MAKERERE UNIVERSITY

THE IMPACT OF TEMPERATURE AND RAINFALL VARIABILITY ON COFFEE PRODUCTION: A CASE STUDY OF ZOMBO DISTRICT, NORTH-WESTERN PART OF UGANDA

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DECLARATION

This serves to declare that the Research report work presented is original; realistic; reliable and has never been submitted by any other academicians to a recognizable Institution for academic awards and in all cases where it is relevant, material from the work of others has been acknowledged.

Signed.. Date 29th November, 2022

JAKER Daniel

Reseacher

APPROVAL

This work has been conducted; compiled; computed and fully executed under my supervision and is now ready for submission with my accreditation and approval:

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DEDICATION

Dedicated to my dearest parents, Mr. Ongei Emmanuel Darius and Ms. Oyenyboth Leonida Timo for their endurance and perseverance towards my education. I also dedicate this work to my wife, Ms. Amarorwoth Carolyn, relatives and friends for the support and encouragement, may the Almighty God reward you all.

AKNOWLEDGEMENT

First and foremost, I would like to thank the Almighty God who gave me strength, endurance and wisdom when I was writing this research and also in the due course of my degree. I would like to thank my University Academic Supervisor, Dr. Ddumba Daniel Saul for the professional guidance and direction rendered to me to achieve this success. I would also like to express my sincere gratitude Mr. Godfrey Ntabazi for his guidance and necessary information he availed me with to finish this research work. Great thanks to my lecturers for imparting their knowledge of meteorology in me. I am grateful for everything I studied and I hope to apply what I learnt in the work field.

Great appreciation goes to my mother, father, wife, children and the family for supporting me both financially, spiritually and emotionally during my research project. And finally, to my fellow classmates, especially Mr. Okoth Francis Okony and Mr. Kyeyune Allan Alloysious without your support, I wouldn't have made it, and to everyone who made any contribution to my life in the form of prayers or any kind of physical support, all I can say is that "may the Almighty GOD bless you abundantly".

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ABSTRACT

Worldwide, climate change and variability have been raising concerns about potential changes to crop yields and production systems. This study focuses on the impacts of climate variability on coffee production in Zombo district, North western part of Uganda. Specifically, this study is aimed at determining how temperature and rainfall variability affects coffee production. The study utilized secondary data for rainfall and temperature all obtained from Uganda National Meteorological Authority for a period of 30 years. Secondary data for coffee production was also obtained from the office of the District Agricultural officer, Zombo district for the period from 2010- 2020. Temperature and rainfall series were analyzed for fluctuation using time series and trend analysis on temperature and rainfall was performed using the Mann-Kendall test.

Correlation analysis was used to establish the relationship between temperature and rainfall with coffee production. The study found out that in the area of study (p-value > alpha 0.05) had insignificant trends in annual maximum temperature. It was also found that the area (p-value < alpha 0.05) had significant trends in rainfall. According to the results of the study, it was established that there was a positive relationship between coffee production and temperature and rainfall during the study period but was insignificant because ($p > 0.05$), this therefore led to the partial rejection of the null hypothesis and that there was a relationship between rainfall and temperature variations with coffee production in Zombo. Trends of coffee production over the period of 2010-2020 showed that coffee production increased linearly.

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

The first World Climate Change Conference took place in 1979 in Geneva to discuss the real impacts of climate change on agriculture and other development sectors (Koo, 2011). Decision makers from Regional and Federal governments, experts from research institutions and universities, and practitioners from civil society organizations and the private sectors came together for expert presentations and plenary discussions on such impacts. Climate change and variability is already having a significant impact on the agriculture sector which is an important activity in the developing world; as the sector is dominated by rain-fed crop production and household's food security is particularly vulnerable to climate variability and change. According to Hulme (1996), rain fed agriculture is an important economic activity in the developing world. Globally, rain fed agriculture is practiced in 80% of the total physical agricultural land on which 62% of the world's staple food is produced (Basu et al., 2011).

Climate change presents a serious threat to agricultural production systems in Uganda. Projections downscaled for the 2015-2045 period show a warming trend of more than 2°C increase by 2030 and a 1.4°C -4.2°C increase by the end of the century. Extreme weather events characterized by floods, droughts and landslides are also expected to continue increasing. The impacts of climate change interacting with poverty, low rural incomes, lack of income diversity and heavy dependence on rain fed agriculture will have serious implications for the economy, livelihoods and food security (Uganda Climate Change Profile, 2018).

The Uganda Climate Action Report For 2016 shows that Uganda is experiencing significant impacts of climate change, which include changing weather patterns, drop in water levels, and increased frequency of extreme weather events like floods, as well as drought, whose social economic impacts make communities very vulnerable.

Uganda produces both Robusta (*Coffea canephora*) and Arabica coffee (*Coffea arabica*), of which 90% is produced by smallholder farmers either in groups, cooperatives or the few large-scale plantations. Arabica coffee is found in the high-altitude areas of the eastern, western and southern regions of the country, while Robusta coffee is a native plant commonly grown in Uganda. The Robusta and Arabica coffee production systems differ and are highly dynamic, co-evolving with the social, economic, ecological and political conditions (Ssebunya et al., 2017). It is an important cash crop in Uganda because the tree crop is the principal cash crop and the country's largest agricultural foreign revenue earner (Munyuli, 2011)

1.2 Statement of the Problem

Changes and variations in climate have been and continue to be the key sources of fluctuations in global food production especially in developing countries (Oseni & Masarirambi, 2011). According to a report of the Intergovernmental Panel on Climate Change (IPCC) (10), climate change is expected to manifest itself in the increase of mean temperature, altered precipitation patterns, greater frequency of extremes, and increased climatic variability.

According to Rosenzweig (1996) heavy rainfall event, excessive soil moisture and flooding disrupt crop production, and temperature rise causes reduced and staggered flowering, different berry growths, and difficulties in timing of operations like disease and pest management, lengthening the harvest and processing seasons and compromising quality.

Coffee is a vulnerable crop which needs special climatic conditions if it is to thrive and give a good harvest. Both Robusta and Arabica coffee varieties require agro-ecological areas with hot-wet or hot-temperate climate with frequent rains of about 1000mm or more per annum and temperatures varying between 15° and 25°C with two months dry spell (*Mbayu*, 2013). Projections from various climatic studies indicate a reduction in crop yields due to changes in surface temperature and precipitation more so in economies that heavily depend on agriculture and lack resources to counter the negative effects of climate change (Kikoyo & Nobert, 2016). This is of serious concern in Uganda where the economy and livelihood of the biggest population relies much on the rain-fed agriculture that is vulnerable to climate change. Therefore, this study is aimed to assess the impact of climate variability on coffee production in Zombo District.

1.3 Objectives

1.3.1 General objective

This main objective of this study was to analyse impact of temperature and rainfall variability on coffee production in Zombo District; North-Western part of Uganda.

1.3.2 Specific objectives

i. To examine the trend of temperature and rainfall over the past 30 years in Zombo district.
ii. To examine the trend of coffee production over the last 10 years.
iii. To establish the relationship between temperature and rainfall with coffee production over the last 10 years.

1.4 Research questions

i. What is the trend of temperature and rainfall over past 30 years in Zombo District?
ii. How has the coffee production varied over the last 10 years in Zombo District?
iii. What is the relationship between temperature and rainfall with coffee production in Zombo District?

1.5 Hypothesis

H0: There is no significant relationship between rainfall, temperature variations and coffee production in Zombo.

H1: There is a significant relationship between rainfall, temperature variations and coffee production in Zombo.

1.6 Significance of the study

A study on the influence of parameters of climate; Rainfall and Temperature on coffee production is important in increasing knowledge and awareness in understanding coffee and how its production is affected by long dry spells, higher appreciation of the importance of coffee by the community, adoption of coffee as a major component by policy makers.

In this thesis, the student aimed at examining variations in temperature and rainfall over time and its contribution to coffee production. From the results of the study, the community will be able to realize the significance of coffee and how its production depends on rainfall and as a result, the community will be encouraged to take on coffee production as an annual economic activity.

More specifically, the results of this research will benefit coffee farmers. Through this research, the gaps and recommendations identified will guide further future studies and contribute to boosting coffee production in Uganda.

CHAPTER TWO: LITERATURE REVIEW

2.1 Climate Change and Variability at Global and Regional Level

Humans are influencing climate through increasing greenhouse gas emissions, consequently, changes in climatological patterns have implications or hazards at the 9 global and regional level (Fatumah et al., 2019). The major hazards caused by climate change are prolonged heavy rainfall and drought. These hazards could have profound implications for farmers at global and regional level. An increase in average temperature can lengthen the growing season in regions with relatively cool spring and fall seasons, adversely affecting crops in regions where summer heat already limits production(EPA, 2004). In Africa, extreme natural occurrences such as floods and droughts are becoming increasingly frequent and severe because of climate change and variability (Sheffield & Wood, 2008). Climate variability and change have further exacerbated the scarcity of natural resources in Africa, this situation led to conflicts with regard to access to, ownership and use of these resources. The scarcity of natural resources is known to cause competition for the insufficient resources available among both individuals and communities, and even institutions, thus affecting human security in the continent (Bernard et al., 2011). Generally, Climate change affects demand for water through direct physical effects and socio-economic effects such as behavioral changes in water consumption in response to higher temperatures (Midgely et al.,2005). In most countries, agriculture is by far the largest sector of water use (especially the large irrigators, Egypt, Sudan, and South Africa) climate change and variability will therefore affect these regions due to higher rates of evaporation (Goulden et al., 2010).

Countries in Sub-Saharan Africa (SSA) are particularly vulnerable to climate change impacts, because of their limited capacity to adapt. The development challenges that many African countries face are already considerable, and climate change will only add to these. At the same time, the economic potential for mitigation through agriculture in the African region is estimated at 17 per cent of the total global mitigation potential for the sector. Moreover, the economic mitigation potential in agriculture is highest in East Africa, at 41 percent of total potential(Bryan et al., 2011)

2.2 Global coffee production

Coffee is one of the legal international transacted commodities of many countries following petroleum oil, consumers from all around purchase and enjoys it in their daily activities. It is the second most transacted goods in the world. In the world, Brazil is the leading coffee producer and exporter followed by Vietnam and Colombia. In countries such as Uganda, Burundi, Rwanda and Ethiopia, coffee is the most source of revenue of their societies since the crop is the main trade commodities of these countries with global trade sales predictable as US$ 90 billion. Among coffee species, only two species, Coffea arabica L. (Arabica coffee) and Coffea canephora (Robusta coffee) economically dominate the world coffee trade. Predominately, Arabica represents 70% of global coffee production and Robusta represents about 30% .The production and productive of both species are largely dependent on the climate for attain high yields and quality.(Ebisa, 2017).

Coffee is a globally traded commodity and an integral part of many people's daily life. The coffee sector is a multi-billion-dollar global business, involving thousands of companies and several million farmers, most of which are smallholders. The sector is facing several sustainability challenges, including water pollution, biodiversity loss, soil erosion, agrochemical use, deforestation, waste generation and labour exploitation ,Other issues include low prices, ageing farmers and climate change.(Bager & Lambin, 2020).

2.2.1 Production of coffee in Sub-Saharan Africa

Coffee is grown mostly in sub-Saharan African countries by smallholder farmers as a cash crop, while the production system employs millions of people in the region. Most of the countries export coffee, which contributes significantly to national foreign exchange earnings (Ogundeji et al., 2019) The governments of coffee-producing countries in Sub-Saharan Africa long considered state control of marketing and pricing systems necessary because of coffee's importance as a source of foreign exchange and government revenue (Akiyama et al., 2001).

2.2.2 Coffee production in Uganda

Uganda is the second largest producer of coffee in Africa, after Ethiopia, and is the tenth largest in the world. Two species of coffee are grown: production comprises 85 per cent Robusta, mainly growing in the Lake Victoria basin, and 15 per cent Arabica, mainly growing on the slopes of Mount Rwenzori and Mount Elgon. The country has a large coffee production system, with 1.321 million smallholder farmers with farms varying between 0.5 and 2.5 hectares in size and about 3.5 million families are employed in coffee-related activities countrywide (Uganda Bureau of Statistics (UBOS, 2005,)(Kasente, 2012)

The commodity is grown in different highland areas of the country. Notably, on the slopes of Mount Elgon, bordered with Kenya and the slopes of the Mount Rwenzori, also known as the 'mountains of the moon' bordered with the Democratic Republic of Congo. Some coffee is also cultivated in the West Nile region in the north-western Uganda. Uganda produces excellent wet-processed Arabica, mainly grown by rural smallholder farmers. Coffee marketed as 'Drugar' (Dry Uganda Arabica) or 'Wugar' (Washed Uganda Arabica) is grown on mountains bordered with Democratic Republic of Congo, along the western Uganda. The crop is mainly cultivated in the southern and central districts (57%), Eastern Uganda (23%) and Western Kassese (10%) and to a lesser extent, in non-traditional areas like Mpigi, Wakiso, and Rakai (10%) (Hlavackova & Brezina, 2015).

Coffee is an important cash crop in Uganda because the tree crop is the principal cash crop and the country's largest agricultural foreign revenue earner. At the farmer level, coffee remains an important source of income since its production accounts for over 10% of total income of the farmer. At the national level, income from coffee currently contributes around 20% - 26% of Uganda's export earnings In 1999, coffee exports totaled 150,000 mt (2.5 million bags of 60 kg) representing US$125.316 million in foreign ex-change earnings (Munyuli, 2011)

2.3 The impact of climate on coffee production

Coffee is a tropical plant which grows between the latitudes of 25°N and 25°S but requires very specific environmental conditions for commercial cultivation. Sequence of weather events like temperature, rainfall, sunlight, wind and soils are all important to coffee production, but requirements vary according to the varieties grown. The crop is a perennial crop that can grow under both humid lowlands and tropical humid/sub-humid highlands. Arabica coffee does best at higher altitudes and is often grown in hilly areas. Average temperature required for coffee Arabica ranges between 15 and 24°C (59 and 75°F), rainfall, 2000 mm per annum and altitudes between 1000 and 2000m above sea level. Ideal climatic conditions for Arabica coffee include, a dry period of three months (to stress trees in order for them to flower well, but not too long of a dry spell, or trees will become weak), a good soaking to initiate flowering (but not continuous rain, as this will affect the fruit set), not too high a temperature (which can cause a range of physiological problems, including flower abortion), regular rainfall throughout the berry development stage, a drier period coming up to harvest and a dry period around harvest to facilitate picking and sun drying (this would be the ideal situation, but is not the case for all coffee production countries). Alteration in precipitation patterns, temperature, storms, strong winds and other extreme weather events directly impact coffee quality and productivity levels. Above the required moderate temperatures, fruit development and ripening in Arabica coffee accelerate. Faster ripening might not sound bad, but it actually degrades coffee bean quality. Continuous exposure to temperatures up to and just over 30°C can severely damage coffee plants, stunting growth, yellowing leaves, even spawning stem tumors. These potentially damaging hydro-meteorological events or phenomena are called Climate Hazards. Robusta coffee which can take hotter, drier conditions but does not tolerate temperatures much below 15°C, as Arabica can for short periods, require average temperature range between 24 and 30°C (75–86°F), rainfall 2,000 mm per year and can be grown between sea level and altitudes of about 800 m above sea level. Heavy rain is needed in the beginning of the season when the fruit is developing and less, later in the season as it ripens. In general, coffee needs an annual rainfall of 1500 to 3000 mm, Arabica needing less than other species. Optimal coffee-growing conditions include cool to warm tropical climates, rich soils, and few pests or diseases (Ogundeji et al., 2019).

Temperature is one of the most critical environmental factors and exerts a great influence in all the physiological activities of plants, controlling the levels of the metabolic reactions within cells. All and any of the physiological functions and chemical reactions present a temperature optimum and any higher or lower discrepancy might decrease their efficiency Plants have different degrees of tolerance to extreme temperatures, each one presenting defined limit for growth and reproduction. For instance, even if the seed of a plant germinates and develops at some temperatures, these same temperatures might not be appropriate for the reproductive phase. So, if the temperature is appropriate for only some phases of plant growth and development, the plant will not necessarily be successful in colonizing that environment. Thus, it is correct to assert that the environmental species distribution can be delimited through temperature oscillations(Silva & Mazzafera, 2008). Arabica coffee grows well in a relatively narrow range of climatic conditions, including temperatures of 15 to 24°C, though best production is achieved at 18 to 22°C. Robusta coffee is hardier at higher temperatures, and is productive up to 30°C, with optimum production between 22 and 28°C (Magrach & Ghazoul, 2015).

CHAPTER THREE: METHODOLOGY

3.1 Study area

The research was conducted in Zombo District. It is found in the West Nile region of Uganda located in the North Western part of the country. It is 70 km (43 miles) South of Arua City, the regional capital and 382 km (237 miles) North-West of Kampala, the Capital City of Uganda. The district is bordered by Arua District to the North, Nebbi District, to the East and the Democratic Republic of Congo to the South and West. It lies at 020 30N, 300 54E; 2.5000N 30.9000E.

3.1.1 Topography

The topography of Zombo is generally hilly steep U shaped and V shaped valleys. This is visible in all the Sub counties. The highest peak is on Agu Hill in Abanga Sub County. The hills are characterized by undulating ranges sweeping across the Sub counties of Paidha, Abanga, Jangokoro, Zeu, Kango and recedes towards, and into, Arua District. A similar pattern is exhibited in Nyapea Sub County running almost parallel cutting through Nebbi and Arua.

3.1.2 Economic activities

The main economic activity in the district is agriculture though most of it is still done on subsistence level as majority of the farmers lack the capacity to venture into extensive farming. Another commonly practiced activity is Apiary also done on small scale. There has been considerable attempt by district leaders to woe investors into the district to add value to the honey harvested. The district also grows a lot of Coffee though the Alur Kingdom is introducing tea growing in the area.

3.1.3 Population

According to the UBOS figures, the district had a total population of 240,081 in 2014 with a projected population of 266,200 in 2018 of which 51.8% are female

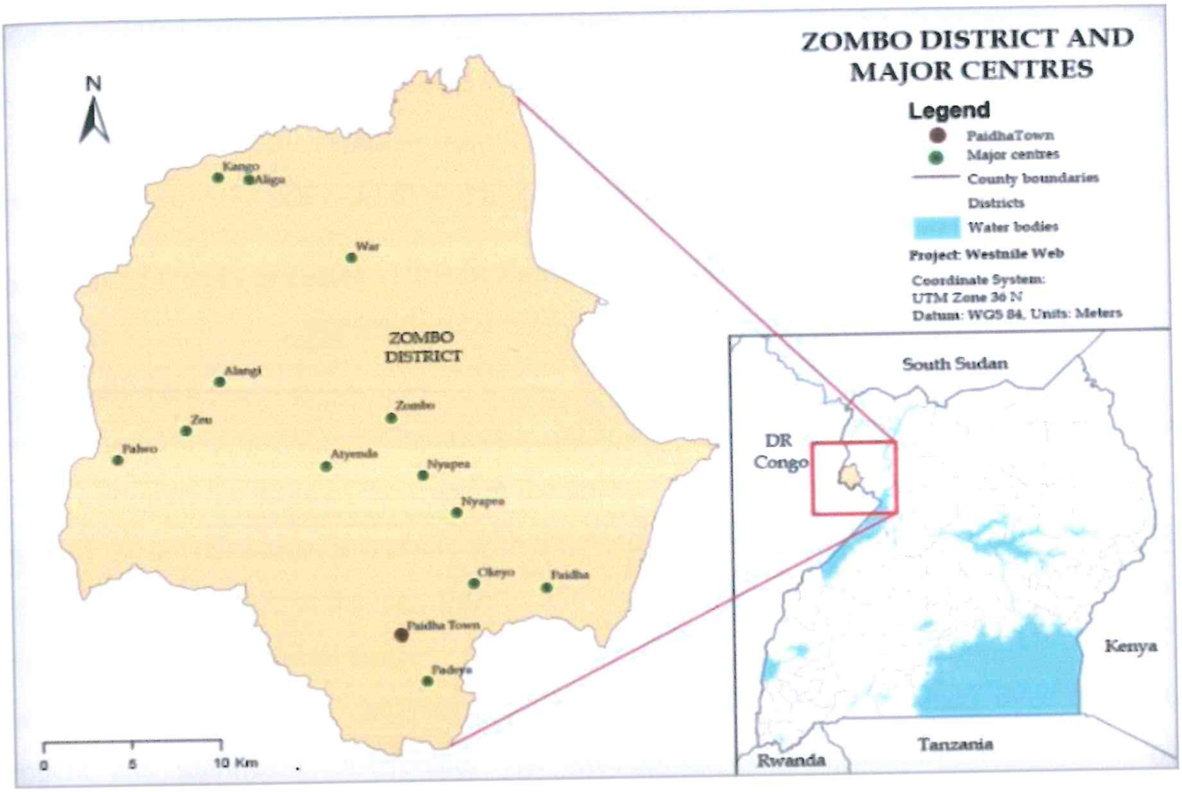

Figure 1: Location of the study area *(Source; Researcher)*

3.2 Data sources

3.2.1 Data sources for temperature and rainfall

Rainfall and temperature data were obtained from Uganda National Meteorological Authority (UNMA), for the period of 30 years (1991-2020)

3.2.2 Data sources of coffee yields

The crop production data (coffee yields) was obtained from the office of the District Agricultural Officer, Zombo district.

3.3 Data Analysis – software for analysis, version

XLSTAT version 2022.1 was used to analyze data

Coefficient of Variation

The Coefficient of Variation (CV) is a value which indicates the level at which observations vary away from the mean value. It is given by the formula in equation

$CV = \frac{\delta}{\mu} * 100\%$..1

Where; δ is standard deviation of the observations and μ is the mean for the observation.

A high value of CV indicates that the observations vary much away from the mean while a small value of CV indicates a small variation from the mean. The coefficient of variation was calculated for temperature and rainfall within Zombo to compare variations with coffee yields.

3.3.1 Analysis of trends in coffee yields in Zombo district between 2010-2020

This was done by computing the trends of coffee yields obtained from the office of the D.A.O

Mann-Kendall Test

It should be noted that the Mann-Kendall test statistic is non-dimensional and it does not offer any quantification of the scale of the trend in the units of the time series under study but is rather a measure of the correlation of a variable with time and as such it simply offers information as to the direction and a measure of the significance of observed trends

Assumption of Mann-Kendall test;

a) When no trend is present, the measurements (observations/data) obtained over time are independent and identically distributed. The assumption of independence means that the observations are not serially correlated over time

b) The observations obtained over time are representative of the true conditions at sampling times

c) The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time.

Advantage of using the Mann-Kendall test;

a) It is non-parametric test and does not require the data to be normally distributed.

b) The test has a low sensitivity to abrupt breaks due to in homogeneous time series i.e. can be computed even if there are missing values.

Mann-Kendall test was used to analyze the trend in data series. This non-parametric rank-based method which is mostly used to evaluate the significance of monotonic trends in time series (Journal et al., 2018).

It does not assume data to have any form of distribution form hence is as influential as other counterparts. The test is as follows; assuming X1, X2, . . ., Xn be a series of data over a time period, Mann proposed that H0, the null hypothesis be tested and the data comes from a series with identically distributed and independent variables

$s=\sum_{i=j}^{n-1} \quad \sum_{j=it1}^{n} sng(Xj - Xi)$

Where;

$$\text{Sgn}(\theta)=\begin{cases} 1\ if\ \theta > 0 \\ 0\ if\ \theta = 0 \\ -1\ if\ \theta < 0 \end{cases}$$

The standard test statistic Z which is used for measuring significance of trend is calculated as follows;

$$z=\begin{cases} \frac{s-1}{\sigma}\ if\ s > 0 \\ 0\ if\ s = 0 \\ \frac{s+1}{\sigma}\ if\ s < 0 \end{cases}$$

It follows that, the null hypothesis (H0) is accepted and that there is no trend when the absolute Z value calculated by the equation above is greater than the critical value, at a chosen level of significance σ for example in this study $\sigma = 0.05$.

3.3.2 Correlation Analysis

To determine the relationship between coffee production with temperature and rainfall, Spearman's Rank Correlation coefficient was used,

$$r_s = 1 - \frac{6\sum D^2}{n(n^2 - 1)}$$

Where:

Rs =is the Spearman's Rank Correlation Coefficient.

N=is the number of pairs.

D =is the rank difference between temperature, rainfall and tea yields.

n is the total number of observations.

$\sum$ =is the summation symbol

CHAPTER FOUR: RESULTS AND DISCUSSION

4.0 Introduction

This chapter presents and discusses results using the methods described in Chapter Three so as to achieve the objectives outlined in Chapter One, Section 1.3 of the study.

4.1 Trend of temperature and rainfall over the past 30 years in Zombo district

The variations of temperature and rainfall were analyzed in temporal terms using time series plots as explained in the subsections below.

4.1.1 Trend of temperature

Under temporal trends of temperature, temperature data (□ C) from the UNMA was used for a long-term period of 31 years (1991–2020) of data and a time series graph was analyzed for the data considered in the study. The graph was fitted with trend line and a trend value that helped to identify the nature of the trend whether it is increasing or decreasing as presented in Figure (4.1.1). The temperature values showed a similar trend of cooler temperatures in the 1990s to 2000s with some warm periods in 1993, 1995 and 1998. However, during the 2000 to 2010 period, there was an extremely increasing trend in temperature with a peak being in 2009, and then a sharp decline up to 2011. From the year 2011 to 2020 there was a gradual increase. Generally, there has been a steady increase in temperature since the 1990 to 2020. The increase in temperature in Zombo could be due to climate variability and change. These results are in agreement with (Obubu et al., 2021) findings who revealed during the 2000 to 2020 period, there was an increasing trend in mean temperature which could be due climate variability and change. It can also further be noted that the average temperature exhibited a cyclic pattern with an increasing trend over the years across the area. This is consistent with the findings (SG Juma et al,2016) that investigated the projected changes in rainfall and temperature over Bungoma County in Kenya.

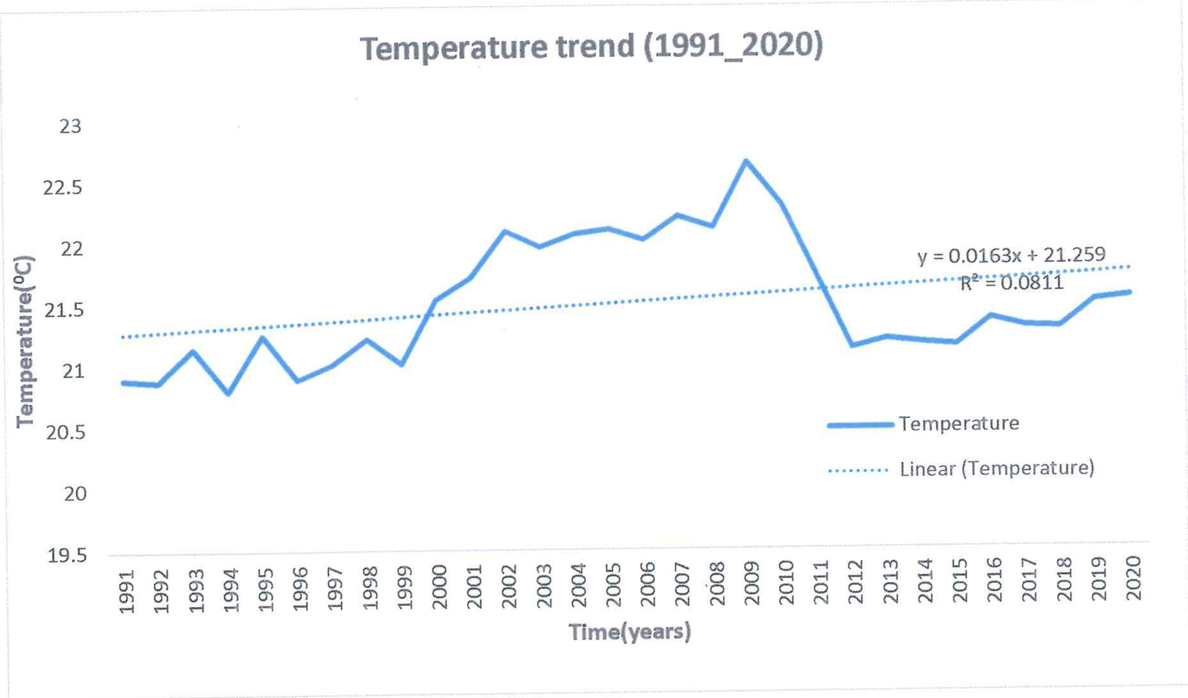

Figure 2: Time series graph showing temperature trend for Zombo

4.1.2 Rainfall trend

The results from time series graph (Figure 3) indicates a slight decrease in annual rainfall for Zombo district. However, there were variations in the annual rainfall values indicated with troughs (low rainfall values) in 1993, 1995, 2000 and 2005 and also with four major peaks (high rainfall values) in 1994, 1996, 2002 and 2006. The rainfall trend from 2011 to 2020 showed a relatively constant value. Rainfall trend results over Zombo district also agrees with other people's findings, for instance (Kansiime et al., 2013) observed a negative, but non-significant trend for annual rainfall for SE L. Kyoga, in the Eastern part of Uganda.

Generally, the rainfall trend in Zombo showed a relatively decreasing trend which probably could be due to climate change and climate variability.

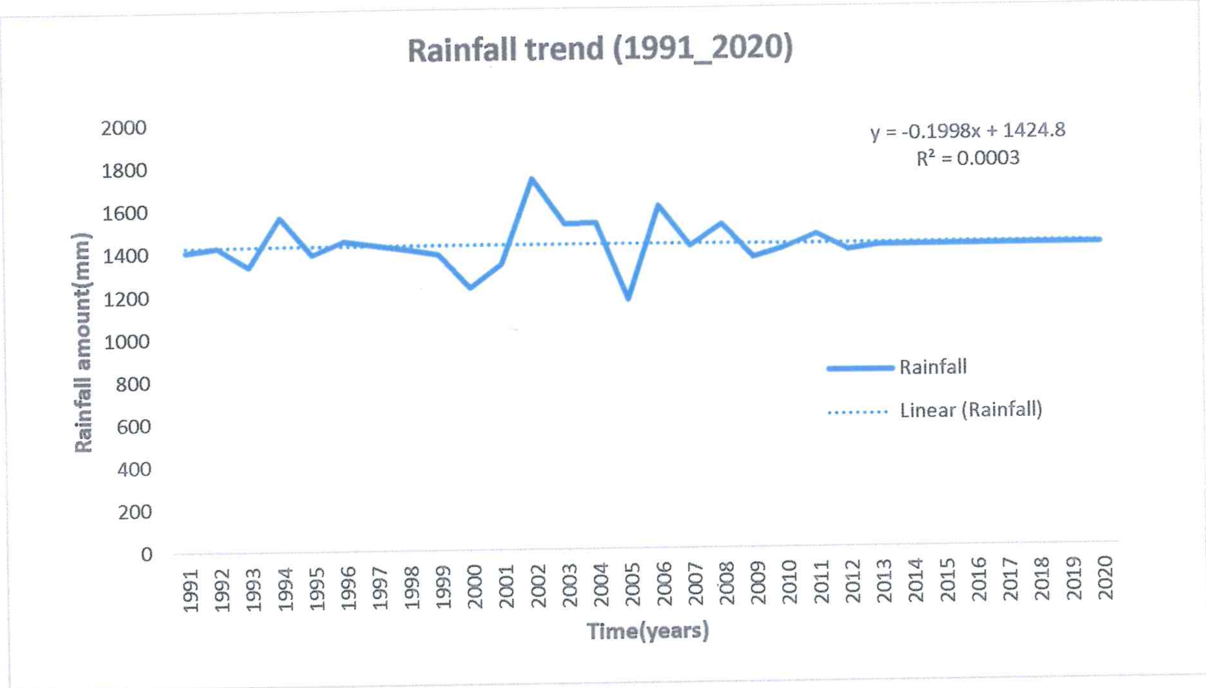

Figure 3: Time series graph showing rainfall trend for Zombo

4.2 Trends of historical coffee production in Zombo district

Time series graph (Figure 4) indicates increases in annual coffee production for Zombo district with (gradient=561.2 and R^2=0.9986) implying significant increase in coffee production over the years. The trend in coffee production increased linearly over the years in Zombo district signifying a 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. This resultant is consistent with (Pham et al., 2019) that shows increased coffee yields in the higher altitudes due to increase in coffee-producing niche.

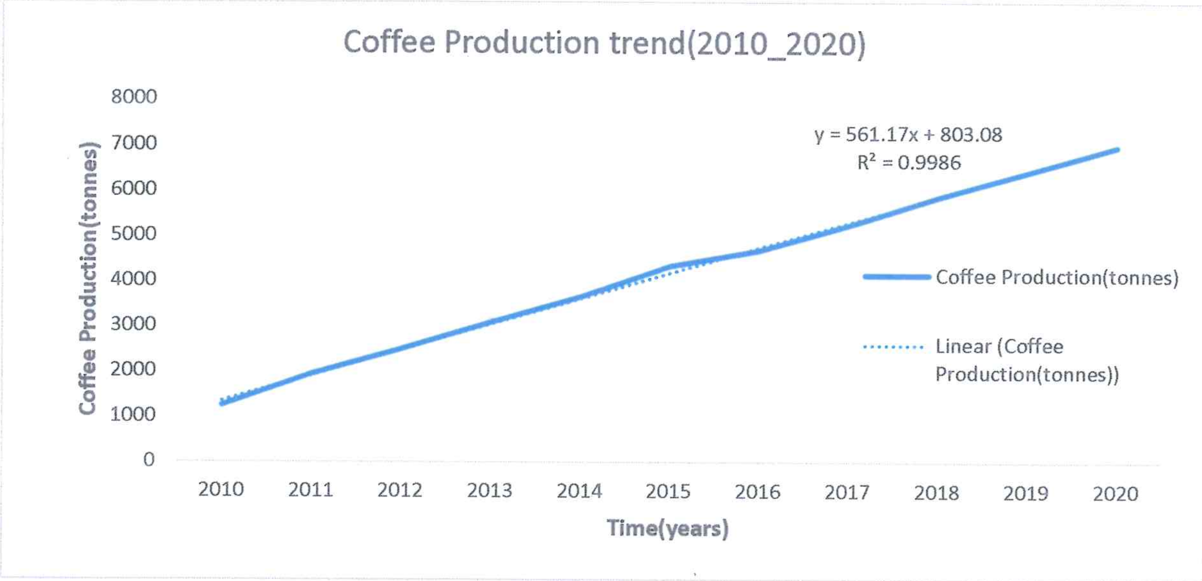

Figure 4: Time series graph showing coffee production trend for Zombo

Mann Kendall results (Table 1) also depict the same scenarios as with temperatures and coffee production all having positive trends except for rainfall with a negative trend. However, statistically significant trends where only observed in temperatures and coffee production since their P-values (0.049 and <0.0001) respectively are less than the critical value (0.05). Insignificant trends in rainfall (P-value=0.822) over Zombo district are in agreement with (Kansiime et al., 2013) who observed a negative, but non-significant trend for annual rainfall for SE L. Kyoga, in the Eastern part of Uganda.

Table 1: Mann Kendall results for climate trends and coffee production

Parameters	**Temperature**	**Rainfall**	**Coffee production**
Kendall_tau	0.262	0.032	1
Kendall score	106	13	55
P value	0.049	0.822	<0.0001
Comment	Significant positive trend	Insignificant positive trend	Significant positive trend

4.3 Relationship between temperature and rainfall with coffee production in Zombo district

4.3.1 Relationship between temperature and coffee production

Under relationship between temperature and coffee production, temperature and coffee production data of Zombo were used to produce a scatter plot for coffee production Vs temperature for the period of (2010–2020) and there was no relationship between them. The scatter plots show that the coffee production yield decreases with increase in temperature. The plots were fitted with a regression line to find equations that fit the data.

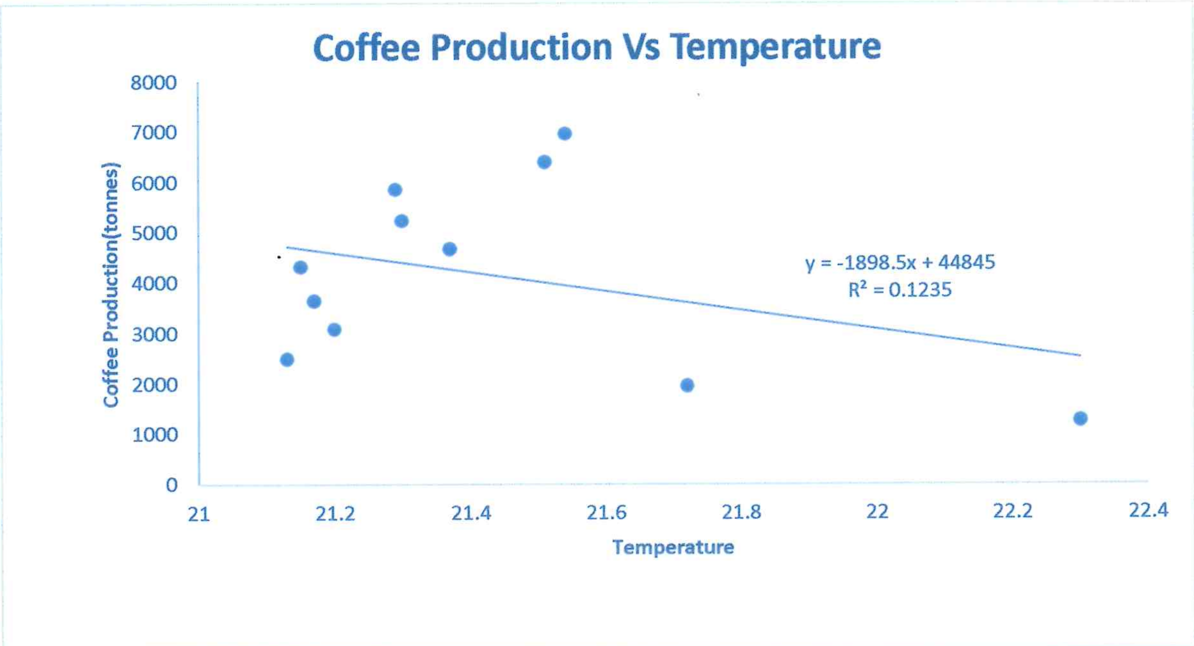

Figure 5: Scatter plot showing the relationship between coffee production and temperature

4.3.2 Relationship between rainfall and coffee production

Under relationship between rainfall and coffee production, rainfall and coffee production data of Zombo were used to produce a scatter plot for coffee production Vs Rainfall for the period of 2010–2020 and there was no relationship between them. The scatter plots were fitted with a regression line to find equations that fit data.

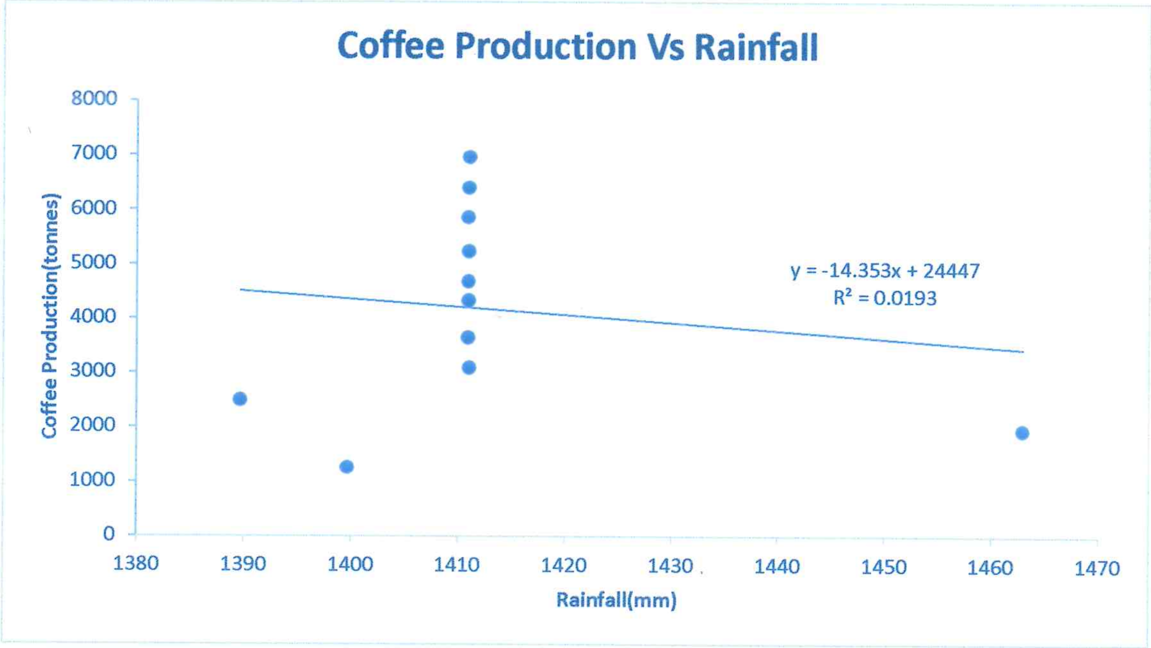

Figure 6: Scatter plot showing the relationship between coffee production and rainfall

Low rainfall during the growing season will reduce fruit development and ultimately coffee bean size and that higher rainfall and temperatures during the growing season and harvest will increase the likelihood of bean defects which leads to the eventual decrease in production. (Kath et al., 2021) showed that higher rainfall and temperatures during the growing season and harvest are associated with an increased chance of coffee bean defects, but that the effect of rainfall interacted with temperature.

4.3.3 Correlation analysis for Rainfall and Temperature Vs coffee production

Numerical data for rainfall and temperature collected from the UNMA were tested against coffee production data collected from D.A.O of Zombo district. Correlation analysis was used to examine the relationship of rainfall and temperature variability and coffee production in the area. Statistically, analysis showed that there was a weak relationship between amounts of coffee in tons produced and amount of rainfall in millimeters from 2010 to 2020.

The relationship between the amount of coffee in tons produced and amount of rainfall in millimeter and temperature was statistically insignificant at 5% level ($p = 0.0378$). 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.

Table 2: Correlation analysis between amount of in tons and amount of rainfall and temperature

		Coffee
Rainfall	R	0.260876
	R square	0.068056
	P value	0.037852
Temperature	R	0.018182
	R square	0.000331
	P value	0.521157

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.0 Introduction

This chapter presents the conclusions and recommendations based on the results obtained from the data analysis.

5.1 Conclusions

The global concern on climate change and its implication on agriculture, which is the most vulnerable sector to climate change, prompted the present study on the assessment of weather and coffee production trends in the district of Zombo. At the same time, climate has continuously been adversely changing over time. Data shows that rainfall amount has been decreasing over time while temperatures have increased. This study, therefore, showed increased temperature warming and a decrease in the rainfall pattern taking place in Zombo district in the last 30 years by using the trend analysis. The climate experienced in Zombo varies in terms of temperature and rainfall. Examining temporal trends of rainfall and temperature was crucial to find out how rainfall and temperature have been varying over the years. This study showed the highest increase in temperature being in 2009. The overall result is warm nights and increasing temperatures in the study area.

It was also derived from the study that there has been a general decrease in wet years especially from the year 2000s in the area of study, this could be due to climate variability and climate change. There has been an increased rainfall in the short term compared to the long term.

Examining trends of coffee production over the period of 2010-2020 showed that coffee production increased steadily from 2010-2020.

Establishing the relationship between temperature and rainfall with coffee production found that there was a positive relationship between coffee production and temperature during the study period but the relationships were insignificant because ($p > 0.05$), this therefore led to a partial rejection of the null hypothesis and there was a relationship between coffee production with rainfall and temperature.

5.2 Recommendation

Based on the findings and conclusions presented, the following recommendations are suggested.

This study recommends that further research on the effect of rainfall and temperature on coffee production in Zombo should be analyzed in terms of the different stages of production say flowering, fruiting. In addition, farmer's perceptions on how rainfall and temperature affect coffee production should be assessed as this can contribute to the knowledge base as far as the effect of climate change on coffee production is concerned.

This study also recommends that appropriate strategies for reducing vulnerability to climate change and variability be designed. On the same note, there must be deliberate efforts for improving and protecting the environment as well as providing environmental management education to farmers.

Because this study has indicated that there was no strong evidence for attributing the trend in coffee production to climate change and variability meaning that the trend could be attributed to other factors, further research is recommended to study the interaction between and among various socio-economic factors and climate variables and their implications in coffee production in the study area and other coffee growing areas in Uganda.

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