UNIVERSITY of RWANDA

Assessing the impact of climate variability on coffee production in Rwanda 2001-2015

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UNIVERSITY OF RWANDA
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Assessing the impact of climate variability on coffee production in Rwanda 2001-2015.

A thesis submitted in partial fulfillment for the degree of Master of Geo-information sciences for environment and sustainable development in the University of Rwanda.

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Declaration

This thesis is my original work and has not been presented for a degree in any other university. It was defended in September 2019, corrected and re-submitted in June 2021.

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The thesis has been submitted for examination with my approval as the university supervisor

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Dedication

I humbly dedicated this research particularly to my loving mother Cecile NYAMBUGA, my wife Agnes UWIMBABAZI, my child Ben Alexis NSANGA CYUBAHIRO and all Rwandans in general for their moral, emotional, commitment and sacrifices towards my education.

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Abstract

Worldwide, climate change and variability have been raising concerns about potential changes to crop yields and production systems. The focus of the present study was to assess the impact of climate variability on coffee production in Rwanda. Climate variables, like rainfall and temperature and coffee production data over the past fifteen years i.e. a period between 2001 and 2015 were used to investigate the evidence of climate variability in Rwanda, changes in coffee production in Rwanda and the likelihood of relationship between agricultural production of coffee and these climatic variables.

Four coffee washing stations were selected from coffee growing regions namely, RWACOF in Karenge sector of Rwamagana District, Musasa CWS in Ruli sector located in Gakenke District, KOPAKAKI in Rubengera, Karongi District and IWACU in Nyagisozi sector of Nyanza District. The Statistical Package for the Social Sciences (SPSS) was used to analyze the relationship between climate variability and the changes in coffee production in study areas. Specifically, correlation analysis was used to determine the relationship of temperature and rainfall variability and coffee production in the focus area. Both climate variables (temperature and rainfall) and coffee production showed an increasing and decreasing trends.

The results of the correlation analysis between coffee production and climate variable show a weak temperature – coffee production correlation in all Districts while significant correlation was found in between coffee production and rainfall. Given the weak correlation between temperature and coffee production it can be concluded that coffee yield was not much influenced by both temperature and rainfall taken altogether, but there might be other factors such as soil type, topography and elevation, socio-economic factors that can be the cause of shortage of agricultural inputs such as fertilizers and pesticides and these are likely to influence coffee production in the study area as well. It is of capital importance to research also on these factors and the likely impact this situation (climate variability and climate change) will put on coffee production and national economy in the future by exploring different scenarios.

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Acronyms and Abbreviations

CBD:	Convention on Biological Diversity
CWS:	Coffee washing station
EAC:	East African Community
GDP:	Gross Domestic Product
ICO:	International Coffee Organization
IPCC:	Intergovernmental Panel on Climate Change
ITCZ:	Inter Tropical Convergence Zone
JICA:	Japan International Cooperation Agency
MINAGRI:	Ministry of Agriculture
NAEB:	National Agriculture Export Board
SPSS:	Statistical Package for Social Sciences
UNFCCC:	United Nations Framework Convention on Climate Change
USAID:	United States Agency for International Development
USD:	United States Dollar
USDA:	United States Development of Agriculture
WMO:	World Meteorological Organization

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CHAPTER 1. INTRODUCTION

1.1. Background

The first World Climate Change Conference took place in 1996 in Geneva to discuss the real impacts of climate change on agriculture and other development sectors. Regional and Federal governments, experts from research institutions and universities, and practitioners from civil society organizations and the private sectors as decision makers came together for expert presentations and plenary discussions on such impacts (Bongase, 2017).

Climate variability is already having a significant impact on the agriculture sector which is an important activity in the developing world; as the sector is dominated by rain-fed crop production and household's food security is particularly vulnerable to climate variability and change. Globally, rain fed agriculture is an important economic activity in the developing world including Rwanda. In recent years, a number of studies conducted in East Africa have documented that climate change and variability is having a significant impact on agriculture production, especially the coffee crop which is the most vulnerable (Bongase, 2017).

Coffee is among the most internationally transacted commodities by many countries and is outpaced by only following petroleum oil. Consumers from all around the planet purchase and enjoy coffee in their daily activities (Iscaro, 2012). Different reports point out that, worldwide, Brazil is the leading coffee producer and exporter followed by Vietnam and Colombia (DaMatta & Cochicho Ramalho, 2006). Despite high export earnings from coffee globally, coffee produced in most African countries fetch low prices compared to the coffee from other continents due to its relatively lower quality. (Watheri et al., 2014). As a result, most coffee farmers get lower incomes from coffee sales, which make very little difference in helping them out of poverty. In our region, coffee is the most source of revenue and the most traded commodity in countries like Uganda, Burundi, Rwanda and Ethiopia(Bongase, 2017). Two coffee species namely *Coffea arabica L*. (Arabica coffee) and *Coffea canephora* (Robusta coffee) economically dominate the world coffee trade (DaMatta & Cochicho Ramalho, 2006). Arabica represents 70% of global coffee production and Robusta represents about 30% (DaMatta & Cochicho Ramalho, 2006).

Since its introduction in Rwanda back in 1904 and its first export in 1917, coffee has been a major source of income and has been since then benefiting from strong political support. It was imposed by the colonialists on farmers in 1927 and its cultivation was made obligatory in 1933. Legislation passed by the Government of Rwanda at Independence in 1963 prohibits the uprooting of coffee trees (Ngabitsinze et al., 2011). The main coffee growing regions in Rwanda are those located at latitude of 1,500-2,000 meters.

In the Western province, the optimal Arabica cultivation areas stretch in a narrow band from north to south along Lake Kivu, particularly in Nyamasheke and Rusizi districts located at the southernmost part of Lake Kivu. In the Southern province, coffee cultivation is concentrated in Huye District. In addition, large amounts of Arabica is also grown across areas stretching from Muhanga District in Southern Province to Gakenke in Northern Province (Hakorimana & Akçaöz, 2017).

Coffee growing is often a small holders' activity. These are mainly poor people who work small, fragmented plots. Coffee is produced to supplement staple production and thus achieve basic food security. According to the National Coffee Census of 2012, there were approximately 72 million coffee trees planted in Rwanda, on a total of approximately 2,900 hectares of cultivated land. There are roughly 500,000 coffee growers and each grows an average of 183 trees in an average cultivation area of 0.07 hectares (Hakorimana & Akçaöz, 2017). Other actors in the sector include private traders, hulling and exporting companies, and government institutions and in the recent decade, many cooperatives have emerged (Gaudiose, 2007).

The production and productive of both species are largely dependent on the climate for attaining high yields and quality (Killeen & Harper, 2016). Most evidence shows that climate variability has appeared in recent years and immediately changed common perception of many people in few years, makes looking forward the serious topics of all stakeholders (Dasaklis & Pappis, 2013). The effect of climate variation on natural systems has become one of the most critical issues of humankind (Haggar & Schepp, 2012). Many findings show that weather alteration is hastening at ample quicker stride than earlier that leading to irreversible changes in major earth systems and ecosystems (ITC, 2010).

Coffee requires very specific environmental conditions for successful production, depending on the coffee variety grown. But the crop is perennial, tropical crop that can grow under both humid lowlands and tropical humid/sub humid highlands. Even though the average temperatures required for coffee arabica range between 15 and 24°C, rain fall 2000 mm per annum and altitudes between 1000 and 2000 m above sea level. Robust coffee required average temperature range between 24 and 30°C, rainfall ~2,000 mm and altitudes of about 800 m above sea level (Killeen & Harper, 2016). Overall, influence of weather variations on coffee producing countries is predicted to be negative (Ovalle-Rivera et al., 2015). Some countries would lose area suitability while others would gain from variation in weather elements especially rainfall and temperatures (Ovalle-Rivera et al., 2015).

1.2. Problem statement

Around the globe, coffee is considered as one of commodities playing a vital role by providing livelihoods to more than 25 million inhabitants of tropical countries and supporting an equivalent to $81 billion industry (Sharf, 2014). This makes it one of the most valuable commodities in the world. In the 1997, there were floods, prolonged droughts in 2000, and El Niño and La Niña episodes which are clear examples of extreme events in weather signifying climate variability in Rwanda that were marked in changes in temperature and rainfall(Niyonsaba, 2016) . However, coffee production is extremely vulnerable to climate change and climate variability. As revealed by different researches, already climate variability and climate change are making disease outbreaks more frequent and shifting suitable growing regions (Guilford, 2014; Malkin, 2014). Although coffee production has considerable potential for supporting sustainability and economic opportunities for the future, its planning requires a better understanding of the interconnections between production, trade, and the environment. As productive coffee regions shift, every aspect of the coffee system will be, from developing country farmers to developed country consumers. It is reported that by 2050, these mentioned long-term shifts may influence and reshape the global coffee market (Sachs et al., 2015).

Severe weather events, particularly droughts, have historically imposed heavy costs in Rwanda. The projected impacts of climate change may increase the frequency and compound the ramifications of these events, potentially undermining food security, health, and economic growth (USAID, 2011).

Agriculture in Rwanda has been since long ago a backbone industry that accounts for over 30% of the national GDP and generating about 90% of employment (FAO, 2019). Coffee in particular was designated as one of the priority industries in securing foreign capital in Rwanda's long-term development plan, "Rwanda Vision 2020."

The present research assessed the effects of climate variability on coffee production from a national perspective. In Rwanda, agricultural production is rain fed dependent and is influenced by specific temperature ranges, and this situation makes the country particularly vulnerable to climate variability and changes. The increased frequency and duration of droughts, floods, landslides and erosion considerably decrease the country's food availability. Decadal and inter-annual climate cycles have impact greatly coffee production in Rwanda. Production in quantity and quality in different regions of Rwanda varies and depend on their degree of sensitivity to current climate variability and increasingly extreme temperatures and rain falls (Hakorimana & Akcaoz, 2017). Understanding effects of these different climatic patterns is an important step towards effective planning. In 2004, actual production was 29,000 tons; 2005 again saw a drop in production to 18,609 tons; while 2006 saw a 30% increase in production at 26,500 tons; 2007 again saw a drastic drop to 14,826 tons and the trend continues (USAID, 2010). In 2010, the production rose to 20,000 tones and started to decrease in the following years especially in 2011 with 16,371 tones.

Recent years have seen fluctuations in coffee yield volume as reported by National Agriculture Export Board(NAEB, 2012). Generally, the crop yield for coffee tended to fluctuate in alternate years, so the production volume swings up and down in alternate years, but taking this factor into account, production volume was flat from 2005 to 2015 or declined slightly. For example, after a good production of 20,724 tons in 2008, the variation in production continue in the following years in declining especially in 2009 with 15,055 and in 2011 with 16,31 in general production (JICA, 2014). The trend of variation in coffee production continues up to 2015. These variations in production might be caused by Rwanda climate variability in these recent years. Climate variability is considered as one of the most significant factors influencing year to year crop production and mainly, changes in temperature and rainfall(Mikova et al., 2015). Rwanda has experienced a series of climate fluctuations in terms of frequency, intensity, and persistence of existing extremes. Heavy rains, storms and droughts are the observed manifestations of climate variability in Rwanda.

Changing weather patterns have an adverse impact on the country's agricultural production and thus on the country's GDP. Based on these fluctuations in coffee growing areas, it is worth to investigate the effects of climate variability on coffee productivity in Rwanda

1.3. Research objectives

a) General objective

The primary purpose of this research is to assess the relationship between climate variability and coffee production in Rwanda.

b) Specific objectives

In order to achieve the primary purpose, the followings are the specific research objectives:

i. To investigate the evidence of climate variability in Rwanda
ii. To analyze the evolution of coffee production from 2001 to 2015
iii. To assess the relationship between the climate variables and coffee production in Rwanda
iv. To suggest recommendations on how coffee production and coffee farmers can adapt to the changing and varying climate in Rwanda

1.4. Research questions

This research report has based the assessment while trying to answer the following were the research questions:

i. What are the evidences of climate variability in Rwanda?
ii. What are the changes of coffee production in Rwanda?
iii. What is the relationship between climate variables and coffee production?
iv. What are the recommendations to improve the future coffee production?

1.5. Significance of the study

The study findings and recommendations from this study are hoped to generate both practical and theoretical awareness important to other researchers, policy- and Decision-makers, policy implementers, coffee Cooperative Societies, coffee factory Management and coffee stakeholders in revitalizing coffee sector. The study will also form the ground for replication by development practitioners while designing coffee revival projects. It is also hoped to provide basis for further studies and also documenting factors affecting low coffee production within the country and beyond which will hasten realization of Sustainable Development Goals and Rwanda Vision 2050.

1.6. Delimitation and limitation of the study

The scope if this research was limited in space and time. Geographically, it will focus on only four coffee washing stations selected from coffee growing regions namely, RWACOF in Karenge sector of Rwamagana District, Musasa CWS located in Ruli sector of Gakenke District, KOPAKAKI found in Rubengera sector, Karongi District and IWACU in Nyagisozi sector of Nyanza District. Due to time and financial constraints, the study will focus on the period covering 15 years, from 2001 to 2015.

1.7. Structure of the study report

This thesis has five chapters. The first chapter is the introduction which describes the general information on the study and why this study was conducted. In addition to the introduction, the next chapter reviews the conceptual and theoretical framework of study. This Chapter demonstrates the relationship between different variables that involved in the study and describe a set of theories related to climate change and variability; and coffee production which guide the researcher in his study. The chapter three describes an overview of the research methodology used in the study. Chapter four is about the results and discussions, is the core chapter of the study that summarizes the major findings on the evidence of climate variability, the evolution of coffee production from 2001 to 2015, the relationship between the climate variables and coffee production in the study areas. The last chapter gives a brief conclusion and suggest recommendations to improve the future coffee production.

CHAPTER 2. CONCEPTUAL AND THEORICAL FRAMEWORK

2.0 Introduction

Theoretical framework refers to the theory that a researcher chooses to guide him/her in his/her research. Therefore, theoretical framework is the application of a theory, or a set of concepts drawn from one and the same theory, to offer an explanation of a particular phenomenon or research problem. The followings are theories that related with coffee and climate variability.

The low quality and quantity of coffee harvested in Rwanda is caused by increase in temperatures, dry spells and erratic rainfall and other factors brought about by these climatic changes, i.e. low water supply for irrigation as a result of prolonged dry spells and spread of pests and diseases (Jessica & Env, 2012). These factors work together to suppress productivity of coffee. Reversing the trend calls for a proper understanding of rainfall and temperature patterns and how growth stages are affected by these climatic variables, which will consequently provide a better understanding on how coffee production is affected.

For the coffee production, different factors are necessary in the process from coffee planting to coffee harvesting and other related activities. The conceptual framework demonstrates a set of relationships among background variables, independent variables and dependent variables. The climate variables can lead to the coffee production negatively or positively and those are the main factors that the study is centered.

The Conceptual Framework of the study is shown below:

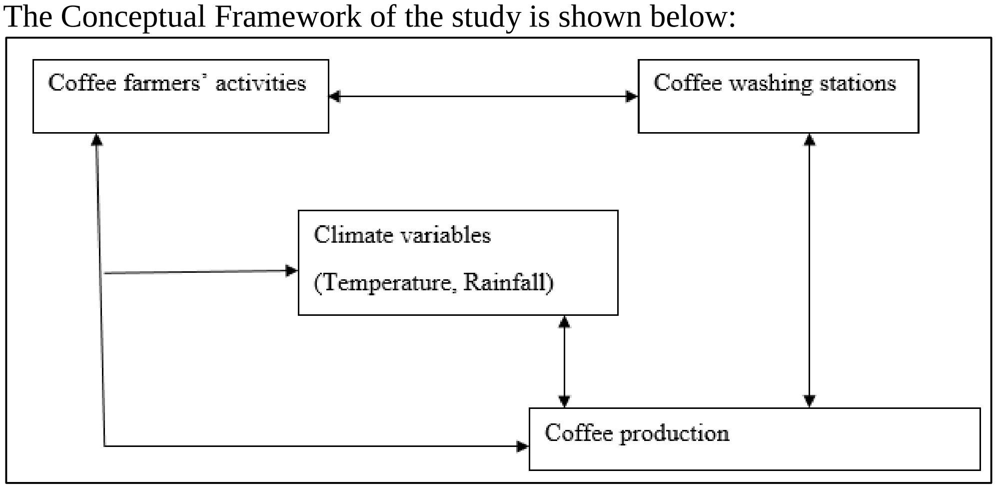


Figure 1: Conceptual Framework

2.1. Theoretical Framework

2.1.1. Linking coffee production and environment

In Rwanda, Arabica coffee is cultivated mainly by smallholder farmers on less than a hectare scattered on hilly slopes essentially as a mono crop. (Nzeyimana et al., 2014). The optimal environmental conditions for coffee Arabica are observed on shore of Kivu Lake, Impala and central plateau agricultural regions. Mayaga and Bugesera regions are characterized by a very suitable soil conditions, though the climate especially low rainfall is a limiting factor to the growth of coffee in these two regions. Towards the East, a decrease in rainfall causes a further reduction in suitability, and hence making the eastern plateau moderately to marginally suitable, whereas the climate is marginal or too dry for coffee in eastern lowland and Bugesera regions. In cool high altitude of the North Western part of Rwanda (Buberuka), an unsuitable climate conditions are recorded (Verdoodt & Ranst, 2003).

Coffee is a highly climate- sensitive plant requiring specific weather patterns such as rainfall, temperature, sunshine and wind during different growing periods. One tangible example is that temperature values and their changes have significant impacts on the growth of coffee trees. The optimum mean temperature for coffee Arabica is observed at 18 ^{0}C during the night and 22^{o}C during the day whereas the optimal average annual temperatures are between 22 ^{0}C and 28^{0}C. Temperatures higher than 25 ^{0}C cause reduced photosynthesis and prolonged exposure to temperatures above 30 ^{0}C incur so-called ‘leaf chlorosis’ and generate ‘star flowers’ (or blossom wilting), and defective fruit sets. High temperatures also initiate the development of plant diseases such as the ‘coffee leaf rust’, fruit blight and accelerate fruit maturation (Mukashema et al., 2016).There six basic environmental factors that need to be taken into account while selecting the best suitable places to plant coffee. These include temperature, water availability, sunshine intensity, and wind, type of soil and topography of land (Wintgens, 2009).

2.1.1.1. Soil

For many, soil is an important natural resource at the heart of farming, especially among coffee farmers who have never really benefitted from an effective extension and training system. Soil is the primary system from which the plant lives and absorbs water and critical nutrients such as nitrogen, phosphorous, potassium, calcium, magnesium, etc.

When the soil system is managed properly and that farmers make sure that their soils receive the requisite amounts of organic matter, moisture, sunlight, aeration, nutrients, vegetative cover, etc., then the soil on their farms will achieve the proper balance of physical, chemical and biological properties that helps to ensure the overall health of plants. This soil system needs to be balanced as well as the plant needs even more nutrients from the soil in order to support overall plant growth and maintenance and to become more tolerant of diseases, pests and moderate changes in weather. The fertility of the soil is considered as its capacity to provide nutrients to plants. High fertility is translated into healthy coffee trees and higher yields, that is, as long as there is enough water in the soil as well. For example, where coffee is grown in acidic soils, the practice most recommend is to control acidity in order to control levels of soluble aluminum and to reduce associated nutrient deficiencies, especially of phosphorus. Soils with low pH (high acidity) tend to be low in phosphorus, which is critical to root development.

2.1.1.2. Topography and elevation

Geographic conditions of an area have a major impact on the test of coffee, and this is the reason why roasters identify a coffee's orgin (both country and region). Another aspect of geography that affects a coffee's quality and taste is elevation. Elevation impacts not only the coffee trees but also the physical aspect of the coffee bean. The next time you get your hands on a bag of green coffee (coffee that isn't roasted), take a very close look at the beans. Are they small and densely formed? Is the fissure line closed, opened, straight or zigzagged? What color are they—jade, light green or blue? All of these characteristics are affected by the elevation at which the coffee is grown. It has been shown that higher elevations produce hard, dense beans that are more sought-after than beans grown at lower elevations. It is also reported that coffee grown at lower elevations can still develop slowly, if this is coupled with other type of adverse growing conditions.

2.1.1.3. Socioeconomic factors

The socioeconomic environment of farmers is critical to farm decisions and performance; hence, factors such as the age, family size, marital status, education, sex and religion of the farmers affect the coffee production negatively or positively. The male farmers are more involved in coffee production, probably because of cultural restraints that deprive women of the right of inheriting land and hindering them from long-term use of land (ayoola, J.B, G.B & Ladele, 2012). Important variables found to have significantly contributed to the coffee yield were access to adequate credit, having some income from other sources. It was also found out that although price has a positive influence on yields, its impact is dampened by the socio-economic factors that farmers encounter all along. This implies that although good prices encourage farmers to invest in coffee, there is need for an enabling environment in terms of adequate credit, extension services provision and diversification of farmers' incomes in order to increase coffee yields significantly (Nyairo & Mbataru, 2014).Note that all the factors discussed above, play a significant role in the coffee production, but the study emphasize on the climate as the main factor that influence coffee production in Rwanda.

2.1.2. The climate variability

Climate variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). Climate plays a central role in agriculture, which in turn shapes the economy and community livelihood (de la Paix et al., 2011).

Climate impacts of significance for agriculture and food security are likely to be temperature increases and more frequent droughts, with the nature and timing of impacts varying across Rwanda. Climate variability impacts may alter the extent of areas suitable for agriculture and the length of growing seasons, affecting crop yields as well as hunger and nutrition (USAID, 2011).

2.2.3 Causes of climate variability

Climate 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). Most of the climate scientists agree that, the current global climate change is due to human activities. In its fourth assessment report, the (IPCC) Intergovernmental Panel on Climate Change conclude that, more than 90% human activities over the past 250 years have warmed the earth's climate. Human activities through land use change and fossil fuel use have increased the emission of carbon dioxide and other greenhouse gases to the atmosphere. This suggests that, the increase in atmospheric carbon dioxide and other greenhouse gases potentially affect climate at regional and global scales. Humans have increased atmospheric carbon dioxide concentration since the Industrial Revolution began and this is the most important long-lived "forcing" of climate change (Azizi M, 2013).

2.2.4 Impacts of climate variability on coffee production

Impacts of Climate variability are consequences of climate variables on natural and human systems. Depending on the consideration of adaptation, one can distinguish between potential impacts and residual impacts. Potential impacts: All impacts that may occur given a projected change in climate variables, without considering adaptation. Residual impacts: The impacts of climate variability that would occur after adaptation.

2.2.6 Coffee sector and climate variability

Coffee sector has a huge ramification that include growers, producers' associations, pulpers, buyers, certification agencies, wholesalers, transporters, retailers, roasters, exporters and consumers and many others (GIZ, 2010). Coffee is considered as the world's most important tropical export crop, however, recent studies predict severe climate change impacts on *Coffea arabica* production (Craparo et al., 2015). This is likely to lead to an important decrease in profitability and posing a major economic risk of coffee production (Schroth et al., 2009). According to Potts (2003),global coffee production and trades are under risk because of declining forests spp.; water contamination, diminishing biodiversity to persistently uncertain revenues and makes currently an imperfect market in action.

Over the next forty years, coffee sector may be affected by climate variations. In a study back in 2016, Killeen and Harper (2016), noted that coffee production area changes because suitable areas becomes too warm or prone to periodic drought (Killeen & Harper, 2016), and this is a consequence of changes in climatic variables (Dekens & Bagamba, 2014). The influence of this climate variation makes the farmers to be indebted, reduces ability to invest in production and affects their livelihood as it reduces their income generation capacity (Craparo et al., 2015). Considered holistically, climate variations affect coffee industry from production to export (Dekens & Bagamba, 2014).

2.2.7 Influence of weather variation on coffee

According to the CBD, Observed changes in climate patterns have already adversely affected biodiversity at the species and ecosystem levels, and further changes in biodiversity are inevitable with further changes in climate (Secretariat of the Convention on Biological Diversity, 2009). Davis

(2012) stated that the profoundly negative trend for the future distribution of Arabica coffee would be 65% reduction in the number of bio climatically suitable localities, and at worst (scenarios of almost 100% reduction, by the year 2080 under the influence of accelerated global climate change) (Davis et al., 2012). According to the same authors, a 90% reduction in area suitable for in situ conservation of coffee genetic resources was projected for the year 2080. Climate change is predicted to increase mean temperatures and change precipitation regimes and as a result, traditional coffee growing regions may disappear and new regions may appear (Laderach et al., 2010). The impact of changes in climatic parameters to coffee production is huge in terms of damages, because it mostly affects the growth and development of the plants at different growth stages (Camargo MBP, 2010).

2.2.8 Impact of climate variability on coffee yield and quality

Haggar and Schepp (2012) highlighted that the potential yield and quality of coffee is determined by temperature and rainfall condition since both have the ability to interfere with the phonological growth of coffee crop. The impacts of this interference include, for example, disrupted flowering cycles in prolonged drought periods, which ultimate result in reduced coffee quantity and quality (Masters et al., 2009). Other climate variation such as soil water balance during different growth stages of the coffee crop, can affect the available soil water and decrease of the final yield (Camargo MBP, 2010). The Arabica coffee is more sensitive to climate variation, specifically during blossoming and fructification stage (Haggar & Schepp, 2012). Specifically, coffee flowering is triggered by the first rainfall at the beginning of rain season, and if rain drops off or becomes too heavy, flowers and fruit may drop from the coffee tree (Craparo et al., 2015). The unpredictable rains can make coffee to flower at various times throughout the year, making the farmers to harvest small quantities continuously, and hence, changes affect the crop physiology especially during the flowering and fruit filling stage (Craparo et al., 2015).

2.2.9 Impact of climate variability on pests' diseases

Over time, climate variation has been considered as the most favorable for the increase of coffee pest diseases; the loss being estimated globally at13% of yield reduction according to different researches (Agegnehu et al., 2015). Major disease that occur because of climate variation during coffee growing period is reported likely to increase pest and disease prevalence, expanding for example, the altitudinal range in which the fungal disease coffee rust and the coffee berry borer can survive (Craparo et al., 2015). One of examples is the rising temperatures which is likely toincrease infestation by the Coffee berry borer (*Hypothenemushampeii*), particularly where coffee grows unshaded and the cropping is continuous throughout the year (Bongase, 2017). Jaramillo et al. (2011). Climate variability is reported to likely worsen pest prevalence like "broca" (berry borer) in Eastern Africa due to climate variability.

CHAPTER 3. MATERIALS AND METHODS

3.0. Introduction

The previous chapter reviewed literature on the study. It was intended to give an understanding of the research topic. This chapter provides an overview of the research methodology which was employed in the study. It gives the Coffee distribution in agro-climatic zones in Rwanda; the way the data have been collected, this includes secondary data gathered from different government institutions and previous related studies, and primary data collected during field visit. The chapter also gives an overall map showing the study area containing the coffee distribution trees in Rwanda, the four coffee washing stations and four weather stations that provide the necessary data of the whole study.

3.1. Coffee distribution in agro-climatic zones in Rwanda

In general, the Agricultural production systems of Rwanda are divided throughout its various agro-ecological zones as illustrated at the following map.

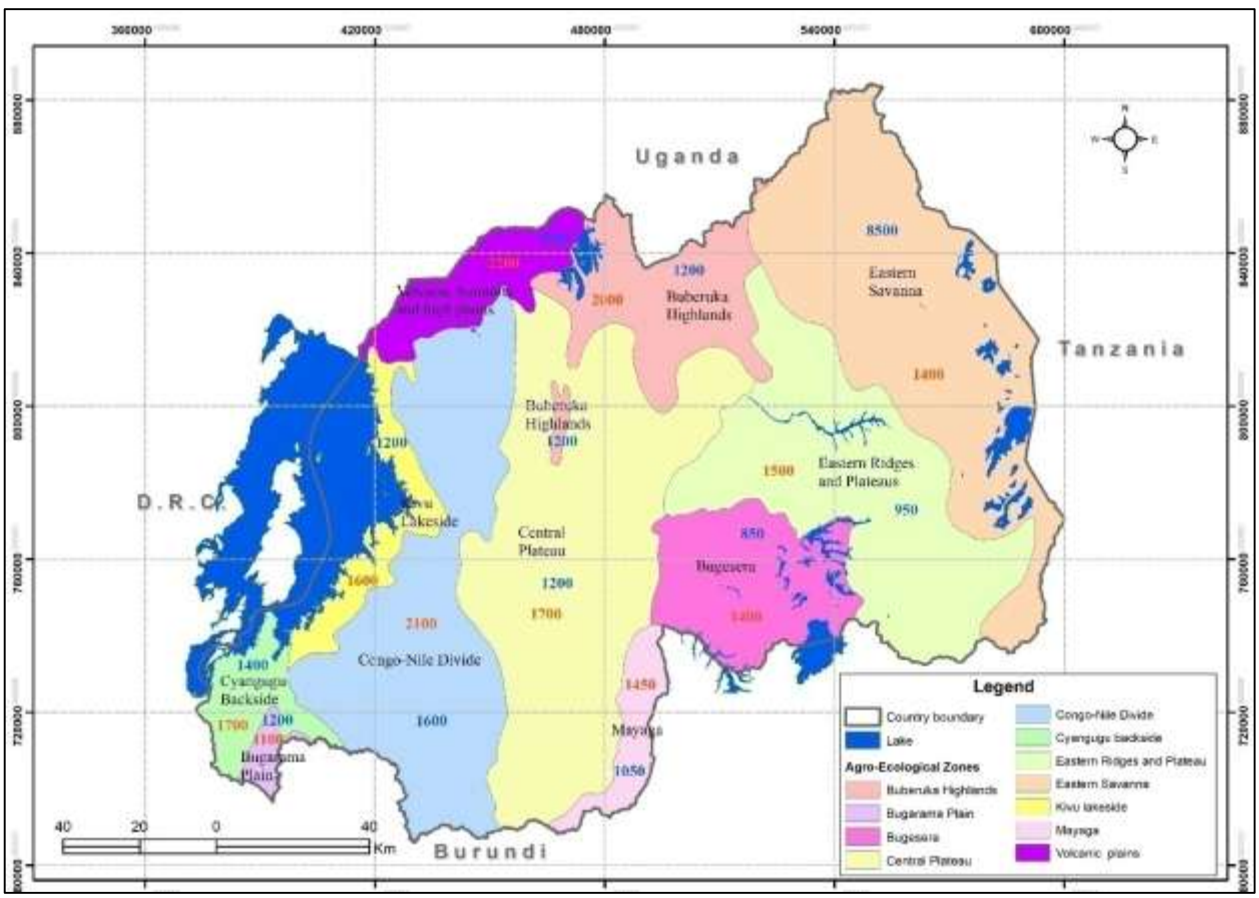


Figure 2: Rwanda agro ecological zones

Rwanda has ten agro-ecological zones namely: Imbo, Impara, Kivu Lake Borders, Birunga (volcano), Congo-Nile Watershed Divide, Buberuka Highlands, Central Plateau, Eastern Plateau, Eastern Savanna and Mayaga-Bugesera,. In Rwanda, coffee is predominantly grown along the shores of Lake Kivu in the west, on the plateau in the central part of Rwanda, and in the Mayaga region in the east. (Nzeyimana et al., 2014).

3.2. Secondary data acquisition

Secondary data come from the literature review. Secondary data may come from published like scientific journals and books and unpublished works. In addition, they may come from the existing quantitative data. Finally, they may also come from the existing geospatial data (aero photos, satellite imagery) (Ranjit Kumar, 2005). The secondary data and information was collected in both hardcopy and softcopy, from different government institutions as earlier mentioned and previous related studies.

3.2.1. Geospatial data acquisition

The Geospatial data also has been used in the present research. It includes Geographical information system datasets of administrative boundaries of Rwanda, distribution of coffee trees in Rwanda, location of coffee washing stations and location of weather stations of the study. The main data of this source were collected from the government institutions like National Agriculture Export Board and Rwanda Meteorological Agency. These spatial data facilitated in the production of maps and visualization of coffee washing stations and weather stations.

3.2.2. Administrative boundaries of Rwanda

Rwanda is a democratic republic is a country in Central Africa and one of the smallest countries on the African mainland. Located a few degrees south of the Equator, Rwanda is bordered by Uganda in the North, Tanzania in the East, Burundi in the south, and the Democratic Republic of the Congo in the West. It has four provinces and Kigali city, 30 districts, 416 sectors, 2,148 cells and 14,837 villages (Government of Rwanda, 2018). According to National Institute of Statistics of Rwanda, Rwanda has Boundary data that contains Provinces, Districts, Sectors and Villages boundaries for Rwanda since 2006. The data was created in 2006 and updated by the 2012 Census mapping. These shapefiles were used in the study in order to develop maps and showing the distribution of coffee trees, location of coffee washing stations and location of weather stations in Rwanda. Location of coffee washing stations.

The present research used four coffee washing station as source of data that helps to analyze the changes in coffee production in Rwanda. These coffee washing stations are RWACOF CWS located in Karenge sector of Rwamagana District in Eastern plateau, Musasa CWS located in Ruli sector of Gakenke District in Buberuka highlands, KOPAKAKI CWS located in Rubengera sector of KarongiDistrict in lake Kivu shores and IWACU CWS located in Nyagisozi sector of Nyanza District in central plateau.

3.2.3. Distribution of coffee trees

The coffee trees are distributed in the countryside according to it suitability.Most of the suitable land for coffee is located on the borders of Lake Kivu. Other agro ecological zones that have a significant number of coffee trees in Rwanda are Buberuka highlands, Eastern plateau,Mayaga region and Central plateau, (Nzeyimana et al., 2014).

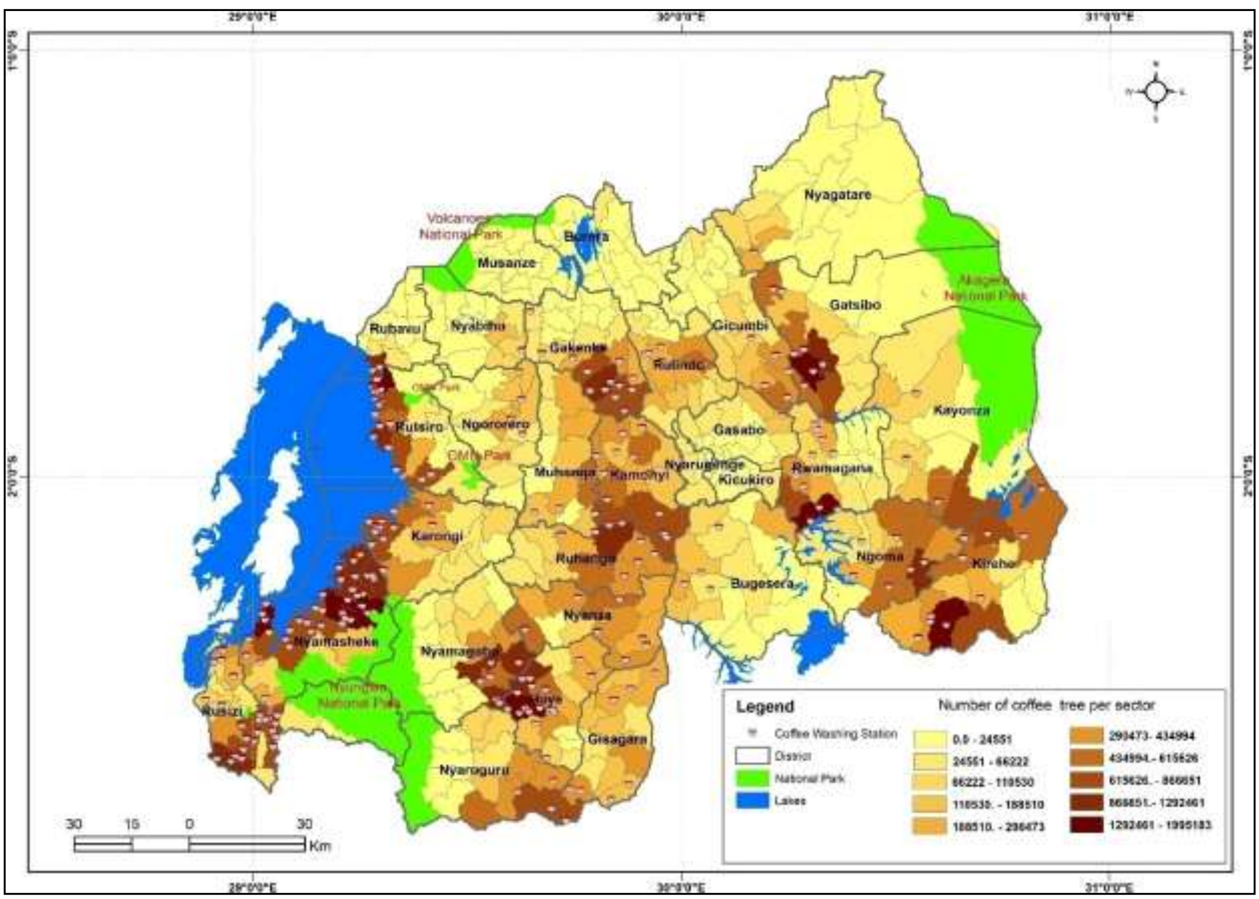


Figure 3: Distribution of coffee trees in Rwanda

The research used the distribution of coffee trees in Rwanda, based specifically on the agro ecological zones that coffee is suitable in order to generate the coffee washing stations used to provide data on coffee production.

3.2.4. Location of weather stations in Rwanda

Four weather stations were used to provide data on climate variables such as temperature and rainfall. These are Rwamagana weather station located in Rwamagana District, Nyamiyaga weather station located in Nyanza District, Rubengera weather station located in Karongi District and Cyabingo weather station located in Gakenke District and they were chosen because they are closely near the selected coffee zones.

Table 1: Location of weather stations

Weather station	Latitude	Longitude	Elevation
Nyamiyaga weather station	- 2.46	29.86	1800
Rubengera weather station	- 2.07	29.41	1700
Cyabingo weather station	- 1.56	29.68	1870
Rwamagana weather station	- 1.93	30.43	1535

3.3. Coffee production in Rwanda

Coffee plays a major role in the economy in Rwanda, contributing significantly to foreign exchange earnings and to the monetization of the rural economy. Coffee is produced mainly by small holder farmers as discussed before. The production has been changed every year. The research used the production of fifteen years from four coffee washing stations namely RWACOF, MUSASA, IWACU and KOPAKAKI to analyze the evolution of coffee production in Rwanda and analyze the relationship between the climate variables (temperature and rainfall) and coffee production.

3.4. Climate data acquisition

The data of climate variables such as temperature and rainfall of the period of the study (2001-2015) was collected from the Rwanda Meteorological Agency. Every year had the monthly rainfall, maximum and minimum temperature data which had been converted to annual average level.

3.5. Primary data collection

This section details the data collection methods utilized in the field, the sampling method and sample size of coffee washing stations, weathers stations and climate variables. Judgmental or Purposive or selective sampling technique was employed to get the study areas based on the objective of this study. (Ranjit Kumar, 2005).

3.6. Sample of coffee washing stations

In coffee growing regions, coffee washing station number is expanding day to day and according to NAEB, its number increased from 2 coffee stations 2002 to 214 in a period of 10 years. However, according to the same source, in 2012 the median coffee washing station utilized just 53% of their installed capacity. One in four of stations processed less than 25 percent of what their installed capacity allowed, and 17 stations were not operating at all. Just 25 percent of stations were operating at 100 percent capacity (Rwanda, 2015).

The following coffee washing stations wereselected purposively according to their locations in agro ecological zones that produce coffee. These coffee washing stations are Rwacof CWS in Karenge sector of Rwamagana District located in Eastern plateau, Musasa CWS in Ruli sector of Gakenke District located in Buberuka highlands, Kopakaki CWS in Rubengera sector of Karongi District located in lake Kivu shores and Iwacu CWS in Nyagisozi sector of Nyanza District located in Central plateau in order to provide the necessary evidences of coffee production.

3.7. Sample of nearest weather stations

According to Rwanda Meteorological Agency, there are 308 currently installed weather stations of different types. Thirteen are Agro-Synoptic stations manned by one or two staff, hundred forty six are automatic weather stations, hundred fifty two are climatological stations. There are also two receivers for Satellite data and one doppler weather Radar (Meteo Rwanda, 2017). The following are the weather stations that provided data on temperature and rainfall as climate variables that affect coffee production. These are Rwamagana weather station in Rwamagana District, Nyamiyaga weather station in Nyanza District, Rubengera weather station in Karongi District and Cyabingo weather station in Gakenke District and all were chosen because they are closely near the selected coffee zones.

3.8. Selection of climate variables

For planting coffee trees, some environmental factors need to be considered while selecting the best suitable areas to plant coffee as elaborated in Chapter II. e. These include for example temperature, water availability, and sunshine intensity, and wind, type of soil and topography of land. The influence of these factors in the coffee production is not at the same level. The research was carried on temperature and rainfall as climate variables considered as the main factor that influence coffee production in Rwanda.

3.9. Data processing and analysis

Once all the data were collected from the field, the data processing and analysis step consisted of filled data entry, database management, statistical analysis, spatial datasets input, enhancement and results visualization for further conclusions.

3.10. Averaging the climate variable of coffee growing season

Monthly rainfall data used was taken from 2001 to early 2015 and also the monthly temperatures were taken from 2001 to December 2015. The monthly data was changed to annual average using Microsoft Excel. The annual average of maximum and minimum temperature and annual average rainfall were used in order to get an evidence of climate varying in the coffee zone areas of the country associated with the research. Thereafter, these data also were used in determining of relationship between climate variables and coffee production.

3.11. Correlation analysis using SPSS

The data entry has been than facilitated with SPSS software program version 23. The software uses multivariate functions to clearly categorize typical information and data to analyze. The bivariate Pearson correlation analysis was performed to find out the correlation coefficients between coffee production and meteorological parameters (rainfall and maximum temperature).

3.12. Conclusion

The construction of a research methodology is the most important aspect of any research endeavor as it determines the nature and quality of the information. The input of the study, primary data and secondary data were collected and the output is entirely dependent upon it. Once all data are available, the following step is data processing and analysis in order to find the answers of the research questions.

CHAPTER 4: RESULTS AND DISCUSSION

4.0 Introduction

Meteorological parameters are important factors for any crop productivity. Research findings indicate that variability in total annual rainfall patterns and temperature patterns between 2001 and 2015, correlation between the 2 climate parameters (temperature and rainfall) vs coffee production in concerned regions. Trend analysis in the concerned climate parameters and their correlation with coffee production are discussed in Rwamagana, Gakenke, Nyanza and Karongi districts of Rwanda. Using SPSS program version 23. The bivariate Pearson correlation analysis was performed to find out the correlation coefficients between coffee production and meteorological parameters (rainfall and maximum temperature).

4.1 Results

4.1.1 Evidence of Climate Variability

For the past 15 years (2001-2015), climate variability has been noticeable in the concerned districts and concerns mainly changes in mean maximum annual rainfall, mean maximum and minimum temperatures and lastly coffee production related to these climate parameters. Temperature and rainfall are variably changing from one to another among the districts. Temperature and rainfall data are collected from January to December for every year.

4.1.2 Variability in Climate patterns

4.1.2.1 Changes in maximum and minimum temperatures

Maximum Temperatures have generally increased over the years for the past 15 years (2001-2015), with annual temperatures that are positively linear in Rwamagana and Nyanza though temperatures also show a general decrease in Gakenke and Karongi districts.The months with most changes in monthly minimum temperatures according to Meteo-Rwanda records were November at Rwamagana WS, March at Gakenke-Cyabingo WS, October at Karongi-Rubengera WS and August at Nyanza-Nyamiyaga WS with large increases and decreases in temperature. Among all of these weather stations, Rwamagana weather station had a great change in minimum temperature with a range of 4.3^0C. The high minimum temperatures are recorded at Rwamagana weather station with 16.80^0C in 2007 (Figure 6), Gakenke-Cyabingo weather station with 12.57^0C in 2015 (Figure 7), Nyanza-Nyamiyaga weather station with 15.25^{0}C (Figure 8) and lastly Karongi-Rubengera weather station with 16.83^{0}C in 2007(Figure 9).

Over 15 years, Rwamagana experienced an increase of maximum temperature and the average of maximum temperature was 28.29^{0}C. On the other hand, the minimum temperature was decreasing in general with an average of 15.48^{0}C (Figure 6).

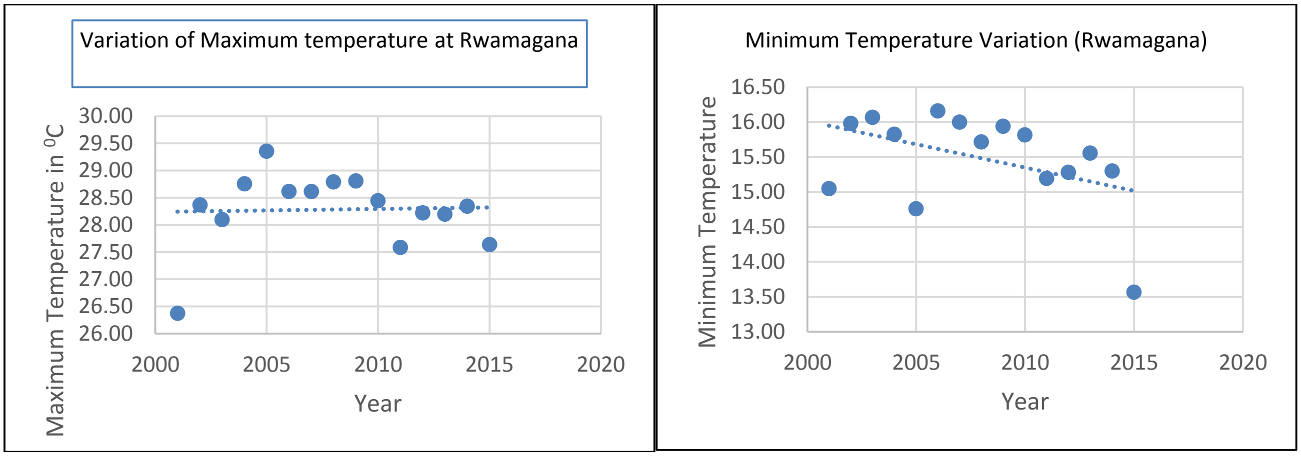


Figure 4: Variation of temperature at Rwamagana weather station

In contrary, linear increase averaging to 27.28^{0}C and linear decrease averaging to 11.430C were observed in Gakenke district at Cyabingo weather station (Figure 7). Over 15, temperature observed at Cyabingo weather station reached a maximum of 28.08^{0}C in 2005 with an average in maximum temperature of 27.28^{0}C.

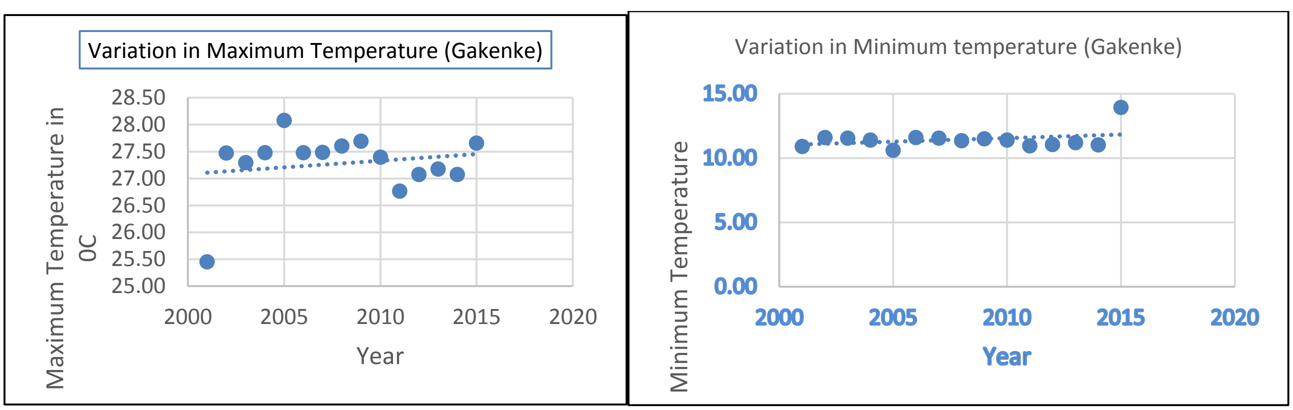


Figure 5: Variation of Temperatures at Gakenke- Cyabingo weather station

Like what was observed at Cyabingo weather station, Nyanza district also show a linear increase in both minimum and maximum temperatures of averages of 14.41^{0}C 27.28^{0}C respectively (Figure 8).

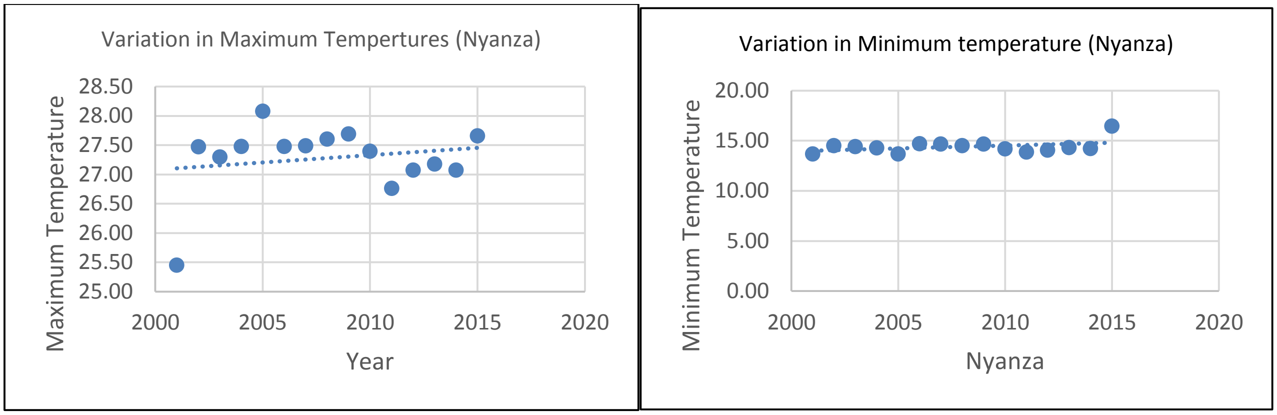


Figure 6: Variation in Temperatures Nyanza-Nyamiyaga weather station

In Karongi Districts, temperatures observed at Rubengera weather station show a decrease trend in both maximum and minimum temperatures over 15 years period (Figure 9).

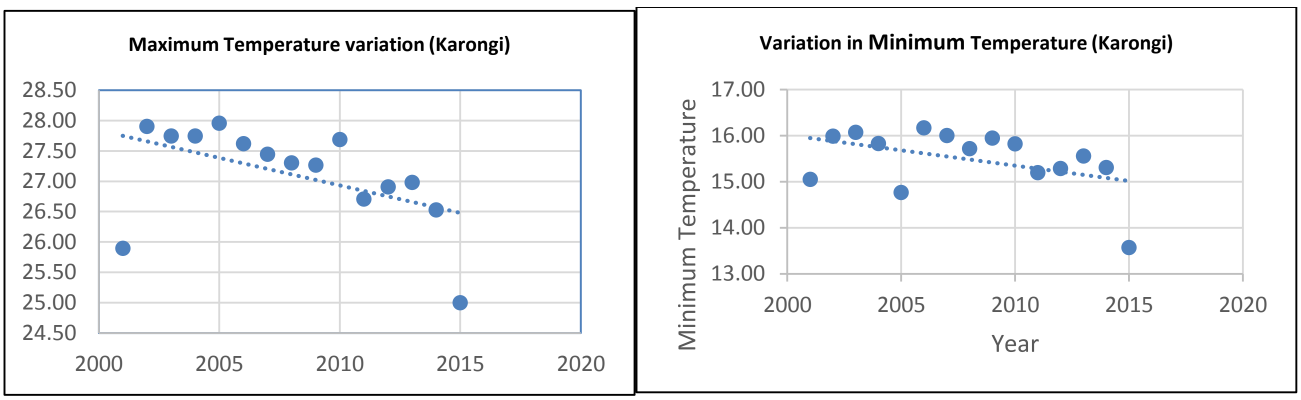


Figure 7: Variation in Temperatures at Karongi- Rubengera weather station

Increases and decreases in maximum temperatures for 2001-2015 time frame are recorded in all months of February in Rwamagana district, in all months of September in Gakenke district, in all months of November in Karongi and in all months of December in Nyanza district (Figure 6 to 9).

4.1.2.2 Variability in Rainfall (mm)

In the four districts, fluctuations in rainfall occurred (Figures 10, 11, 12& 13)) according to Meteo-Rwanda records. Out of 15 years, variability in rainfall occurred from one year to the next. Maximum mean annual rainfall appeared in 2012 at Rwamagana station with 171.55mm (Figure 10), in 2014 at Gakenke-Cyabingostation with 146.64mm (figure 11), in 2013 at Nyanza-Nyamiyaga station with 157.33mm (figure 12), and similarly in 2013 at Karongi-Rubengera station (figure 13). Minimum annual rainfall among four districts is varying between 73.27mm and 90.33mm.

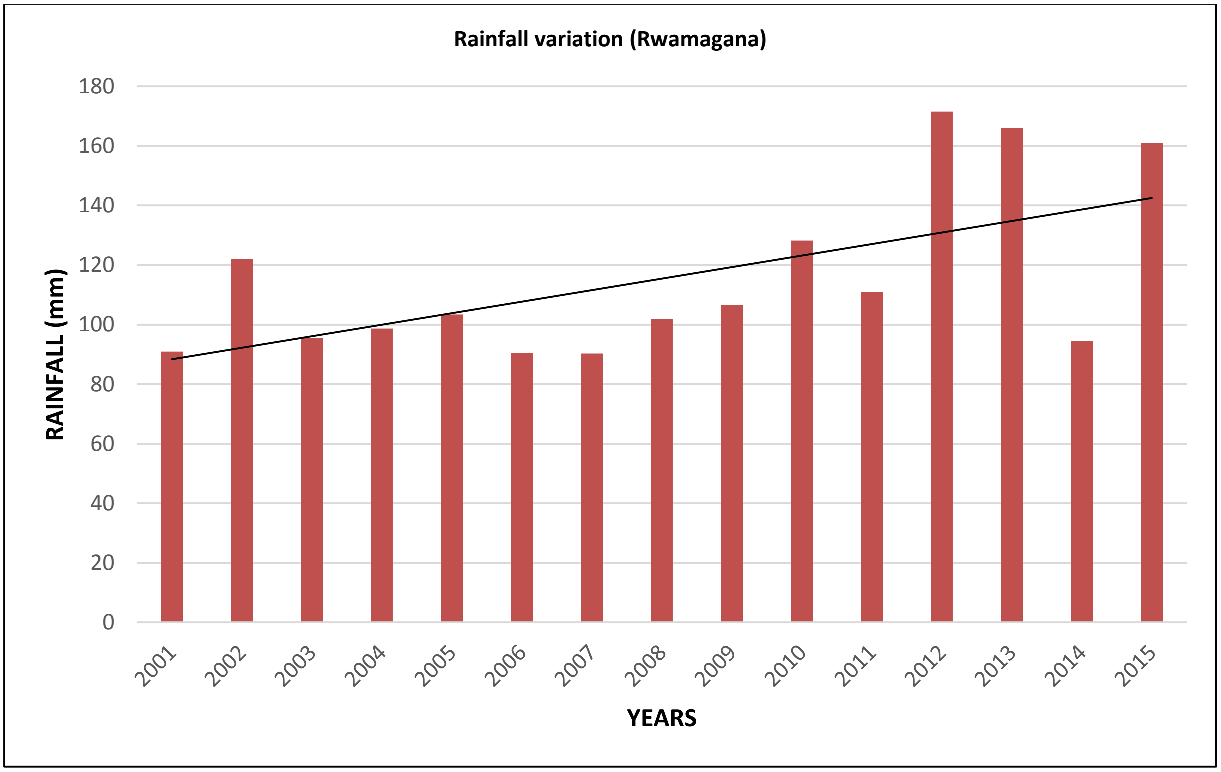


Figure 8: Rainfall variation at Rwamagana weather station

Countrywide, precipitation ranges from 1,000 to 1,400 millimeters) per year depending on area. Generally, Rwanda experiences a dry season from June to August (with July as the driest month) and a rainy season from September to May, countrywide. On closer view, there would be two rainy seasons, caused by the zenith passages of the sun, from March to May and from September to November. However, the decrease in rainfall from December to February is small, and it's just more pronounced in the north, including Gakenke District (Figure 11). Over 15 years, Gakenke received an average of monthly rainfall equivalent to 102.93 mm with the highest annual rainfall recorded in 2014 (1429.1 mm, see Annex 1).

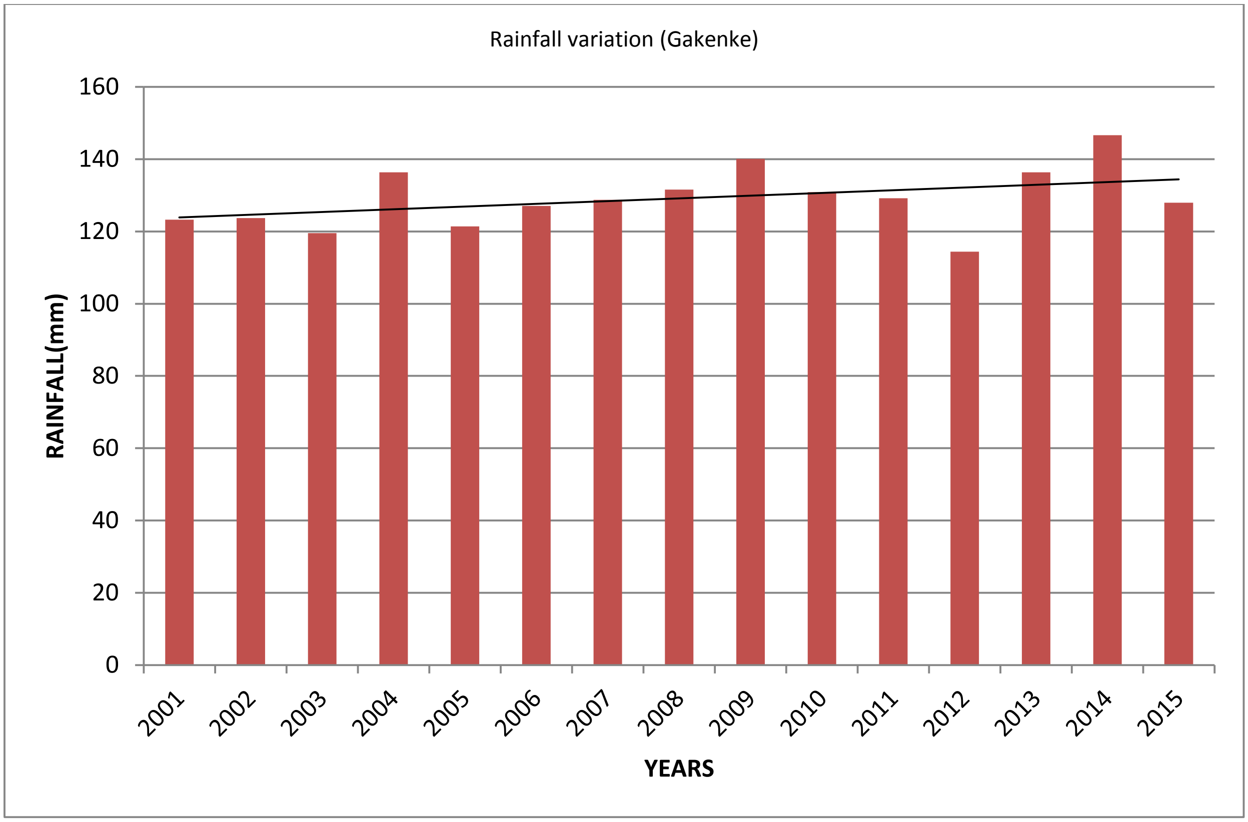


Figure 9: Rainfall variation at Gakenke-Cyabingo weather station

The eastern parts of Nyanza district has been reported as one of the parts of Rwanda prone to drought. Such districts suffer from a high frequency of rainfall deficit, late rainfall onsets, early rainfall cessations, and a significant number of dry spells(REMA, 2017). Over a period of 15 years, average monthly rainfall was 86.61 mm. The 2011 year recorded the lowest precipitation (Figure 12 and Annex 2).

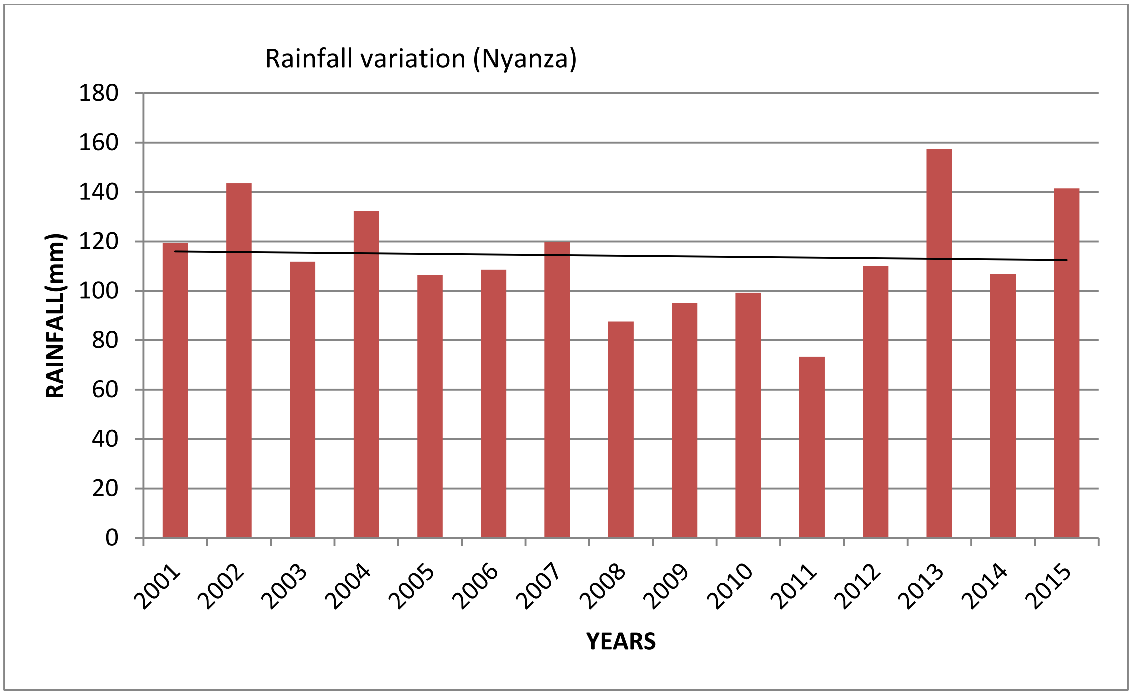


Figure 10: Rainfall variation at Nyanza-Nyamiyaga weather station

On the other hand, Karongi District experiences tropical climate of high altitude. It is one of Rwanda regions which have high rainfall. In general, annual rainfall range from 1100 to 1500 mm in Karongi, and this condition is favorable to agriculture and livestock development though it can be the source of erosion and environmental degradation in the regions of high altitude such as Karongi. From 201 to 2015, rainfall variation recorded at Karongi-Rubengera weather station indicates an average annual rainfall of 1,920 mm which exceeds the districts average.

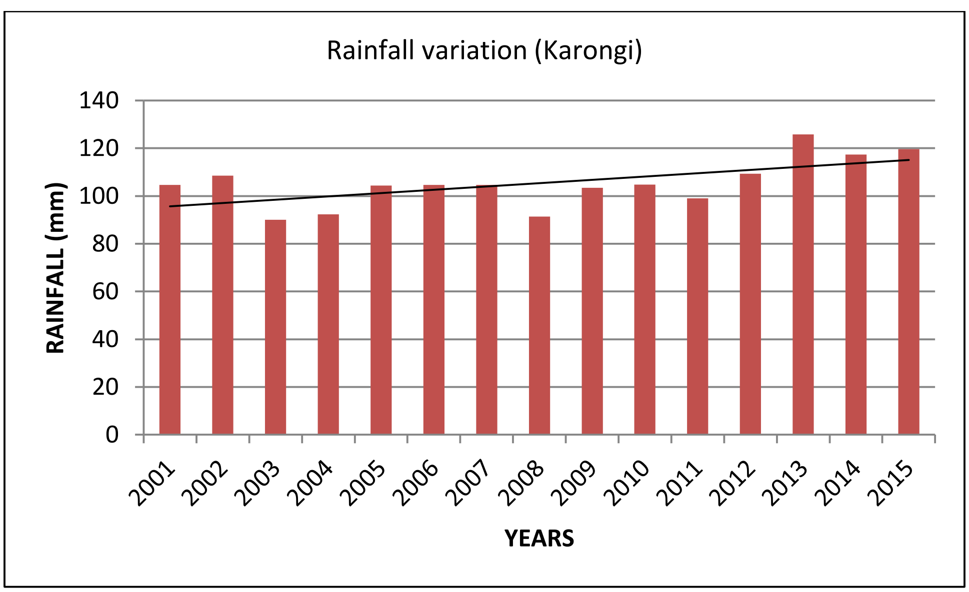


Figure 11: Rainfall variation at Karongi-Rubengera weather station

Rwamagana, Gakenke and Karongi districts showed growing rainfall trends while Nyanza district is marked by a declining rainfall trend.

4.1.2.3 Trends in Coffee Production for past 15 years

Based on the collected data of coffee harvest, coffee production in the four districts is different. Rwamagana, Gakenke Nyanza and Karongi Districts are indicated by an increasing trend in coffee production (Figure 14, Figure 16 and Figure 17) while only Nyanza district showed the growing trend (figure 15) over the fifteen years period. Over 15 years, RWACOF Coffee Washing Station located in Rwamagana district produced an average of 1,082.13 tons per year with the highest yield of 1583 tons recorded in 2011 and lowest production recorded in 2005 (Figure 14).

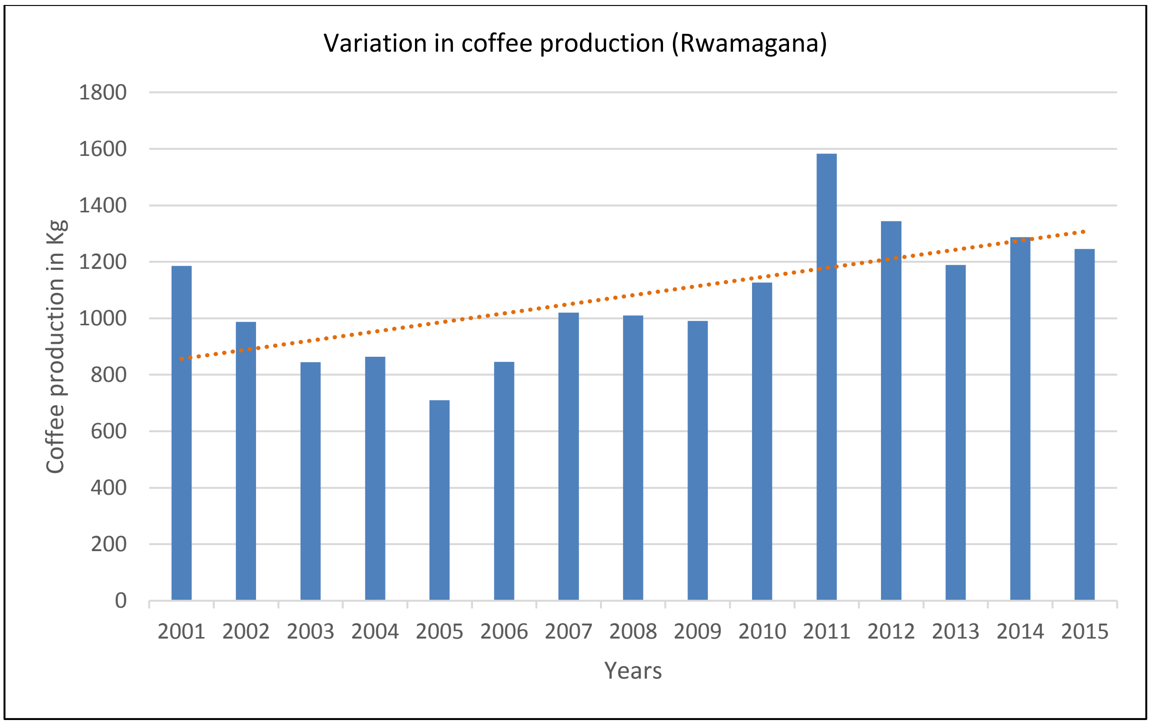


Figure 12: Variation coffee production at RWACOF CWS

On the other hand, coffee production of IWACU Coffee Washing Station located in Nyagisozi sector of Nyanza District was an averaged by of 218.07tons per year with the highest yield of 308.00 tons recorded in 2013 and lowest production recorded in 2003 (Figure 15).

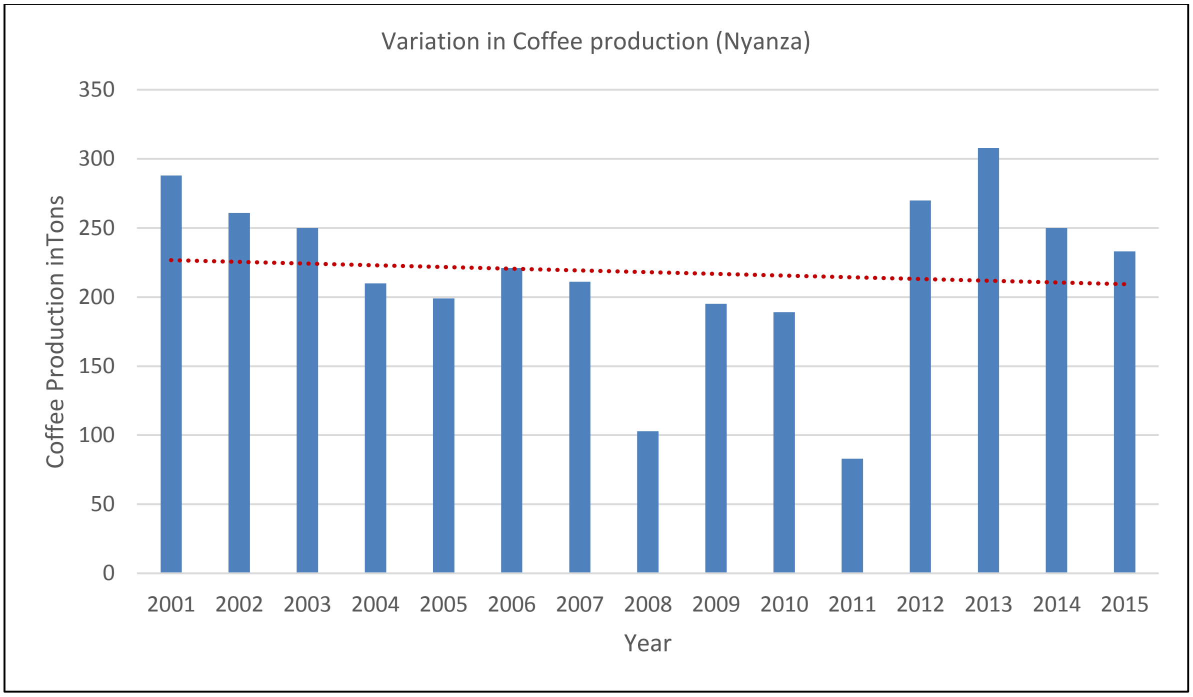


Figure 13: Variation in coffee production at IWACU CWS

In Karongi, KOPAKAKI CWS recorded an increasing coffee production with an average of 428.3 tons per year (Figure 16).

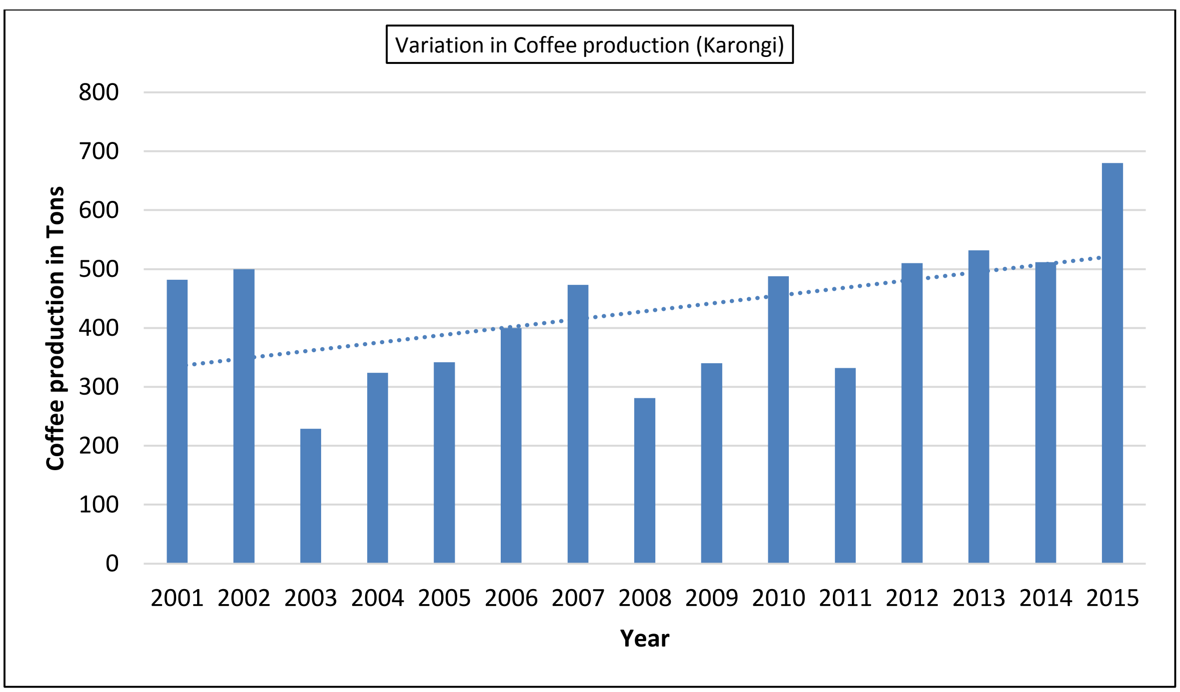


Figure 14: Variation in coffee production at KOPAKAKI CWS

Similar to Karongi District, records at MUSASA CWS show an average of 865.93 tons per year with an increasing linear trend over 15 year. The most productive year was 2014 whole the least was 2004.

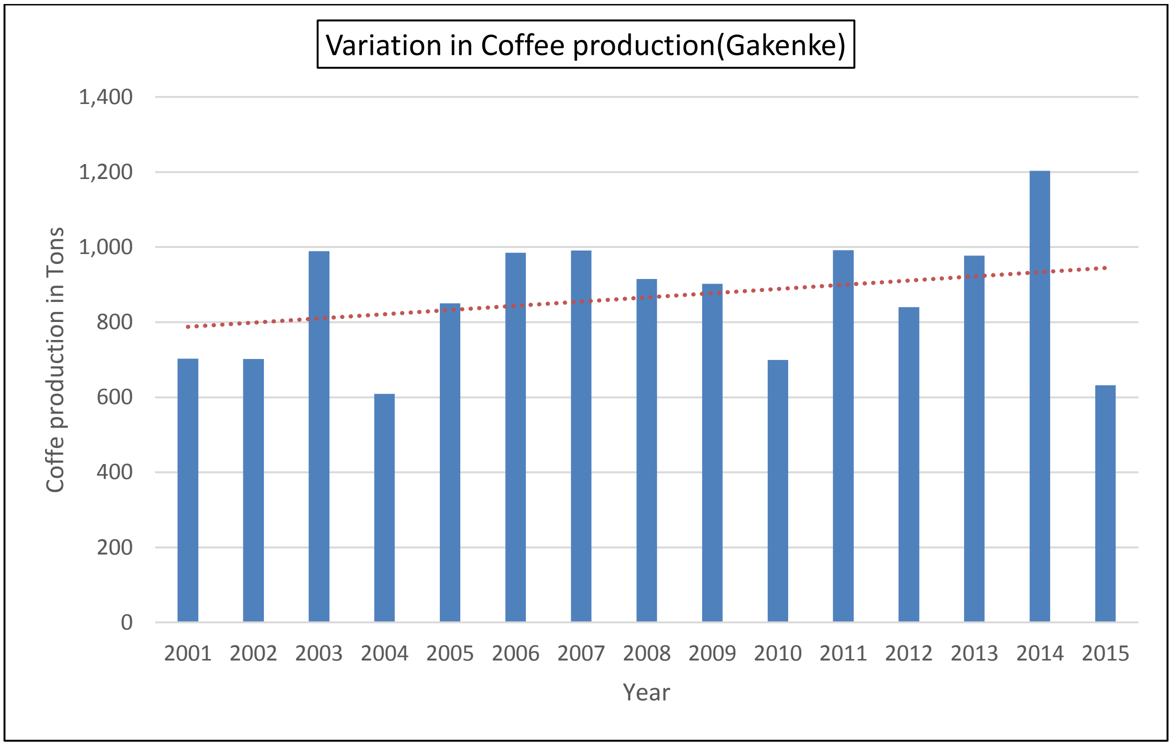


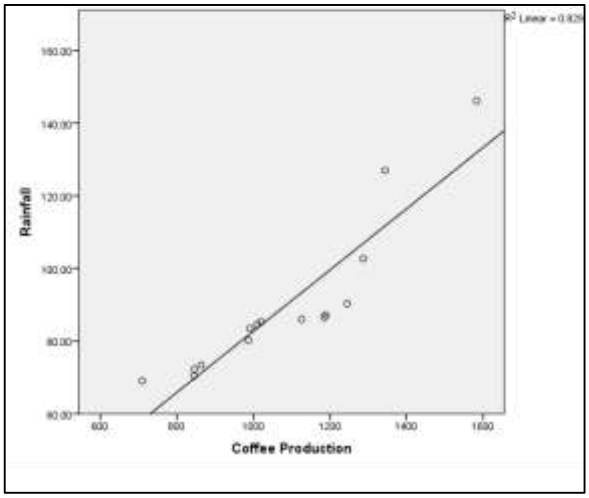
Figure 15: Variation in coffee production at MUSASA CWS

According to the data, maximum total annual coffee production was 680tons in Karongi (Figure 21), 308 tons in Nyanza (Figure 15), 1,203 tons in Gakenke (Figure 14) and lastly 1583 tons in Rwamagana (Figure 19). Comparing amount of coffee tons of the recent year (2015) among all the districts to their maximum amounts over 15 years' period, the recent production of coffee is low.

4.1.3 Rainfall and coffee production in Rwanda

The relationship between rainfall and coffee harvested for the past 15 years in the districts is determined using Bivariate Pearson correlation associated with a significance of 0.05.Among all concerned districts, the correlation r between the amount of coffee produced (in tons) and amount of rainfall in millimeter shows **p** values which are less than 0.05, hence suggesting that this relationship was statistically significant. There a positive correlation as shown by **r** values which are all positive in all districts. Positive correlation (r) suggests that an increase in rainfall, automatically trigger the increase in coffee that will harvested.

For example, in Rwamagana, p value equivalent to 0.00 and r value of 0.9 show a strong relationship between coffee harvested and annual rain fall (Figure 18).



		Rainfall	Coffee Production
Rainfall	Pearson Correlation	1	.910**
	Sig. (2-tailed)		.000
	N	15	15

**. Correlation is significant at the 0.01 level (2-tailed).

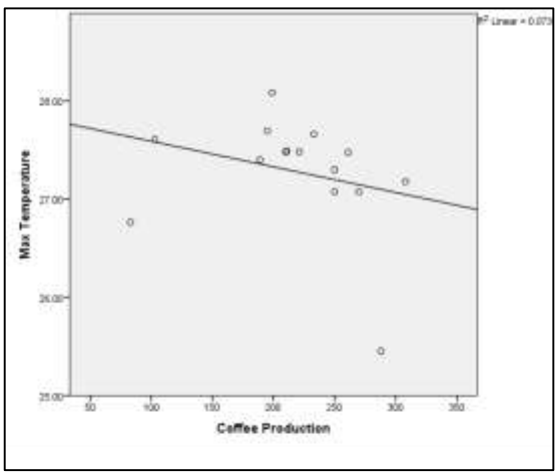
Figure 16:Correlation between coffee yield and rainfall in Rwamagana

Rainfall requirements depend on the retention properties of the soil, atmospheric humidity and cloud cover, as well as cultivation practices. The optimum annual rainfall range is 1200-1800 mm for Arabica coffee (DaMatta & Cochicho Ramalho, 2006). However, abundant rainfall throughout the year is often responsible for scattered harvest and low yields. All districts showed p values of 0.00 and r values around 0.9 (see Annex 1), which emphasizes the important contribution of rainfall in coffee production.

4.1.4 Maximum temperatures versus coffee production

The relationship between maximum temperatures and coffee harvested for the past 15 years in the districts was determined by the aid of Bivariate Pearson correlation associated with a significance of 0.05. Unlike the relationship between rainfall and coffee production, the correlation relationship between maximum temperatures and coffee production was insignificant in two districts and significant in the two remaining. Some districts are indicated by negative correlation (r) and others by positive correlation(r). Negative correlation (r) implies that when there is an increase in temperature, yield harvested reduces and vice versa.

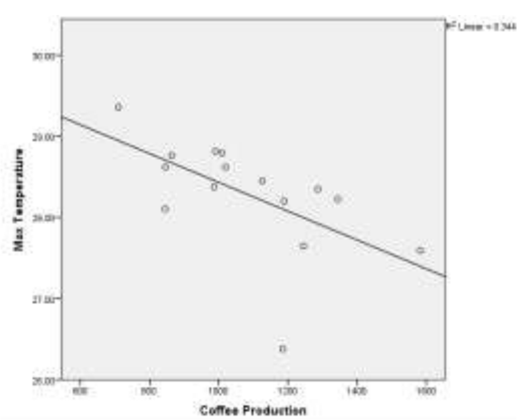
Among all concerned districts, the correlation between the amount of produced coffee with temperature variation shows **p** values which are too greater than 0.05, hence this relationship was statistically not significant. For the districts showing negative correlation, the outcomes are in line with research according to the ICO (2009) which shows that an increase in temperature inhibits photosynthesis and results in changes in planting periods, reducing growth and resulting in smaller yields. On the other hand, positive correlation (r) suggests that when there is an increase in temperature, there is also an increase in coffee production. For the present work, there was a weak relationship between the two variables and this implies there must be other parameters accountable for this issue. The following tables depict the results of the correlation analysis between amount of coffee in tons and maximum temperatures in degree Celsius for the four districts.



		Coffee Production	Max Temperature
Max T^0	Pearson Correlation	-.270	1
	Sig. (2-tailed)	.330	
	N	15	15

Figure 17: Correlation between coffee yield and maximum temperatures in Nyanza

In Rwamagana, the same case as Nyanza (Figure 18) the correlation (although weak correlation) suggests that an increase in Temperature is associated with a decrease in coffee production and vice versa (Figure 19).

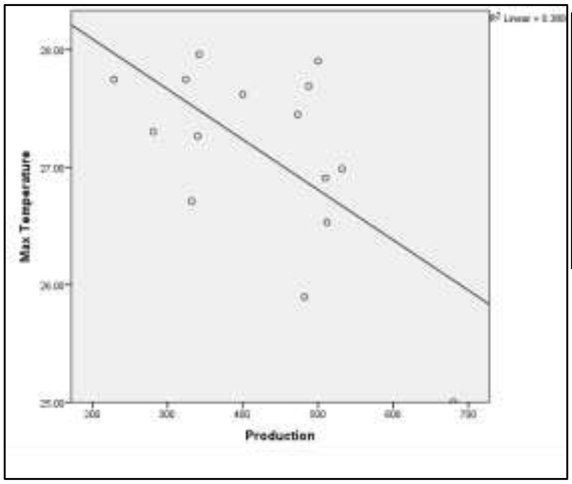


		Coffee Production	Max Temperature
Max T^0	Pearson Correlation	-.586*	1
	Sig. (2-tailed)	.022	
	N	15	15

*. Correlation is significant at the 0.05 level (2-tailed).

Figure 18: Correlation between coffee yield and maximum temperatures in Rwamagana

In Karongi, like other previous districts namely Nyanza and Rwamagana, correlation suggest that when there is an increase of temperature, coffee yield decreases and vice versa (Figure 20).

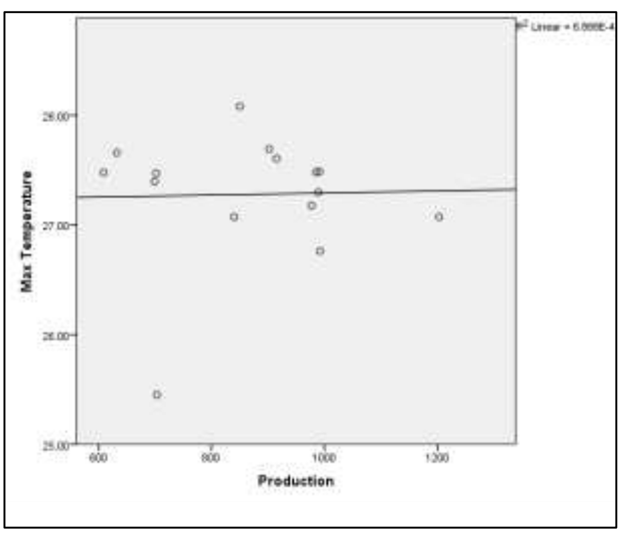


		Production	Max Temperature
Max T^0	Pearson Correlation	$-.623^*$	1
	Sig. (2-tailed)	.013	
	N	15	15

*. Correlation is significant at the 0.05 level (2-tailed).

Figure 19: Correlation between coffee yield and maximum temperatures in Karongi

In Gakenke, results show that there is no correlation between temperature variation and coffee production. Generally, drought and unfavorable temperatures are the major climatic limitations for coffee production. However, optimum temperature conditions ranging from 20°-32°C are said to be normal for coffee growth (DaMatta & Cochicho Ramalho, 2006), which explains the weak correlation between temperature and coffee yield in Gakenke (Figure 22).



		Production	Max Temperature
Max T^0	Pearson Correlation	.026	1
	Sig. (2-tailed)	.926	
	N	15	15

Figure 20: Correlation between coffee yield and maximum temperatures in Gakenke

4.2 Discussion

An occurrence of climate variability may be seasonal, annual and inter decadal variation in rainfall and temperature, prolonged droughts, floods and other conditions that result from periodic El Nino and La Nina events and these has been observed in Rwanda in different times (Samuel, 2018).

Coffee is a tropical plant which is also grown in semi-tropical climate. The coffee tree requires heat, humidity and abundant rainfall. Coffee requires an average temperature between 20°-32°C. Growth is most rapid during hot rainy season and during cool dry season berries ripen and ready for picking. Bright sunshine and warm weather are necessary for the harvesting. This situation explains the fact that results have revealed that there is a strong correlation between rainfall and coffee production but no correlation between coffee production and temperatures variation in study areas. Overall, unfavorable temperatures are the major climatic limitations for coffee production (DaMatta & Cochicho Ramalho, 2006).

Analysis of trends in mean temperatures is important in estimating warming and aridity trends which may lead to more occurrences of droughts episodes, and these events are likely to impact agricultural production including coffee (Liu et al., 2008). These extreme events a variety of negative consequences to human live and other living things. The figure below shows both negative and positive trends in mean temperatures over Rwanda.

However, researches have shown that the mean annual temperature in East African region are likely to increase from1.0°C to 2.7°C by the next 40 years , and from 1.5°C to 4.5°C by the next 50 years (Haggar & Schepp, 2012). On individual countries and by comparing Kenya and Uganda, it is likely the impact of climate change could drive a significant redistribution of coffee growing areas with the minimum altitude for Arabica production increasing by up to 400 m, and Robusta cultivation move to higher rainfall zones (Haggar & Schepp, 2012).

4.3 Conclusion

This chapter has presented results and discussions of the study on the impact of climate variability on coffee production in Rwanda. Results showed that there was annual variation in temperature and rainfall at all sampled coffee washing stations.

The relationship between maximum temperatures and coffee harvested for the past 15 years in the districts was determined by the aid of Bivariate Pearson correlation associated with a significance of

0.05. Correlation analysis revealed that rainfall is the most climate parameter which caused changes in coffee production, while temperature did not impact coffee production. This situation suggests that they might be other factors influencing coffee production.

CHAPTER 5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

This research has shown that there has been variability in rainfall and temperature which are climatic patterns playing an important role in coffee production. Temperatures and rainfall distribution appear to be the key climatic parameters that favor the development of coffee production. Results suggest that the agro-ecological zones of sampled coffee washing stations, the coffee production is determined by rainfall patterns. On the other hand, temperature does not influence coffee production. The results show that there were evidences of climate variability in terms of temperatures and rainfall that cause the change in coffee production. This might be explained by the fact that optimum temperatures for coffee production range from15 to 24ºC.This situation suggests there may be other factors, or a combination (or interactions) of the later with rainfall together with temperature which play a role in coffee production. Studies have shown that the number of rainy days inevitably influences the amount of rainfall received in any given area throughout the year. Hence, it can be hypothesized that the higher the number of rainy days results into more amount of rainfall if the intensity is more or less the same though the contrary is possible in the areas where the rainfall intensity are much fluctuating throughout the year (REMA, 2009).

However, the study has not used all parameters susceptible to influence coffee yield and was limited to only one coffee washing station per agro ecological zone. The assessment used available primary data collected, which has the limitation of considering few parameters of climate variability namely rainfall and temperature. In addition, the study has the limitation of generalizability, as it was conducted in few districts - due to time and financial constraints - that could not represent the national-level coffee production and climate parameters.

5.2. Recommendation

The present study revealed the impact of climate variability on coffee production. In addition, long term climate variability which leads to climate change is likely to have an impact on agricultural production with particular effect on coffee production in Rwanda. The global warming caused by increase of greenhouse gas emissions (carbon dioxide and methane) in the atmosphere is causing wide changes in atmospheric events resulting to climate change. These include, shifting of optimal growing zones, changes in rainfall (amount and distribution), and changes in dynamics of crop diseases and pests, loss of agricultural land due to either rising sea levels and/or desertification (Ameyu & Agricultural, 2017).

In this regard, future studies should focus on the likely impact this situation (climate variability and climate change) will put on coffee production and national economy. Approaches may include exploring deferent scenarios considering vulnerability indexes, adaptive capacities and options available in different regions of the country. In addition, given the fact that the study revealed a strong correlation between rainfall and coffee production, studies should go further and assess the impact of the number of rainy days on coffee production.

Among adaptation and mitigation measures to effects of climate variability on coffee production, off-farm and non-farm are one of activities recommended to reduce pressure on land due to human quest for livelihood options. This can reduce the effect of climate variability through having a diversified source of income. This can be combined with Integrated Pest Management which can reduce significantly the impact of long-term climate variability.

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ANNEXES

Annex 1: Rainfall at Cyabingo

Weather Stations	Months	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Gakenke-Cyabingo	**Jan**	66.8	57.1	33.0	75.2	55.7	50.5	47.4	23.4	80.2	79.9	75.2	6.8	88.7	92.3	16.6
	Feb	38.6	79.3	65.8	91.9	82.9	85.3	110.4	112.8	139.9	156.6	118.9	87.0	71.8	114.9	134.8
	Mar	151.5	127.5	131.7	188.8	193.4	182.2	124.0	191.9	147.3	166.3	218.4	114.4	164.9	165.7	83.6
	App	147.0	161.0	199.0	178.0	178.0	180.0	189.0	143.0	171.0	123.0	149.0	130.0	123.0	190.0	124.0
	May	125.8	172.7	200.7	119.9	162.1	194.1	135.0	153.4	183.9	103.9	119.0	201.1	139.3	52.3	104.9
	Jun	0.0	0.0	22.0	0.0	0.0	0.0	26.0	76.0	20.0	26.0	28.0	13.0	0.0	40.0	48.0
	Jul	13.8	0.0	0.0	0.0	0.0	0.0	19.2	4.3	0.0	0.0	24.5	0.0	0.0	4.3	0.0
	Aug	34.7	22.4	70.5	8.7	40.6	50.5	14.5	0.0	25.2	3.2	65.2	32.2	53.3	105.0	0.0
	Sep	107.0	84.0	115.0	97.0	76.0	121.0	153.0	117.0	93.0	50.0	158.0	100.0	109.0	86.0	89.0
	Oct	186.8	169.0	181.5	151.1	181.0	161.2	154.5	170.0	175.0	137.2	134.6	238.8	91.3	162.0	129.8
	Nov	149.0	135.0	143.0	103.0	143.0	174.0	153.0	145.0	145.0	169.0	160.0	150.0	138.0	202.0	163.0
	Dec	121.6	138.6	117.8	110.3	118.3	102.8	121.2	150.5	108.4	115.6	124.1	153.3	272.0	214.7	171.2
		95.2	**95.5**	**106.7**	**93.7**	**102.6**	**108.5**	**103.9**	**107.3**	**107.4**	**94.2**	**114.6**	**102.2**	**104.3**	**119.1**	**88.7**
	Total	**1142.7**	**1146.5**	**1280.1**	**1123.9**	**1231.0**	**1301.7**	**1247.0**	**1287.2**	**1288.8**	**1130.8**	**1375.0**	**1226.6**	**1251.3**	**1429.1**	**1064.9**

Annex 2: Rainfall in at Nyamiyaga

Weather Stations	Months/Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Nyanza - Nyamiyaga	Jan	122.32	129.29	81.10	98.52	54.58	61.16	63.19	11.71	109.35	59.03	53.42	66.77	109.16	80.52	63.19
	Feb	69.21	73.93	64.50	71.38	84.64	64.50	77.57	103.76	104.14	160.71	51.43	25.14	30.00	35.57	34.29
	Mar	174.97	159.00	153.19	174.68	179.03	160.16	149.32	127.74	75.97	73.06	56.13	204.48	263.71	83.81	151.74
	App	240.00	315.00	246.00	279.00	177.00	249.00	255.00	126.00	140.00	160.00	120.00	202.00	276.00	157.00	251.00
	May	80.71	122.52	94.45	66.68	85.26	103.74	80.13	58.45	84.77	76.45	80.23	76.94	40.65	9.68	78.39
	Jun	0.00	0.00	0.00	0.00	0.00	0.00	35.00	65.00	11.00	31.00	34.00	22.00	0.00	44.00	7.00
	Jul	58.06	0.00	0.00	0.00	0.00	0.00	14.90	20.32	0.00	0.00	22.35	0.00	0.00	0.00	0.00
	Aug	30.97	0.00	43.16	0.00	35.81	0.00	39.68	0.00	11.61	5.32	2.90	10.65	39.87	37.94	0.00
	Sep	72.00	0.00	61.00	12.00	16.00	29.00	51.00	15.00	33.00	82.00	45.00	52.00	136.00	87.00	29.00
	Oct	112.84	69.19	118.94	81.97	84.19	76.35	56.32	80.32	99.29	25.26	77.61	118.16	82.74	162.00	117.77
	Nov	202.00	166.00	177.00	162.00	146.00	182.00	117.00	157.00	108.00	85.00	156.00	226.00	100.00	219.00	186.00
	Dec	84.29	114.00	78.77	100.16	87.00	125.42	107.32	79.16	100.35	112.94	103.06	183.68	179.03	163.00	143.71
	Average	103.95	95.74	93.18	87.20	79.13	87.61	87.20	70.37	73.12	72.56	66.84	98.98	104.76	89.96	88.51
	Annual rainfall	1247.38	1148.93	1118.11	1046.38	949.51	1051.34	1046.44	844.47	877.50	870.78	802.14	1187.82	1257.16	1079.51	1062.09

Annex 3: Rainfall at Rubengera

Stations	Months	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Karongi-Rubengera	**Jan**	57.3	56.5	35.1	47.8	56.5	78.2	59.6	20.2	70.1	61.5	58.5	31.9	81.9	88.6	81.1
	Feb	75.2	94.9	87.0	81.6	98.8	89.1	112.7	93.4	88.9	107.6	105.4	84.8	53.8	91.9	77.6
	Mar	142.8	135.3	125.5	155.1	141.7	142.1	128.1	127.2	128.8	104.2	141.8	159.6	230.8	110.1	112.5
	App	118.0	116.0	106.0	110.0	114.0	117.0	105.0	128.0	123.0	146.0	89.0	112.0	199.0	120.0	94.0
	May	104.6	119.0	105.8	96.3	111.5	115.7	116.2	106.9	115.5	145.3	88.3	130.1	116.8	47.4	169.0
	Jun	0.0	0.0	36.0	0.0	0.0	0.0	38.0	77.0	11.0	40.0	98.0	28.0	4.0	66.0	169.0
	Jul	29.8	0.0	0.0	0.0	0.0	0.0	25.5	0.0	0.0	0.0	23.4	0.0	0.0	13.3	0.0
	Aug	0.0	18.1	17.4	14.5	41.6	63.5	22.3	53.7	23.2	0.0	52.8	45.8	32.4	97.5	16.0
	Sep	83.0	87.0	79.0	84.0	85.0	94.0	82.0	85.0	58.0	121.0	103.0	80.0	90.0	148.0	115.0
	Oct	63.2	52.8	71.9	60.9	70.5	91.8	81.2	80.7	93.9	83.0	85.0	97.5	54.8	148.5	187.5
	Nov	168.0	91.0	119.0	117.0	135.0	120.0	85.0	112.0	127.0	69.0	130.0	75.0	166.0	91.0	186.0
	Dec	151.5	135.6	73.5	162.1	119.7	126.0	114.4	139.1	139.6	124.1	168.7	188.8	217.8	204.3	147.2
	Av	230.3	223.7	219.9	225.6	229.2	234.1	229.0	233.2	229.9	231.7	242.7	234.3	250.8	249.3	259.2
	Total	230.3	223.7	219.9	225.6	229.2	234.1	229.0	233.2	229.9	231.7	242.7	234.3	250.8	249.3	259.2

Annex 4: Rainfall at Rwamagana

Rwamagana Weather Stations	Month	2001		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
	Jan	69.2		76.8	49.8	45.7	20.2	0.0	49.8	22.4	37.3	52.3	38.3	4.8	80.5	29.9	32.3
	Feb	25.1		55.1	42.2	44.1	72.2	39.4	67.1	92.7	73.7	221.4	165.0	27.7	45.0	57.2	87.4
	Mar	105.8		116.7	46.7	117.0	104.2	123.7	53.2	107.5	99.7	110.0	152.7	94.8	167.0	85.1	84.0
	App	98.0		144.0	139.0	135.0	134.0	138.0	143.0	133.0	148.0	140.0	149.0	262.0	164.0	89.0	248.0
	May	68.3		83.6	96.0	31.9	39.4	78.9	108.5	94.0	107.1	120.7	127.3	161.7	79.4	60.9	155.0
	Jun	0.0		0.0	0.0	0.0	0.0	0.0	35.0	72.0	9.0	6.0	80.0	11.0	0.0	0.0	23.0
	Jul	45.8		0.0	0.0	0.0	0.0	28.7	49.0	0.0	0.0	0.0	2.1	0.0	0.0	4.8	0.0
	Aug	42.6		0.0	23.4	10.6	35.8	49.4	58.1	0.0	25.2	0.0	56.0	91.2	16.1	69.2	0.0
	Sep	117.0		81.0	125.0	96.0	125.0	79.0	73.0	95.0	59.0	53.0	207.0	149.0	156.0	115.0	51.0
	Oct	172.8		145.6	153.4	124.6	113.2	97.7	149.8	139.7	160.1	112.7	293.3	339.5	74.3	267.0	138.1
	Nov	157.0		126.0	95.0	102.0	91.0	101.0	121.0	122.0	147.0	109.0	223.0	209.0	149.0	272.0	152.0
	Dec	137.1		133.9	74.5	173.9	93.6	131.8	116.1	136.6	136.3	107.5	259.7	173.2	115.2	182.3	112.8
	Av	86.6		80.2	70.4	73.4	69.1	72.3	85.3	84.6	83.5	86.0	146.1	127.0	87.2	102.7	90.3
	Total	1038.7		962.8	845.1	880.9	828.7	867.6	1023.6	1014.9	1002.3	1032.6	1753.5	1524.0	1046.5	1232.4	1083.7

Annex 5: Rwamagana climate patterns

Year	Max Temperature	Min Temperature	Average Temp	Monthly Rainfall
2005	29.36	14.76	22.06	69.06
2003	28.10	16.07	22.09	70.43
2006	28.62	16.16	22.39	72.30
2004	28.76	15.82	22.29	73.41
2002	28.37	15.98	22.18	80.23
2009	28.82	15.94	22.38	83.52
2008	28.79	15.72	22.26	84.58
2007	28.62	16.00	22.31	85.30
2010	28.45	15.82	22.13	86.05
2001	26.38	15.05	20.71	86.56
2013	28.20	15.56	21.88	87.20
2015	27.65	13.57	20.61	90.31
2014	28.35	15.30	21.82	102.70
2012	28.22	15.28	21.75	127.00
2011	27.59	15.20	21.39	146.13

Annex 6. Nyanza Climate patterns

Year	Max Temperature	Min Temperature	Average Temp	Rainfall
2011	26.76	13.87	20.32	66.84
2008	27.61	14.50	21.05	70.37
2010	27.40	14.17	20.78	72.56
2009	27.69	14.65	21.17	73.12
2005	28.08	13.66	20.87	79.13
2004	27.48	14.29	20.89	87.20
2007	27.49	14.65	21.07	87.20
2006	27.48	14.70	21.09	87.61
2015	27.66	16.43	22.05	88.51
2014	27.07	14.21	20.64	89.96
2003	27.30	14.42	20.86	93.18
2002	27.47	14.50	20.99	95.74
2012	27.07	14.06	20.57	98.98
2001	25.45	13.66	19.56	103.95
2013	27.18	14.32	20.75	104.76

Annex 7: Gakenke climate patterns

Year	Max Temperature	Min Temperature	Average Temp	Rainfall
2015	27.66	13.92	13.74	88.74
2004	27.48	11.39	16.09	93.66
2010	27.40	11.39	16.00	94.24
2001	25.45	10.89	14.57	95.23
2002	27.47	11.59	15.88	95.54
2012	27.07	11.04	16.03	102.22
2005	28.08	10.61	17.48	102.58
2007	27.49	11.55	15.94	103.92
2013	27.18	11.18	15.99	104.28
2003	27.30	11.53	15.76	106.67
2008	27.61	11.35	16.25	107.27
2009	27.69	11.50	16.19	107.40
2006	27.48	11.60	15.88	108.47
2011	26.76	10.95	15.82	114.58
2014	27.07	11.03	16.04	119.09

Annex 8: Karongi Climate patterns

Year	Max Temperature	Min Temperature	Average Temp	Monthly Rainfall
2003	27.75	16.07	21.91	90.01
2008	27.30	15.72	21.51	91.42
2004	27.75	15.82	21.79	92.25
2011	26.71	15.20	20.95	98.98
2009	27.26	15.94	21.60	103.45
2005	27.96	14.76	21.36	104.37
2006	27.62	16.16	21.89	104.58
2007	27.45	16.00	21.72	104.66
2001	25.90	15.05	20.47	104.68
2010	27.69	15.82	21.75	104.73
2002	27.90	15.98	21.94	108.56
2012	26.91	15.28	21.10	109.37
2014	26.53	15.30	20.92	117.41
2015	25.00	13.57	19.28	119.63
2013	26.98	15.56	21.27	125.85