IMPACT OF TEMPERATURE AND RAINFALL VARIABILITY ON COFFEE PRODUCTION IN MARABA

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IMPACT OF TEMPERATURE AND RAINFALL VARIABILITY ON COFFEE PRODUCTION IN MARABA

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DECLARATION

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

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ABSTRACT

Agriculture is the mainstay of the Rwandan economy, since it accounts for 43 per cent of GDP and sustains almost 90 per cent of the population.

Since agricultural production in Rwanda depends almost exclusively on the quality of the rainy season and specific temperature ranges, it makes the country particularly vulnerable to climate variability and change. A change in temperature and rainfall has been considered to affect agriculture production in many parts of the country.

In Rwanda, the coffee industry plays an important role in the country’s economic development. For many years coffee used to be Rwanda’s top export product and thus main source of foreign exchange income.

In this study the programming language (python) was used to calculate coefficient of correlation ($r$), coefficient of determination ($r^2$) and the p-value ($p$) at the significance of 0.05 to determine relationship between climate variables rainfall and temperature and coffee yield from 2002-2017.

The relationship between the amount of coffee in kg/ha produced and amount of rainfall in mm was statistically insignificant at 5% level $p = 0.58$. This indicates that coffee production was not much influenced by rainfall, but there must be other factors like shortage of agricultural inputs such as fertilizers and pesticides which influence coffee production in the study area.

The relationship between the amount of coffee in kg/ha produced and maximum temperature was statistically significant at 5% level, results show that $p = 0.001$ which is less than 0.05, hence the relationship was significant. Negative correlation $r = -0.663$ suggests that when there is an increase in maximum temperature, yield harvested reduces and vice versa.

The relationship between the amount of coffee in kg/ha produced and mean temperature was statistically significant at 5% level, results show that $p = 0.001$ which is less than 0.05, hence the relationship was significant. Negative correlation $r = -0.663$ suggests that when there is an increase in mean temperature, yield harvested reduces and vice versa.

These results may be associated with attack by pests and diseases associated with high temperature conditions. These results are in line with research according to [13] which shows that increase in temperature inhibits photosynthesis and results in changes in planting periods, reducing growth and resulting in smaller yields.
OPERATIONAL DEFINITION OF TERMS

**Climate Change** refers to a change in the state of the climate that can be identified by changes in the mean and in the variability of precipitation and temperature that persists for an extended period typically decades or longer.

**Climate Variability** refers to variation in the mean states, on all temporal scales beyond those of individual weather events.

**Vulnerability** refers to the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, the sensitivity and adaptive capacity of that system.
LIST OF SYMBOLS AND ACRONYMS

CBB : coffee Berry Borer  
DJF : December-January-February  
ENSO : El Nino Southern Oscillation  
FAO : Food and Agriculture Organization  
GCM : General Circulation Model  
GDP : Gross Domestic Product  
IPCC : Intergovernmental Panel on Climate Change  
ITCZ : Inter Tropical Convergence Zone  
JJA : June-July-August  
MAM : March-April-May  
MCIP : Maraba Coffee Intensification Program  
MMD : multi-model-dataset  
NAEB : National Agricultural Export Development Board  
RAB : Rwanda Agricultural Board  
SON : September-October-November  
\( p \) : p-value  
\( r \) : Correlation coefficient  
\( r^2 \) : coefficient of determination
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CHAPTER ONE

1. INTRODUCTION

1.1 Background

Agriculture is the mainstay of the Rwandan economy, since it accounts for 43 per cent of GDP and sustains almost 90 per cent of the population[1], [2]. It contributes to food security and employment of rural households. Climate variability and change have adversely affected this sector and the situation is expected to worsen in the future.

Agricultural production in Rwanda can be grouped into two main categories: staple crops (leguminous, cereals, roots, tubers and banana) and cash crops (coffee, tea, and pyrethrum). Among these cash crops coffee is the most source of revenue of Rwandan society since the crop is the main trade commodity of our country. Today, Rwandan coffee is increasingly recognized as a high quality product[3].

Since agricultural production in Rwanda depends almost exclusively on the quality of the rainy season and specific temperature ranges, it makes the country particularly vulnerable to climate variability and change.

The climate variability of Rwanda is one of the most significant factors influencing year to year crop production. Even in high-technology agricultural areas that factor remains one of the most important.

In recent years, more and more attention has been paid to the risks associated with climate change, and the increase uncertainty with respect to food production. In Rwanda water regime of fields and wetlands is closely linked to rainfall. It could be one of the limiting constraints for crop production and food security[4].

Climate change and variability are closely linked in the climatic system, with long term scale climate change manifesting itself with episodes being observed in short term climate variability. Instances of climate variability consist of seasonal, annual and inter decadal variation in temperature and rainfall, extensive droughts, floods and conditions that result from periodic El Nino and La Nina events[5].
Due to their close association, climate change and climate variability are simultaneously used together in research as well as in policy.

Beside the changes in temperature, over the years rainfall patterns have changed, with cases of heavy rainfall at crop maturity and droughts occurring at critical stages of crop growth being common. These changes are likely to severely, compromise crop production and food security with colossal economic consequences in many African countries especially in sub Saharan Africa.

Rwanda has experienced a temperature increase of 1.4°C since 1970, higher than the global average, and can expect an increase in temperature of up to 2.5°C by the 2050s. Rainfall is highly variable in Rwanda but average annual rainfall may increase by up to 20 per cent by the 2050s from 1970[6].

There is likelihood that changes in temperature and rainfall patterns, will affect the potential of crop production. The effects of climate variability on crop production could be direct or indirect. Directly the effect is through changes in temperature and precipitation that affect the timing of crop development.

Rising temperatures are likely to reduce crop production in the long-term especially through reduction in the number of reliable crop growing days while changes in precipitation patterns are likely to increase short term crop failures and long term production declines[5]. Indirectly, climate variability may increase the population and growth of pests, insects, weeds and diseases making crop management difficult and costly. These conditions are likely to impact on crop production in a negative way.

Moreover, the changing patterns of temperature, precipitation and the extreme events of storms and droughts lead not only to a decline in land productivity but also to an increase of plant disease incidences in the study area.

In Rwanda, the coffee industry plays an important role in the country’s economic development. For many years coffee used to be Rwanda’s top export product and thus main source of foreign exchange income.
Traditionally, agriculture export commodities in Rwanda comprised of coffee, tea and pyrethrum. However, over the years the scope of agriculture export crops development has been expanded to include other crops like fruits and vegetables, flowers and new export value chains like livestock products, cereal, and grains to name a few.

Coffee is ranked the first in the coffee value chain, the 2014-2015 fiscal year registered a production of 16,924 MT and exports of 16,529 MT that generated an export revenue of 64.02 Million USD[7].

For many countries in East Africa as shown in table below, coffee is an important agricultural commodity in terms of economic value, and several of the countries in East Africa are amongst the largest coffee exporting nations in the world[8]. The table 1.1 shows the total export value of coffee, and the contribution of coffee to the total agricultural export value in eight East African countries.

According to [2], coffee provides a livelihood for almost 500,000 Rwandan families (corresponding to approximately 2 million people and 25 per cent of the total population) who belong to cooperatives and grow coffee in small plots.

The example is Abahuzamugambi Ba Kawa cooperative of Maraba founded in 1999 in order to improve the quality and the value of coffee because before this year, the farmers did not have the means to wash and prepare their coffee cherries to specifications in a timely manner. Buyers paid only US$0.33 per kilogram, a price that kept the farmers poor.

Climate change is the greatest challenge facing humankind worldwide in this century. Africa is one of the most vulnerable regions to climate change and is likely the most debilitated.

Global warming is the observed temperature increase due to the increase of greenhouse gas concentrations in the atmosphere. Green house gases contribute to the greenhouse effect on the earth’s surface. The largest contributing source of greenhouse gas is the burning of fossil fuels leading to the emission of carbon dioxide.

The emission of carbon dioxide into the environment mainly from burning of fossil fuels (oil, gas, petrol, kerosene, etc.) has been increased dramatically over the past 50 years[9].
Climate variability has begun to affect coffee production, while demand for coffee is growing. This thesis aims to examine how a change in temperature as a climate condition is affecting coffee production.

The climate change challenge is complicated further by limited climate change research resources. Therefore, climate dynamics are still poorly understood. This project aims to build capacity within the Rwandan coffee sector on climate change impacts. This may assist in policy making in climate change mitigation to secure the future livelihoods of coffee producers and make these livelihoods more environmentally and economically sustainable.

Human beings depend for their livelihood on agriculture more than on any other economic activity. This is particularly true for small farmers in Maraba (Huye District) whose economic well-being and food security depends primarily on farming.

The key environmental factors that influence coffee productivity are temperature, water availability, sunshine intensity, wind, type of soil and topography of land. The optimal mean temperature for *C. Arabica* is considered to be 18°C during the night and 22°C during daytime. Extremes should not be lower than 15°C during night and not exceed 25-30°C at daytime.

Reduced photosynthesis at temperatures above 25°C and a loss of flowers or fruit degeneration at temperatures above 30°C compromise productivity. Low temperatures favor diseases. Temperatures lower than minus 2°C for more than 6h are potentially lethal for the plant. *C. canephora* var. Robusta is generally more tolerant towards high temperatures but may die at 4-5°C[10].

Bunn, 2015 added that Arabica requires about 1400 to 2000mm of annual rainfall, Robusta between 2000 and 2500mm. Values lower than the minimum are potentially damaging for production. Excessive rainfalls are mostly a problem because of top soil erosion. A dry season of about 3 months is considered to promote productivity.

Atmospheric humidity has an influence on transpiration and is therefore linked with necessary rainfalls. Ideal humidity is 60% for Arabica and 70% for Robusta.

Arabica coffee is confirmed as a climate sensitive species, supporting data and inference that existing plantations will be negatively impacted by climate change[11].
Maraba’s coffee plants are the Bourbon variety of the Coffea arabica species and are grown on fertile volcanic soils on high-altitude hills. The fruit is handpicked, mostly during the rainy season between March and May, and brought to a washing station in Maraba, where the coffee beans are extracted and dried. At several stages, the beans are sorted according to quality.

1.2 Problem statement and justification for the study

Like many other African countries, the agriculture sector in Rwanda accounts for about half of the national income. For example in Rwanda, coffee accounts for 42.7% of the total value of agricultural exports[12].

The study conducted by Ngabitsinze in 2014 found that in the last 30 years, Rwanda has experienced a series of climate fluctuations in terms of frequency, intensity, and persistence of existing extremes.

Heavy rains, storms, heat waves and droughts are the observed manifestations of climate change in specific areas of Rwanda. Changing weather patterns have an adverse impact on the country’s agricultural production and thus on the country’s GDP.

However, the coffee production in Rwanda is mostly dependent on rain and temperature which make it vulnerable to climate change and climate variability. This is due to the fact that, climate change affects the two most important agricultural production inputs which are rainfall and temperature.

A change in temperature and rainfall has been considered to affect agriculture production in many parts of the country. Coffee is a vulnerable crop which needs special climatic conditions if it is to grow well and give a good harvest.

Both Robusta and Arabica coffee varieties require agro-ecological areas with hot-wet or hot-temperate climate with frequent rainfall of about 1000mm or more per annum and temperatures varying between narrow range 19ºC and 25ºC with two months dry spell.

Temperatures above that affect photosynthesis and in some cases the coffee trees dry up. For coffee to flower, it needs at least 3 months of dry weather followed by showers [13].

Past research has focused mainly of effects of climate variability on agricultural crop production in general. Hence there is the need to pay attention particularly on coffee
production as well, as they strive to meet the high demand for coffee while coping with challenges posed by climate variability.

1.3 Objective

The main objective of this study is to assess the impact of temperature and rainfall variability on coffee production in Maraba for the period (2002-2017).

Specific objectives

2. To analyze the relationship between temperature trend and coffee production trend in Maraba for the period (2002-2017).
3. To analyze the relationship between rainfall trend and coffee production trend in Maraba for the period (2002-2017).

1.4 Research questions

The following research questions have to be investigated in this study:

1. Have fluctuations in rainfall and temperature patterns been experienced in Maraba during the period (2002-2017)?
2. How have prevalent changes in temperature affected coffee production during that period?
3. How have prevalent changes in rainfall affected coffee production during that period?

1.5 Hypotheses

The following hypotheses have to be derived from the objectives:

1. Fluctuations in rainfall and temperature patterns have been experienced in Maraba for the period (2002-2017).
2. Fluctuations in rainfall and temperature patterns have affected yields of coffee harvested in Maraba for the period (2002-2017).
CHAPTER TWO

2. LITERATURE REVIEW

2.1 Definition of key terms

2.1.1 The concept of climate
Climate encompasses the statistic of temperature, humidity, atmospheric pressure, wind, rainfall atmospheric particles count and other meteorological elements in a given region over the long period of time. However, any statistical significant change of these climatic components over a long period of time from 30 years period to another is regarded as climate change[14].

2.1.2 Climate variability
Climate variability can be defined as temporary changes in climatic components such as precipitation, temperature, humidity and atmospheric pressure. The IPCC (2007) defines climate variability as the variations in the mean state and other statistics (such as standard deviations, statistics of extremes) of the climate on all temporal and spatial scales beyond that of individual weather events[15].

2.2 Causes of climate change and variability
Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forces (external variability)[15].

The key cause of the climate change is the burning of coal, oil, natural gas and mineralization of organic matter; these lead to increase in the carbon dioxide (CO$_2$) content of the atmosphere. Carbon dioxide (CO$_2$) and methane (CH$_4$) are the most greenhouse gases that influence global climate through emissions.

Most times, the climate change is felt through changing climate weather such as when the rainy season does not start when it is forecasted to rain, dry season lasts longer than usual, rains too much and causes flood, temperature becomes much colder or hotter than usual. This climatic variability has always been the main factor responsible for the reduction of coffee yields in the world and determines the future coffee production status in the coffee producer’s countries [16].
2.3 Predicted climate changes

Temperature increases: it is probable that the temperature will increase by the year 2050 between 1.5°C (optimistic scenario) and 4.5°C (pessimistic scenario) with the month of May being the hottest one with temperatures exceeding 28°C; an expansion of the areas with higher temperatures is to be expected at the expense of the one where currently there are lower temperatures such as the mountainous areas[14].

For the case of Rwanda temperature predictions suggest that the country’s temperature will increase another 1-2.5°C between 2000 and 2050, and 1-6°C by 2100. The increase is expected to be consistent across the country and across seasons although the increase in the long dry season may be slightly higher than in other seasons[17].

Projections for medium to high emissions scenarios indicate that maximum and minimum temperatures over equatorial East Africa will rise and that there will be more warmer days compared to the baseline by the middle and end of this century[18].

Moreover, estimates from the Fourth IPCC Assessment Report indicate that average surface temperature in Africa has increased by 0.2 to 2.0°C in the last four decades (1970–2004), suggesting an overall increase in annual temperatures (by 1.0°C–2.0°C) over the next century (2010–2100) in Rwanda[19].

Temperature changes indicate an increase of between +0.2 to +0.5°C. Based on the multi-model-dataset (MMD) of 21 global models and on the A1B scenario, the seasonal average temperature projections for East Africa indicate that the median near-surface temperature in the 2080 to 2099 period will increase by 3°C to 4°C, compared to the 1980 to 1999 period. This increase is about 1.5 times the projected global mean response[20].

The clearest evidence for surface warming comes from widespread thermometer records. In some places, these records extend back to the late 19th century. Today, temperatures are monitored at many thousands of locations, over both the land and ocean surface. Indirect estimates of temperature change from such sources as tree rings and ice cores help to place recent temperature changes in the context of the past. In terms of the average surface temperature of Earth, these indirect estimates show that 1983 to 2012 was probably the warmest 30-year period in more than 800 year[21].
Increase in minimum and maximum temperature make countries in tropical regions where water availability is low to be at high risk of reduced crop yield, even at 1 to 2°C warming. Rising temperatures result to increased evapotranspiration, with low moisture levels adversely affecting crop growth and development. Increased temperatures make arable land become less suitable for crop production resulting in decline in yields with the severity being mild or extreme depending on the locality[5].

**Precipitation reduction:** all three scenarios (optimistic, moderate, pessimistic) point to an average reduction in precipitations by the year 2050 for the trimester July, September with the month of August presenting the most severe reduction.

In addition, the Intergovernmental Panel on Climate Change (IPCC) predicts an increase in the mean global temperature of 1.4° to 5.8°C by the end of the twenty-first century[18].

Climate change is also projected to cause more frequent and intense El Nino-Southern Oscillation (ENSO) events leading to widespread drought in some areas and extensive flooding in others. Consequently, such events will have negative impacts on availability of water resources, food and agricultural security, human health and biodiversity.

Average annual rainfall models predict a change between -100 mm and +400 mm for the period 2000-2050. Rwanda perceives itself as a water rich country and therefore does not see climate change planning on water resources as a priority. Although these predictions seem to support that perception, they do not account for regional and seasonal differences[17].

The principal factor for influencing the rainfall seasons in Rwanda is the Inter-Tropical Convergence Zone (ITCZ) due to the low pressure and high humidity, together with the convergence of winds, that are its typical characteristics. The ITCZ crosses Rwanda twice a year and creates two rainy seasons: a short rainy season ranging from mid-September to mid-December, and the long rainy season from March to May. It is also controlled by the altitude and subtropical anticyclones such as the Mascarene, Saint Helen, Acores, and Arabian Dorsal.

Moreover, further impacting weather patterns exist: subtropical anticyclones, tropical cyclones, monsoons, and episodes linked to El Nino/the Southern Oscillation (ENSO) [2].
According to a 2015 global study, hotter weather and changes in rainfall patterns are projected to cut the area suitable for coffee in half by 2050 across different emissions scenarios. The details differ markedly with locality, but the impacts are likely to be heaviest at low latitudes and low altitudes[22].

Today, the CO\textsubscript{2} concentration in the air is 40 per cent higher than at any time for at least 800,000 years, and may double before 2100, unless emissions are cut. One recent two-year study suggests that extra CO\textsubscript{2} boosts coffee yields significantly[22].

Decrease in precipitation coupled with increased temperatures could result in loss of arable land due to decreased soil moisture. Inadequate quality water at critical stages of crop growth in certain times of the crop-growing season will negatively influence crop production[5]. Consequently, with climate variability, greater impacts are likely to be experienced in countries that largely depend on rain fed agriculture like Rwanda as changing rainfall patterns may limit crop production. June-July-August (JJA) temperature, and March-April-May (MAM) precipitation were highly correlated with arabica coffee yields[8].

Projections of climate change suggest that East Africa will experience unpredictable but increasingly visible effects of climate change which will make life in the future even more uncertain. Climatic parameters with significant changes include temperature and rainfall.

In spite of the declining rainfall trend observed, global projections suggest that by the end of the 21\textsuperscript{st} century, the climate in eastern Africa will be wetter, with more intense wet seasons and less severe droughts in October-November-December and March-April-May, a reversal of recent historical trends. Regional models suggest that most parts of Uganda, Kenya and South Sudan will be drier in August and September by the end of the 21\textsuperscript{st} century. Projections indicate shorter spring rains in the mid-21\textsuperscript{st} century for Ethiopia, Somalia, Tanzania and southern Kenya, and longer autumn rains in southern Kenya and Tanzania[18].

The changes have been analysed in future rainfall, maximum and minimum temperature under two climatic scenarios leading to a radiative forcing of 4.5 Wm\textsuperscript{-2} and 8.5 Wm\textsuperscript{-2}; to assess the climate change impact on crop production[23].
2.4 Impact of Climate Variability on Coffee Production

The Rwandan agricultural sector is highly vulnerable to climate and weather-related risks, including prolonged droughts (especially in the eastern and south-eastern regions), erratic rains, floods, hailstorms and mudslides (particularly in the northern and western regions). Recent events provide clear evidence of the disastrous impacts of extreme events on agricultural production. For instance, erratic rainfall in 2008 caused maize yield losses of 37% in the eastern provinces and 26% in the southern provinces[19].

According to the global circulation models, climate change is forecasted to increase mean temperatures and change precipitation patterns. This will cause traditional coffee regions to disappear and new regions may appear. Climate changes such as years that are too wet or too dry can have significant effects on coffee, being that coffee is a sensitive crop.

Too low or too high temperatures can affect the coffee plant's flowering stage and the coffee plant's diseases and pests become a persistent and devastating problem. Diseases such as coffee rust can also be caused by weather that is too wet, and if the climate is not sufficiently dry after harvest it can affect the sun drying process of the coffee beans[13]. The figure 2.1 shows proposed coffee calendar for western and southern Rwanda.

Globally, the production of coffee and the livelihoods of households producing coffee, in almost every major coffee producing country are being threatened by climate change. Changing temperature and weather patterns including increases in the frequency and intensity of droughts, rainfall and flooding, are reducing coffee production, income and livelihoods of families relying on coffee as a significant source of income.

Changing climatic conditions have also allowed pests, such as the coffee borer, and diseases like coffee rust to thrive in areas previously unaffected by these threats[24]. The table 2.1 shows direct and indirect effects of extreme or unusual weather events on Coffee Arabica.

2.5 Climate Variability and Coffee Production in Rwanda

In Rwanda, coffee is grown only in certain areas of the country, where the soil, temperature and rainfall are suitable.

Temperature and rainfall conditions are considered to be important factors in determining growing of coffee. A study conducted by Marengo and Antonio (2009) states that mean temperatures above 23°C hinder the development of coffee and a continuous exposure to daily temperatures as high as 30°C could result in reduced production.
In Rwanda, little is known with regard to the impact of climate on coffee production. However, a low yield was reported in 2007 and climate variability was quoted among the causes. Insufficient rainfall in the last three months of 2006 (the period of coffee flowering) proceeding the short dry season in the first two months of 2007 was recorded. The reduced rainfall was also poorly distributed across coffee growing regions in Rwanda[25].

Coffee is also a highly climate sensitive crop, especially Arabica which is the dominant variety in Rwanda. Again, there is a temperature suitability range and most production is between 1000 and 1700 metres above sea level. Coffee is also vulnerable to rainfall variability, especially in key phases of the maturation cycle. There are also important impacts from the climate on pests and diseases, many of which are temperature sensitive.

Coffee (leaf) rust is found in Rwanda, and while this used to be constrained to the drier, lower areas, it has been spreading upwards. This existing vulnerability also has to be seen in the context of recent trends in the climate: there are observations of increasing temperature over recent decades in Rwanda, and while changes in average precipitation are more uncertain, there is increasing rainfall variability[26].
CHAPTER THREE

3. METHODOLOGY

3.1 Description of the Study Area
Maraba coffee is grown in the south of Rwanda at coordinates 2°35’S 29°40’E, roughly 12 kilometres from Butare and 150 kilometres from the capital, Kigali. The area is very hilly, due to its proximity to the Western Rift Valley and the montane Nyungwe Forest, and features rich volcanic soils. The coffee is grown at altitudes between 1,700 and 2,100 metres above sea level, often on steep hillsides with terrace farming. The area experiences an average of 1150 millimetres of rainfall annually.

The majority of this falls during the rainy season of March to May, the major coffee harvesting season. The high altitude lowers the temperature slightly to an average of about 20 °C. The main harvesting season for coffee in Rwanda is during the major rainy season, running from March to the end of May. The figure 3.1 shows variation of temperature and precipitation in Rwanda.

3.2 Research Design
Quantitative research was used in the study which comprised of collection of data, recording, analysis and interpretation as well as comparison of data to establish relationships between variables. Annual temperature and rainfall amounts (2002-2017) were compared to the quantity of coffee in each crop year for the same number of years to establish the relationship between the climate variables and the quantity of coffee harvested.

3.3 Temperature and rainfall data
The meteorological data used for the climate analysis in this study were recorded at the meteorological station of Maraba (2°35’S 29°40’E). The database contained long-term (from 2002 to 2017) records of monthly rainfall and minimum and maximum temperatures. Annual minimum and maximum temperature were averaged to get the mean annual temperatures.

3.4 Coffee production data
Coffee production data from Maraba (Huye district) were obtained from Abahuzamugambi Ba Kawa cooperative of Maraba. From the available data, the average annual yields for coffee (2002-2017), yields from the database represent annual farmers’ crop yields in (Kg/ha) that were recorded by the cooperative in the villages of Maraba.
The data have been used to make the scatter plots to analyse the relationship between temperature and coffee production trend as well as the relationship between rainfall and coffee production trend.

3.5 Data Analysis

For the first objective, time series was used to obtain the trends for annual minimum, maximum and mean temperatures, annual rainfall and annual coffee yield to observe whether there are some fluctuations in the climate data and coffee production in Maraba over the period (2002-2017).

For the second objective, the graph of coffee production against the temperature of Maraba area for the period 2002-2017 was plotted to show how the coffee production increases or decreases with temperature increase or decrease respectively within that period.

The programming language (python) was used to calculate to calculate coefficient of correlation ($r$), coefficient of determination ($r^2$) and the p-value (p) at the significance of 0.05 to determine relationship between temperature (°C) and coffee yield (kg/ha) from 2002-2017. Data on yields of coffee harvested was available in records provided by the cooperative.

For the third objective, also by using python, the scatter plot of annual coffee production against annual rainfall of Maraba area for the period 2002-2017 was plotted to show how the coffee production increases or decreases with the rainfall increase or decrease respectively within that period.

The programming language (python) was used to calculate to calculate coefficient of correlation ($r$), coefficient of determination ($r^2$) and the p-value at the significance of 0.05 to determine relationship between rainfall (mm) and coffee yield (kg/ha) from 2002-2017.
CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Introduction
Results show variability in annual rainfall and total annual coffee production patterns in Maraba for the period (2002-2017) and annual temperature (Objective 1), correlation relationships between the temperature and coffee yields harvested (Objective 2), and a weak correlation relationships between the rainfall and coffee yields harvested (Objective 3).

4.2 Evidence of Climate Variability
Climate variability has indeed been experienced at Maraba Coffee production area. This has manifested itself through changes in maximum annual temperatures, minimum annual and mean annual temperatures and changes in annual rainfall for the period (2002-2017).

Changes in temperature and rainfall have been experienced. Temperature in some years varied greatly from one year to another and rainfall varied from one year to the next as shown in the results and discussion that follow, thus creating unpredictability of weather conditions. Figure 4.1 and 4.2 display the year to year variability of temperature and rainfall in coffee growing area in Maraba.

Largest variations from annual mean occurred in 2011 (1431mm), 2009 (1358mm) and 2016 (869mm). These fluctuations in rainfall show variability and unpredictability in rainfall during the period (2002-2017). From the figure 4.2, the strong fluctuations were observed from 2009 to 2017 and the rainfall has decreased during last three years (2015-2017).

4.2.1 Variability in Temperature
Changes in temperature were observed over the years in the period (2002-2016), with some years experiencing bigger changes in both maximum and minimum temperature than others and whose temperatures greatly vary from the mean temperature for those years. This has further been elaborated in the form of line graphs that show sharp increases and decreases in temperature.
4.2.1.1 Changes in Maximum Temperatures (°C)
Results indicated that the Maraba coffee Estate experienced a decreasing maximum temperature trend with an average fall of about 0.063°C per year \( r^2 = 0.74 \) from 2002 to 2017. Generally the temperature of the country is expected to increase as cited by many author in the literature review. Contrary, for the case of Maraba, maximum temperature have decreased in the period (2002-2017) with the greatest value 25.4°C in 2005 and the least value of 24.2°C in 2015.

The results illustrates a significant \( p < 0.05 \) negative correlation between annual maximum temperature and time in years over the study period of 16 years (from 2002 to 2017). The figure 4.1 indicates changes in annual maximum temperature for the period (2002-2017).

4.2.1.2 Changes in Minimum Temperatures (°C)
The results illustrates a non significant \( p > 0.05, r^2 = 0.038 \) positive relationship between annual minimum temperature and time in years over the study period of 16 years (from 2002 to 2017). This means that the mean temperature has been increased but the increase in that period was not significant. The figure 4.2 indicates changes in annual minimum temperature for the period (2002-2016).

4.2.1.3 Changes in Mean Monthly Temperatures (°C)
The results illustrates a non significant \( p > 0.05, r^2 = 0.26 \) negative relationship between annual mean temperature and time in years over the study period of 16 years (from 2002 to 2017). This means that the mean temperature has been decreased but at small rate (0.024°C per year).

The figure 4.3 shows changes in annual mean temperature for the period (2002-2017).

Unlike other studies considered in literature review, in this study, results show that the mean and maximum temperatures decrease with time even if the decrease is not significant. This can be attributed to the fact that the time considered is less than thirty years which is threshold time for climate study. It may also caused by that the small region considered in this study its topography and the cloud cover since the region is mountainous.

4.3 Trends in Rainfall
Rainy season in Maraba is from March to May and dry period occurs from June to August.
Trend analysis of rainfall data (Fig.4.4) indicates variation in inter-annual rainfall. Overall rainfall amount was found to decrease over the years.

Geographically, the area has an altitude of between 1700 and 2100 m above sea level with characteristics of an average annual rainfall of 1160mm.

Over the sixteen years period (2002-2017) the lowest rainfall recorded in the area occurred in 2016 with an amount of 869 mm while the highest rainfall recorded within the period was 1431 mm in 2011.

However, Data showed that, within the time (2002-2017) fourteen years experienced annual rainfall of more than 1000 mm, while two years only experienced rainfall less than 1000 mm. This illustrates the fact that rainfall is much in the area.

The results illustrates a non significant ($p > 0.05, r^2 = 0.015$) negative relationship between annual rainfall and time in years over the study period of 16 years (from 2002 to 2017). This means that the annual rainfall has been decreased but at small rate.

Figure 4.4 indicates annual rainfall trend at Maraba (2002-2017).

Decline of rainfall trend in the study area is also supported by the IPCC report (2007) which forecasted increasing warming in most part of East Africa. In the same manner, [5] forecast a rise in temperature and decline in rainfall for East Africa.

4.4 Trends in Coffee Production

Based on data recorded by Abahuzamugambi Ba Kawa Cooperative, coffee production has shown an increasing trend over the sixteen years period (2002-2017). According to the data, maximum total annual coffee production in the area was 1090kg/ha in 2015 followed by 1061kg/ha in 2013 and minimum total annual coffee production in the area was 567.7kg/ha in 2007. This low production in 2007 will be explained in the following sections and the low coffee production in two first years may be caused by the fact that the cooperative was at the beginning stages. Figure 4.5 illustrates annual coffee production trend at Maraba (2002-2017).
The case of Maraba, the results illustrates a significant ($p < 0.05, r^2 = 0.61$) positive relationship between coffee production (kg/ha) and time in years over the study period of 16 years (from 2002 to 2017). The low coffee yield observed in 2007 caused by insufficient rainfall in the last three months of 2006 (the period of coffee flowering) proceeding the short dry season in the first two months of 2007 was recorded. The reduced rainfall was also poorly distributed across coffee growing regions in Rwanda[25],[1].

The increase in coffee production in Rwanda does not depend only on climatic parameters but also on parameters such as application of fertilisers. The policy of Rwanda to increase coffee production has put in action through:

- Increase awareness in sustainable coffee farming, thus increasing production.
- Improve soil fertility (fertilizer distribution, soil and leaf analysis).
- Strengthening farmer organizations
- Value addition

For the case of Maraba in recent years a program known as Maraba Coffee Intensification Program (MCIP) has been installed with the aim of rising both quantity and quality of coffee in Maraba.

4.5 Relationship between Rainfall and Coffee Production

Numerical data for rainfall collected at the meteorological stations were tested against coffee production data collected from Abahuzamugambi Ba Kawa cooperative. Correlation analysis was used to examine the relationship of rainfall variability and coffee production in the area while a simple linear regression was used to study the effect of the independent variable (amount of rainfall in millimeter) on the dependent variable (amount of coffee in kg/ha).

Statistically, analysis showed that there was a positive relationship ($r = 0.022$) between amounts of coffee in kg/ha produced and amount of rainfall in mm from 2002 to 2017. The relationship between the amount of coffee in kg/ha produced and amount of rainfall in mm was statistically insignificant at 5% level ($p = 0.58$). This indicates that coffee production was not much influenced by rainfall, but there must be other factors like shortage of agricultural inputs such as fertilizers and pesticides which influence coffee production in the study area.
This is supported by [14] in his study 'Impact of climate variability on coffee production'. Figure 4.6 shows the scatter plot demonstrating the amount of coffee in kg/ha versus the amount of rainfall in mm.

According to [2] the average annual water requirement for coffee was studied over 12 years and was found to be 951 mm during normal dry seasons. Therefore, overall rainfall distribution throughout the year is a decisive factor for scheduling cultivation practices and harvesting.

Figures 4.7 and 4.10 indicate average rainfall of SON and DJF from 2002 to 2017 respectively.

In Rwanda, little is known with regard to the impact of climate on coffee production. However, a low yield was reported in 2007 and climate variability was quoted among the causes. Insufficient rainfall in the last three months of 2006 (the period of coffee flowering) proceeding the short dry season in the first two months of 2007 was recorded. The reduced rainfall was also poorly distributed across coffee growing regions in Rwanda[25]. Table 4.1 shows seasonal rainfall in mm.

4.6 Relationship between Temperature and Coffee Production

The productivity of Arabica coffee is tightly linked to climatic variability. Temperature in particular is a very important driver in different phases of the life cycle.

4.6.1 Relationship between Annual Mean Temperature and Coffee Production

Results show that $p = 0.039$ which is less than 0.05, hence the relationship was significant. Negative correlation $r = -0.268$ suggests that when there is a decrease in mean temperature, yield harvested increases and vice versa. Temperature has a greater impact on crop production than rainfall[28].Figure 4.8: shows scatter plot demonstrating the amount of coffee in kg/ha versus the mean temperature in °C.

4.6.2 Relationship between Annual Maximum Temperature and Coffee Production

Results show that $p = 0.001$ which is less than 0.05, hence the relationship was significant. Negative correlation $r = -0.663$ suggests that when there is an increase in maximum temperature, yield harvested reduces and vice versa. Temperature variations play a critical role in coffee behaviour[29]. Figure 4.9 shows scatter plot demonstrating the amount of coffee in kg/ha versus the maximum temperature in °C.
These results may be associated with attack by pests and diseases associated with high temperature conditions. These results are in line with research according to the Jessica (2012) which shows that increase in temperature inhibits photosynthesis and results in changes in planting periods, reducing growth and resulting in smaller yields.

4.6.3 Relationship between Annual Minimum Temperature and Coffee Production

Results show that $p = 0.74$ which is greater than 0.05, hence the relationship was insignificant. Positive weak correlation $r = 0.008$ suggests that when there is an increase in minimum temperature, yield harvested increases but with very low rate.

According to the results, the decline in yields is not solely due to minimum temperature increases.

All aspects of climate change variables play a role but rising maximum temperatures certainly have the greatest influence. Figure 4.10 shows scatter plot demonstrating the amount of coffee in kg/ha versus the minimum temperature in °C
CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Coffee production forms a strong base of food security and a source of livelihood to a large percentage of the rural people. Coffee production is largely dependent on climate conditions, making it vulnerable to climate variability. The study findings indicate that coffee production affected by climate variability. The productivity of Arabica coffee is tightly linked to climatic variability. Temperature in particular is a very important driver in different phases of the life cycle.

On the response of coffee production to rainfall and rainfall variability, the study findings indicate that: a general decrease in rainfall have no significant effects on the coffee production but its distribution matters. The rainfall decrease in months from December to February (flowering period for coffee) implies the coffee production decrease as the case of low coffee production in 2007.

On the response of coffee yield to changes in temperature and temperature variability, the study found that changes in temperature and temperature variability have the significant effects on coffee yield. This shows that observed changes in temperature have influenced expansion of coffee production.

A decrease in mean and maximum temperatures implies the increase of coffee production in Maraba for the period (2002-2017), but the change in minimum temperature had no significant influence on coffee yield in the study area.

An increase in mean and maximum temperatures implies the reduction of coffee production. These conditions increase climate risk and greatly compromise the economic viability of the coffee crop, making coffee farming less desirable. In some instances, this may have resulted to farmers uprooting coffee and adopting new crops that are better suited to new climate conditions or converting are under crop to other land uses other than farming.

Although rainfall has been decreasing over the sixteen years, overall, this study concludes that; the increase in coffee production in Maraba is strongly attributing to the decline of
temperature and its variability. However, while the increase could be attributed to other factors, the trends of rainfall, temperature indicate that the study area is vulnerable to the impact of climate change and variability.

5.2 Recommendation
i. Climate change and climate variability study requires data for long period this study recommends like RAB, NAEB and other concerned institutions to keep and conserve data since they are needed for research for example about the crop production.

ii. This study also recommends the coffee producers to focus on Rwandan policy of increasing both quantity and quality of coffee since it is one of the most sustainable way to enhance coffee production.

5.3 Recommendations for further studies
Because this study has indicated that there was no strong evidence for attributing the increase in coffee production to climate change and variability meaning that the increase could be attributed to other factors such as application of fertilizers, further research is recommended to study the interaction between and among various socio-economic factors and climate variables and their implications as well as the impact of climate variability on quality of coffee production in the study area and other places in Rwanda.
ADDENDUM

Addendum 1. FIGURES

Figure 2.2: Proposed coffee calendar for western and southern Rwanda. Taken from[2]

Figure 3.2: Variation of temperature and precipitation in Rwanda. Taken from[27]
Figure 4.11 Annual Mean Temperature Variations in Maraba (2002-2017)

Figure 4.12: Annual Rainfall Deviations From the Mean in Maraba (2002-2017)
Figure 4.13: Changes in annual maximum temperature for the period (2002-2017).

Figure 4.14: Changes in annual minimum temperature for the period (2002-2016).
Figure 4. 15: Changes in annual mean temperature for the period (2002-2017).

Figure 4. 16: Annual rainfall trend at Maraba (2002-2017).
Figure 4. 17: Annual coffee production trend at Maraba (2002-2017).

Figure 4. 18: Scatter plot demonstrating the amount of coffee in kg/ha versus the amount of rainfall in mm
Figure 4. 19: Average rainfall of SON from 2002-2017.

Figure 4. 20: Average rainfall of DJF from 2002-2017

Figure 4. 21: Scatter plot demonstrating the amount of coffee in kg/ha versus the mean temperature in °C.
Figure 4. 22: Scatter plot demonstrating the amount of coffee in kg/ha versus the maximum temperature in °C

Figure 4. 23: Scatter plot demonstrating the amount of coffee in kg/ha versus the minimum temperature in °C
Addendum 2. TABLES

Table 1. 2: The total export value of coffee, and the contribution of coffee to the total agricultural export value in eight East African countries.

<table>
<thead>
<tr>
<th>Country</th>
<th>2007 Export Value of Coffee (US$ 000)</th>
<th>Contribution of Coffee to total Agricultural Export (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burundi</td>
<td>46,895</td>
<td>83.9</td>
</tr>
<tr>
<td>Rwanda</td>
<td>32,460</td>
<td>42.7</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>416,783</td>
<td>40.6</td>
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<tr>
<td>Uganda</td>
<td>226,966</td>
<td>33.7</td>
</tr>
<tr>
<td>Tanzania</td>
<td>113,064</td>
<td>16.7</td>
</tr>
<tr>
<td>Kenya</td>
<td>416,783</td>
<td>7.2</td>
</tr>
<tr>
<td>Zambia</td>
<td>8,756</td>
<td>3.3</td>
</tr>
<tr>
<td>Malawi</td>
<td>3,388</td>
<td>0.4</td>
</tr>
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</table>

Taken from [8].

Table 2. 2: Direct and indirect effects of extreme or unusual weather events on Coffee Arabica

<table>
<thead>
<tr>
<th>Climate hazard</th>
<th>Direct impact on the tree</th>
<th>Indirect impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>➢ Above 23°C: Fruit ripening accelerates, leading to progressive quality loss&lt;br&gt;✈ Above 25°C: Photosynthetic rate is reduced&lt;br&gt;✈ Above 30°C: Tree growth is depressed&lt;br&gt;✈ High temperature can cause leaf, stem and flower abnormalities and abortion</td>
<td>Pests and diseases may increase</td>
</tr>
<tr>
<td>Heavy rain, hail,</td>
<td>➢ Tree damage, increased fruit fall, especially near harvest</td>
<td>➢ Soil erosion, landslides, subsidence, wash-away of agronomical applications&lt;br&gt;✈ Damage to roads and other</td>
</tr>
<tr>
<td>strong winds</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Intermittent and unseasonal rain

- Greater flowering frequency

- Possible increase of some diseases
- Post-harvest drying difficulties

Prolonged rain

- May reduce flowering, affect fruit set, lower photosynthesis because of continual cloudiness

- Increased humidity may favour some fungal diseases; may increase mortality of some insect pests such as coffee Berry Borer (CBB)

Prolonged drought

- Weaker trees, wilting, increased mortality of young trees

- Stressed trees more susceptible to some pests

Taken from [24]

Table 4. 2: Seasonal rainfall in mm from 2002 to 2017.

<table>
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<tbody>
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<td>SON</td>
<td>85.7</td>
<td>86.6</td>
<td>104.2</td>
<td>93.6</td>
<td>103.8</td>
<td>110.1</td>
<td>71.2</td>
<td>142.5</td>
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<td>82.1</td>
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<td>112.0</td>
<td>151.8</td>
<td>156.2</td>
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REFERENCE


[20] “EAST AFRICAN COMMUNITY.”
[22] “The Climate The climate change risks to coffee A Brewing Storm : The climate change risks to coffee.”