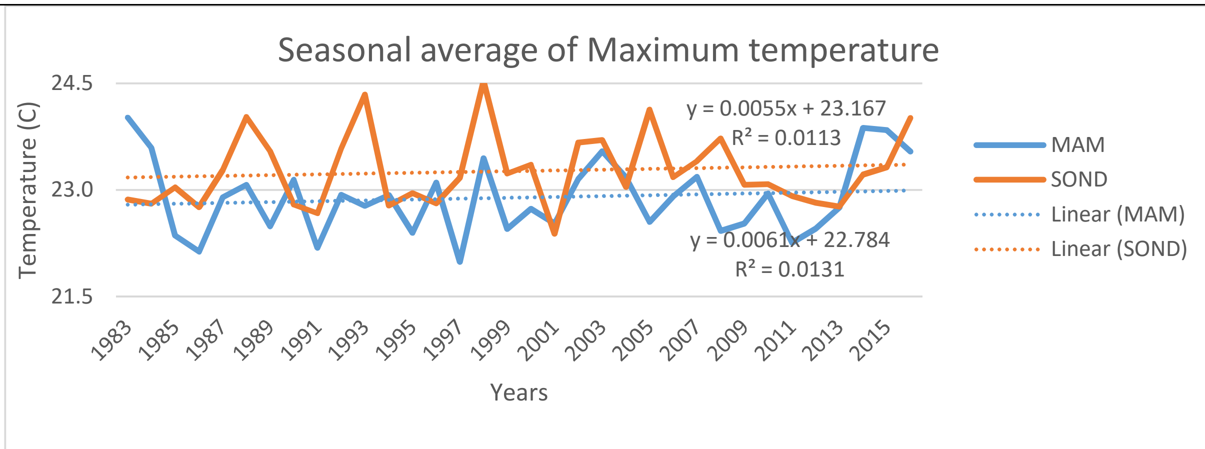


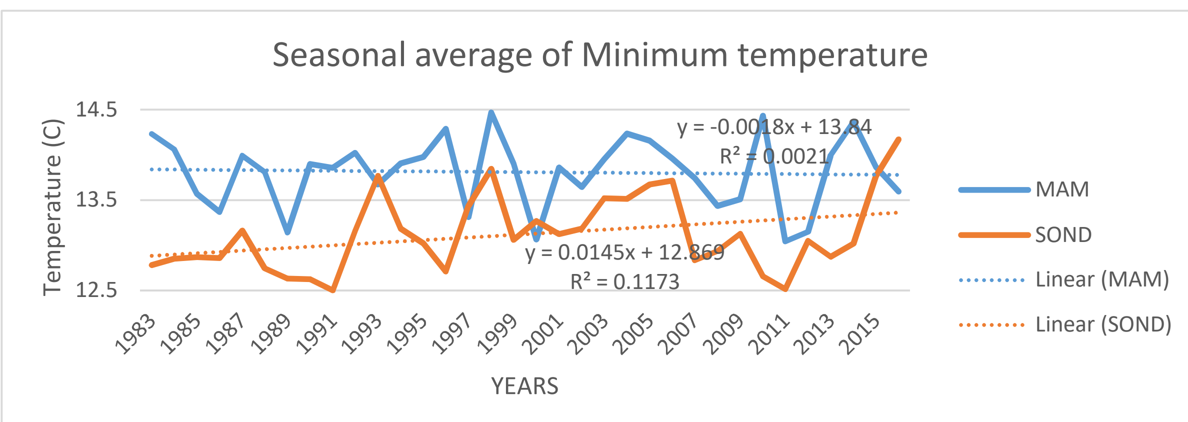
Seasonal trend analysis of temperature characteristics for Butare

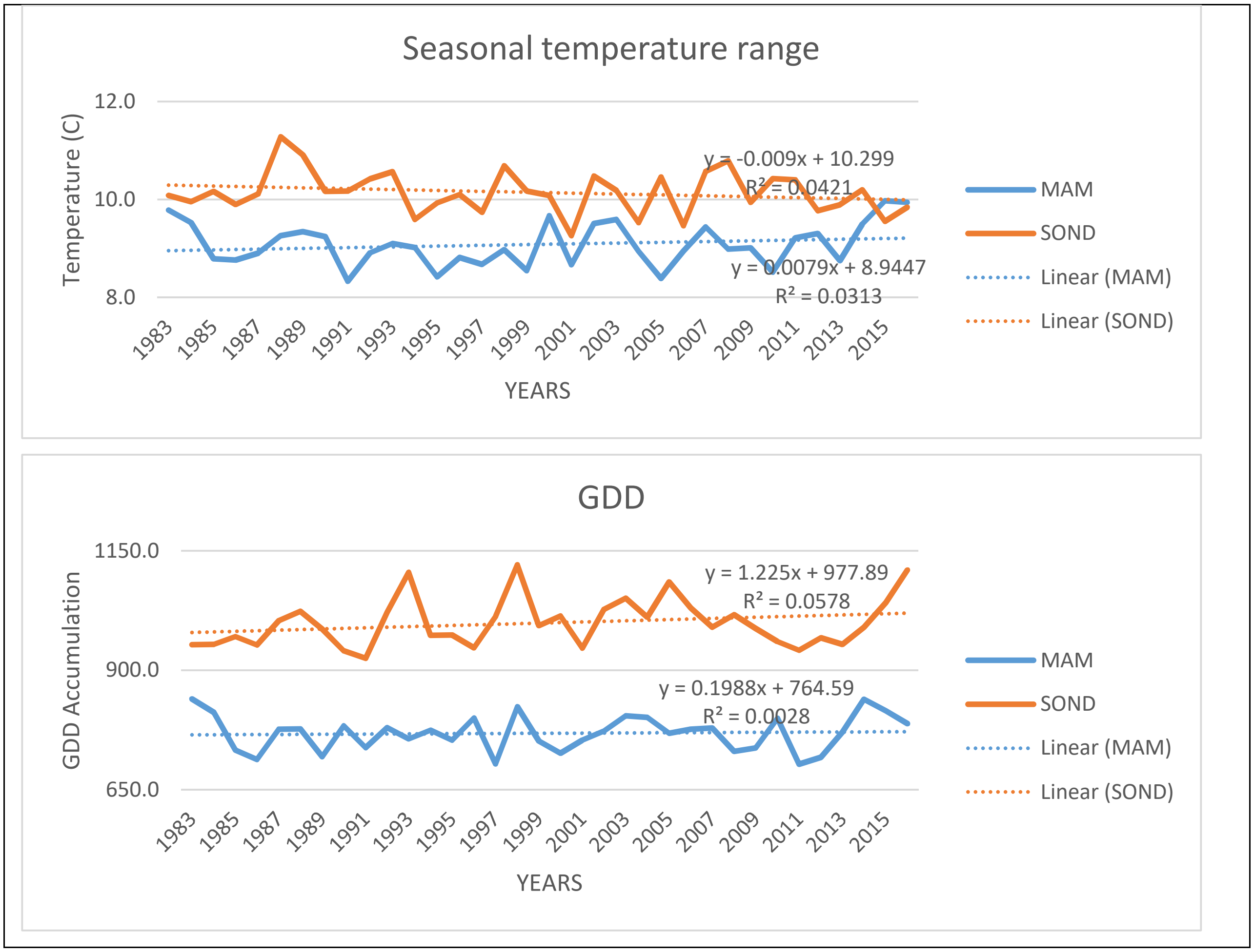

Seasonal average of Maximum temperature
Temperature (C)
26.5
25.0
23.5
y = -0.005x + 25.26
R² = 0.0072
y = -0.0073x + 24.683
R² = 0.0173
1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
YEARS
MAM
SOND
Linear (MAM)
Linear (SOND)
Seasonal average of Minimum temperature
Temperature(C)
15.5
14.5
13.5
y = 0.0012x + 14.684
R² = 0.0008
y = 0.0085x + 14.18
R² = 0.0476
1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
YEARS
MAM
SOND
Linear (MAM)
Linear (SOND)
Seasonal temperature average
Temperature (C)
12.5
10.5
8.5
y = -0.0135x + 11.081
R² = 0.0646
y = -0.0085x + 9.9988
R² = 0.0362
1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
Years
MAM
SOND
Linear (MAM)
Linear (SOND)



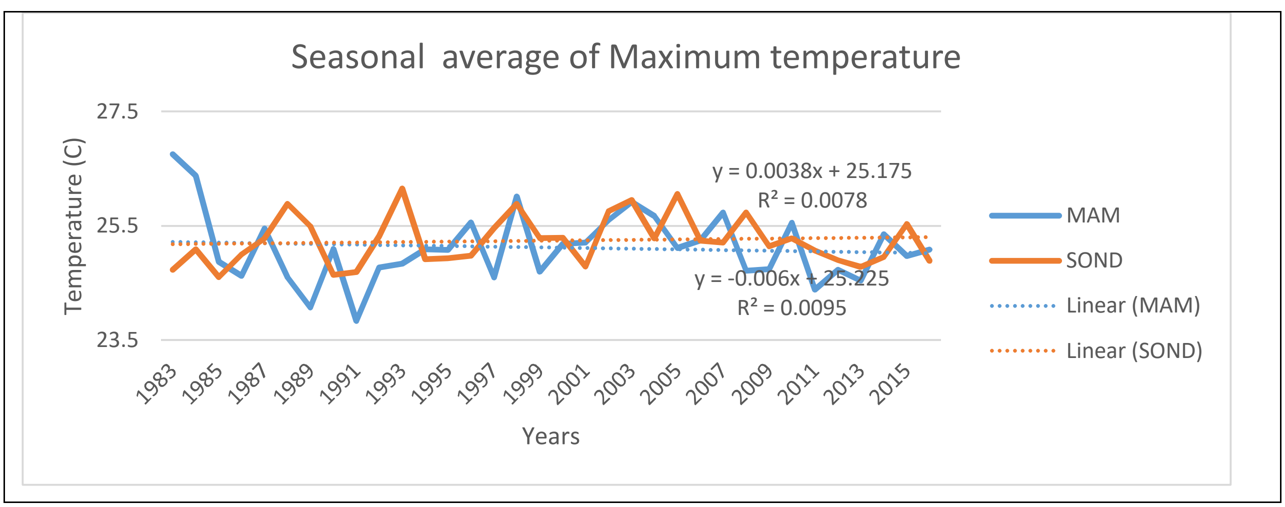
Seasonal trend analysis of temperature characteristics for Byimana

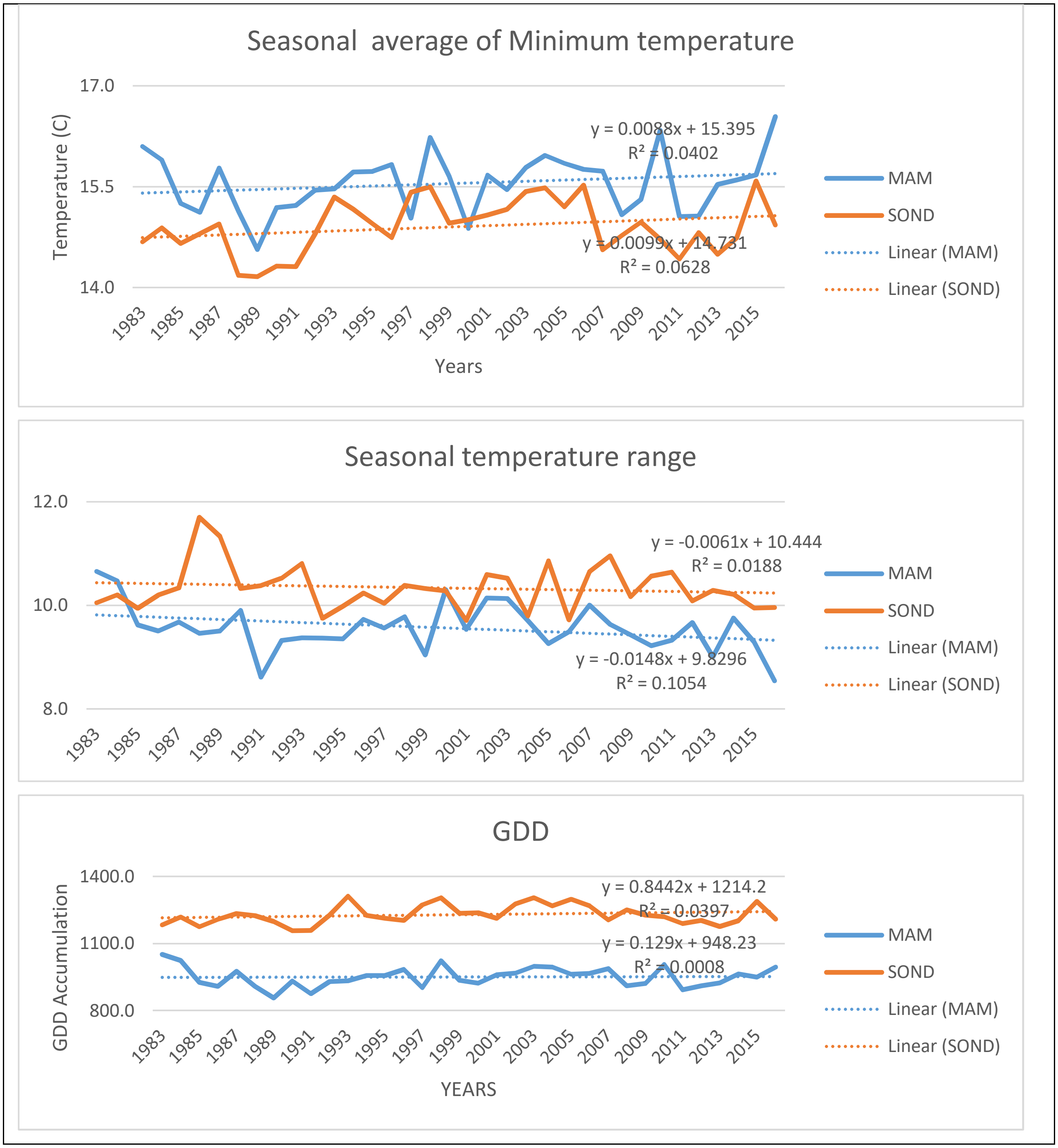




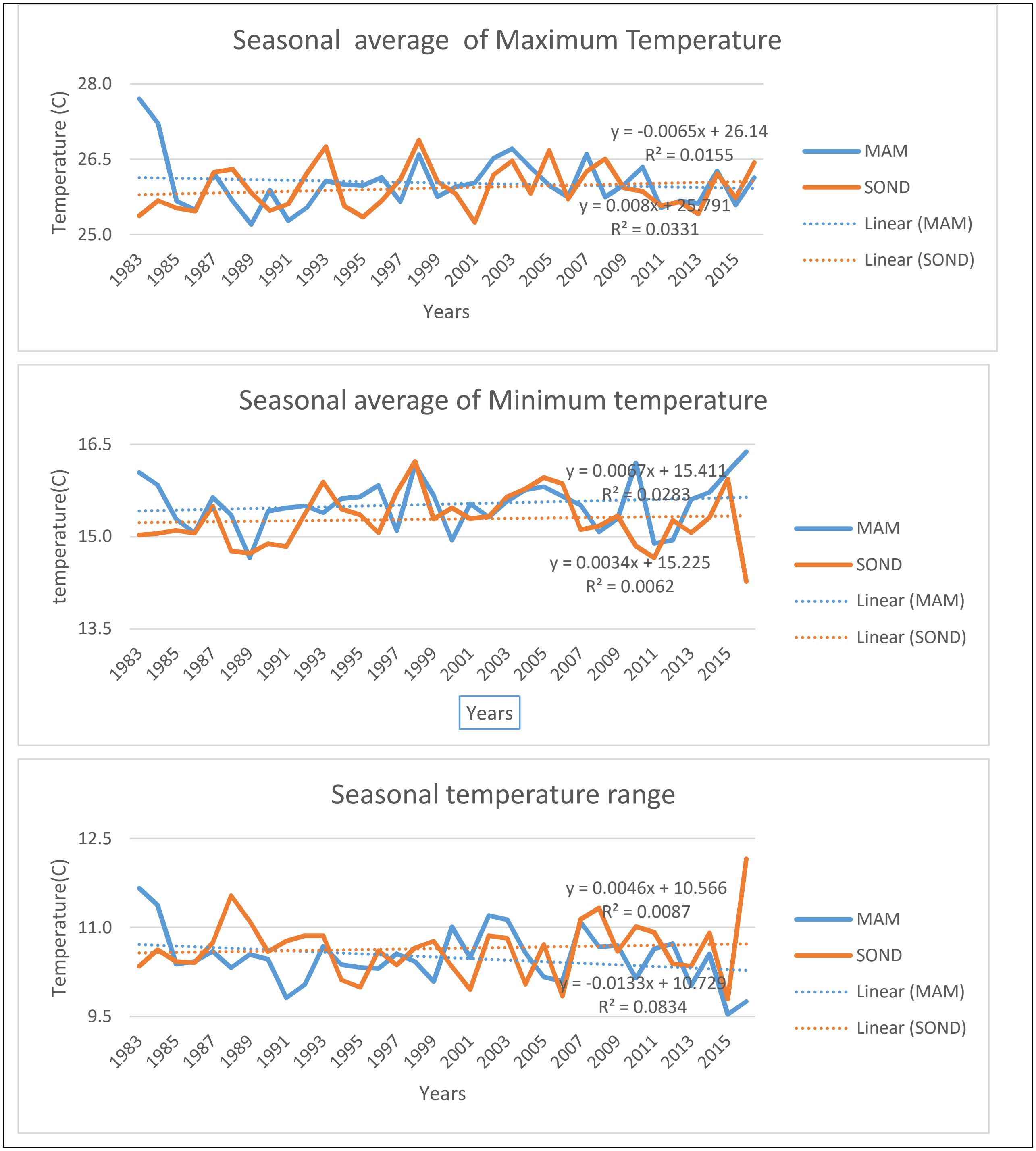


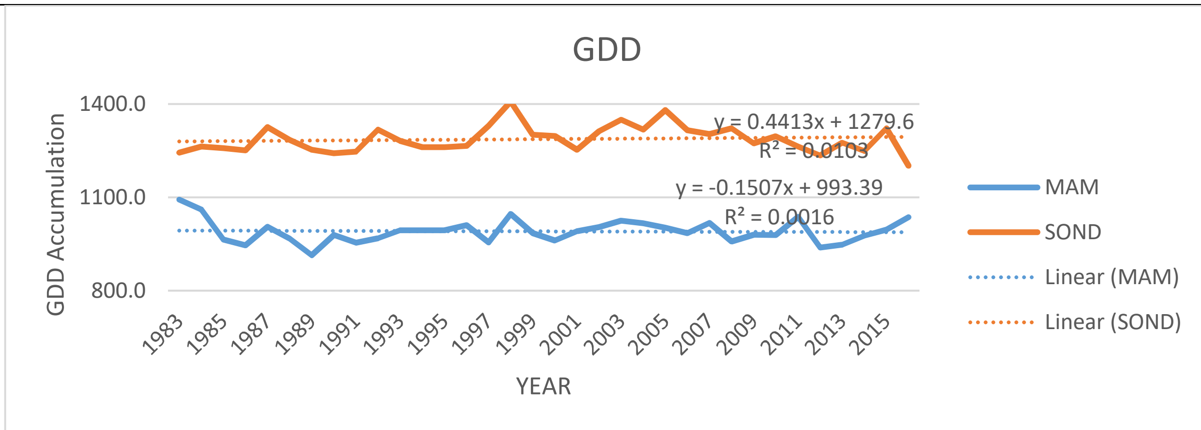
Seasonal trend analysis of temperature characteristics for Gikongoro



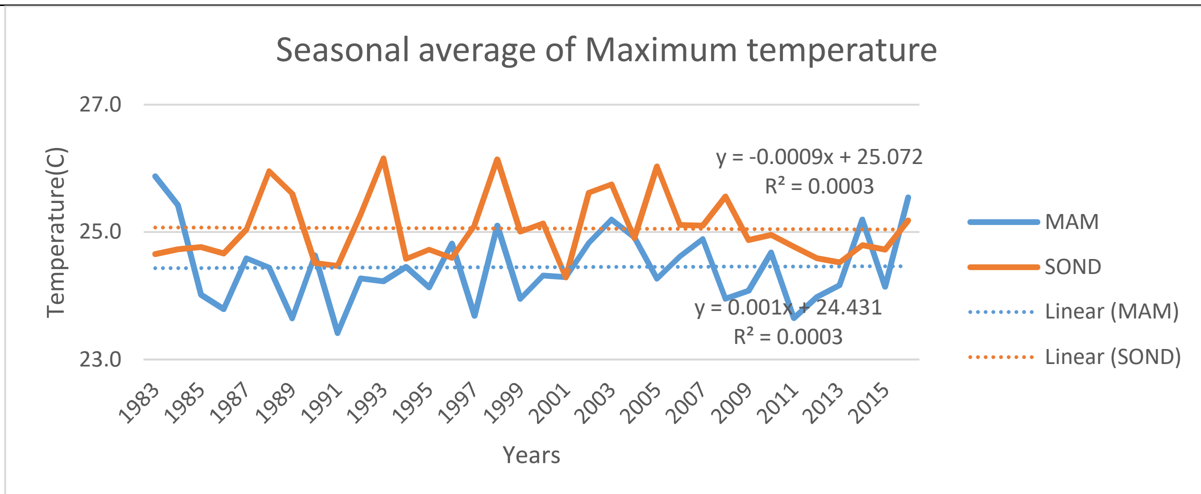


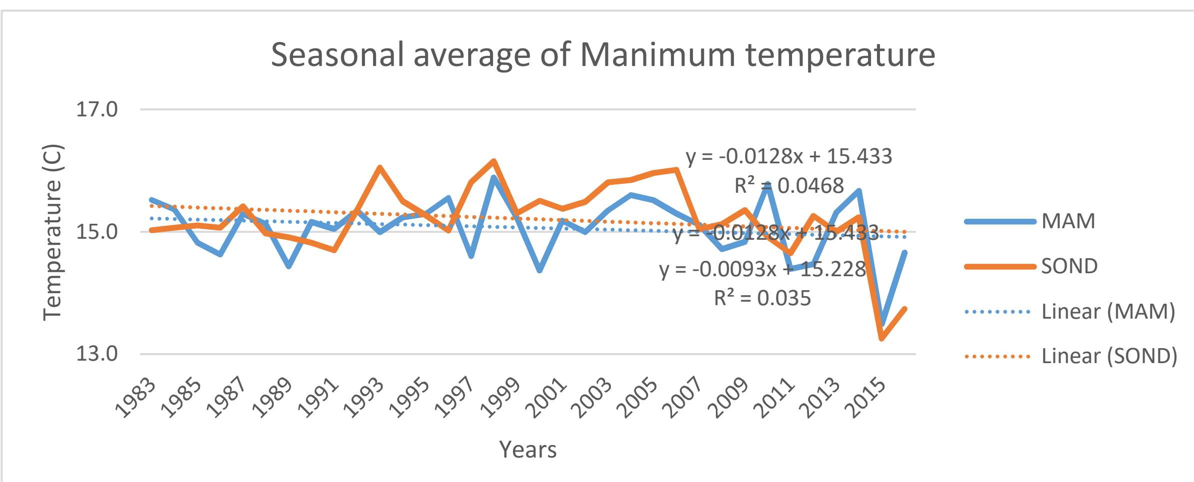
Seasonal trend analysis of temperature characteristics for Gisenyi

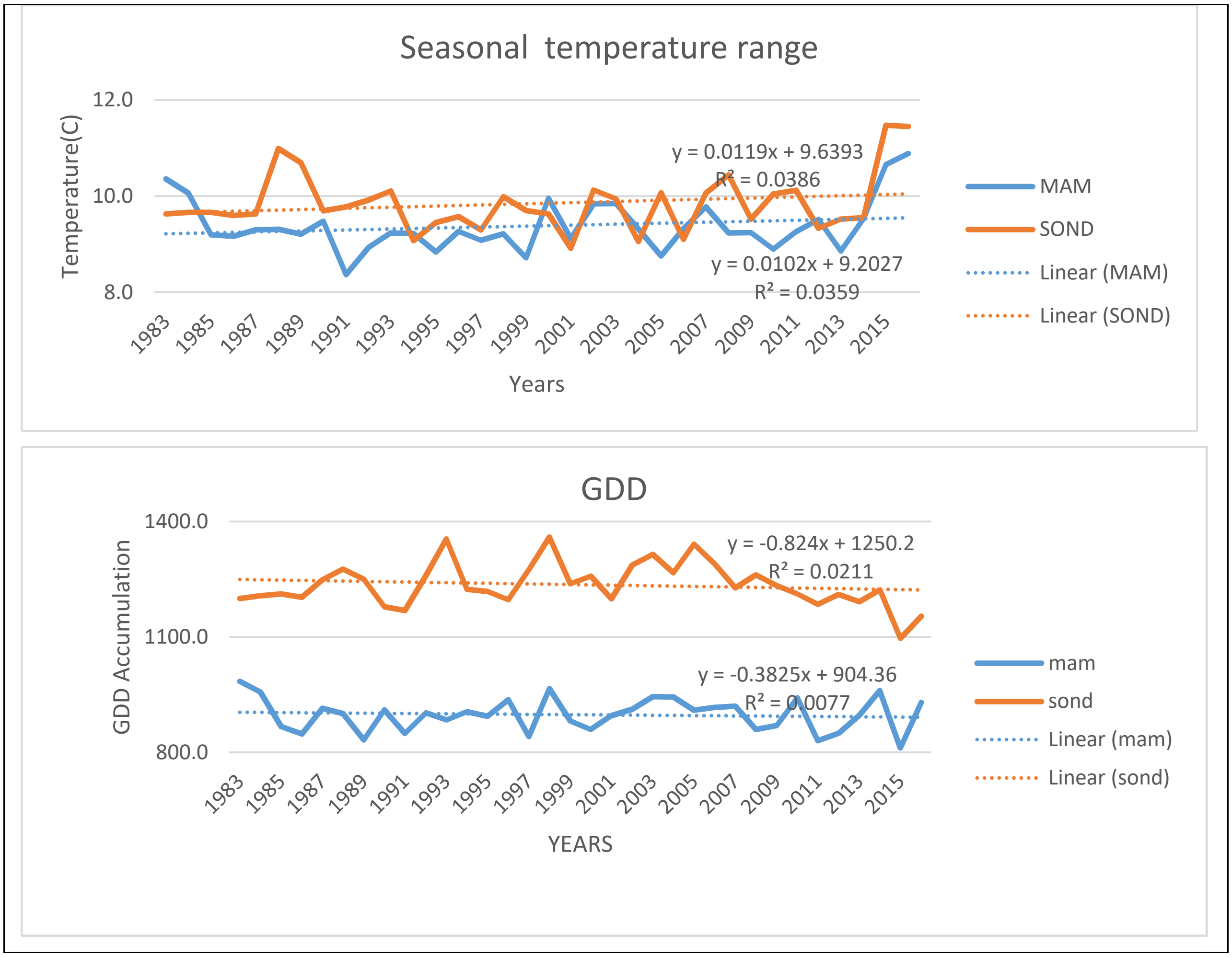

Seasonal average of Maximum Temperature
Temperature (C)
28.0
26.5
25.0
Years
y = -0.0065x + 26.14
R² = 0.0155
y = 0.008x + 25.791
R² = 0.0331
MAM
SOND
Linear (MAM)
Linear (SOND)
Seasonal average of Minimum temperature
temperature(C)
16.5
15.0
13.5
Years
y = 0.0067x + 15.411
R² = 0.0283
y = 0.0034x + 15.225
R² = 0.0062
MAM
SOND
Linear (MAM)
Linear (SOND)
Seasonal temperature range
Temperature(C)
12.5
11.0
9.5
Years
y = 0.0046x + 10.566
R² = 0.0087
y = -0.0133x + 10.729
R² = 0.0834
MAM
SOND
Linear (MAM)
Linear (SOND)
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015



Seasonal trend analysis of temperature characteristics for Kamembe







Seasonal trend analysis of temperature characteristics for Rubengera

AppendixIII

Correlation analysis between maize yield and climate characteristics Onset, Cessation, Length of the season, rainy days, total seasonal rainfall, Maximum temperature, Minimum temperature, temperature range and GDD) for Mageregere, Rubirizi, Masaka, Butare Aero, Gikongoro Met, Byimana, Gisenyi Aero, Kamembe Aero, Rubengera Met, Busogo-ISAE Rushashi, Byumba Met, Kawangire and Kibungo- Kazo.

Correlation analysis between maize yield and climate characteristics for KAWANGIRE

Climate characteristics	MAM season				SOND season			
	Correlation coefficient	T cal	T tab	Interpretation	Correlation coefficient	T cal	T tab	Interpretation
Onset Date	-0.17	0.492	1.812	No Sign	-0.26	0.830	1.812	No Sign
Cessation Date	0.14	0.407	1.812	No Sign	0.25	0.709	1.812	No Sign
Season Length	0.27	0.855	1.812	No Sign	0.23	0.648	1.812	No Sign
Rainy Days	0.46	1.465	1.812	No Sign	0.06	0.546	1.812	No Sign
Seasonal Rainfall	0.33	1.109	1.812	No Sign	0.15	0.429	1.812	No Sign
T Max	-0.40	1.234	1.812	No Sign	-0.33	1.109	1.812	No Sign
T Min	-0.37	1.126	1.812	No Sign	-0.01	0.028	1.812	No Sign
T Range	-0.06	0.546	1.812	No Sign	-0.38	1.161	1.812	No Sign
GDD	-0.46	1.645	1.812	No Sign	-0.26	0.830	1.812	No Sign

Correlation analysis between maize yield and climate characteristics for Kibungo-Kazo

Climate characteristics	MAM season				SOND season			
	Correlation coefficient	T cal	T tab	Interpretation	Correlation coefficient	T cal	T tab	Interpretation
Onset Date	-0.12	0.344	1.812	No Sign	-0.32	0.916	1.812	No Sign
Cessation Date	0.37	1.126	1.812	No Sign	0.15	0.429	1.812	No Sign
Season Length	0.20	0.577	1.812	No Sing	0.40	1.234	1.812	No Sign
Rainy Days	0.69	2.696	1.812	Sign	0.21	0.607	1.812	No Sign
Seasonal Rainfall	0.72	2.934	1.812	Sign	-0.62	2.235	1.812	Sign
T Max	-0.66	2.484	1.812	sign	-0.62	2.235	1.812	Sign
T Min	-0.33	0.988	1.812	No Sign	-0.39	1.197	1.812	Sign
T Range	-0.51	1.676	1.812	No Sign	-0.62	2.235	1.812	Sign
GDD	-0.55	1.862	1.812	Sign	-0.58	2.013	1.812	Sign

Correlation analysis between maize yield and climate characteristics for NYAGATARE

Climate characteristics	MAM season				SOND season			
	Correlation coefficient	T cal	T tab	Interpretation	Correlation coefficient	T cal	T tab	Interpretation
Onset Date	0.35	1.142	1.812	No Sign	-0.12	0.344	1.812	No Sign
Cessation Date	0.58	2.013	1.812	Sign	-0.29	0.891	1.812	No Sign
Season Length	-0.29	0.857	1.812	No Sign	0.15	0.429	1.812	No Sign
Rainy Days	-0.57	1.962	1.812	Sign	-0.09	0.255	1.812	No Sign
Seasonal Rainfall	-0.004	0.001	1.812	No Sign	-0.07	0.019	1.812	No Sign
T Max	-0.83	4.208	1.812	Sign	-0.75	3.207	1.812	Sign
T Min	-0.49	1.589	1.812	No Sign	-0.001	0.028	1.812	No Sign
T Range	-0.27	0.857	1.812	No Sign	-0.81	3.906	1.812	Sign
GDD	-0.74	3.045	1.812	Sign	-0.45	1.415	1.812	No Sign

Correlation analysis between maize yield and climate characteristics for Rushashi

Climate characteristics	MAM season				SOND season			
	Correlation coefficient	T cal	T tab	Interpretation	Correlation coefficient	T cal	T tab	Interpretation
Onset Date	0.04	0.112	1.812	No Sign	0.45	1.538	1.812	No Sign
Cessation Date	0.57	1.962	1.812	Sign	0.40	1.234	1.812	No Sign
Season Length	0.37	1.148	1.812	No Sign	-0.42	1.279	1.812	No Sign
Rainy Days	-0.16	0.458	1.812	No Sign	-0.82	4.102	1.812	Sign
Seasonal Rainfall	-0.16	0.458	1.812	No Sign	-0.35	1.102	1.812	No Sign
T Max	-0.64	2.128	1.812	Sign	-0.88	5.240	1.812	Sign
T Min	-0.38	1.161	1.812	No Sign	0.47	1.721	1.812	No Sign
T Range	0.08	0.210	1.812	No Sign	-0.72	2.934	1.812	Sign
GDD	-0.50	1.616	1.812	No Sign	0.13	0.349	1.812	No Sign

Correlation analysis between maize yield and climate characteristics for Byumba

Climate characteristics	MAM season				SOND season			
	Correlation coefficient	T cal	T tab	Interpretation	Correlation Coefficient	T cal	T tab	Interpretation
Onset Date	0.28	0.912	1.812	No Sign	-0.07	0.197	1.812	No Sign
Cessation Date	0.12	0.344	1.812	No Sign	0.27	0.855	1.812	No Sign
Season Length	-0.06	0.178	1.812	No Sign	0.16	0.458	1.812	Sign
Rainy Days	-0.15	0.429	1.812	No Sign	0.55	1.862	1.812	Sign
Seasonal Rainfall	0.55	1.862	1.812	Sign	0.16	0.458	1.812	No Sign
T Max	-0.67	2.513	1.812	Sign	-0.78	3.821	1.812	Sign
T Min	-0.45	1.602	1.812	No Sign	-0.41	1.319	1.812	No Sign
T Range	-0.27	0.855	1.812	No Sign	-0.32	0.916	1.812	No Sign
GDD	-0.58	2.013	1.812	Sign	-0.62	2.261	1.812	Sign

Correlation analysis between maize yield and climate characteristics for Busogo-Isae

Climate characteristics	MAM season				SOND season			
	Correlation coefficient	T cal	T tab	Interpretation	Correlation coefficient	T cal	T tab	Interpretation
Onset Date	-0.21	0.599	1.812	No Sign	-0.30	0.902	1.812	No Sign
Cessation Date	0.57	1.962	1.812	No Sign	-0.57	1.962	1.812	Sign
Season Length	0.25	0.709.	1.812	No Sign	0.06	0.178	1.812	No Sign
Rainy Days	-0.004	0.001	1.812	No Sign	0.42	1.421	1.812	No Sign
Seasonal Rainfall	0.22	0.612	1.812	No Sign	-0.10	0.284	1.812	No Sign
T Max	-0.68	2.612	1.812	Sign	-0.28	0.896	1.812	No Sign
T Min	-0.45	1.602	1.812	No Sign	-0.32	0.916	1.812	No Sign
T Range	-0.08	0.210	1.812	No Sign	-0.05	0.145	1.812	No Sign
GDD	-0.56	1.915	1.812	Sign	0.31	0.901	1.812	No Sign

Correlation analysis between maize yield and climate characteristics for Butare

Climate characteristics	MAM season				SOND season			
	Correlation coefficient	T cal	T tab	Interpretation	Correlation coefficient	T cal	T tab	Interpretation
Onset Date	-0.17	0.492	1.812	No Sign	0.16	0.458	1.812	No Sign
Cessation Date	-0.15	0.429	1.812	No Sign	-0.21	0.599	1.812	No Sign
Season Length	-0.01	0.028	1.812	No Sign	-0.19	0.547	1.812	No Sign
Rainy Days	-0.50	1.629	1.812	No Sign	-0.15	0.429	1.812	No Sign
Seasonal Rainfall	-0.20	0.577	1.812	No Sign	-0.08	0.212	1.812	No Sign
T Max	-0.35	1.056	1.812	No Sign	-0.73	3.012	1.812	Sign
T Min	-0.25	0.709	1.812	No Sign	-0.03	0.068	1.812	No Sign
T Range	-0.02	0.035	1.812	No Sign	-0.47	1.511	1.812	No Sign
GDD	-0.32	0.916	1.812	No Sign	-0.37	1.126	1.812	No Sign

Correlation analysis between maize yield and climate characteristics for Byimana

Climate characteristics	MAM season				SOND season			
	Correlation coefficient	T cal	T tab	Interpretation	Correlation coefficient	T cal	T tab	Interpretation
Onset Date	-0.84	4.310	1.812	No Sign	-0.76	3.267	1.812	Sign
Cessation Date	0.54	1.814	1.812	Sign	0.65	2.412	1.812	Sign
Season Length	0.76	3.267	1.812	Sign	0.80	3.852	1.812	Sign
Rainy Days	-0.31	0.901	1.812	No Sign	-0.30	0.897	1.812	No Sign
Seasonal Rainfall	0.76	3.267	1.812	Sign	0.79	3.725	1.812	Sign
T Max	0.37	1.126	1.812	No Sign	-0.90	5.839	1.812	Sign
T Min	0.80	3.852	1.812	Sign	-0.75	3.196	1.812	Sign
T Range	-0.45	1.602	1.812	No Sign	-0.61	2.178	1.812	Sign
GDD	0.70	3.012	1.812	Sign	-0.93	7.156	1.812	Sign

Correlation analysis between maize yield and climate characteristics for Kamembe

Climate characteristics	MAM season				SOND season			
	Correlation coefficient	T cal	T tab	Interpretation	Correlation coefficient	T cal	T tab	Interpretation
Onset Date	0.24	0.669	1.812	No Sign	-0.03	0.098	1.812	No Sign
Cessation Date	0.51	1.676	1.812	No Sign	-0.02	0.092	1.812	No Sign
Season Length	0.50	1.632	1.812	No Sign	0.01	0.028	1.812	No Sign
Rainy Days	-0.13	0.349	1.812	No Sign	-0.31	0.901	1.812	No Sign
Seasonal Rainfall	0.40	1.234	1.812	No Sign	-0.02	0.092	1.812	No Sign
T Max	-0.35	1.042	1.812	No Sign	-0.55	1.862	1.812	Sign
T Min	-0.06	0.170	1.812	No Sign	-0.02	0.092	1.812	No Sign
T Range	-0.21	0.599	1.812	No Sign	-0.21	0.599	1.811	No Sign
GDD	-0.04	0.110	1.812	No Sign	-0.14	0.407	1.812	No Sign

Correlation analysis between maize yield and climate characteristics for Gisenyi

Climate characteristics	MAM season				SOND season			
	Correlation coefficient	T cal	T tab	Interpretation	Correlation coefficient	T cal	T tab	Interpretation
Onset Date	-0.09	0.255	1.812	No Sign	0.16	0.458	1.812	No Sign
Cessation Date	0.39	1.197	1.812	No Sign	-0.03	0.098	1.812	No Sign
Season Length	0.32	0.916	1.812	No Sign	-0.17	0.492	1.812	No Sign
Rainy Days	-0.02	0.092	1.812	No Sign	0.06	0.170	1.812	No Sign
Seasonal Rainfall	0.54	1.814	1.812	Sign	0.72	2.934	1.812	Sign
T Max	-0.57	1.962	1.812	Sign	-0.33	1.109	1.812	No Sign
T Min	-0.38	1.161	1.812	No Sign	-0.21	0.599	1.812	No Sign
T Range	-0.18	0.514	1.812	No Sign	-0.18	0.514	1.812	No Sign
GDD	-0.53	1.767	1.812	No Sign	-0.36	1.096	1.812	No Sign

Correlation analysis between maize yield and climate characteristics for Rubengera

Climate characteristics	MAM season				SOND season			
	Correlation coefficient	T cal	T tab	Interpretation	Correlation coefficient	T cal	T tab	Interpretation
Onset Date	-0.52	1.689	1.812	No Sign	0.27	0.855	1.812	No Sign
Cessation Date	0.63	2.214	1.812	Sign	0.43	1.462	1.812	No Sign
Season Length	0.74	3.045	1.812	Sign	-0.001	0.001	1.812	No Sign
Rainy Days	0.15	0.429	1.812	No Sign	-0.14	0.407	1.812	No Sign
Seasonal Rainfall	0.42	1.421	1.812	No Sign	0.70	3.012	1.812	Sign
T Max	-0.36	1.096	1.812	No Sign	-0.68	2.612	1.812	Sign
T Min	0.24	0.697	1.812	No Sign	-0.58	2.013	1.812	Sign
T Range	-0.56	1.915	1.812	Sign	0.32	0.916	1.812	No Sign
GDD	-0.07	0.019	1.812	No Sign	-0.78	3.698	1.812	Sign

Correlation analysis between maize yield and climate characteristics for Mageragere

Climate characteristics	MAM season				SOND season			
	Correlation coefficient	T cal	T tab	Interpretation	Correlation coefficient	T cal	T tab	Interpretation
Onset Date	-0.60	2.113	1.812	Sign	-0.29	0.942	1.812	No Sign
Cessation Date	0.64	2.355	1.812	Sign	0.25	0.709	1.812	No Sign
Season Length	0.71	3.089	1.812	Sign	0.15	0.429	1.812	No Sign
Rainy Days	0.52	1.689	1.812	No Sign	-0.16	0.458	1.812	No Sign
Seasonal Rainfall	0.50	1.632	1.812	No Sign	0.47	1.511	1.812	No Sign
T Max	-0.32	0.916	1.812	No Sign	-0.81	3.906	1.812	Sign
T Min	-0.47	1.511	1.812	No Sign	-0.34	1.132	1.812	No Sign
T Range	0.14	0.407	1.812	No Sign	-0.38	1.161	1.812	No Sign
GDD	-0.54	1.814	1.812	Sign	-0.75	3.196	1.812	Sign

Correlation analysis between maize yield and climate characteristics for Masaka

Climate characteristics	MAM season				SOND season			
	Correlation coefficient	T cal	T tab	Interpretation	Correlation coefficient	T cal	T tab	Interpretation
Onset Date	-0.81	3.906	1.812	Sign	0.22	0.612	1.812	No Sign
Cessation Date	-0.20	0.577	1.812	No Sign	0.12	0.344	1.812	No Sign
Season Length	0.70	3.012	1.812	Sign	-0.09	0.255	1.812	No Sign
Rainy Days	0.28	0.912	1.812	No Sign	0.67	2.513	1.812	Sign
Seasonal Rainfall	0.18	0.514	1.812	No Sign	0.001	0.000	1.812	No Sign
T Max	-0.54	1.814	1.812	Sign	-0.73	3.012	1.812	Sign
T Min	-0.58	2.013	1.812	Sign	-073	3.012	1.812	Sign
T Range	-0.11	0.312	1.812	No Sign	-0.53	1.767	1.812	No Sign
GDD	-0.58	2.013	1.812	Sign	-0.53	1.767	1.812	No Sign

Correlation analysis between maize yield and climate characteristics for Rubirizi

Climate characteristics	MAM season				SOND season			
	Correlation coefficient	T cal	T tab	Interpretation	Correlation coefficient	T cal	T tab	Interpretation
Onset Date	-0.68	2.612	1.812	Sign	-0.19	0.547	1.812	No Sign
Cessation Date	0.45	1.602	1.812	No Sign	0.003	0.098	1.812	No Sign
Season Length	0.76	3.267	1.812	Sign	0.20	0.577	1.812	No Sign
Rainy Days	0.53	1.767	1.812	No Sign	0.74	3.045	1.812	Sign
Seasonal Rainfall	0.37	1.126	1.812	No Sign	-0.09	0.255	1.812	No Sign
T Max	-0.47	1.511	1.812	No Sign	-0.82	4.006	1.812	Sign
T Min	-0.48	1.548	1.812	No Sign	-0.28	0.912	1.812	No Sign
T Range	0.06	0.170	1.812	No Sign	-0.49	1.589	1.812	No Sign
GDD	-0.53	1.767	1.812	No Sign	-0.62	2.261	1.812	Sign