ANALYSIS OF ADAPTATION PRACTICES TO CLIMATE CHANGE AND VARIABILITY BY SMALLHOLDER COFFEE FARMERS IN RWANDA: A CASE STUDY OF HUYE DISTRICT

BY

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DECLARATION

I declare that this research is my original work and has not been submitted elsewhere for examination, the award of degree or publication. Where other people's work has been used, this has properly been acknowledged and referenced in accordance with the University if Nairobi's requirements.

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DEDICATION

Dedicated to my wonderful parents, NDUWAYEZU FIDELE and MUSANGANIRE JUSTE, Thank you for your unconditional support with my studies. I am honored to have you as my parents. Thank you for giving me a chance to prove and improve myself through all my walks of life. I love you.

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ABSTRACT

Coffee farming is an important sub-sector to the economy of Rwanda and it contributes substantially to the national economy. The general objective of this study was to investigate the adaptation practices employed to mitigate adverse impacts of climate change and variability by smallholder coffee farmers in Huye district of Rwanda, with specific objectives of determining climate change related challenges and the adaptation practices employed by smallholder coffee farmers and to analyze trends for climate variables (rainfall and temperature) and coffee production in Huye district. Primary data was collected from the smallholder coffee farmers through interview guide through six focus group discussions, while Secondary data for climatic variables (rainfall and temperature) and coffee production over a period spanning 30 years were collected from Rwanda Meteorological Agency and National Agriculture Export Board respectively. Quantitative data were analyzed through descriptive statistical measures, and inferential analysis was done through comparison of group means through unpaired t-tests and simple linear regression to test for nature of relationship between the climatic variables and level of coffee production (tons); while the qualitative variables were analyzed through thematic analysis. Results showed a significant change in annual maximum temperature; while climate variables only explained 23% of the total variability in level of coffee production in Huye. The farmers reported that they were aware of seasonal change and the decline in level of coffee production. The main challenges facing coffee farmers in Huye were drought and occurrence of hails and storm, but other challenges including pests, diseases, soil infertility and landslides also presented challenges to coffee farmers. These farmers employed a number of adaptation practices including tree planting, mulching, pruning, trench digging, water canalization, application of fertilizers and quick lime. Furthermore, results from thematic analysis presented that most of the listed adaptation practices were linked on adapting and coping measures with temperature rise which emphasizes that increase in temperature was the most challenging climate related challenge coffee farmers were facing in Huye district. These findings are important for policy making on need for support for extension services for coffee farming in Rwanda; while future research should investigate what other factors are responsible for variation in the level of coffee production in Huye, including challenges around pest and disease control and land tenure changes.

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CSA	Climate Smart Agriculture
CSIUP	Climate Smart Investment Pathway
IITA	International Institute of Tropical Agriculture
IPCC	International Panel for Climate Change
NAEB	National Agriculture Export Board
REMA	Rwanda Environmental Management
RMA	Rwanda Meteorological Agency
MINAGRI	Ministry of Agriculture
$\mathbf{T_{max}}$	Maximum Temperature
$\mathbf{T_{min}}$	Minimum Temperature
CV	Coefficient of Variation
SD	Standard Deviation
Min	Minimum
Max	Maximum
Df	Degree of Freedom
FGDS	Focus Group Discussions
NAPA	National Adaptation Programme of Action

CHAPTER ONE: INTRODUCTION

1.1Background

Scientific evidence have shown that globally, the expected patterns of average weather has changed which is usually referred to as global climate change because that change has persisted for a long time, and the trend is expected to continue into the future (IPCC Working Group 1 *et al*. 2013). The long term effects of climate change and variability is also expected to challenge traditional farming practices within most agricultural sectors because, crops and livestock production systems are reportedly sensitivity to the destructive effects of climate characterized with heat stress and water shortages (Ramirez-Villegas & Challinor, 2012).

Furthermore, studies have predicted that these adverse effects of climate change on agriculture will affect mostly the tropics and subtropics (Vergara *et al.* 2014). Indeed, climate change impacts causes serious challenges on coffee production including a reduction in the area for optimal coffee production and an increase of pest within the coffee plantations (Ovalle-Rivera, Läderach, Bunn, Obersteiner, & Schroth, 2015). These impacts of climate change and variability on coffee production has been reported to occur in the major coffee producing regions in the World (Jassogne *et al.* 2013; Jaramillo *et al*. 2011; Davis *et al*. 2012).

In Rwanda, coffee farming is an important sub-sector to the economy and it contributes considerable funds to the national economy, with the coffee sector alone contributing about 36% of the total earnings from agricultural exports (The World Bank *et al* 2015).

Coffee is grown mainly in the country's Western and Southern provinces, and is produced by smallholder farmers on farms of an average size of less than one hectare with an estimated annual production of 700kg of green coffee per hector (Nzeyimana et al. 2013). In the Southern province, coffee cultivation is concentrated in Huye district (Nzeyimana *et al*. 2013). However, the average coffee production in Rwanda has not risen since 2002, stagnation has been attributed to cyclical nature or ecological succession of coffee production within the region.

But further analysis has shown that the years associated with low levels of coffee production have coincided with unfavorable weather conditions for coffee, unfavorable for coffee production (USAID, 2010).

The gravity of these impacts of climate change on smallholder coffee farmers may largely depend on the adaptation practices that coffee farmers and the extension agents have implemented to enhance coffee production under these unstable climatic conditions. It has been hypothesized that, implementation of appropriate mitigation measures to tackle climate change and variability would have a positive impact on coffee sector, besides enhancing resilience of the coffee farmers (World Bank & CIAT, 2015).

1.2 Problem Statement

Different studies have investigated the impact of climate change on coffee production around the World, with significant findings suggesting that effects of climate change and variability has negatively affected Arabica coffee production (Davis *et al*. 2012 ; Schroth *et al*. 2015 ; Craparo *et al*. 2015). Similarly, it is projected that in Rwanda there would be changes in the country's suitability for coffee farming with the increasing adverse effects of climate change and variability on the level of production for Arabica coffee (Bunn *et al*. 2015). This presents a great threat to the farming communities that produce Arabica coffee in Rwanda. Nevertheless, there is no study that has been done to investigate effects of climate change and variability on the level of coffee production, and adaptation practices coffee farmers employ to adjust to these negative impacts of climate change on coffee sector in Rwanda. This study investigated relationships between the level of coffee production and climate variables in Huye district, which is one of major coffee producing areas in Rwanda, and also analyzed the adaption measures that coffee farmers use to adapt to the effects of climate change and variability.

1.3 Research Question

1. What are the climate change and variability related challenges that affect coffee production in Huye district Rwanda?

2. What are adaptation practices used to adjust to those challenges in Huye district, Rwanda?

3. What are the trends of climate variables and coffee production for thirty years and what is the relationship between them?

1.4 Objectives

The general objective:

To investigate the challenges facing smallholder coffee farmers and the adaptation practices employed to mitigate the adverse impacts of climate change and variability by smallholder coffee farmers in Huye district, Rwanda.

Specific objectives:

1. To determine the climate change related challenges facing smallholder coffee farmers to in Huye district
2. To determine adaptation practices employed by smallholder coffee farmers to in Huye district
3. To analyze the trends for climate variables (rainfall and temperature) and coffee production in Huye district, and the relationship between them

1.5 Justification, Significance of Research

Coffee sector is important for both Rwandan micro and macro economy especially in Huye district where a vast majority of farmers rely on it for their family survival. As literature shows, Climate change is a serious threat to coffee farming. The findings in this report are important for policy makers with regard to support of extension services offered to the smallholder coffee farmers on application of appropriate adaption practices to climate change effects and variability, which will build sustainable short term and long term adaptation to climate change and variability in coffee sector.

1.6 Scope of the Research

This study focused on determining adaptation practices to climate change and variability by smallholder coffee farmers, in Huye district, in the South province of Rwanda.

The focus was on the adaptation practices to the adverse consequences of climate change and variability on coffee sector. Annual Climate variables (temperature and rainfall) and annual coffee production trends for thirty years were used to evaluate the impacts of climate change variability on the level of coffee production.

Then climate change and variability related challenges that were identified by coffee farmers in group discussion as well as the adaptation measures they practiced to adjust to those effects were analyzed to demonstrate to what extent farmers were adapting to climate change and variability. This was to examine the sustainability of the employed practices in order to plan better and more robust short term and long term adaptation planning. Several scientific facts have proved the existence of climate change and variability as documented by a large number of scientific researches. A study done by Abraham Alemu (2017) stated that negative impact of climate change can be withstood through diverse mitigation and adaptation practices like afforestation and use of shade trees. This study also added that these practices would support in lessening impacts of climate change. Therefore implementation of adaptation measures is necessary to address the effects of the increasing global average temperatures which can not be prevented because the emissions have overstepped the threshold (*Climate Change: Adaptation for Queensland* 2011).

However, in Rwanda, there have been no studies that have investigated effects of climate change on coffee farmers; neither have the adaptation measures that the farmers are practicing been documented. This study addressed this problem through analyzing climate change affect on coffee sector, and the adaptation practices farmers are using to adapt to those effects. This will assist in planning and implementation of strong, sustainable and practice oriented adaptation practices that would help to withstand climate change and variability negative effects in coffee sector.

1.7 Overview of the methodological approach

The methodology that was used in this study is the Transdisciplinarity approach. Transdisciplinarity encourages learning and problem solving through cooperation among different members of society and academia in order to find solutions to the complex challenges of society (Klein 2013).Transdisciplinarity is a suitable methodology for sustainable development and has been endorsed because it put into application the theories developed through the research process, and thus supports a research process that better reflects the complexity and multidimensionality of sustainability (Mertens 2005).

The theory of transdisciplanarity is built around the following concepts: participation, knowledge integration and reflection (Gibbons & Nowotny 2001). Through participation: stakeholders are actively involved in all phases of research process; this means none of the stakeholders have a priority than the other in the research framing. Instead, they corporate in the entire research development, to come up with sustainable outcomes and results. An interdisciplinary team guides the process and end-users have a prominent role in decision-making and this is the key component in bringing about transformation in the society (Thompson Klein 2004).

Under knowledge integration, reciprocal learning between various actors and sources is a basic pillar, and it involves explicit and implicit forms of knowledge from different academic and societal backgrounds (Mauser *et al*. 2013).

Reflection comprises of personal and collective reflection on how researchers and stakeholders' perception and ideas influence the research process and outcome. This is important because it helps in changing perspectives on problem, behavior and routines of actors, which brings practical solution to serious problems like climate change (Ramadier 2004).

Use of transdisciplinarity research in climate change research is anticipated to contribute to the achievement of resilience to climate change impacts, sustainable adaptation options, Improved livelihoods, Policy influence; Institutionalization of practice and Long-term societal impact (Mauser *et al.* 2013).

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

This section reviews the general studies on climate science and, the adaptation measures that are implemented by various actors within the farming systems to mitigate effects of climate change and variability. The structure will include an introduction to climate science, adaptation measures practiced in different sectors; adaptation measures practiced within agricultural sectors; and empirical review of studies of adaptation measures applied by coffee farmers.

2.1 Introduction to climate science

Global climate is changing, and a part of this variation happens because of natural changes that have always been there for several years. However, progressively anthropogenic activities increase green house gases into the atmosphere which in turn give rise to global warming (IPCC, 2013). Studies reveal that even after important mitigation measures are implemented to cut back greenhouse emissions, some further degree of global climate change effects are inescapable and will result into important economic, social and environmental negative impacts. Climate change adaptation insinuates activities to lessen the destructive effects of climate change, while benefiting possible advantages of new opportunities that may arise from it (Conde *et al*. 2007). It is reported that Climate change and variability will amplify natural climate variability features through its negative impacts. Failure to adapt to climate change has the possibility to negatively affect the lives of population (*Climate Change: Adaptation for Queensland* 2011). Actions to tackle impacts of climate change have been so far dedicated on two approaches, mitigation and adaptation. The two approaches have been intensely specified in different IPCC report. Adaptation focuses to managing impacts of climate change, while mitigation aims to cut off greenhouse gases emission to prevent further rise of global temperature (IPCC 2001).

Studies display an extensive documentation of practices to cope with impacts of climate change and variability. These practices encompass proactive measures, which engage in long-term decision making to enhance the capability to survive the impacts of permanent climate fluctuation and stay resilient. Moreover, they include instantaneous solutions done to face negative consequences of change and variability of climate (Sperling & Szekely 2005).

Reactive adaptation is criticized to be incompetent and can fail in addressing irreparable harm that may originate from climate change and variability such as species extinction. Thus proactive adaptation has an advantage over reactive adaptation (IPCC 2014).

2.2 Empirical studies on application of adaptation practices in different sector

There are numerous activities, which are already on the ground to face both experienced and future consequences of climate alteration in different sectors. For example to address snow melting problem, various methods as artificial snowmaking have been placed in the winter tourism sector in Alpine areas to respond to experienced impacts such like snow cover decrease (Mayer, 2008). Other measures incorporate technologies such as high elevation water reservoirs and insurance (Freire-gonz 2018).

Adaptation practices are also being applied to address glacier retreat and linked risks, through extension of water bodies originating from melted glacier, which is a grave danger to the population's life as well as the general environmental set up. The Tsho Rolpa risk management plan in Nepal demonstrates actions implemented to tackle the sneaking threat of glacial lake upsurge flooding resulting from rising temperature (Conde *et al*. 2007).

In the infrastructure sector, there is a big figure of measures implemented to endure risks stemming from negative results of temporary and permanent climate fluctuation. An example is the Confederation Bridge in Canada that has been designed, taking into account future projection on sea level rise (Sea Level Rise Adaptation Primer 2013).

2.3 Empirical studies on application of adaptation measures in agricultural sector

In the agriculture sector, Adaptation practices emphasize on applying actions that support building farmers livelihoods that are more resistant to climate change impacts. There are numerous practices employed to address climate change and variability risks on crops Including genetic engineering to produce drought resistant crops, delivering shade, income divergence and use of good practices.

A review that has been done by Below *et al*. (2010) on 17 studies pertaining to adaptation practice to climate change and variability World wide, showed that African smallholder farmers have started to exercise different practices to survive the negative consequences of climate change .

Those activities can be grouped into five (Below *et al*. 2010): plantation planning and use of modernized agriculture; plantation economic planning; broadening income source; political involvement in developing different sector and modernization in all sectors.

It suggested that there should be harmony between government adaptation plans and coping activities developed by farmers across different practices done to adapt to climate change and variability. Integrating adaptation planning with the related policy developments and decision phases can increase efficacy and competence of adaptation planning (OECD 2009 ; Tripathi and Mishra 2017). The role of linking policies to adaptation practices in the adjustment to the impacts of climate change process has been emphasized by (Sterrett 2011), where it is shown that adaptation potency in South Asia has been disjointed, due to the missing of solid connection amongst national climate change strategies and other related policies.

The study that was done on adaptation approaches implemented by farmers in Benin (Fadina & Barjolle 2018), showed that farmers use numerous tactics to respond to negative impacts of climate fluctuation. These activities comprise of diverting from farming and animal husbandry and additional activities for farm management (shading, use of natural manure), Usage of upgraded hybrid, compound composts and pest management, tree intercropping and expansion of source of funds activities, but utmost these strategies are used in combination.

Another study conducted in the Mount Rwenzori region of Southwestern Uganda exhibited the main practices implemented by agriculturalists to adjust to the negative effects of climate fluctuation. The main adjustment activities revealed encompassed the usage of crop hybrid with upgraded traits, Agroforestry, and land and rainwater conservation (Zizinga *et al.* 2017).

A research that was done in Sri Lanka identified that farmers grow short season crops as a response to climate change and variability in order to lessen possible losses on their crop. Furthermore, results of this study indicated that a number of factors linked to environment, economy of the society and institutions play a big role in determining activities that agriculturalists partake to adjust to the negative impacts of climate instability (Menike & Arachchi 2016). Findings from this study complemented results by a study that has been done in Vietnam (Van *et al.* 2015) , which showed that adaptation strategies implemented by farmers are highly influenced by the financial status of farmers.

This research revealed that adaptation practices to climate change and variability implemented by poor farmers are strongly differing from those of better financial status. The study suggested that these differences are caused by dissimilarities in revenue, financial ability and education. Adaptation actions taken by farmers habitually include quite low cost activities. Financially stable farmers on the contrary, tend to adopt more advanced responses and these farmers are more liable to respond to climate change with superior effectiveness.

2.3.1 Empirical studies on adaptation measures applied on coffee farmers

Coffee is a crop that is quite sensitive to climate change and variability and there are adaptation measures that have been put into place to address negative impacts of climate change and variability (Jassogne, Läderach, & Asten 2013; Läderach *et al*. 2017; Davis et al. 2012; Craparo *et al*. 2015).

An investigation done by Eakin *et al*. (2011) on survey and policy summary in Costa Rica showed that Mesoamerican coffee producers used Social organization and Participation in new marketing as the key responses practiced to face climate change and variability. The same strategy was identified by study by (Zuluaga, Labarta, & Läderach, 2015), which reported some adjustment methodologies utilized by Nicaragua coffee ranchers. Those practices included changes in the amount of fertilizers utilized, changes in family work utilized as a part of generation plots, and changes in harvests or crop varieties. In Uganda, farmers have been using shade in the coffee system as a way to adjust to climate change and variability since shade can lower temperature in coffee canopy up to 2 ^{o}C (Jassogne *et al.* 2013). Intercropping coffee with bananas has a lot of benefits including giving both nourishment and money from a same plot of land; in-situ mulch from banana for coffee and reduction of land insufficiency problem (Moguel & Toledo 1999). The drawback of this method is that adding shade or shade crop can cause competition among the distinctive plants for nutrients, and light (Wairegi *et al.* 2014).This opposition should be overseen by utilizing great agronomic practices. Another strategy amongst the frequently cited adaptation practices in coffee sector is income diversification. This involves stopping to totally or partially depend on coffee through production of complementary crops, so as to spread the revenue sources (Fischersworring *et al.* 2015). However, a research done in India showed that off-farm income divergence is embraced by a few coffee cultivators (Chengappa, Devika, & Rudragouda, 2017).

Some studies have recommended genetic engineering as a method for adjustment to climate change and variability impacts in coffee sector. Genetic traits such as resistance to diseases and drought are transferred into coffee cultivation. These help coffee bushes to withstand climate change impact and contributes to long-term sustainability.

An example is a plant breeding programme that has been done by the Instituto Agrono□mico de Campinas (IAC), where coffee resistant leaf rust disease and nematodes, like IAC 125 RN have been produced (Tombolato *et al.* 2009). Regardless of the advances made, genetic engineering in coffee is still tedious and relentless which make it to be less utilized as an adaptation measure to climate change and variability (Mishra & Slater 2012 ; Hellmann & Pineda-Krch 2007). Because of these drawbacks of genetic engineering, Hellmann and Pineda-Krch (2007) suggested usage of multidisciplinary approach combining both modern biotechnology along with traditional method for a more efficient and easily applicable approach.

For some smallholder coffee farmers, their capability to adjust to climate change is restricted by inadequate or lack of access to the assets required, including technical help, financial access and capacity building support at the community level (Tropical Commodity Coalition 2009 ; Läderach *et al.* 2017). Climate smart agriculture (CSA) is also one of the approaches suggested to support community to adapt to climate change challenges in agriculture taking into consideration community adaptive capacity. This approach incorporates community in development of activities aimed to withstand impacts of climate. CSA gives a guidance of activities required for renovation and adjustment of agronomic schemes to stand impacts of climate change, while efficiently up keeping progress and food (FANRPAN 2014).

It has as key goals: 1) productivity 2) adaptation and 3) mitigation (McCarthy *et al*. 2011). An investigation that was carried out in Tanzania on CSA practices in coffee sector and other different crops demonstrated that it is an sustainable method to face climate change and variability in coffee sector (Nyasimi *et al.* 2017). CSA has been proposed as a solution in El Salvador where climate change has cause devastating damages on coffee sector, and made it to stay in a condition of emergency, with around 40% of coffee crops diseased (FAO 2013; Mccarthy 2018). To respond to the impacts of climate change and climate variability on coffee smallholder farmers through Climate Smart Agriculture (CSA), Farmers are required to invest in agricultural practices that must be timely implemented to boost income.

For example, the International Institute of Tropical Agriculture (IITA) and partners developed Climate Smart Investment Pathway (CSIP) to help coffee farmers' adoption levels of climate-smart agricultural practices. This study suggested that climate smart practices should be applied in other coffee producing regions as it showed to be promising in adapting to climate change in Uganda.

Another promising method to tackle climate adaptation that has been suggested by literature is transdisciplinarity approach. Adaptation to climate change necessitates a broad cognizance of the compound nature of climate change, thus a joined and transdisciplinary structure is needed to effectively address the complexity of climate change impacts, so that important decision can be made in a system where diverse knowledge from different stakeholders are considered (LaurelA.Murray 2005). This was accentuated by a research by (Olazabal *et al.* 2018), where they stated that participatory techniques involving community knowledge and knowledge from other various discipline such as transdisciplinarity in research and decision making process, are prominent to build resilience and social knowledge acquiring needed for sustainable adaptation.

A project done by (Mendoza *et al* 2014), in *Santiago de Chile* that was addressing floods confirmed the effectiveness of transdisciplinarity in addressing climate change impacts. Knowledge from different academic and non-academic sources as well as the community was involved to evaluate vulnerabilities of the communities and determination of promising adaptation measures.

In Rwanda Adaptation to climate change can be described to be under development in agriculture as well as other sectors (Huggins 2017). Rwanda agriculture policy does not give climate change a big priority, instead it is designed around commercialization and farming intensification technique, neither of which consider climate change adaptation(MINAGRI, 2004). Additionally, Huggins (2017) described Rwanda National Adaptation Programme of Action (NAPA) as being paper wise instead of being practical, and that it lacks a clear indication to the necessity for systematic adaptation to climate change. Huggins (2017) judgments were based on the fact that adaptation to climate change is underestimated in most agriculture planning and projects, which compromises farmers' adaptive capacity. Thus a call for emergency practical actions is needed to build farmers adapting capacity so that they can stay robust to the impacts of climate change in Agriculture sector in Rwanda (Jubelwerk.De 2018).

CHAPTER THREE: DATA AND METHODS

3.1 Description of Study Area

The geographic location of Rwanda is in Central-East of Africa. Its latitude is between 1°04' and 2°51' South, whereas its longitude is set between 28°45' and 31°15' East. It occupies an area of 26,338 km^2, with a population density of about 321 people per km^2. Rwanda borders Burundi to the South, Tanzania to the East, Uganda to the North and Democratic Republic of Congo to the West; and it has four administrative provinces: North, East, West and South Province where Huye District is located. This study was conducted in Huye, which is one of the districts located in the south province, and it occupies a land area of 581.5Km^2. This district has 14 sectors, 77 cells and 509 villages with a population of approximately 314,022 people. The Figure 1 below shows the location of Huye district in Rwanda.

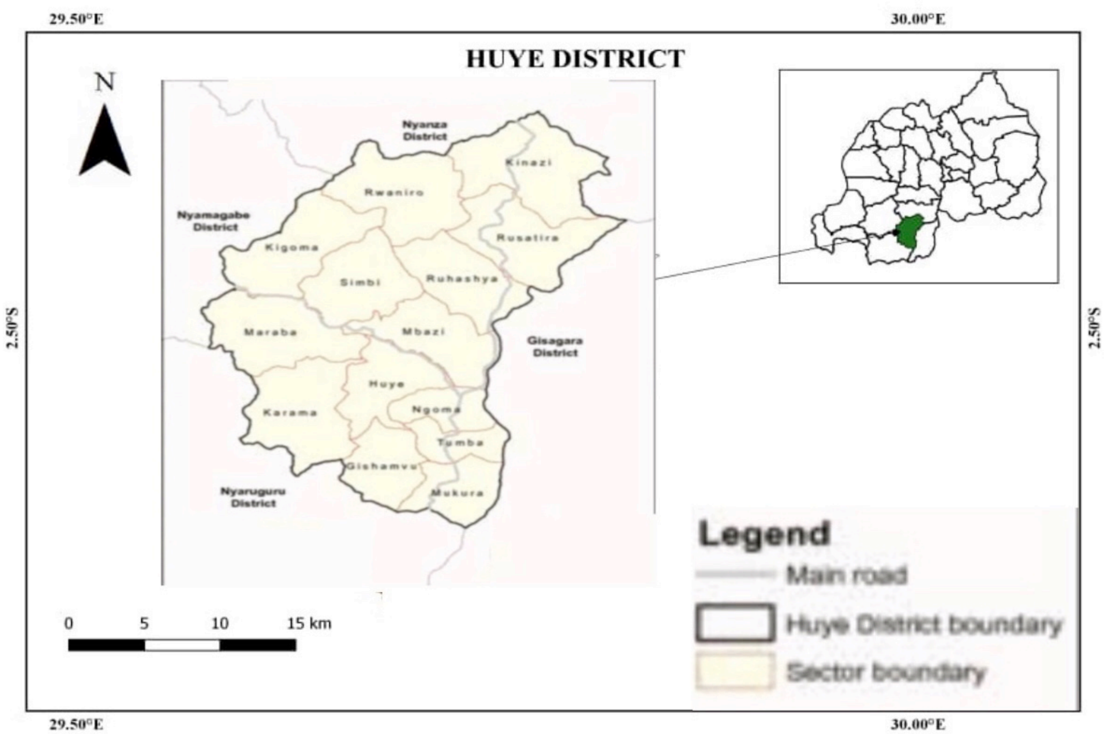

Figure 1: Huye District Location (Source: http://www.southernprovince.gov.rw)

3.2 Overview of Huye district

Huye district has an average monthly temperature fluctuations alternating between 16^oC and 24^oC, with variable amounts of rainfall. The district has four distinct climatic seasons: Extended rainy period (ranging between February and May); extended dry period (ranging between June and mid-September); short rainy period (ranging between mid-September up to December); and short dry period (ranging between January and February). The cyclical rainfall distribution in Rwanda is impacted by three main elements: (i) its Geographical location; (ii) the southern Asia wind, and (iii) the regulating part of the Great Lakes (REMA 2011). Just like in the rest of Rwanda, Crop farming is the important economic activity in Huye region that offers a source of livelihood to over 80% of population. Crop farming which is the main source of income for the families rely largely on the rain fed food production, of which coffee is one of the main cash crops. Huye just like the other regions of Rwanda has biophysical vulnerability to climate change and variability originating largely from the geo-political and socio-demographic aspects. A large part of the province has steep slopes, dry rangelands, wetlands, which imply that communities are exposed to extreme climate events like droughts, landslides and floods (REMA 2011).

3.3 Conceptual framework

The conceptual framework (Figure 2) shows an established relationship between coffee production, which is a dependent variable and climate change, which is an independent variable, as well as some of factors that influence the relationship between the two variables. This conceptual framework, starts with a number of farming practices done prior to coffee production, where farmers and institution in charges of agriculture (NAEB, MINAGRI) work together to enhance coffee production. The conceptual framework shows also that, in that process between farming practices and coffee production, there are a number of challenges that can be caused or exacerbated by climate change, which in turn negatively impact coffee production. On the other hand, there are adaptation practices that can lessen the impacts of climate change and enhance coffee production.

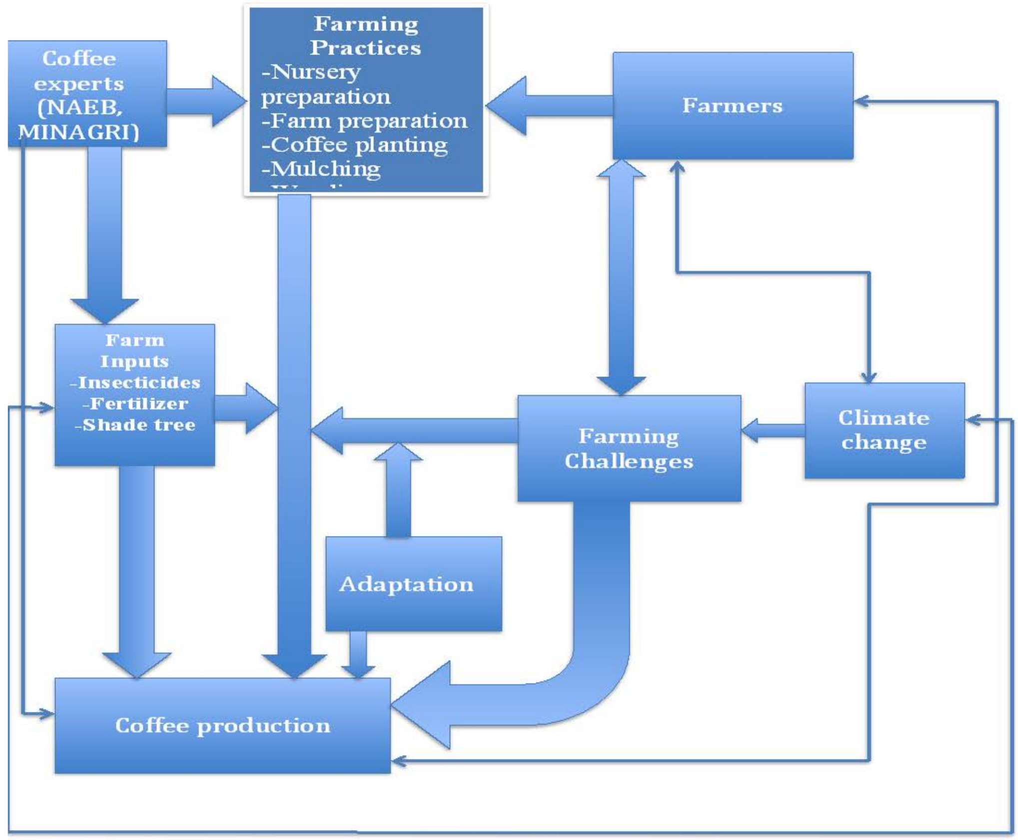

Figure 2: Conceptual framework for the study

3.4 Selection of study units

Data on the level of coffee production was obtained from corporative societies that are registered to operate in Huye district. The list of cooperatives societies operating in Huye district was obtained from the local government offices. From this list, six cooperative societies were recruited to participate in the study; and the registered cooperative members of the society were invited to attend focus group discussions. The participants comprised smallholder coffee farmers who were invited to attend the group meetings through their elected representatives. These groups of farmers were used for data collection on the various challenges that faces coffee farming and also the types of adaptation practices that they implemented to mitigate the various identified challenges.

3.5 Data on challenges facing coffee farmers and their adaptation measures

In all the six coffee cooperatives that were operating in Huye district, 15 farmers were purposively selected to participant in their interview by the head of the cooperative society. Focus group discussions were conducted with these 15 selected coffee farmers in each cooperative, and data were collected based on the following checklist questions: List of challenges affecting coffee production in the area; of the listed challenges which ones affect coffee production most, while giving reasons for the choices made, lastly, farmers were asked the actions they took when faced with the listed challenges. In addition, the discussions were recorded after consent was obtained from the respondents with the assurance that the information was not going to be shared with any other persons or organizations apart from the intended use for research. Pair wise ranking method was used for data collection, and probing done to obtain reasons for the kind of rankings, which were provided by the participants.

3.6 Collection of secondary data on climate variables and coffee production

Secondary data on climatic variables and coffee production were obtained from the Rwanda meteorological Agency. These data included annual maximum and minimum temperature as well as average annual rainfall amounts for 30 years for Huye district. Similarly, data on level of coffee production (kg/ha) in Huye district for thirty years was obtained from National Agriculture Export Board (NAEB). These data were obtained after presenting a letter of introduction from the Institute of climate change and adaptation of the University of Nairobi to the management of the various governmental institutions in Rwanda.

3.7 Data management and analysis

The qualitative data obtained during the focus group discussions including scores and their corresponding descriptive summaries obtained during the focus group discussions were entered into templates developed in Microsoft Word and analysis involved identifying patterns which were based on different themes. Further analysis involved descriptive summary on scores for climate change related challenges which were analyzed using Kruskal Wallis One-Way analysis of variance to test whether median ranks for scores obtained for coffee production challenges were significantly different from zero, and the analysis was performed using GenStat statistical package (VSN International 2011). On the other hand, qualitative data on adaptation practices were analyzed through thematic analysis, to identify patterns of coping practices employed by the stallholder coffee farmers based on the framework analytical approach (Gale *et al.* 2009; Gale et *al.*2013). The data on maximum and minimum temperatures, rainfall amounts (which were the independent variables) and the levels of coffee production (which was dependent variable) for Huye district were entered in Microsoft Excel package and these quantitative variables were summarized by obtaining the descriptive statistical measures including mean, median, minimum, maximum and the standard deviations. Further analysis involved splitting the data into two groups with equal numbers o years, between the years 1987 to 2001, and the years 2002 to 2016 and comparing the means of the two groups to test whether there was evidence for a significant change on the climatic variables and the level of coffee production. This analysis was achieved through conducting t-tests and for all analysis the level of significance was set at 5%. Simple and multivariate linear regression analysis was also done to test for any relationship between level of coffee production and climate variables (Temperature and rainfall) for thirty years in Huye district.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.0 Results

4.1 Description of climate change related challenges In Huye District, Rwanda

Challenges that have affected coffee production in Huye district were identified by the smallholder farmers in focus group discussion (Table 1). These included persistence dry spells, hail and storms, occurrence of coffee pests, diseases, landslides, soil degradation, erosion, lightning and thunder and mold.

Table 1: Climate change related challenges and their implications for coffee production in Huye, Rwanda

Challenges	Implications for coffee production
Dry spell	Affect plant growth; hinder farm maintenance; optimal for diseases and pest
Hail and storm	Plants and farm destruction; obstructs farm maintenance activities
Pests	Affects coffee production quality and quantity
Diseases	Affects coffee production quantity and quality
Land slide	Farm demolition
Soil degradation	Decreases of coffee production
Erosion	Impedes farm maintenance activities
Lightning and Thunders	Farm distraction and loss of crops
Mold	Decline coffee production quality and quantity

4.1.1 Dry spell

The participants reported that coffee often flowered around the month of September, which is a season that is characterized by optimum rainfall amount for coffee farming, and which is suitable for the flowering season. But the coffee farmers argued that this trend had changed; and that presently this period is mostly dry and sunny which makes coffee flowers to fall off, hence no cherries are formed.

In addition, the young cherries that forms around the month of February, which was a period of moderate sunshine, and which was optimal for cherry maturing, is also characterized by dry spell, which in turn dries up young cherries, thus compromising the level of coffee production.

Additionally, farmers stated that dry spells (which they were referring too as too much sun) interfere with the fertilizer uptake, since fertilization is often done in October and March, which are the period of moderate rainfall. Nevertheless, this has changed and this period is also characterized by occasional dry spell. Consequently, when they apply fertilizer, it does not sink because there is no rain. Subsequently, the fertilizer dries in case it is manure, which is a loss to the farmer. If it is a chemical fertilizer it remains above the ground and it absorb water in soil as it contains dehydrating components thus coffee tree die back due to dehydration. Moreover, dry spell provides optimal conditions for emergence of some coffee diseases like coffee leaf rust and pests like ants. Therefore the long periods of dry spell results to high prevalence of these diseases and pests which lead to poor coffee production in farms.

Plate 1: Focus Group Discussion session with smallholder coffee farmers

"the lead researcher conduction a focus group discussion with smallholder coffee farmers at Gishamvu Cooperative society"

4.1.2 Hail and storm

Farmers also reported that heavy rains also poses a great challenge to their coffee production activities, would hits cherries or flowers and they fall off the tree. Those that do not fall as well as the whole tree are also destroyed which compromises future coffee production. Unpredictable hailstorm, which occurs in the month of October and March, which are months that used to be characterized with optimum rainfall for coffee. These were the periods during which farmers would apply fertilizer, but due to climate variability, at times the farmers would they apply fertilizer in this period and a heavy rain would come and wash away fertilizer and the mulching materials. Additionally, unusual heavy rains flood trenches, as they are not big enough to accommodate all water. Farmers reported that when tranches flood is a worse scenario than the erosion itself, because it results into flash floods since water would come from these tranches that were in the farms and uproot coffee bushes as well as washing away the mulching materials.

Likewise, farmers argued that the unpredictable hail and storm which comes in the month of June which is a harvesting period and used to be a dried period, results in losses since there are no sunlight to dry the washed coffee bushes, and consequently coffee stations stop buying coffee as there is no sun to dry them. This situation would give rise to coffee price depreciation, because it would make the farmers to sell coffee at a very low price since they lack sufficient storage capacity.

Another problem that farmers reported was that with heavy rains which lasted for a long period would impede coffee maintenance activities, since the farmers could not go to farms when it was heavily raining, which also reduces coffee production. For example, farmers' reported that sometimes they would spray fungicides in a period, which used to be sunny, and instead it rains heavily, and washes away those fungicides.

Plate 2: Participants of a FGD in Huye, Rwanda

"Lead researcher posing for a photo with participants of a focus group discussion at Gishamvu sector, in Huye district, Rwanda"

4.1.3 Pest (new emerging/ increase in prevalence of existing one)

Farmers stated that pests were also a threat to their coffee production. Farmers argued that these Pests included new emerging pest like *Epilachna spp* and existing pest whose prevalence had increased like antestia bugs. These pests posed a challenge to the level of coffee production, for example, *Epilachna spp would* enter the tree and eventually the tree would die. When coffee tree dies, farmers could try to rejuvenate them, but this rejuvenation would not help since it would not be done at the right time required for the rejuvenation, hence it might lack the necessary elements to grow (like optimal weather condition). Pests, like antestia bug would reduce level of coffee production in the farm as well as coffee quality, because a coffee tree that has been attacked by antestia bug usually produce beans with an Irish potato smell.

4.1.4 Occurrence of coffee diseases

Farmers reported that coffee diseases were causing a big loss on their production. These diseases include Die back disease that emerged around 2013, which causes immature ripening of berries, which eventually leads to their dryness. Farmers also reported that existing disease like coffee leaf rust disease had increased incidences due to long dry spell period that have been occurring recently.

Plate 3: Coffee bush affected by coffee berry disease (*Colletotricum coffeanum)*

"A coffee bush that is infected with coffee berry disease is characterized by young diseased berries on the branches with a progressive damage to the tree that causes the rot of the whole berry and the berries are often shed from the branch"

4.1.5 Incidences of landslide

Huye is a mountainous region hence coffee farms are on steep mountains, which are highly prone to landslides during the rainy seasons. There are recent cases of farms that had been destroyed by landslides, which lead to huge losses to the coffee farmers.

4.1.6 Soil degradation/infertility

Farmers argued that some years back farms used to be cultivated without using fertilizer, or just little compost manure would be used. But nowadays, they cannot obtain coffee production without using fertilizers: "the soil we had before is different from the one we have now, time has changed" one farmer stated.

Plate 4: Coffee farm in Simbi Sector, Huye District Rwanda

"One of coffee farms showing example of water canalization to mitigate against soil degradation through erosion during excessive rainfall"

4.1.7 Erosion

Soil erosion was reported to wash away the mulching materials and the fertilizer that had been applied in the farm. This was considered a serious challenge to farmers, because chemical fertilizers were given once in a year by the government, therefore when they are put into the farm and washed away before they sink into the soil, the farm would not receive fertilizer that year, and consequently this decreases coffee production. Moreover, erosion sometimes uprooted the young coffee seedlings.

4.1.8 Lightning and thunderstorm

Farmers also reported cases of thunder that would strike a coffee farm: a part or the whole coffee farm and farmers reported that this is an emerging problem. When thunder pass in a coffee farms, coffee trees located in the line where it had passed immediately dry starting from the roots, up to the top of the tree, which was considered a total destruction of a tree. Such trees cannot be rejuvenated and have just to be uprooted. And finally, white molds caused by excess humidity which covers coffee cherries during too much cold period would make the coffee cherry to turn black and eventually rot.

The scores obtained by ranking these challenges were analysed through Kruskall Wallis Anova to test whether the median ranked obtained were significantly different from zero. Then result obtained from the analysis of climate change related challenges faced by smallholder coffee farmers in different focus group discussions are presented in Table 2. The challenges identified to have significantly high ranks were occurrence of dry spells (Z= 3.52) and hail storms (Z= 2.39).

Table 2: Ranking of climate change related challenges on coffee production according to farmers in Huye district

Sample	Sample size	Median	Ave rank	Z- score
Dry spell	6	8	48.8	3.52
Hail and storm	6	6.5	42	2.39
Pests	6	4	27.5	0
Diseases	6	5.5	37.3	1.61
Land slides	6	1	12.1	-2.55
Soil infertility	6	3	22.2	-0.88
Erosion	6	4	27.4	-0.01
Lights and thunder	6	3.5	24.3	-0.54
Emerging crop fungus	6	0.5	6	-3.55

H = 36.67 (adjusted for ties) with 8 d.f, χ= 15.5

Probability > 36.67 = 0.0

4.2 Adaptation practices implemented to mitigate challenges facing coffee farming

4.2.1 Tree planting and intercropping

Farmers mentioned that they would plant trees that are termed to be mixed with coffee plantation (like Grevillea, Sycamore, banana and avocado tree). These trees provide shade to coffee trees since they are tall and have big canopy. Also their foliage serve as mulch and fertilizer when they fall of, and when compared to other trees like Eucalyptus, their leaves are not acidic hence they do not increase acidity in the soil. Furthermore farmer claimed banana rhizome increases water retention in their environment. Farmers often added that these trees should be regularly pruned not to obstruct light from sun needed for photosynthesis. Farmer also mentioned that they intercropped pineapples with coffee for the purpose of income diversification because they tolerate long sunny season, thus they can serve as a secondary source of income from the same farm when coffee does not give enough production due to dry spell. Trees (sycamore and Grevillea) also were used to face hail and storm damages in the farm. They reduced the amount of solid hail that hits coffee, though still they do not moderate much as they should not be many in the coffee farm. Trees in the farm complemented with grasses like *vetiver, tripsacum and Themeda* were ideal for hindering erosion.

4.2.2 Mulching

The farmers acknowledged that mulching had a big role in bouncing back damage brought by dry spell in a coffee plantation. The mulch often reduces evaporation prior to dry spell period. Additionally, farmers claimed that when the mulch was put horizontally in the farm, they would resist water current than when in placed in vertical direction, hence they were not easily washed away by erosion thus preventing erosion damages. Moreover, farmers alleged that when mulch rots, it becomes compost, which increases nutrients in the soil for better growth of plants.

4.2.3 Trenches and water canalization

Farmers reported that efficient water canalization and trenches would help to reduce the erosions and landslides that could also capture water and reduce water current in coffee farm. Efficient canalization was done through measuring of slope before digging water canal.

This also reduced the risks of landslides creation since landslides usually occurred due to erosion. Additionally farmers would put counter banks in the farm to reduce water runoff.

4.2.4 Use of pesticide and chemicals

Farmers reported that they would use pesticide and chemicals provided by government to fight against coffee diseases and pests. An example was copper oxychloride, which was usually used to treat, and control common plant diseases like coffee leaf rust. In case the pesticides were not provided on time or they come in a small number to be accessed by all farmers, some farmers said that they would use traditional methods, which were not sometimes very effective.

Some of those methods included use of palm oil in controlling *Epilachna spp*, and use *vernonia amygdalina* and *Tetradenia riparia* to control Antestia bugs.

4.2.5 Trainings and inter-learning

Farmers reported that as a way of adaptation to climate change related challenges as well as other challenges they encountered in their farming activity, they would interact with each other and learn from each other for there were a few of them who got training from government or other non-governmental organization on good coffee farming practices.

Thus, those who were trained would take initiative to teach others goof farming practices to face climate variation challenges, without waiting for them to be trained by government or other organization trainings. Furthermore, farmers worked with district agriculture officers and often consulted them on how efficiently put into actions what they were trained on. Some of the practices they were trained on included pruning to reduce habitat for pests, putting the mulch efficiently without placing it near the coffee tree, because when it was near the coffee tree that mulch could be a home for some paste like indoor ants. Also, farmers consulted agronomist technician before planting coffee, to see if that place is not too prone to landslides or whether it was at the right elevation, which does not have high humidity since it attracted mold, which compromises coffee production.

4.2.6 Application of fertilizers

Farmers reported that they usually used chemical fertilizers given by the government, and compost to address challenges of soil infertility. Moreover, they claimed that compost performed better as compared to the chemical fertilizer and they said that they had been trained on how to make compost themselves using bio waste from animals and the farms. Additionally, farmers said that they often used quicklime to reduce soil acidity. In case the compost was not enough, farmers said they had been trained on fertilizer management where a farm would be divided into two parts and then they would put fertilizer in one part while the other one was left. Then for the next round they put much fertilizer in the remainder part and a little one in the part that had received fertilizer in the previous season.

Table 3: Adaptation and coping practices that farmers mentioned to use to face climate change and variability related challenges

Challenges	Adaptation practices adopted to mitigate effects of challenges on coffee production
Dry spell	Tree planting; Mulching
Hail and storm	Tree planting
Pest	Use of pesticide; Putting well; Pruning
Disease	Use of chemicals; Use of fertilizers and mulch
Land slide	Slope measurement before digging tranches; Water canalization on the mountains
Soil degradation	Fertilizer application; Quicklime usage to reduce soil acidity
Erosion	Tree planting and grass planting; Efficient water canalization Tranches digging; Put the mulch horizontally not vertically.
Lightning and Thunders	
Mold	Planting new coffee bushes at right elevation

4.3 Description of climatic variables and Coffee production in Huye District

Results for Weather variables (Rainfall and temperature) and coffee production were summarized using descriptive statistics Table 4**.** For Annual maximum temperature, the highest mean annual temperature was recorded to be 25.66^{0}C whereas the lowest was 24.25^{0}C. For the average annual minimum temperature, the highest recorded was 15.68^{0}C while the lowest was recorded at 13.5^{0}C.The temperatures showed an equal distribution since their mean and median estimates were more or less the same with a coefficient of variation of 1.3% and 3.5% for the maximum and minimum temperatures respectively. On the other hand, average annual rainfall amounts and the level of coffee production were more highly variable around the mean compared to temperatures, and this was reflected by a high estimated of the coefficient of variation of 12.2% and 13.26% for annual rainfall and level of coffee production respectively.

Table 4: Description of Climatic Variable (temperature and rainfall) and coffee production in Huye district

Variable	**CV (%)**	**Mean**	**Median**	**SD**	**Min**	**Max**
Annual T_{max} (^{0}C)	1.30	25.09	25.13	0.33	24.25	25.66
Annual T_{min} (^{0}C)	3.50	14.20	14.10	0.50	13.50	15.68
Annual rainfall (mm)	12.20	1033.00	1014.00	126.72	776.00	1280.00
Annual coffee production (Tons)	13.26	1991.50	1794.00	833.67	1000.00	4200.00

4.3.1 Analysis of trends for climatic variables and coffee production

A general trends analysis of climatic variables and level of coffee production revealed an increasing trend in both annual maximum and minimum temperature for the considered period of thirty years as shown in **figures 3 and 4**. On the other hand, annual coffee production revealed a slight decrease in trend while annual rainfall amounts remained unchanged for the period considered in the analysis as shown in **figures 5 and 6**.

Univariate analysis for the difference between climatic variables and coffee production between the period of (1987-2001) and (2002-2016), reveal that there has been a statistically significant change in annual maximum temperature during the period (P = 0.039), but other variable had no significant differences observed (P > 0.05) (Table 5).

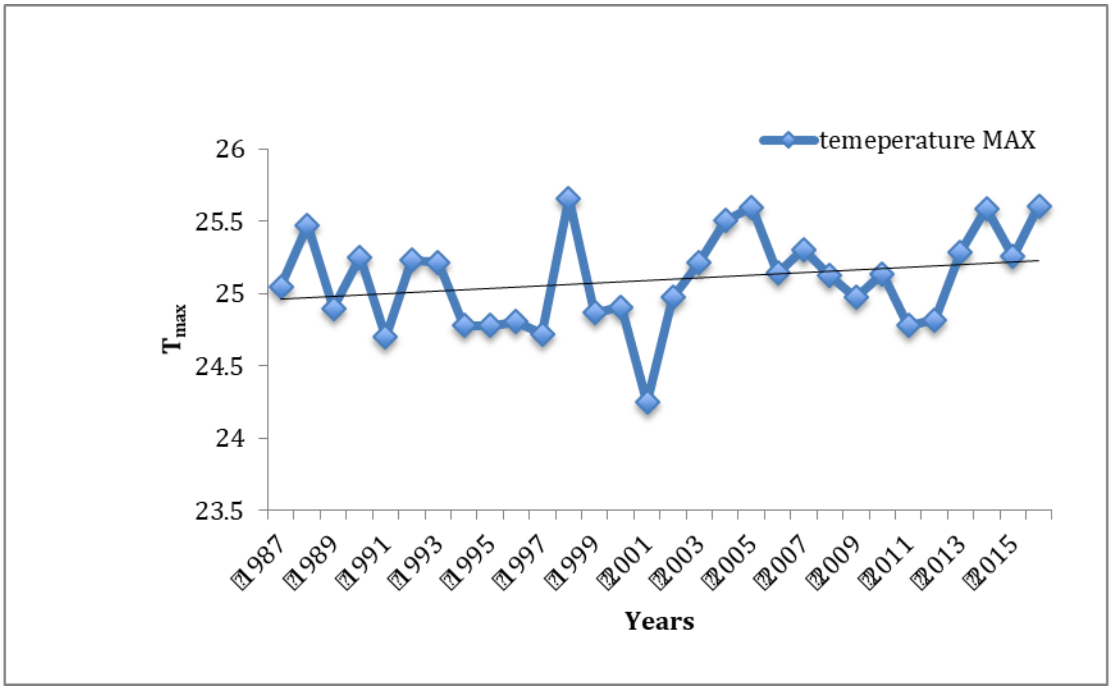

Figure 3: Annual maximum Temperature (^{O}C) for Huye district from 1987 to 2016

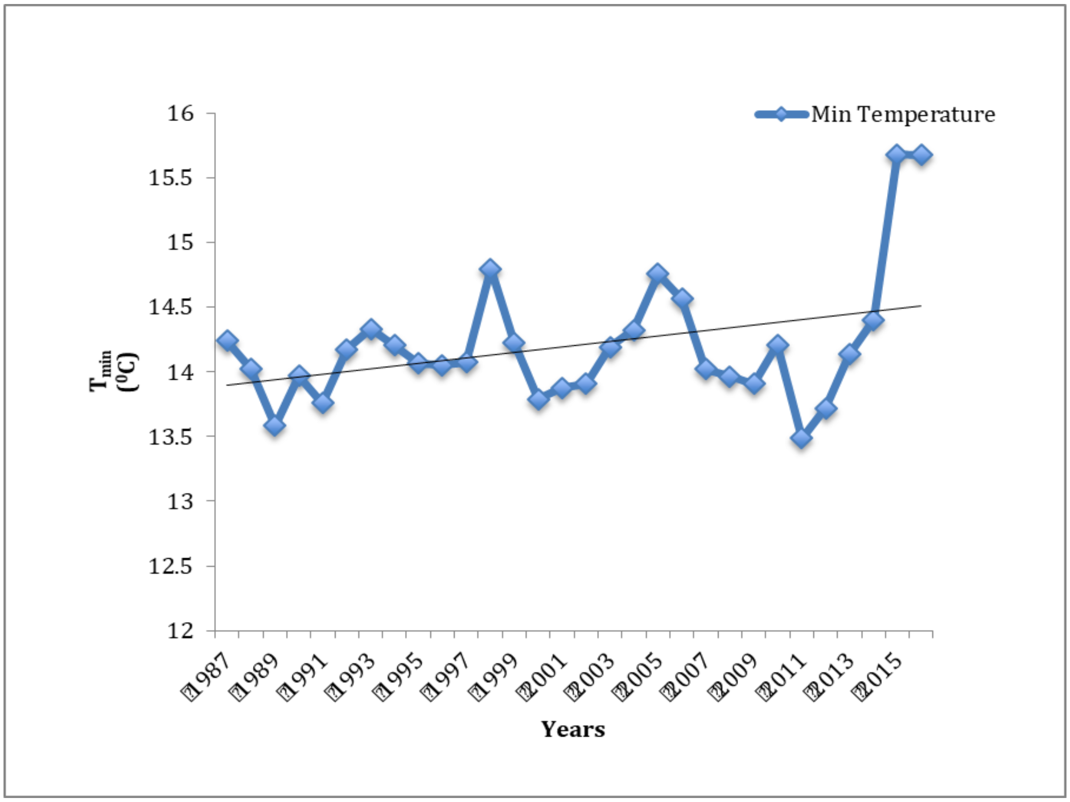

Figure 4: Annual minimum temperature (^{O}C) for Huye district from 1987-2016

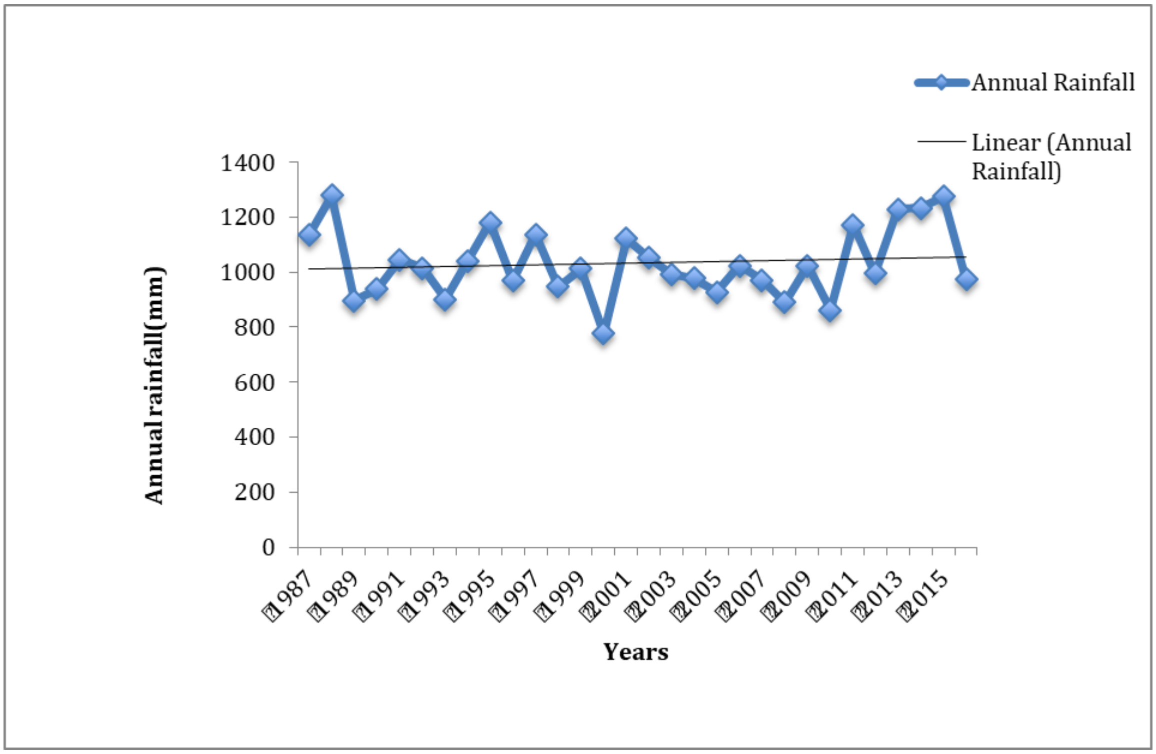

Figure 5: Huye Annual Rainfall (mm) from 1987 to 2016

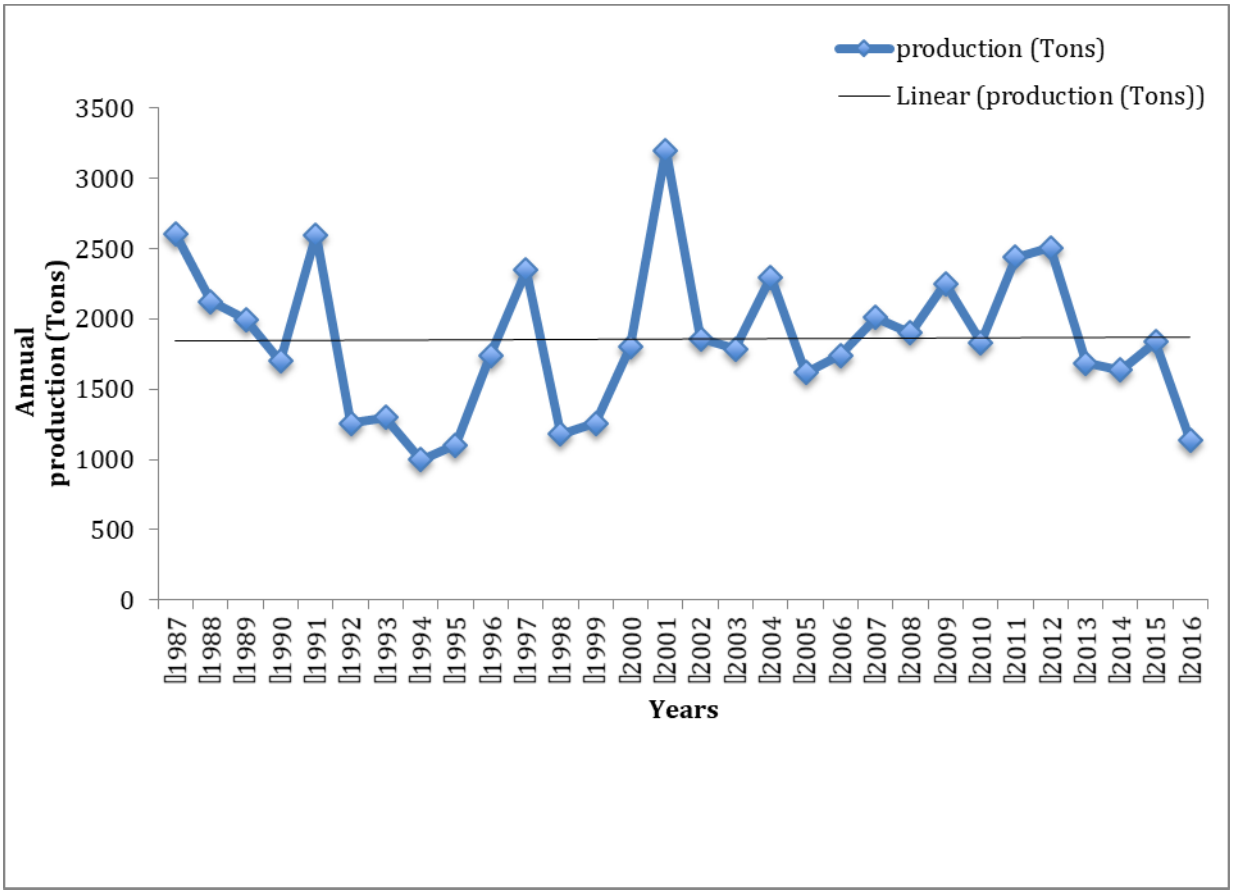

Figure 6: Huye annual coffee production (tons) from 1987 to 2016.

Table 5: Univariate analysis for mean differences between climatic variables and level of Coffee Production between the period of (1987-2001) and (2002-2016).

Variable	**Groups**	**Sample size**	**Mean**	**SD**	**P < value**
Annual coffee production	Group A (1987-2001)	15	1814.53	657.08	0.65
	Group B (2002-2016)	15	1903.73	355.55	
Annual T_{min}	Group A (1987-2001)	15	14.08	0.28	0.17
	Group B (2002-2016)	15	14.33	0.63	
Annual T_{max}	Group A (1987-2001)	15	24.97	0.35	0.04
	Group B (2002-2016)	15	25.22	0.27	
Annual rainfall	Group A (1987-2001)	15	1026.20	129.20	0.77
	Group B (2002-2016)	15	1039.80	128.33	

4.3.2 Association between climatic variables and coffee production

Regression analysis results of the relationship between climatic variables and level of coffee production showed that the amount of variation in levels of coffee production explained by the independent variables of amount of rainfall and both minimum and maximum temperatures which were included in the analysis was only 22.3% (Table 3). Furthermore, results of the regression showed a positive coefficient for annual rainfall of 0.94, which imply that if annual rainfall increased by 1mm, there would be a corresponding annual increase in the level of annual coffee production by of 0.94 unit tons. On the other hand, both annual maximum and minimum temperatures presented negative coefficients of –397.99 and –336.84 respectively, which indicated that if annual maximum temperature increased by 1^0C, then annual coffee production would decrease of 397.99 tons, while in case annual minimum temperature increases of 1^0C, annual coffee production would decrease of 336.84 tons.

Table 6&7: Relationship between climatic variables and coffee production between 1987 and 2016

Table6

R	0.55
R-Squared	0.30
Adjusted R-Squared	0.22
Predicted R-Squared	0.06
N	30

The regression equation:
Production (Tons) = 15,656.3364 - 397.99837 * Maximum Temperature - 336.8472 * Minimum Temperature + 0.94407 * RAINFALL

Table7

	Coefficient	*Standard Error*	*LCL*	*UCL*	*t Stat*	*P-value*	*H0 (5%)*
Intercept	15,656.34	6,777.81	1,724.36	29,588.31	2.31	0.03	
Maximum Temperature	-398.00	320.45	-1,056.69	260.69	-1.24	0.23	*Accepted*
Minimum Temperature	-336.85	215.17	-779.15	105.45	-1.57	0.13	*Accepted*
Rainfall	0.94	0.69	-0.47	2.35	1.376	0.18	*Accepted*
T (5%)	2.056						

LCL - Lower limit of the 95% confidence interval
UCL - Upper limit of the 95% confidence interval

4.2 Discussion and Synthesis

The result obtained from the trend analysis of whether variables and coffee production showed that both annual maximum and minimum temperature were increasing, while the level of coffee production was decreasing. Furthermore, results of univariate analysis revealed that there was a significant change in the mean annual maximum temperature between the two periods.

Results for temperature trend analysis were in line with what other reports have previously recorded (Wolff *et al*. 2014; Michaels 2009), which stated that from the year 1900, global average temperature has risen by approximately 0.8^0C, and provided other observations including glacier melting and species extinction, that would jointly provide unquestionable proof of global warming. This temperature change has been argued to be causing degradation of the agricultural sector including reduction of level of crop production and shifts in suitable land for crop farming (Cline2008; Aydinalp & Cresser 2008).

Previous reports have suggested that there is a decline in coffee production (tons), which is captured in International Coffee Organization report findings (Camargo 2010), which revealed that coffee production in Africa has declined. The findings from this research however, reveal that coffee production in Rwanda has not significantly declined. But from the discussions with the farmers groups, it was reported that coffee production at the farm level had actually declined. These farmers associated the decline in coffee production with climatic harsh condition and other non-climatic factors. Nevertheless, regression analysis showed that though both annual maximum and minimum temperature increased, they have not affected coffee production. But according to (DaMatta *et al*. 2007 ; Alègre 1959), it has been reported that the ideal optimum temperature for Arabica coffee production ranges between 18^0C and 21^0C, while at a temperature of 23^0C, the growth and ripening of the coffee berry are often accelerated, which would often result in a decrease in quality of the produced coffee (Camargo 1985). Therefore, the increasing maximum temperatures in Huye district might have caused loss in coffee quality instead of quantity.

Additionally, this decline could be associated with other factors like insufficient agriculture inputs and incompetent extension services which in one way or another are indirectly, connected to social aspect of climate change impacts.

Furthermore, while results of the regression analysis revealed that temperature had not affected coffee production, it is predicted that an increase in temperature would cut down coffee production while rain was presented as an increase factor. There are numerous researches that have linked rise in temperatures and other challenges to impact on the level of coffee production. Some of those challenges included coffee diseases and pests (Ebisa 2017, Center, 2010). Research by FAO (2008) has shown that coffee berry borer thrives under warmer temperatures. In addition, warm temperatures have been shown to be suitable for multiplication of coffee pests like *antestiopsis* and white *stemborer*, and they would establish new territories when the temperatures continue to rise (Suryavanshi *et al.* 2012).

Therefore adaptation measures are encouraged as temperatures are expected to increases in the near future. For without sufficient adaptation practices and sustainable agriculture extension, coffee production would significantly decline (Craparo *et al*. 2015).On the other hand the average annual rainfall ideal for Arabica coffee production ranges between 800mm-1500mm (Yamane *et al* 2014), which is supported by the findings that annual rainfall did not significantly influence the level of coffee production in Huye district since the amount of rainfall was within the optimum range.

Further analysis of coffee farmers' views during focus group discussion revealed that most of the identified challenges like diseases and pests are in some ways linked to dry spell. Huye's coffee farmers view on climate change challenges agree with what other coffee farmers around the World argued. According to the study that has been done by (Jassogne *et al* 2013 ;Asayehegn *et al* 2017; Eakin *et al* 2014), farmers claimed that seasons had changed indeed, and they were now characterized by long drought period which often lead to low levels of production, which agrees with what this study in Huye district found.

Though different studies around the World show that coffee sector is on the risk of being negatively impacted by climate change, the severity of impacts varies depending on the vulnerability of that particular region which is determined by the exposure, sensitivity and adaptive capacity of that region (Baca *et al* 2014), which implies that some regions are more affected by climate change impacts because they are located at a certain location, and this also influences how they adapt and what kind of practices they engage in in order to adapt to the impacts of climate change.

In Huye District, a number of adaptation practices that other coffee farmers have also declared in different studies that have been done around the World. For example the adaptation practices used to mitigate challenges associated with the dry spell, which has been stated to be the most challenging climate related problem in Huye district, farmers aforementioned that they often used shade trees and mulching to mitigate its negative impact on their coffee bushes. The same practice was previously reported in studies done by (Garedew *et al* 2017; Menike & Arachchi 2016), where farmers described it to be with benefits of keeping soil moisture and providing mulch which in turn serve as organic matter in the soil and, thus increasing soil fertility. Furthermore shade trees also are known to reduce hail drop that reach coffee trees as well as uphold soil against erosion. Tough shade trees in coffee plantation also provide numerous benefits, however farmers should be careful on which type of trees they put in their farm and how they are planted, because at times, these shade trees compete with coffee for nutrient and water, which in turn might reduce coffee production(Perfect Daily Grind), and this is why in some places intercropping is discouraged.

In economically advanced countries like Brazil, they use irrigation to cope with water deficiency in their farms and it helps them to sustain their production (Global Coffee Farming). However, many coffee farmers in other countries are not yet conforming with the use of irrigation due to financial constrain, they use trenches that keep water in rain season which also prevent erosion in the farm. Another measure to address drought that has been thought by scientist is the introduction of heat and drought resistant coffee breeds, some drought resistant coffee are under trial in farm but they are still under development, therefore these breeds are not distributed across many countries around the World (Mofatto *et al* 2016;Cheserek & Gichimu 2012).

Concerning other challenges like diseases and pest, farmers around the World uses pesticide. However this also had concern in the ecological food web (Krishnan *et al* 2017), but always a cost and benefits analysis would be applied in order to assess whether there is a need of using these pesticides as mitigating technologies. The same applies on the use of chemical fertilizers used to enhance soil fertility as scientist argue that they contribute to environmental pollution and soil degradation in long term which is why the manure is preferred over chemical fertilizer (Savci 2012).

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Findings from This study showed that there is evidence that minimum and maximum temperatures in Huye have increased while annual rainfall showed to be steady over the period of thirty years (1987-2016), but they have not affected coffee production. However, the amounts of rainfall have remained constant. Additionally, the regression result showed that climate variables explains 23% which implies that the other percentage could be attributed by other factors as social economic, environmental and physiological one.

Farmers declared that they were aware of the season change as well as the decrease in their coffee production. The main challenges facing coffee farmers in Huye are drought and occurrence of hails and storm, but other challenges including pests, diseases, soil infertility and land slides also present challenges to coffee farmers. These farmers employed a number of adaptation practices including tree planting, mulching, pruning, trench digging, water canalization, application of fertilizers and quick lime.

Practices employed by farmers to cope and adapt to consequences brought by climate change and variability were mostly based on practices to cope with dry spell. Nonetheless they claimed that they meet challenges linked to financial means and education while coping and adapting to the consequences of climate change and variability. Furthermore farmers stated that they encounter challenges linked to the fact that government is the one buying fertilizers and pesticide then it charges the money used on coffee price. This is a challenge to farmers as sometimes come late due to a lot of bureaucracy in between and find diseases or pest have already have attacked their crop, an ideal weather for fertilization application has passed.

5.2 Recommendations

Results showed a significant change in the annual maximum temperature; and this was also supported by farmers' assertion that dry spells in addition to storm were the main challenges affecting coffee farming. However, the level of coffee production was not affected by these climatic variables alone since they only contributed to about 23% of the total variation in level of coffee production. Additionally, Most of the coping and adaptation practices that farmers are using are short term or sometimes inappropriate. Thus this study proposes.

5.2.1: Recommendations for Future Study

I. Future studies that should investigate these other potential causes of variation on level of coffee production, which may include occurrence of diseases and pests; changes inland tenure and sizes of farms; issues around coffee breeding.

5.2.2 Recommendation for Policy Makers

I. There should be a transidisciplinary committee to plan and assist the implementation of long term suitable coping adaptation practices to the impact of climate change and variability on coffee sector.

II. Furthermore, there is a necessity to incorporate broadening of agricultural production, enhancing agriculture inputs and supporting farmers to use their indigenous knowledge in joint with modern agriculture technology to strengthen local adaptation to climate change.

III. Government as well as other stakeholders working around agriculture sector, should work together to provide trainings and other agriculture extension services that would provide farmers with adequate knowledge on good practices and maintenance of coffee farms as well the environment in general.

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APPENDICES

Appendix 1: Annual Coffee production, maximum temperature; Minimum temperature and Rainfall in Huye district from 1987 to 2016

Year	Annual T_{max} (^{0}c)	Annual T_{min} (0C)	Annual Rainfall (mm)	Production (Tons)
1987	25.049	14.239	1134	2607
1988	25.472	14.024	1280	2125
1989	24.898	13.582	896	1995
1990	25.253	13.970	939	1700
1991	24.697	13.761	1045	2600
1992	25.231	14.173	1016	1260
1993	25.217	14.332	902	1300
1994	24.777	14.204	1038	1000
1995	24.779	14.063	1180	1102
1996	24.803	14.054	969	1740
1997	24.718	14.073	1137	2346
1998	25.660	14.796	948	1183
1999	24.867	14.222	1012	1260
2000	24.904	13.790	776	1800
2001	24.247	13.878	1121	3200
2002	24.971	13.910	1052	1860
2003	25.217	14.191	993	1789
2004	25.502	14.324	978	2300
2005	25.598	14.756	927	1620
2006	25.141	14.565	1023	1740
2007	25.305	14.020	972	2012
2008	25.123	13.966	890	1900
2009	24.973	13.906	1023	2253
2010	25.135	14.211	862	1835
2011	24.778	13.490	1172	2437
2012	24.817	13.719	995	2506
2013	25.285	14.135	1228	1689
2014	25.588	14.403	1233	1637
2015	25.257	15.679	1276	1838
2016	25.605	15.675	973	1140

Appedix 2:Pairwise ranking for climate change related challenges per cooperative.

Rusatira Cooperative

	Unpredictable Dry season	Unpredictable rain season	Pests		Diseases Land slides	Soil Infertility	Erosion	Lights and Thunder	Emerging crop fungus	Total Score
Unpredictable Dry season		1	1	1	1	1	1	1	1	8
Unpredictable rain season	0		1	0	1	1	1	0	1	5
Pests	0	0		0	1	0	0	1	1	3
Diseases	0	1	1		1	1	1	1	1	7
Land slides	0	0	0	0		0	0	1	1	2
Soil infertility	0	0	1	0	1		0	0	1	3
Erosion	0	0	1	0	1	1		1	1	5
Lights and thunder	0	1	0	0	0	1	0		1	3
Emerging crop fungus	0	0	0	0	0	0	0	0		0

Simbi Cooperative

	Unpredictable Dry season	Unpredictable rain season	Pests	Diseases	Land slides	Soil Infertility	Erosion	Lights and Thunder	Emerging crop fungus	Total Score
Unpredictable Dry season		1	1	1	1	1	1	1	1	8
Unpredictable rain season	0		0	0	1	1	1	0	1	4
Pests	0	1		0	1	1	1	1	1	6
Diseases	0	1	1		1	1	1	1	1	7
Land slides	0	0	0	0		1	1	1	1	4
Soil infertility	0	0	0	0	0		0	0	0	0
Erosion	0	0	0	0	0	1		0	1	2
Lights and thunder	0	1	0	0	0	1	1		1	4
Emerging crop fungus	0	0	0	0	0	1	0	0		1

Maraba Cooperative

	Unpredictable Dry season	Unpredictable rain season	Pests	Diseases	Land slides	Soil Infertility	Erosion	Lights and Thunder	Emerging crop fungus	Total Score
Unpredictable Dry season		1	1	1	1	1	1	1	1	8
Unpredictable rain season	0		1	1	1	0	1	1	1	6
Pests	0	0		0	1	0	0	1	1	3
Diseases	0	0	1		1	0	0	1	1	4
Land slides	0	0	0	0		0	0	0	1	1
Soil infertility	0	1	1	1	1		0	1	1	6
Erosion	0	0	1	1	1	1		1	1	6
Lights and thunder	0	0	0	0	1	0	0		1	2
Emerging crop fungus	0	0	0	0	0	0	0	0		0

Gishamvu cooperative

	Unpredictable Dry season	Unpredictable rain season	Pests	Diseases	Land slides	Soil Infertility	Erosion	Lights and Thunder	Emerging crop fungus	Total Score
Unpredictable Dry season		0	1	0	1	1	1	1	1	6
Unpredictable rain season	1		1	1	1	1	1	1	1	8
Pests	0	0		1	1	1	1	1	1	6
Diseases	1	0	0		1	1	1	1	1	6
Land slides	0	0	0	0		0	0	0	1	1
Soil infertility	0	0	0	0	1		0	1	1	3
Erosion	0	0	0	0	1	1		0	1	3
Lights and thunder	0	0	0	0	1	0	1		1	3
Emerging crop fungus	0	0	0	0	0	0	0	0		0

Huye Cooperative

	Unpredictable Dry season	Unpredictable rain season	Pests	Diseases	Land slides	Soil Infertility	Erosion	Lights and Thunder	Emerging crop fungus	Total Score
Unpredictable Dry season		0	1	1	1	1	1	1	1	7
Unpredictable rain season	1		1	1	1	1	1	1	1	8
Pests	0	0		1	1	1	1	0	1	5
Diseases	0	0	0		1	1	1	1	1	5
Land slides	0	0	0	0		0	0	0	0	0
Soil infertility	0	0	0	0	1		1	1	1	4
Erosion	0	0	0	0	1	0		0	1	2
Lights and thunder	0	0	1	0	1	0	1		1	4
Emerging crop fungus	0	0	0	0	1	0	0	0		1

Kigoma Cooperative

	Unpredictable Dry season	Unpredictable rain season	Pests	Diseases	Land slides	Soil Infertility	Erosion	Lights and Thunder	Emerging crop fungus	Total Score
Unpredictable Dry season		1	1	1	1	1	1	1	1	8
Unpredictable rain season	0		1	1	1	1	1	1	1	7
Pests	0	0		0	0	0	0	0	1	1
Diseases	0	0	1		1	1	0	0	1	4
Land slides	0	0	1	0		0	0	0	0	1
Soil infertility	0	0	1	0	1		0	0	1	3
Erosion	0	0	1	1	1	1		1	1	6
Lights and thunder	0	0	1	1	1	1	0		1	5
Emerging crop fungus	0	0	0	0	1	0	0	0		1