MAKERERE UNIVERSITY

THE IMPACT OF TEMPERATURE VARIABILITY ON COFFEE PRODUCTIVITY IN MUBENDE DISTRICT

BY

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A DISSERTATION SUBMITTED TO THE DEPARTMENT OF GEOGRAPHY, GEOINFORMATICS AND CLIMATIC SCIENCES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE IN METEOROLOGY

MARCH 2022

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DECLARATION

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

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Signed..............................

Date.....15/03/2022..............

APPROVAL

The research project has been submitted for examination with my approval as supervisor.

Signature……………………………………Date……15/03/2022……………

DR. SAUL DANIEL DDUMBA

ACKNOWLEDGEMENTS

The completion of this work was made possible through the guidance and cooperation of many people. First gratitude goes towards my supervisor Dr. Saul Daniel Ddumba for his guidance and support throughout my study.

I also want to thank my family members for the support and resources they provided me with so that I could carry out my research successfully and effectively.

My special thanks go to Mubende Coffee Cooperative for providing data for the study. I am also highly indebted to others for their assistance and support. I appreciate the sacrifice made by the farmers in the cooperative Union and those who cultivate at Kaweri coffee plantation in Mubende for their answers to my questions.

Lastly, I want to thank Mr. Godfrey Ntabazi for helping me fix my laptop when it had crushed and special thanks go to my colleague Anena Lisa Marion who guided on how to use the programming language R for making plots. This thesis has successfully been completed because of each everyone who supported and encouraged me.

DEFINITION TERMS

Climate change: Refers to long-term shifts in temperatures and weather patterns.

Climate Variability: Refers to the climatic parameter of a region varying from its long-term mean.

Agricultural Productivity: Agricultural productivity is measured as the ratio of agricultural outputs to inputs.

LIST OF SYMBOLS AND ACRONYMS

CSIP: Climate smart investment pathways

BCTB: Black coffee twig borer

CBB: Coffee berry borer

CWD: Coffee wilt disease

ANOVA: ANalysis Of VAriation

GDP: Gross Domestic Product

GCM: Global climate models

CV: Coefficient of Variation

UCDA: Uganda Coffee Development Authority

CSA: Climate smart agriculture

GHGS: Greenhouse gases

μ: theoretical value

ABSTRACT

With liberalization of coffee production, the number of private farmers in Uganda has increased and so did the competition for coffee production among the coffee farmers (Hons, 2009). Annual temperatures have risen across the country, potential evapotranspiration increased, and the distribution of precipitation has become more variable.

In this study both Temperature and rainfall data was used, data analysis methods included the use of the students t test, regression analysis which was done to reveal the general movement of the temperature pattern, examining evidence of any changes in the trend of temperature amounts. Such patterns were investigated by use of both graphical and statistical methods. Graphical methods were used as a tool for visualization of temporal variation of annual temperature amounts over the study period – 2001 to 2020. A programming language R was used for both graphical and statistical analysis.

The results from student t test showed that data: t = 229.16, df = 19, p-value < 2.2e-16 hence the alternative hypothesis: true mean is not equal to 0,95 percent confidence interval:79.8143 81.2857, sample estimates: mean of x (max temp) =80.55. and regression analysis results showed, $Y = 4144.2 - 162.7x$. for the relationship between temperature and coffee productivity and $Y = 463.113 + 2.574x$ for relationship between rainfall and coffee productivity.

On the response of coffee yield to changes in temperature variability, the study found that changes in temperature and temperature variability have the significant effects on coffee yield. Therefore, this study has indicated that there was and there is no strong evidence for attributing the increase in coffee productivity to climate change and variability meaning that the increase could be attributed to other factors such as application of fertilizers, planting of shade trees among others.

CHAPTER ONE: INTRODUCTION

1.0 BACKGROUND TO THE STUDY

Agriculture is the backbone of Uganda's economy. It is the major source of employment, food and export earnings to the country and considerably contributes to the GDP. (Shinyekwa et al., n.d.) Since agricultural production in Uganda depends exclusively on the quality of rainy season and specific temperature ranges, it makes the country particularly vulnerable to climate variability and change. A change in temperature and rainfall has been considered to affect agriculture production in many parts of the country. In Uganda, the coffee industry plays an important role in the country's economic development. For many years' coffee production has heavily contributed to both domestic and foreign earnings in the country, coffee also serves as a primary source of labor especially for rural smallholder farmers (Verter et al., 2015) and is therefore Uganda's top export product and thus main source of foreign exchange income.

Since 1930, Uganda has been in coffee farming, although, serious coffee business picked in the 1960s, it is grown in the various highland areas of the country. Important to note, is that western, central and highlands in Eastern Uganda regions are the most participating districts. The paper therefore examines the economic the economic effects of trade liberalization of coffee subsector in Uganda.(Dastan & Natasa, 2015)

The climate variability of Uganda is one of the most significant factors influencing year to year crop production. Even in recent years, more and more attention has been paid to the risks associated with climate change and an increase in uncertainty with respect to food production. In Uganda, lakes and wetlands are closely linked to rainfall which could be one of the limiting factors for crop production and food security.

Climate change and variability are linked in the climatic system, with long term scale. Climate change manifesting itself and seasons being observed in short term climate variability. Instances of climate variability consist of seasonal, annual and inter decadal variation in temperature and rainfall, extensive droughts, floods and conditions that result from periodic El Nino and La Nina events. (Kariuki, 2016)

There is also likelihood that changes in temperature and rainfall patterns will affect the potential of crop production. The effects of climate variability on crop production could be direct or indirect. Directly the effect is through changes in temperature and precipitation that affect the timing of crop development. Increase in temperatures is likely to reduce crop production in the long-term period especially through reduction in the number of reliable crops growing days while changes in precipitation patterns are likely to increase to a short-term period and long term production declines. (Kariuki, 2016)

Climate variability may increase the population and growth of pests, insects, weeds and diseases making crop management difficult and costly. These conditions are likely to impact on crop production in a negative way. The changing patterns of temperature, precipitation and extreme events of storms and droughts lead not only to a decline in land productivity but also to an increase of plant disease incidences in the study area.

Climate change is the main challenge facing the current generation worldwide in this century. Uganda in particular is one of the most vulnerable countries to climate change for example global warming which is the observed temperature increase due to the increase of greenhouse gas concentrations in the atmosphere. Greenhouse gases contribute to the greenhouse effect on the earth's surface. The largest contributing source of greenhouse gas is the burning of fossils fuels leading to the emission of carbon dioxide.

The key environmental factors that influence coffee productivity are temperature, water availability, sunshine intensity, wind, type of soil and topography of land. The optimal mean temperature for C. Arabica is considered to be 18°C during the night and 22°C during day time. Extremes should not be lower than 15°C during night and not exceed 25-30°Cat daytime. Reduced photosynthesis at temperatures above 25°C and a loss of flowers or fruit degeneration at temperatures above 30°C compromise productivity. Low temperatures favor diseases. Temperatures lower than minus 2°C for more than 6h are potentially lethal for the plant. C. canephora var. Robusta is generally more tolerant towards high temperatures but may die at 4-5°C. (Bunn, n.d.)

(Bunn et al., 2015)also added that Arabica requires about 1400 to 2000mm of annual rainfall, Robusta between 2000 and 2500m. Values lower than the minimum are potentially damaging for production. Excessive rainfalls are mostly a problem because of top soil erosion and a dry season of about three to four months is considered to promote productivity. Atmospheric humidity also has an influence on transpiration and is therefore linked with necessary rainfalls; ideal humidity is 60% for Arabica and 70% for Robusta.

Mubende's coffee plants are the Bourbon variety of the Robusta coffee species and are grown on fertile soils on low altitude land. The fruit is handpicked mostly during the rainy season between March and May.

1.1 Problem Statement

With liberalization of coffee production, the number of private farmers in Uganda has increased and so did the competition for coffee production among the coffee farmers (Hons, 2009).

Annual temperatures have risen across the country, potential evapotranspiration increased, and the distribution of precipitation has become more variable. (GCM)Global climate models project annual mean temperature to increase by 1.7^0C – 1.8^0C until mid-century. In line with the current trend, the increase was projected to be higher in the South-West, than in the East of Uganda. The projected increase in total annual precipitation are substantial and range from $^+$6.8% (South West) to $^+$11.5% (South-East) averaged over all projections.(*Climate-Smart Coffee in Uganda*, n.d.).

1.2 Objectives

The general objective of the study was to assess the impact of rainfall and temperature variability on coffee productivity in Mubende district.

1.3 The study was informed by the following specific objectives

i. To assess the trends in temperature and coffee productivity in Mubende district.
ii. To describe the trends of rainfall, temperature on coffee productivity in Mubende district.
iii. To analyze the relationship between coffee productivity and climate variables in Mubende district.

1.4 Research questions

1. How have prevalent changes in temperature affected coffee productivity?
2. How have fluctuations in temperature patterns affected coffee productivity in Mubende district during the period of (2001-2020).

1.5 Significance of study

The findings of this research study will be significant to both academicians and farmers in various ways. It will add more knowledge to researchers and farmers in this field of study and it will also help in predicting weather changes within the region for better planning by coffee farmers as well the coffee growers and coffee producers.

Hypotheses

The study followed the following hypotheses:

Fluctuations in temperature patterns have been experienced in Mubende for the period (2001-2020).

Fluctuations in temperature patterns have affected yields of coffee harvested in Mubende for the period (2001-2020).

CHAPTERTWO: LITERATURE REVIEW

2.1 Agricultural Productivity in Uganda

The economic structure of Uganda, just as other East African economies is dominated by the agricultural sector. Agriculture is the key determinant factor in the country’s efforts to reduce poverty and hunger as well as foreign earning. (Verter et al., 2015)Agriculture is the backbone of Uganda’s economy. It is the major source of employment, food and export earnings to the country and considerably contributes to the GDP. The agriculture sector employs 66 per cent of the working population and contributes about 40 per cent of the total goods export earnings and about 23.5 per cent of Gross Domestic Product. (Shinyekwa et al., n.d.) like most of the poorest countries in Africa, Uganda receives more of its income from agriculture than from any other sector.(Appleton, 1996)

Uganda's economy is heavily dependent on agriculture and over 70% of GDP comes front this sector. Coffee is the country's major foreign exchange earner it accounted for 98% of the total export earnings in I980. (Managemenr, 1996)

Uganda is led by the agricultural sector and the major employer and also earns foreign exchange. Nevertheless, other sectors have grown up rapidly. Among other sectors are services sector includes the public sector is fastest growing; it contributes substantially to the country’s GDP. Coffee has continued to play a primary role in the agriculture sector and economy of Uganda, contributing over 18% of the export earnings over decades. The coffee subsector has grown through its value chain and employs over 5 million people accounting for over 500,000 households. Over 95% of the total annual coffee produced per year is exported as green beans.(Dastan & Natasa, 2015)

(Shinyekwa et al., n.d.)However, the sector has experienced slower growth compared to the other sectors over the recent years. Among the factors affecting agriculture productivity is land scarcity that has resulted into land fragmentation, less adoption of better farming technologies such as high yielding seed varieties, fertilizers application and irrigation, pests and diseases and weather shocks. Uganda's agricultural output is heavily reliant in natural climatic conditions. Agriculture is rain fed, which makes it susceptible to weather shocks such as prolonged droughts that lead to crop losses and hence threatening food security. Farmers heavily depend on poor and rudimentary production technologies and still practice extensive farming systems. The sector is faced with poor market access by most farmers especially those in remote areas due to inadequate infrastructure and information asymmetry.

Among the factors affecting agriculture productivity is land scarcity that has resulted into land fragmentation, less adoption of better of better farming technologies such as high yielding seed varieties, fertilizers application and irrigation, pests and diseases, and weather shocks. Others include over-exploitation of fish stocks; uncertain land rights leading to under-investment in agricultural land; and the struggle to comply with increasingly demanding international quality standards for traded food and agricultural products. (Report, 2012)

2.2 Coffee productivity

Coffee is the oldest, most significant commercial agricultural commodity and major foreign exchange earner, contributing an annual average of 15%11 to Uganda's total export revenue in the last ten years. Uganda is the fourth largest Robusta producer in the world, after Vietnam, Brazil and Indonesia. Some Arabica is also grown in different highland areas of the country, most notably on the slopes of Mount Elgon on the border with Kenya and on the slopes of the Mount Rwenzori, popularly known as the 'Mountains of the Moon', on the border with the Democratic Republic of the Congo. Some Arabica coffee is also grown in the West Nile region in the northwestern part of the country. Uganda is the origin of Robusta coffee, which was cultivated along the Lake Victoria crescent. While the milder Arabica varieties originated in Ethiopia; the Robusta species are indigenous to the Nganda regions of Uganda. Wild varieties are still found in the foothills of the Rwenzori Mountains in western Uganda, where they are harvested as a specialty ECO coffee and marketed as the "Kibaale wild". Robusta makes up 80% (by weight) of the coffee exported by Uganda.(Profile, n.d.)

Robusta is dominantly cultivated at lower elevations (>1400m) such as in Central and Northern Uganda and Arabica is dominant at higher elevations (>1400) such as Eastern, Southwest, and Northwest Uganda (Wang et al., 2015). The Robusta coffee is the most heat tolerant and therefore considered more resistant to climate change than other types of coffee, however, the optimum production range of Robusta has never been quantified, with current estimates of its optimal mean annual temperature range (22-30^{0}C) based solely on the climatic conditions of its native range in the Congo basin.

Robusta coffee is the primary source of income for millions of smallholder farmers throughout the world's tropics. The price smallholder farmers can get for their coffee is strongly influenced by bean characteristics (i.e. beans are of a sufficient size and have minimal defects). Climate is a key determinant of successful coffee production.(Kath et al., 2021)

Coffee is produced by an estimated 1.7 million coffee farmers from 108 districts. The altitude ranges from 800 to 1,400 meters above sea level for Robusta and 2,300 to 6,000 meters above sea level for Arabica. The high altitude, especially for Ugandan Robusta, makes it very unique and characterised by intrinsic quality characteristics/attributes. Sustainable and specialty.

Uganda is Africa's second largest coffee producer. Its 1.7million smallholder coffee households represent 10% of global coffee farms. The annual production of 3-4million bags coffee accounts for 18% of the country's annual exports. About 77% of annual production is Robusta coffee produced in Central Uganda. Arabica is produced on the borders with Rwanda and Kenya. Most production is on small plots (0.25ha) that are intercropped with banana and other food crops.(*Climate-Smart Coffee in Uganda*, n.d.)

Uganda is one of the world's major coffee producers. Coffee production has heavily contributed to both domestic and foreign earnings in the country. Moreover, coffee also serves as a primary source of labor, especially for the rural smallholder farmers. The commodity is grown in different highland areas of the country. For example, on the slopes of mount Elgon on the border with Kenya and the slopes of mount Rwenzori also known as the mountains of the moon on the border with Democratic Republic of Congo. Some Coffee is also cultivated in the central and the west Nile region in the north western part of the country. (Verter et al., 2015)

According to the international coffee council (2014), climate variability is the major factor responsible for considerable instability in global coffee production with large output in one year followed by a smaller output in the subsequent year. Climatic variables influencing coffee production include; air temperature, solar radiation and relative humidity.(Kariuki, 2016)

Coffee is the world's favorite beverage, with an estimated 400 billion cups consumed per year. Coffee provides livelihoods for at least 60 million people, across dozens of countries. Coffee is healthful and protective against many chronic diseases. For these and other reasons, promoting the long-term health, well-being and environmental sub stainability of the much beloved coffee sector should be a clear priority.(Sachs et al., 2019)

2.2.1 Trends of coffee productivity (global, continental, regional, Uganda scales and district level)

Coffee is one of the most important globally traded commodities and substantially contributes to the livelihoods of millions of smallholders worldwide. As a climate-sensitive perennial crop, coffee is likely to be highly susceptible to changes in climate. (Pham et al., 2019)

Current research also identified positive effects of climate change such as increases in coffee-producing niche, particularly in areas at higher altitudes; however, whether these gains might offset losses from other production areas requires further investigation. Other advantages include increases in pollination services and the beneficial effects of elevated carbon concentration, leading to potential yield improvements. Future priorities should focus on major coffee-growing regions projected to be adversely affected by climate change, with specific attention given to potential adaptation strategies tailored to particular farming conditions such as relocation of coffee plantations to more climatically suitable areas, irrigation and agroforestry. The majority of studies were based in the Americas and concentrated on Arabica coffee. A broader spread of research is therefore required, especially for the large growing regions in Asia and for Robusta coffee, to support sustainable production of the global coffee industry.(Pham et al., 2019)

Climate change will reduce the global area suitable for coffee by about 50 % across emission scenarios. Impacts are highest at low latitudes and low altitudes. Impacts at higher altitudes and higher latitudes are still negative but less pronounced. The world's dominant production regions in Brazil and Vietnam may experience substantial reductions in area available for coffee. Some regions in East Africa and Asia may become more suitable, but these are partially in forested areas, which could pose a challenge to mitigation efforts.(Bunn et al., 2015)

2.2.2 Coffee varieties

For Robusta, there are two varieties, Nganda and Erecta. High yielding Clonal Robusta Coffee, which yields almost four times as much as traditional varieties, is being planted to replace old and diseased trees.(Profile, n.d.)

Uganda cultivates two main types of Robusta coffee, distinctive enough to be called varieties, the erect form "erecta" (known as Coffea quillou) and the more spreading type locally known as "Nganda" (Coffea ugandae). The "erecta" types tend to have strong stems, pale large leaves with bigger berries. The "Nganda" types usually have weaker upright stems that tend to bend or break with heavy crop.(Pauline, 2013)

2.2.3 Coffee growth conditions (time to maturity, amount of moisture, basic and optimum temperatures for coffee growth.

1.Time to maturity

The development of the cherry, from unfertilized ovary to maturity at picking time, takes about 10 months for the Robusta type of Coffea canephora in Uganda. Flowering of the samples taken for analyses took place in the second to third week of February in both years of the study and picking of the ripe cherry took place at the beginning of December.(Trust & Phytologist, 2021)

2. Amount of moisture

All coffee grown in Uganda is rain fed. Usually, coffee trees are planted at variable spacing, often intercropped, naturally lightly shaded and rarely mulched. Fertilizer, herbicides or pesticides are rarely applied. Co-existence of coffee with other crop and shade species play a significant role in the ecosystem conservation, survival capacity of the species, food security and alternative source of income. Hoes, slashers, pangas, and bow saws are rudimentary tools commonly used to clear weeds and manage tree canopy.(Pauline, 2013)

Robusta coffee is more sensitive to moisture stress as compared to Arabica coffee.(Pauline, 2013)

3.Basic and optimum temperatures for coffee growth

Robusta coffee prefers warm temperature range of 24-30^{0}C but not below 15^{0}C.Temperatures of up to 30^{0}C are also needed for floral bud initiation. For adequate root development, the best soil temperature is 24-27^{0}C. It is also estimated that a 2^{0}C rise in temperature would affect coffee production in Uganda drastically, reducing the total coffee area by three quarters.

High temperatures may lead to an early maturation of the fruits due to the earlier break of dormancy of the buds High temperatures in the period from January to March could lead to a quality problem due to early and excessive ripening of fruits. (Venancio et al., 2020)

Uganda Robusta varieties grow best at annual mean temperatures of 22°C to 26°C.(Bunn, n.d.)

4. Optimum rainfall amounts for Robusta coffee growth

The pattern of rainy and dry periods is important for growth, budding and flowering.

Rainfall requirements depend on the retention properties of the soil, atmospheric humidity, cloud cover and cultivation practices. An optimum annual rainfall range of

Robusta coffee adapts to intensive rainfall exceeding 2000 mm at a relative humidity of 80-90% and for a short while in less humid sites during dry season (On, 1992)

At the same time Robusta coffee does not perform well in very high rainfall regimes. Generally, coffee growing areas receive rainfall of 1500-2500 mm per annum. After fertilization, a well distributed rainfall of 1200 mm to 2000 mm over a 9month period is ideal for Robusta coffee bean development.(Cannell, 1985),(Castro & Marraccini, 2006).

2.2.4 Challenges to Robusta coffee growth

Environmental challenges of coffee sector include drought, erratic rainfall, soil erosion and deforestation. Increased incidences of pests and diseases are caused by rising temperatures. It should also be noted frequent flooding and mudslides occur across the country.(Profile, n.d.)

i. Climate variability

Climate variability is considered to be one of the major challenges affecting agricultural production. It affects all crops, with Robusta coffee being one of the major crops affected in Uganda. Climate variability affects the eco physiology of Robusta coffee, favoring associated pest build-up and damage, flower and fruit abortion. The associated yield devastating pests at the moment are the Black Coffee Twig Borer (BCTB) (Xylosandrus compactus (Eickhoff)), the Coffee Berry Borer (CBB) (Hypothenemus hampei) and coffee mealy bug (Plano coccus kenyae).

Climate change and variability and drought are also likely to influence the entire coffee supply chain including harvesting and processing activities (Pham et al., 2019)

ii Pests and diseases

Two main pests and diseases affect Robusta production in Uganda: Coffee Wilt Disease (CWD, Fusarium xylarioides) and Black Coffee Twig Borer (BCTB, Xylosandrus compactus). The Coffee wilt disease was first detected in Uganda in 1993; by the end of 2000 it had spread to all Robusta zones of the country. Ugandan Robusta production reached a peak in 1996 and then fell steadily up to 2005, when it attained only 42% of peak production. It is very likely that most or all of the fall in Robusta was due to Coffee Wilt Disease.(*Climate-Smart Coffee in Uganda*, n.d.)

BCTB was currently considered the major pest. The pest was relatively new to Uganda but causing devastating yield losses with drying and complete death of the coffee twigs (primary branches). First observed in Kanungu, Rukungiri and Bushenyi in 2002, it had covered over 50% of all the districts in central Uganda by 2012 and 100% of all Robusta coffee growing districts in the central region by 2014; causing an estimated 8.6% yield loss. The emergency of this pest was attributed to climate variability (temperature and rainfall). The BCTB was a small black beetle that makes tinny holes on twigs (primary bearing branches) and tender stems (suckers). It was said to introduce an ambrosia fungus which it uses as feed for its brood/eggs. (Winfred et al., n.d.)

Black coffee twig borer was another threat to coffee production in Uganda as its incidence has been registered at 8.6% of coffee farms, causing a loss of 40% in affected areas. Financial losses were estimated at US$40.1 million in 2014. Following a concern expressed by the head of the Ugandan delegation regarding the outbreak of the black coffee twig borer, the International Coffee Council approved Resolution Number 453 at its 111th Session in September 2013, which calls on members of the international community, through relevant cooperation mechanisms, to offer assistance to the affected countries by, among other things, technical knowledge, exchange of information, best practices and management of the pest.(Profile, n.d.)

Other constraints include low farm gate prices paid to farmers by coffee buyers or middlemen in addition to low and fluctuating world coffee price, which results in very small returns to the farmers. In the absence of stabilization funds, many farmers have found coffee production increasingly less profitable. Moreover, there was no incentive to produce good quality coffee because there was no grading system to reward those who produce good coffee. Poor agronomic practices by farmers contribute to reduced productivity. For instance, stumping of coffee was one of the recommended practices for rejuvenation of coffee, but very few farmers practice it. The low adoption of recommended agronomic practices can be attributed to limited access to information/technologies due to inadequate extension services and to limited access to inputs. Inputs may also be available but are too expensive for most smallholders. The declining soil fertility was another concern because farmers do not use fertilizer or organic manure and was considered as the main cause of low productivity.(*Coffee Wilt Disease*, n.d.).

2.2.5 Climate smart coffee productivity

The first step consists of low-cost approaches, and costs increase in the steps that follow. Through building up slowly, the farmer can obtain an incremental increase in yields after each step, with the aim that this yield increase will motivate farmers to re-invest part of the income from the previous harvest in the next step of the CSIP (Climate smart investment pathways). The pathway shows how farmers can breakdown a recommended extension package for coffee farming to efficiently increase yield. The CSIP requires an understanding of the different needs of the various farmer's types. The farmer segmentation tool was a way to highlight this heterogeneity of farmers. Designing extension processes that cater to these differences will help improve adoption of CSA practices. Farmers are segmented based on structural (resource endowments) and functional (entrepreneurship) indicators. Farmer segmentation was likely to vary between project regions and should be carried out when designing appropriate CSIPs for project interventions.(*Climate-Smart Coffee in Uganda*, n.d.).

2.3 Climate of Uganda and how it favors coffee productivity

Understanding the consequences of climate change on agricultural production requires knowledge of the climate change situation or status in Uganda. Basically, (Shinyekwa et al., n.d.) climate change refers to the long-term alteration of weather patterns and was reflected through variations in the mean state of temperature, precipitation and wind. The change occurs over time and may be attributed to natural variability or human-induced activities such as deforestation, urbanization, agriculture and population explosion etc., which increase Green House Gases (GHGs) in the atmosphere.

2.3.1 Rainfall

Uganda is characterized by an equatorial climate and is relatively humid. The topography, prevailing winds, lakes and rivers cause local variations in annual precipitation and temperatures are responsible for the large differences and pattern of annual rainfall. Most of the country (especially the southern region) experiences two rainy seasons, which occur in early April and October. Little rainfalls in June and December. As one moves to the north eastern parts, the two seasons merge into one main rain season. Rainfall was the most sensitive climate variable given that it affects the social and economic activities. (Shinyekwa et al., n.d.)

The average long-term annual rainfall for Uganda registers at about 1,318 mm, and was considered adequate for agricultural activities. Mean annual rainfall was highest in areas near Lake Victoria (often exceeds 2,100 mm), moderate in the mountainous regions of the south-east and south-west (about 1,500 mm) and lowest in the north-east regions (about 500 mm). Recent years have witnessed erratic onset and cessation of rainfall seasons. The western, northern and northeastern districts are experiencing frequent longer droughts and become more vulnerable to climate change.

It has been observed that floods and droughts have become more frequently heavier and more violent than before in some parts of the country.

2.3.2 Temperatures

Temperatures were moderate throughout the year with the mean daily being 28°C. The lowest temperatures of below 0°C were experienced in the mountainous regions of the Rwenzori and Mt Elgon. Rwenzori has a permanent ice cap, which was vulnerable to global warming. The highest temperatures of about 30°C and over are in the north and north-eastern part of the country particularly Gulu, Lira and

Soroti districts (Statistics, 2009). Scientific evidence shows that Uganda is getting warmer especially in the two decades as demonstrated (Shinyekwa et al., n.d.).

2.4 Research gaps

As coffee plantations have, on average, a 30-year lifespan and can remain productive for more than 50 years(Bunn et al., 2015). they are likely to be subjected to the influence of climate change and variability. Smallholder coffee farmers might also be highly vulnerable to changes in climate as adaptation in perennial crops like coffee may take several or even many years to take effect (Läderach et al., 2017) As the risks of pest and disease outbreaks are likely to increase, Further, little research has specifically analyzed the impacts of drought on coffee production in contrast to the more extensive literature on the effects of climate variability and change.(Pham et al., 2019) Yet coffee was experiencing a sustainability crisis. This crisis stems from currently unsustainable economic, social, and environmental aspects of coffee production. Despite the hundreds of millions of dollars annually put towards coffee sustainability, and despite the fact that over 50 percent of all coffee has been grown (but not necessarily sold) under a sustainability standard in recent years, coffee production was still burdened by persistent poverty, child labor, and environmental damages and threats, such as deforestation and climate change. In many coffee-growing regions in low income countries, basic services remain out of reach for millions of coffee farmers and laborers and their respective families. (Sachs et al., 2019)

CHAPTER THREE: METHODOLOGY

3.1 Research design

Quantitative research was used in the study which comprised of collection of data, analysis and interpretation as well as comparison of data to establish relationships between variables. Annual temperature and rainfall amounts (2001-2020) were compared to the quantity of coffee in each crop year for the same number of years to establish the relationship between the climate variables and the quantity of coffee harvested.

3.2 Study area

The research was carried out in Mubende District which is bordered by Kyankwanzi District to the north, Kiboga District and Kassanda to the northeast and Mityana District to the east. Gomba District and Sembabule District lie to the south, Kyegegwa District to the southwest and Kibaale District to the northwest of Mubende District. Mubende, the district headquarters, is located approximately 172 kilometers (107 mi), by road, west of Kampala, the capital of Uganda, and the largest city in that country. The coordinates of Mubende District are:00 36N, 31 24E. the district covers an area of approximately 4,620 square kilometers (1,780 sq mi). It comprises three counties, namely Buwekula, Kassanda and Kasambya. The district has eighteen sub counties and one town council which include: Kassanda is no longer among its counties. It has been confirmed to be an independent district.

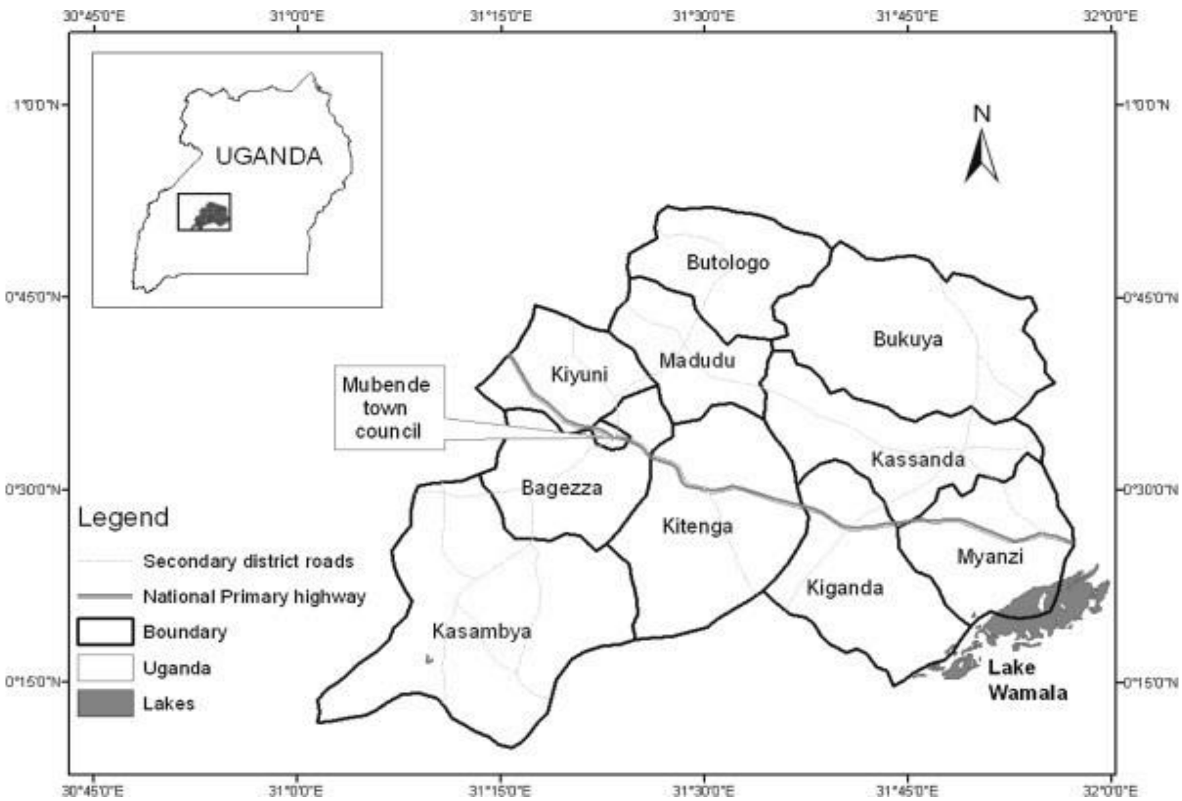

Figure 3.2: A Map of Mubende and its counties

Taken from(Max & Krombholz, n.d.)

3.3 Sample size determination

Both random and purposive sampling techniques were used in selecting the study sample. Out of the 17 sub counties found in Mubende district, 14 sub-counties were purposively selected because it is in these sub-counties that coffee production takes place. From the 14 sub-counties, 3 were randomly selected to include Kibinge, Kisekka and Kabonera. Five parishes were then randomly selected from each sub-county. With the help of area extension workers, a list of all coffee farmers was generated in each parish from which 5 farmers per parish were randomly selected to make a total of 25 farmers per sub-county and study sample of 25 coffee farmers.

3.4 Data collection methods

In collecting the primary data for this study, household survey and interview methods were used; documentary method was used for collecting secondary data. The study collected both quantitative and qualitative data. In gathering the evidence of climate variability on coffee productivity in Mubende, semi-structured questionnaires with both open-ended and close-ended questions were used to get information from the farmers. Also, individual interviews were carried out to get information from the farmers within the targeted households. Questions that capture the trends in coffee crop production and climate change and variability were used to identify changes over time and farmers perceptions on these changes. See appendix 1

3.5 Data analysis

Analysis of data was carried out in line with the objectives of the study. For the first objective, time series was used to obtain the trends for annual minimum, maximum and mean temperatures, annual rainfall and annual coffee yield to observe whether there are some fluctuations in the climate data and coffee productivity in Mubende over the period (2001-2020). To identify local temperature variability in Mubende, this study quantified trends and variability in total maximum and minimum temperature derived from monthly temperature observations. Data was first evaluated for discontinuities by inspection of each time series and then tested for homogeneity using the Student's t-test and found to be homogenous. The student's t-test formula was given by;

$$t = \frac{\mathbf{m} - \boldsymbol{\mu}}{\mathbf{s}/\sqrt{\mathbf{n}}}$$

Trend analysis was also done to reveal the general movement of the temperature pattern, examining evidence of any changes in the trend of temperature amounts. Such patterns were investigated by use of both graphical and statistical methods. Graphical methods were used as a tool for visualization of temporal variation of annual temperature amounts over the study period – 2001 to 2020. Regression analysis was done to determine the magnitude, direction and significance of the trends in maximum and minimum temperature both annually and seasonally for each sample sub county. The regression equation was defined as:

$$\boldsymbol{Yi = f(Xi, \beta) + ei}$$

Where Y_i = total annual temperature, and X_i = time measure in years. It was hypothesized that there was no trend in the amount of temperature over time. Thus, the null hypothesis was stated as; H0: $\beta = 0$. Variability of annual and seasonal temperature was assessed using Coefficient of Variation (CV), and Analysis of Variance (ANOVA) techniques. In addition, first moments of variation (minimum, maximum, mean, and standard deviation) were obtained using descriptive analysis. Standard temperature anomalies were plotted against time (in years) using a programming language R to visualize the time series variation of annual and seasonal temperature about the mean and to calculate the coefficient of variation (r) and the p-value (p) at the significance of 0.05 to determine the relationship between Temperature in ^{0}C, Rainfall in mm and coffee productivity in kg/ha.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents and discusses the major findings of the study. The first part gives the findings of climate variability on coffee production areas in Mubende, the second part presents the variability of temperature, the third part presents the variability of rainfall while the fourth part presents the trends in coffee productivity in Mubende district. The fifth and sixth part present the relationship between temperature and rainfall on coffee productivity respectively.

The case of Mubende, the results illustrate a significant ($r^2 = 0.75\ and\ 0.99$) (Agric, 2021) positive relationship between coffee productivity (kg/ha) and time in years over the study period of 20years (from 2001 to 2022). While a majority of existing literature specified substantial reductions in the suitability of coffee-growing areas globally, regionally and nationally, a few papers indicated that, under a changing climate, areas which are currently less optimal for coffee cultivation may become more productive. For example, several studies projected increases in coffee-suitable areas in South America, East and Central Africa and Asia.(Bunn et al., 2015)

4.2 Evidence of Climate Variability

Climate variability has indeed been experienced at Kaweri Coffee plantation. This has manifested itself through changes in maximum annual temperatures, minimum annual and mean annual temperatures and changes in annual rainfall for the period (2001-2020). This information was given by a respondent from the surveys and interviews that were carried out. Changes in temperature and rainfall have been experienced. Temperature in some years varied greatly from one year to another and rainfall varied from one year to the next as shown in the results and discussion that follow, thus creating unpredictability of weather conditions. Generally, rainfall and temperature changes are likely to reduce yields of desirable crops. Changes in rainfall patterns may increase the likelihood of crop failures in the short run and decline in production in the long run.(*IMPACT OF CLIMATE VARIABILITY ON COFFEE PRODUCTION AND*, 2013). Previous studies in the key Robusta growing areas of South East Asia have focused on Robusta coffee yields sensitivity to climate variability.(Kath et al., 2021)

4.3 Variability in Temperature

Changes in temperature were observed over the years in the period (2001-2020), with some years experiencing bigger changes in both maximum and minimum temperature than others and whose temperatures greatly vary from the mean temperature for those years. This has further been elaborated in the form of line graphs that show sharp increases and decreases in temperature. Figure 4.3 shows the annual temperature variations from 2001 to 2020. Temperatures will increase by the year 2050 between 1.5^0C (optimum scenario) and 4.5^0C (worst scenario) with the month of May being the hottest one with temperatures exceeding 28^0C.(Lemma & Megersa, 2021). high temperature are harmful for coffee production. (Venancio et al., 2020)

4.3.1 Changes in Maximum Temperatures (˚C)

Results indicated that the Kaweri coffee plantation experienced a decreasing maximum temperature trend with an average fall of about from 2001 to 2020. Generally, the temperature of the country was expected to increase as cited by many authors in the literature review. Contrary, for the case of Mubende, maximum temperature has slightly decreased in the period (2001-2020) with the greatest value 28.9^0C per year in 2003 and the least value of 26.1^0C in 2017. Increasing temperatures and precipitation shortages have negative impacts on flowering, fruiting and bean quality.(Pham et al., 2019), The results from student t test showed that data: t = 229.16, df = 19, p-value < 2.2e-16 hence the alternative hypothesis: true mean is not equal to 0,95 percent confidence interval:79.8143 81.2857, sample estimates: mean of x (max temp) =80.55

4.3.2 Changes in Minimum Temperatures (°C)

The results indicate that Kaweri coffee plantation experienced a slightly increasing and decreasing minimum temperature (from 2001 to 2020). This means that the mean temperature has been increased but the increase in that period was not significant because $p = 0.73$ which is greater than $p = 0.05$ hence the relationship is insignificant. The results from the students t test indicated that the data=222.98, df=19, p-value < 2.2e-16 hence the alternative hypothesis; true mean is not equal to 0,95 percent confidence interval;57.55463 58.64537, sample estimates; mean of x(min temp)=58.1.The figure 4.3.1 indicates changes in annual minimum temperature for the period (2001-2020).

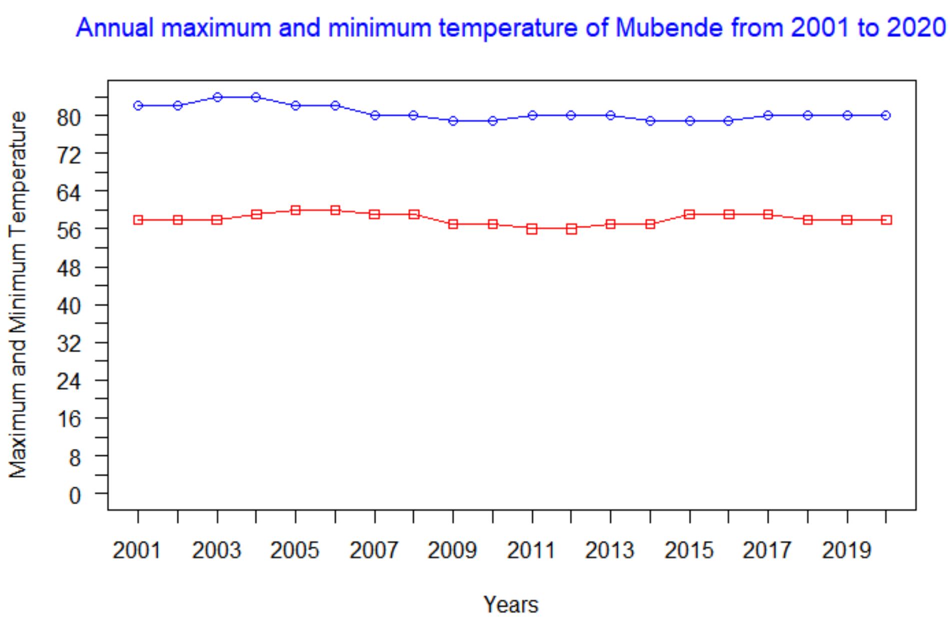

Figure 4.3.1: Annual maximum and minimum temperature for the period 2001-2020

4.3.3 Changes in Mean Monthly Temperatures (°C)

The results indicate that Kaweri coffee plantation experienced both an increase and decrease in mean monthly temperatures (from 2001 to2020). This means that the mean temperature has been decreased but at small rate (20.5 ^{0}C per year). The results from the students t test for the case of monthly mean temperature showed t = 86.658, df = 11, p-value < 2.2e-16 hence the alternative hypothesis: true mean is not equal to 0,95 percent confidence interval:20.66155 21.73845 sample estimates: mean of x =21.2

The figure 4.3 shows changes in annual mean temperature variations for the period (2001-2020). Unlike other studies considered in literature review, in this study, results show that the mean and maximum temperatures decrease with time even if the decrease was not significant. This can be attributed to the fact that the time considered was less than thirty years which was threshold time for climate study. It may also cause by that the small region considered in this study its topography and the cloud cover since the region was a plateau.

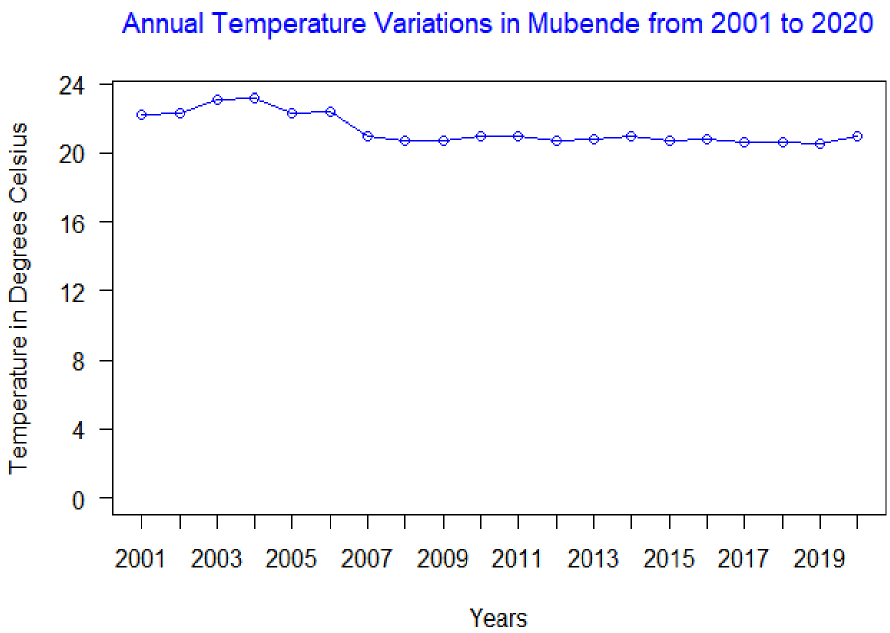

Figure 4.3: Annual Temperature variations in Mubende from 2001 to 2020

4.4 Variability in Rainfall

Changes in rainfall were also observed over the years in the (2001-2020), with some years experiencing bigger changes in both maximum and minimum temperature than others and whose temperatures greatly vary from the mean temperature for those years. Evidence is emerging that climate change is increasing rainfall variability and the frequency of extreme events such as drought, floods, and hurricanes.(Kansiime et al., 2013). it has been reported that rainfall variability affects the production of traditional crops, increases crop diseases incidents, and causes drastic reductions in soil fertility.(Kyei-mensah et al., 2019),This has further been elaborated in the form of bar graphs that show increases and decreases in rainfall.

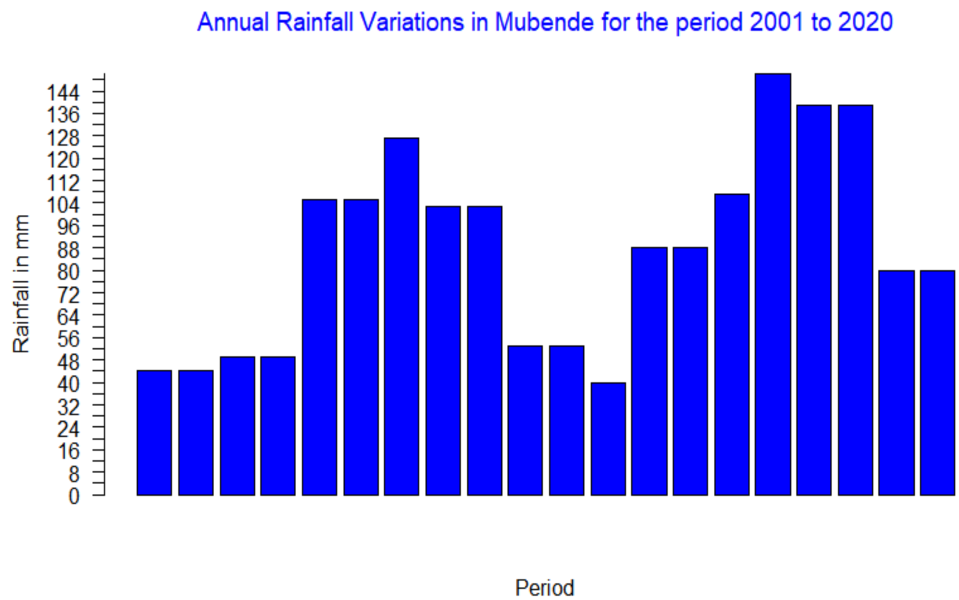

Figure 4.4: Annual Rainfall Variations in Mubende for the period 2001 to 2020.

4.5 Relationship between Temperature and coffee productivity

Statistically, analysis showed that there was a positive relationship $r = 0.04$ and $r = 0.23$ between amounts of coffee in kg/ha produced and temperature in degrees Celsius respectively from 2001 to 2020. The relationship between the amount of coffee in kg/ha produced and amount of temperature in degrees Celsius was statistically significant at $(p = 0.01)$ since it is less than $(p = 0.05)$ hence the relationship was significant. This indicates that coffee productivity was not much influenced by temperature, but there must be other factors such as shortage of agricultural inputs such as fertilizers and pesticides which influence coffee productivity in the study area.

The influence of temperature also varied between seasons. During flowering, high temperatures corresponded to a decreased likelihood of large beans or an increased likelihood of particular small bean size classes occurring. In contrast, high temperatures during the early and/or late growing season corresponded to an increased likelihood of large beans or similarly a decreased likelihood of small beans.(Kath et al., 2021).fig 4.5 a scatterplot of coffee productivity against Temperature in Degrees Celsius. Regression analysis results show that $Y = 4144.2 - 162.7x$.

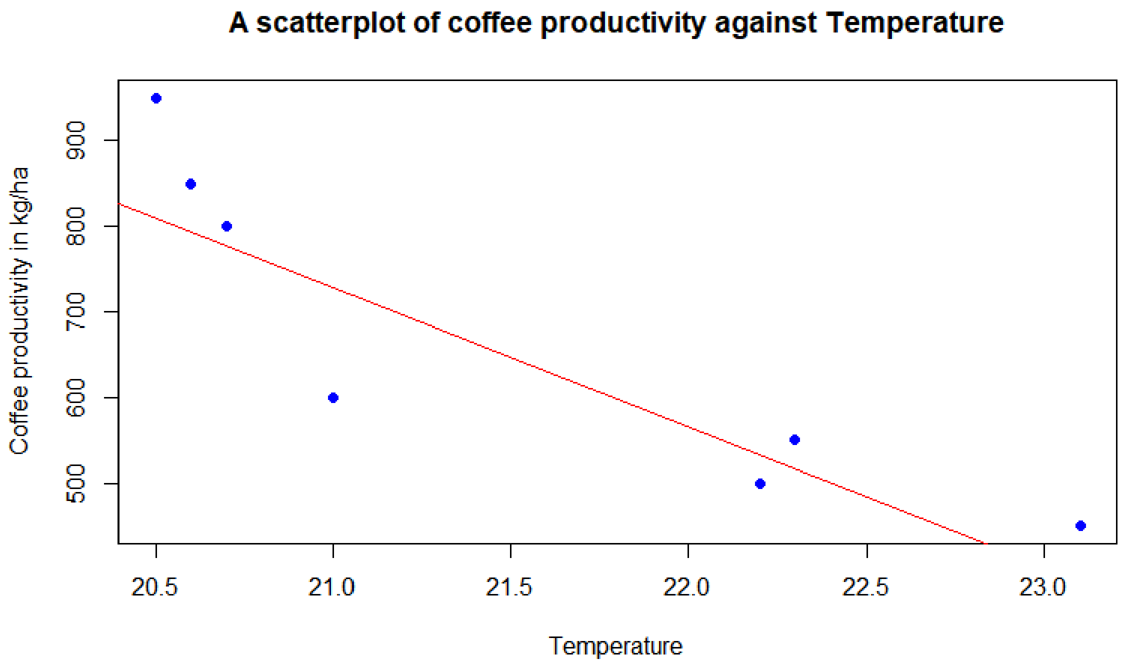

Figure 4.5: A scatterplot of coffee productivity in kg/ha against Temperature.

4.6 Relationship between rainfall and coffee productivity

Correlation analysis was used to examine the relationship of rainfall variability and coffee productivity in the area while a simple linear regression was used to study the effect of the independent variable (amount of rainfall in millimeter) on the dependent variable (amount of coffee in kg/ha).

Statistical analysis showed that there was a positive relationship $r = 0.42$ and $r = 0.23$ between amounts of coffee in kg/ha produced and amount of rainfall in mm respectively from 2001 to

2020.The relationship between the amount of coffee in kg/ha produced and amount of rainfall in mm was statistically significant at ($p = 0.02$) since it is less than ($p = 0.05$) hence the relationship was significant. This indicates that coffee production was not much influenced by rainfall, but there must be other factors like shortage of agricultural inputs such as fertilizers and pesticides which influence coffee production in the study area. See table 4.4, Regression analysis results indicated that $Y = 463.113 + 2.574x$.

Table 4.4: Table showing values Coefficient of variance-value and regression equation.

Variable	Coefficient of Variation	p-value	Regression equation
Temperature	$r = 0.04$ $r = 0.23$	$p = 0.01$ $p = 0.05$	$y = 4144.2 - 162.7X$
Rainfall	$r = 0.42$ $r = 0.23$	$p = 0.02$ $p = 0.05$	$y = 463.113 + 2.574X$

Coffee output had a positive response to rainfall amount in October to December period. However, coffee output had a negative response to: mean temperature in March to May period, temperature variability, price of fertilizer and effective exchange rate. Coffee output had an elastic response real effective exchange rate and an inelastic response to rainfall amount, fertilizer price and spending on roads transport and communication. The negative effect of rainfall in January to February period showed that early rains were detrimental to coffee yield. Normally, coffee trees require a dry weather period also known as a period of stress before the onset of rains for them to flower. Therefore, rainfall in the dry months of January and February inhibit flowering and growth of berries consequently lowering yield. (Kariuki, 2016). Figure 4.6 shows a scatterplot of coffee productivity against rainfall in mm.

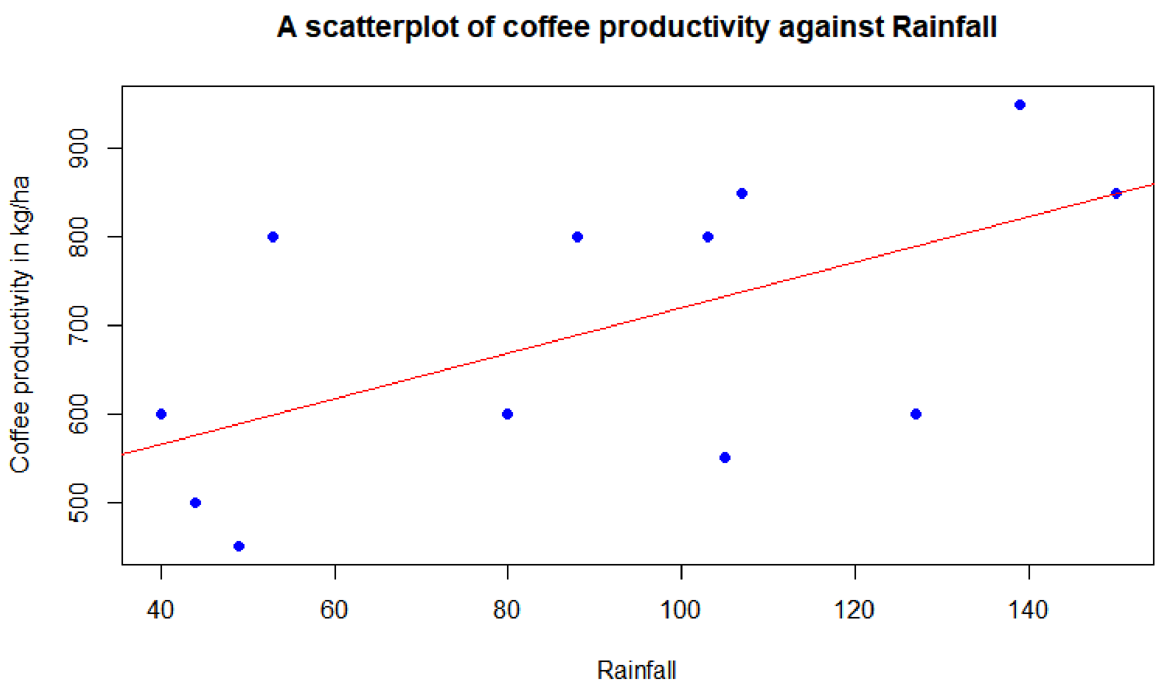

Figure 4.6: A scatterplot of coffee productivity against Rainfall in mm.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Coffee productivity forms a strong base for food security and is a source of livelihood to a large percentage of the rural people. Coffee productivity is largely dependent on climate conditions, making it vulnerable to climate variability. The study findings indicate that coffee productivity is affected by climate variability. The productivity of Robusta coffee is tightly linked to climate variability. Temperature in particular is a very important driver in different phases of the lifecycle of Robusta coffee. On the response of coffee productivity to rainfall and temperature variability, the study findings indicate that, a general decrease in rainfall have no significant effects on coffee productivity but its distribution matters. The rainfall decreases in months from December to February (flowering period for coffee) implies the coffee productivity decrease as the case of low coffee productivity in 2015.

On the response of coffee yield to changes in temperature and temperature variability, the study found that changes in temperature and temperature variability have the significant effects on coffee yield. This shows that observed changes in temperature have influenced expansion of coffee productivity. A decrease in mean and maximum temperatures implies the increase of coffee productivity in Mubende for the period (2001-2020), but the change in minimum temperature had no significant influence on coffee yield in the study area. An increase in mean and maximum temperatures implies the reduction of coffee productivity. These conditions increase climate risk and greatly compromise the economic viability of the coffee crop, making coffee farming less desirable. In some instances, this may result some to farmers adopting new crops such as matooke that is reliable and can adapt different climatic conditions. Although rainfall has been decreasing over the nineteen years, overall, this study concludes that; the increase in coffee productivity in

Mubende is strongly attributed to the decline of temperature and its variability. However, while the increase could be attributed to other factors, the trends of rainfall and temperature indicate that Mubende is vulnerable to the impact of climate change and variability.

5.2 Recommendations

Climate change and climate variability study requires data for long period this study recommends that UCDA and other concerned institutions to keep and conserve data since they are needed for research for example about the crop production**.**

This study also recommends the coffee producers to focus on Uganda coffee profile of increasing both quantity and quality of coffee since it is one of the most sustainable way to enhance coffee productivity.

This study has indicated that there was and there is no strong evidence for attributing the increase in coffee productivity to climate change and variability meaning that the increase could be attributed to other factors such as application of fertilizers, planting of shade trees among others. Therefore, further research is recommended to study the interaction between and among various socio-economic factors and climate variables and their implications as well as the impact of climate variability on quality of Robusta coffee productivity in Mubende district and other districts in Uganda that grow the crop.

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APPENDICES

Appendix 1: INTERVIEW

Farm; Interview

1. What is the purpose of planting coffee especially Robusta coffee?

   The fertile soils of Mubende favor the growth of Robusta coffee.

   Robusta coffee is easier to maintain, plant and can be resistant to harsh weather conditions for example high temperatures.

   We grow coffee earn income and to improve our standards of living.
2. What was the amount of coffee in kg harvested in the last season.?
3. Did you sell the product? If sold for how much, to whom and when.
4. Where do you get your seedling plants from?
   Tree nursery
   Government
   Organizations
5. Do you get any funding, if yes?
   a) where?
      From the cooperative union.
   b) What kind of support and how much?
      Monetary
      Teaching
      Tools

6. How have Temperature variations affected coffee productivity?
7. How have rainfall variations affected coffee productivity?
8. Do you plan to continue planting coffee seedlings?
9. Are you satisfied with growth of the planted coffee?
10. How have prevalent changes in temperature and rainfall affected the trends of coffee productivity.