CLIMATE VARIABILITY AND ITS EFFECTS ON SMALL-SCALE TEA PRODUCTION IN KISII COUNTY, KENYA

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A Thesis submitted to the School of Post Graduate Studies in partial fulfilment of the requirements of the Degree of Doctor of Philosophy of the School of Arts and Social Sciences, Department of Geography

Kisii University

MARCH, 2022

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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DEDICATION

This work is dedicated to my parents, Mary and the late Joseph Nyaiyo for laying the basic foundation of my education. I also, dedicate this work to my husband Vincent Onditi and my children Brian, Mildred and Bradford for the social and moral support accorded in this endeavor.

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ABSTRACT

Climate variability has affected the economies and agricultural sectors of the world in the 21st century negatively. This is because crop growth, development and subsequent yields depend on climatic conditions such as seasonal temperature, rainfall amounts, distribution and reliability. Currently, climate variation and change have become a global challenge and have no spatial boundary. These have had profound negative effects on the economies of the world and in particular tea production. Severe weather such as torrential rains, dry spells and hailstones have become frequent and these have affected tea production. Kisii County's tea farming largely depend on rain-fed conditions which are affected by the weather instabilities that cause climate variability, leading to fluctuations of diverse crop production and particularly tea yields. This study examined the effects of climate variability on small-scale tea production in Kisii County. The objectives of the study were: to examine the trends of temperature, precipitation and tea yields from 1995 to 2019 in Kisii County; to evaluate the effects of rainfall and temperature variations on tea yields in Kisii County; to assess the perception of tea farmers on the effect of temperature and rainfall variations on tea production and; to evaluate mitigative measures put in place by tea farmers to curb the effects of climate variability in Kisii County. The study adopted a correlational research design to examine the relationship between rainfall and temperature variations and tea yields. The study targeted 120,000 small-scale tea farmers, Kisii Meteorological Department and six Kenya Tea Development Agency factories in Kisii County. The sample size was 400 small scale tea farmers and three KTDA factories. Inclusion and exclusion criteria were used to choose three factories, while random sampling was used to select 400 small scale tea farmers. The study used questionnaires to collect primary data from small-scale tea farmers and document analysis was used to collect secondary data. Interview schedules were used to collect data from the field service coordinators. Data collected from questionnaires was analyzed using measures of central tendency and presented in line and bar graphs, tables and pie charts. Mann-Kendall (MK) test and Sen's slope was used to detect trends of meteorological variables while Karl Pearson Coefficient of Correlation was used to analyze the effect of rainfall and temperature variation on tea production. The results indicated that there was a significant negative rainfall trend for January where rainfall had been decreasing at an average of 3.415 mm during the study period. Temperatures also depicted a positive trend though only trends for January and July were statistically significant ($p<0.05$). Concerning tea yields, there were negative significant trends in February, March, June, July and December. The study will be significant to tea farmers and will contribute to existing literature. The study recommends that farmers should keep records of monthly tea production, harvest water during the rainy season, and use protective clothing, cloves, overalls and caps to keep warm during the cold season and conserve soil moisture through mulching. The study suggests that a comparative study be done in other counties in Kenya

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LIST ACRONYMS AND ABBREVIATIONS

AFFA	Agriculture, Fisheries and Food Authority
ASDP	Agricultural Sector Development Support Program
CV	Coefficient of variation
DSSAT	Decision Supporting Framework for Agro-Technology
EATA	East African Tea Association
ENSO	El Niño-Southern Oscillation
FAO	Food and Agricultural Organization
FAOSTAT	Food and Agricultural Organization Statistical Databases
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
GOK	Government of Kenya
IPCC	Intergovernmental Panel on Climate Change
JA	Jasmonic Acid
KALRO	Kenya Agricultural Livestock and Research Organization
KMD	Kisii Meteorological Department
KNBS	Kenya National Bureau of Statitics
KTDA	Kenya Tea Development Agency
MK	Mann-Kendall

MVT	Monthly Variation in temperature
NACOSTI	National Commission Science and Technology Innovation
NASA	National Acronautics and Space Administration
NGOs	Non-governmental organizations
PPM	Part per Million
PRECIS	Providing Regional Climates for Impact Studies
ROK	Republic of Kenya
SAT	Surface Air temperatures
SPSS	Social Package of Social Sciences
SSA	Sub-Saharan-Africa
TAPRA	Tegemeo Agricultural policies Research and Analysis
TEK	Traditional Ecological Knowledge
TRFK	Tea Research Foundation of Kenya
TRI	Tea Research Institute
UKCIP	UK Climate Impact Programme
UNEP	United Nation Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development

VAR Vector Auto -Regressive

WMO World Meteorological Organization

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Climate variability has seriously affected the economies and agricultural sectors of the world in the 21st century (FAO, 2018: Muoki, 2020). This is because crop growth, development and subsequent yields depend on climatic conditions such as seasonal temperature, rainfall amounts, distribution and reliability. These variations affect the quantity and quality of crop yields (Kabubo- Mariara & Karaja 2007; Di Falco & Veronesi, 2013; Attavanich & Mc Carl, 2014; Serdeczny et al., 2016; Pereira, 2017; Somboonsuke, Phittayaphinant, Sdoodee & Kongomance, 2018; Yamba et al., 2019). IPCC, (2019), has observed that food security in the world has been threatened by changes and variations in climate majorly because of variations in temperatures, unreliable rainfall cycles and greater frequency of some severe weather events with these changes differing in many regions of the world. It has also been observed that outputs for crops such as cereals have decreased in low latitude areas while the output of the same crops have increased in many higher-latitude regions over recent decades.

Further, it has been noted that climate extremes have been on the rise since the 19th century (Asadieh et al., 2016). The evaluation report by IPCC shows that in many nations of the world temperatures have risen, prolonged dry spell and rainfall phases have been experienced (Mann & Gleick, 2015; Campell, Vermeulen & aggarwal, 2016; IPCC, 2019), which have had serious effects on crop production. Changes in these climatic elements have affected natural ecosystems, food systems, livelihoods, infrastructure and cash crop production (IPCC, 2019). Climate variability which is measured in terms of climatic anomalies, such as floods and prolonged droughts as observed since 1950s, have been attributed to anthropogenic influences have led to the increase of global mean surface temperatures (IPCC, 2014; 2019) which have affected crop production. Further from 1970 it has been observed that worldwide arid-like conditions have risen drastically as evidenced by drought which has been experienced areas found in South part of Europe, East and South Asia, East parts of Australia and Africa with dry areas increasing from seventeen percent in 1950 to about twenty seven percent in 2000 (Dai, 2010, 2011).

In Thailand, climate variability has had tremendous impacts on agriculture in many parts especially Southern part of the country including Songkhla Lake Basin. This is attributed to increased temperatures, irregular rainfall patterns, abnormal tropical storms and severe flooding (Somboonsuke, Phittayaphinant, Sdoodee & Kongomance, 2018). In California, climate variability evidenced by prolonged droughts from 1995 to 2014 has also had negative impacts on the agricultural sector. These droughts are caused by increase of temperatures as a result of anthropogenic activities (Diffenbaugh, Swain &Touma, 2015; Mann & Gleick, 2015). A study by Serdeczny et al. (2016), shows that in Sub-Saharan Africa crop production has been affected by climate variability and change as a result of increase in temperature, rainfall variations and patterns, severe weather events and rise of water levels in the sea.

According to the World Meteorological Organization (WMO, 2018), the physical signs and socio- economic impacts of climate variability and change are accelerating as increase in greenhouse gas concentrations drive global temperatures towards increasing dangerous levels. Studies have shown that in the last a hundred years, world temperatures have increased by 0.74^0 c (GoK, 2017). The IPCC fifth report (AR5) has indicated that the last thirty years have been warmest as per the records from the meteorological data with each preceeding decade being warmer than the previous (IPCC, 2014).

Changes in precipitation patterns have increased short- term and long-term failures and rises in crop production (IPCC, 2007). Most tea growing countries have experienced drastic reduction in tea production which may be attributed to variations of local climate variation and other factors such as soil health and agronomic practices (Owour et al., 2011; Bore, 2015). It has been noted that in India, warmer monthly temperatures and precipitation variability and in particular intensity affect tea yield negatively (Duncan et al., 2016). Also, Gawahati, (2013) as quoted by Bett (2018) noted that tea production in India is expected to consistently pick up from the month of April but due to variation of weather conditions in the preceding months of February and March, there has been drastic fluctuations in production. Further, heavy precipitation and high temperatures lowers production and tea quality (Nianthi, 2018).

Extremely high daytime temperatures damage and occasionally make the tea plant to wilt and dry (Lehmann, 2011). It has also been observed that variations in rainfall and temperature can lead to the multiplication and growth of weeds and diseases causing organisms like pests and diseases which makes it expensive to control them (FAO, 2016). Further, it has been noted that increase in the population of tea mosquito bugs which affect tea leaves is associated with higher temperatures, humidity and rainfall (Roy, 2015; Reay, 2019). These changes in precipitation and temperature variations are brought by the El Nino Southern Oscillation and have affected most crop species and the entire ecosystems, human economy and society at large (IPCC, 2007).

Agriculture is the mainstay of local livelihoods and a major contributor of income and Gross Domestic Product (GDP) especially in developing economies in Africa. But it has been observed that most of these countries are vulnerable to climate variability and change, which results from over dependence on rain-fed conditions and lower capacities in adaptability

(Belloumi, 2014; Mendelsohn, 2009; Muema, Mburu, Coulibaly, & Mutune, 2018). As a result of the above, climate variability has posed a major challenge in many sectors of Sub-Saharan Africa (SSA) countries including agriculture as its effects are manifested by droughts, floods and unpredictable rains (FAO, 2016; IPCC, 2001).

Observational records have also shown that during the 20th century the temperatures in the African continent rose by about 0.05°C per every ten years with slightly higher temperatures in the season from June to November as compared from December to May (Hulme et al., 1998; IPCC, 2001). Such extreme temperatures affect the rate of plant development which in turn affect crop yields (Hatfield & Prueger, 2015). It is reported that the warmst years were 1988 and 1995 in the 20th century. The same trend was experienced worldwide with rapid increase in temperature being experienced from 1910 to 1930 and post 1970 (IPCC, 2001). The WMO report and NASA have also indicated that the years that is 2015, 2016 2017 and 2018 were warmest in record with the global average temperatures in 2018 being higher in nearly 140 years of records kept (WMO, 2019).

These changes in temperatures have affected precipitation patterns which in turn has affected crop productivity. It has also been noted that the patterns of the average and maximum temperatures in tea producing regions have undergone marked changes in the recent past (Dutta, 2014). Further, extreme weather events, such as drought, heavy, torrential rains and frosts, have become more frequent, and these phenomena have had negative effects on agricultural systems in general and on tea production in particular (Bett, 2018; FAO, 2016; Gunathilaka, Smart & Fleming, 2017).

Climate variability and change have been experienced in East Africa as clearly shown by the disappearance on snow from the Mountain tops of Mount Kenya, Ruwenzori and Kilimanjaro.

Further climate data has revealed that temperatures have increased by between 0.9^0c and 1.2^0c while rainfall has declined at an average of 20 to 100 millimeters for every ten years (USAID, 2017). Climate forecasts and predictions in the region have indicated that areas receiving high rainfall are likely to become wetter while arid and semi-arid regions are expected to become drier (Orindi & Eriksen, 2005). These changes in rainfall patterns and temperature variations in East Africa have had profound effects on agricultural production and ecosystem services.

In Kenya, climatic variability and change have threatened crop production through unreliable rainfall, increased temperatures and insufficient soil moisture. Temperature increases have been observed across all seasons, in western and central parts of Kenya, especially from March to May and the long rainy season has become shorter and drier, and the short rainy seasons have become longer and wetter while the annual rainfall remains low (Ayugi & Tan, 2018; GOK, 2018; Sagero, Shisanya & Makokha, 2018). According RoK (2013) temperatures have increased by 0.7^0c- 2.0^0c over the last forty years. A study conducted by Ochieng, Kirimi and Mathenge (2016) in Kenya has revealed that variation and change in climate have adversely affected the agricultural sector and the situation will worsen in future as a result of these variations.

Since 1960s, minimum and maximum temperatures in Kenya have increased by approximately 1.0^0 c at an average rate of 0.21^0 c for every ten years. Precipitation fluctuations have been experienced with rainfall extremes of greater intensity being experienced (World Bank, 2020). Data obtained from the Kenya Meteorological Department (KMD) has shown an increasing trend of temperature since 1960. In the continental areas, both minimum and maximum temperatures have increased (GOK, 2017). Further, droughts have been experienced after every 3 to 4 years and utmost droughts occurring every ten years since 2000

(NEMA, 2015). These climate variations have affected rain-fed agriculture which supports a large portion of the Kenyan population. About seventy five percent of Kenyan people depend on agricultural foods and earning from cash crops that contributes twenty six percent of the Gross Domestic Product and sixty percent of the foreign exchange earnings (Perret, 2006). These climate variations have potentially affected agricultural production which essentially affects the rural economy, food security, and balance of trade leading to reduced foreign exchange earnings (Kariuki, 2016). A study by Thornton (2011) found out that climate change has negatively affected crop production in Kenya due to dominance of rain-fed agriculture, low adaptive capacity, and inadequate funds to cope with these changes.

In Kenya, an estimated 560,000 smallholders account for 62% of total tea production. But research has shown that regions of the world which relie on rain fed have been affected by climate variability (Thornton, Ericksen, Herrero & Challinor, 2014). Further, changes and variations in climate have endangered the lives of smaller holder farmers because most of them rely on rain-fed agriculture and financial support that can help them invest in more climate resilient agriculture (Morton, 200; Holland, 2017). During the recent years, the tea industry has been faced with challenges such as; low yields from smallholder farms, high cost of production and impacts caused by climate change and variability (Nyaga, 2017).

In Kenya tea is grown in several sub counties which include Kericho, Bomet, Nandi, Kiambu, Thika Maragua, Sotik, Muranga, Kisii, Nyamira, Nyambene, Meru, Nyeri, Kirinyaga, Embu, Kakamega, and Trans-Nzoia (Gesimba, Liu, Langat & Wolukau, 2005). Although, these sub counties that grow tea receive adequate amounts of rainfall, prolonged drought which occur during some months of the year, yearly and after three to four years (USAID, 2017; Kogo, 2020), high intensity rains, hailstones and frosts (Muoki, 2020), have affected production leading to fluctuations in output which can be as high as between 285 million to 300 million kilograms per year (Gesimba et al., 2005; USAID, 2017*)*. It has also been noted that Kenya will continue experiencing losses in production due to rainfall and temperature variations (Herrero et al., 2010).

In Kisii County, smallholders play an important role in tea sub-sector and other parts of the world. Tea production in this County mainly rely on rain-fed conditions which is highly vulnerable to environmental instabilities (FAO, 2016; CIAT, 2019). Weather instabilities such as heavy and unreliable rainfall and extreme temperatures have been experienced (ASDP, 2014). Agriculture, Fisheries and Food Authority, AFFA, (2014) has noted that over the last decade, tea production per hectare has been fluctuating in tea growing regions of Kenya. Despite the debate on climate variability and crop production, most studies have been carried in the arid and semi-arid areas and others in tea estates (Bett, 2018). Only a few studies have analyzed variation in temperature and rainfall on tea production in the last thirty years in Kisii County. Lesthatma (2017) who did a study on the suitability of tea growing area in Kenya under changing climate. It is on this basis that this research was conducted in Kisii County to evaluate the effect of climate variability on fluctuations of tea yield in the County.

1.2 Statement of the Problem

Tea production in the world depends on stability of weather as the crop is cultivated under rain fed conditions. Currently, climate variation and change have become a global challenge and have no spatial boundary. This has affected crop production from region to region in different ways. In the Asian and African continents, tea farming is a major source of livelihood for millions of people, but in the past three decades, tea growing countries have witnessed disturbing trends of decline in tea yield and its productivity (FAO, 2016). Studies have indicated that Kenya has been experiencing increasing temperatures and decreasing trends in annual rainfall with high variability within seasons in many parts of the country (Government of Netherlands, 2019; USAID, 2018). Leshamta, (2017) and Kenya Meteorological Department (2020) that have shown in Kisii County Day time temperatures have increased by 0.5^0c and minimum temperature by 0.6^0c and; increased inter-annual rainfall variability and increased recurrency of extreme climatic episodes such as floods and droughts. These have affected tea production which in turn affected small scale tea farmers who have limited options as they rely on rain–fed conditions for their production.

As a result of this, smallholder tea farmers who depend on rains for their tea production have become more vulnerable and experience unsteady production as revealed by Kenya Tea Development Agency and Tea Directorate in table 1.1

Table 1.1: Tea Production in Kenya for selected years for smallholder, Kenya Tea Development Agency (KTDA)

Year	Production in kg	Area in hectares	Production in kg per hectare
1995	138,945,451	80,355	1729
1996	144,070,653	81,159	1775
1997	129,707792	84,657	1532
1999	153,855,363	84, 658	1817
2000	145,546,258	85,085	1710
2001	181,725,815	85,511	2125
2004	192,552,108	87,954	2189
2005	197,721,421	92,682	2133
2006	191,177,061	95,779	1996
2013	249,835,115	127,352	1961
2014	262,418,610	128,621	2040
2015	237,596,298	134,187	1770
2016	265,609,320	138,382	1919
2017	246,127,077	141,150	1743

Source: East Africa Tea Trade Association, EATA (2015), AFFA, 2014, Tea Directorate, 2019

From the table 1.1, it is evident that even though land under tea acreage is increasing production has been fluctuating. Though, Bett (2018) has done a study on the effects of climate variability on tea production in the tea estates of Kericho County; Leshamta (2017) has examined the suitability of tea-growing zones in Kenya under changing climate and Otiso (2016), examined the effects of rainfall on farming practices among households of Kisii Central Sub- County, there is no known study that has typified the association of climate variability and tea yields in Kisii County. To fill this knowledge gap, the study correlated the effect of climate variability on tea production in Kisii County.

1.3 Justification for the Study

Climate variation has led to declining agricultural production in Kenya. The majority of the Kenyan population depend on rain-fed conditions whereas their economic, social, political and technological advancements in adaptation to climate variability and change is low. Forecasts and analysis on climatic trends from the past to the present times have shown that small-scale farmers in Africa, Kenya included are vulnerable to dangers posed by climate due to their low adaptive capacity.

Kisii County largely depends on rain-fed conditions which are highly vulnerable to environmental instabilities. Temperature and rainfall variables were selected because of their effects on crop productivity. Variation of these climatic elements interfere with tea yields and in the long run affects production hence the livelihood of the small-scale tea farmers. The period from 1995 to 2019 was selected because it is representative of the current average climate of the study region, it includes the current climate variations as it encompasses enough climate anomalies and lastly a period for which data of the climatic parameters was available.

Tea was considered because it is one of the largest enterprises in Kisii County upon which a large number of families depend on as a source of livelihood. Presently, anthropogenic activities have triggered global warming, leading to variation and change of climate in different parts of the world. These variations and changes in climate pose a major threat to the resilience of agricultural systems where tea is included as a result of increased periodicity of extreme events. Further, increased temperatures, unreliable rainfall distribution, coupled with major shifts in other meteorological parameters in comparison with long term observations have further complicated the agricultural activities.

Kisii County as an area of study was chosen because few studies have been done on climate variation and crop production (Leshamta 2017 and Otiso 2016). This study therefore examined the correlation between temperature, rainfall and tea yields.

1.4 Purpose of the Study

The purpose of the study was to examine climate variability and its effects on small-scale tea production in Kisii County

1.4.1 Specific Objectives for the Study

The study was guided by the following specific objectives:

i) To examine the trends of temperature, rainfall and tea yields from 1995 to 2019 in Kisii County.

ii) To evaluate the effect of temperature and rainfall variations on tea production from 1995 to 2019 in Kisii County.

iii) To assess the perceptions of tea farmers on the effect of temperature and rainfall variation on tea production in Kisii County.

iv) To evaluate mitigative measures put in place by tea farmers to curb the effects of climate variability in Kisii County.

1.5 Study Hypotheses

The hypotheses of the study were:

H_{01}**:** There is no trend for temperature, rainfall and tea yields from 1995 to 2019 in Kisii County.

H_{02}: There is no significant effect of temperature and rainfall on tea yields from 1995 to 2019 in Kisii County.

1.6 Research Questions

i). What are the perceptions of farmers on the effect of temperature and rainfall variation on tea production in Kisii County?

ii). What are the mitigative measures put in place by tea farmers the to curb the effects of climate variability in Kisii County?

1.7 Significance of the Study

Impacts of climate variation on tea productivity have had major economic implications. Results from this study will contribute to initiatives geared towards enhanced tea productivity by both farmers and policy makers over the area of study and in the whole country. The findings from this study will be of great importance to farmers, agricultural policy makers, general public and people carrying out research as follows: It will help farmers to identify sustainable adaptation strategies and diversify their farming activities, policy makers in the Ministry of Agriculture and County Government to adopt policies which will enhance sustained production, it will also contribute to existing body of knowledge on the effects of rainfall and temperature variation on tea production and generate ideas for further research and scholarly reviews.

1.8 Assumptions of the Study

The study was guided by the following assumptions:

i) Farmers had the knowledge and were willing to give the required information.

ii) Meteorological data for rainfall and temperature were available for the stipulated period from 1995 to 2019

iii) Data for tea yields from the factories was available for the stipulated period from 1995 to 2019

1.9 Scope and Delimitation of the Study

The study only focused on climate variability and its effects on tea production in Kisii County. The climatic variables used were mean monthly temperature and rainfall from 1995 to 2019 which were obtained from Kisii Meteorological Department. On tea production, total monthly yields from 1996 to 2019 obtained from KTDA factories were used. The study targeted small-scale tea farmers who sell their yields to KTDA in Kisii County.

1.10 Limitation of the Study

Some tea production data was missing for some factories but the researcher made use of the available data. Since the research was done during the time there were changes in the management of KTDA, some managers of the factories were afraid that the research was done for the same but the researcher explained that the study was purely academic. Further, this study was done during the Corona virus (Covid-19) pandemic and some respondents felt that their lives were put at risk, but during interactions both the researcher, the assistants and the farmers observed the Ministry of Health safety guidelines such as keeping social distance, washing and sanitazing hands in addition to wearing masks at all times.

1.11 Theoretical Framework

The study was guided by two theories:

1.11.1 Anthropogenic Global Warming Theory

It is a theory that explains the long-term increase of average temperature in the earth's troposphere as a result of man's engagement in industrial and agricultural activities (Lawrence & Mao, 2019). This theory was advanced by Bast, (2010) and it asserts that anthropogenic activities are responsible for the increase of greenhouse gases especially carbon dioxide (Co_2) which has led to global warming. For over a century, scientists have been concerned that as the increase of greenhouse gases from industrial and agricultural activities in the atmosphere increase, so will the troposphere's temperature increase.

According to Manstrandrea and Schneider, (2009); Martin, Kathrin and Ulrich, (2009), anthropogenic activities such as burning fossil fuels are responsible for the global warming experienced in the world today which has led to about 40 % increase in carbon dioxide in the atmosphere. Further, in support of the above, Oreske and Conway, (2008) have estimated that the concentration of carbon dioxide has increased from 280 parts per million (ppm) in the pre-industrial period to about 385 ppm in the present. This has led to variation and change in the climate.

This theory was applicable to this study because anthropogenic activities are responsible for changes in temperatures and rainfall patterns in the troposphere of any given area. This has led to climate variability and change which have affected various agricultural activities in terms of production across the world including tea. Increased temperatures result in high evapotranspiration rates in plants which eventually lead to withering and sometimes drying of crops when such conditions are experienced over long periods. The variations of these temperatures also lead to fluctuations in rainfall patterns thus affecting crop productivity. Though the theory explains the causes of global warming, it does not give solutions to the ways to curb and cope with global warming. This, therefore, calls for a second theory.

1.11.2 Action Theory of Adaptation to Climate Change

This theory was developed by Klaus & Stecker, (2010). The theory asserts that adaptations are processes of entities and systems or adjustments of human activities. Adaptation is a process that may help in reducing harm or risk or maximizing benefits associated with climate variation (UKCIP, 2004). Adaptation can be viewed as having three dimensions namely:

changes in social and economic development which ensure outputs and outcomes are sustainable from a climate variation perspective; adaptation in terms of preparedness for and being ready to deal with natural disasters that may increase in intensity due to climate variability; and resilience of population and societies to solve unexpected occurrences in their environment (Uitto, et al., 2017). This theory asserts that there must be a deviation from the statistical average in a climatic variable which will pose an effect on crop production. The effect is felt by the farmer who will use knowledge and resources to adapt to climatic change or reduce the harm caused by the change. In this study, this theory formed a basis for farmers' adaptation strategies and mechanisms for opting for measures to take to ensure continued and sustainable tea production despite climate change and variability.

1.12 Conceptual Framework

The study examined climate variability and its effects on small- scale tea production in Kisii County. The independent variable was climate variability and the dependent was tea production.

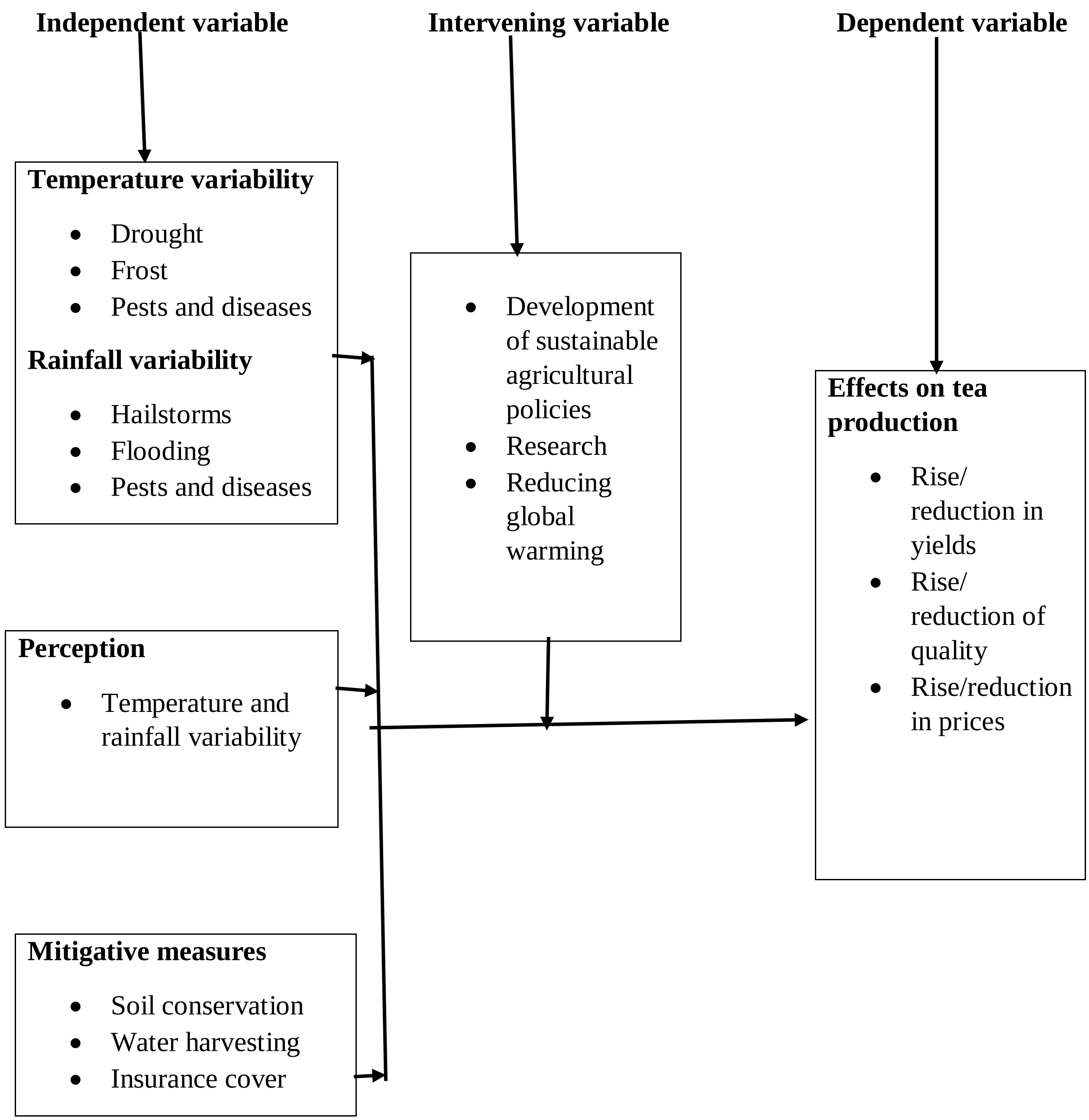

Figure 1.1: Conceptual Framework
Source: Researcher, 2020

The concenceptual model in figure 1.1 shows the relationship between the independent variable climate variability and dependent variable, tea production. Climate variability refers to the short or long-term fluctuation of climate variables such as temperature and rainfall from their mean. This study examined the effect of temperature and rainfall variability on tea production. Temperature variability leads to droughts and frost- like conditions which affect tea production negatively. Rainfall variability leads to flooding and falling of hailstones which damages the tea crop leading to reduced yields. But if the floods are controlled by harvesting and storing rain water, it can be used during the dry period to irrigate the farms.

Farmer's perception on climate variability forms the basis on which mitigative measures to be put in place to curb the effects caused on tea production. Therefore, farmers need to perceive variations on temperature and rainfall then, find the best ways to cope with these variations. Farmers curb the effect of climate variability through soil conservation, water harvesting and insuring their crop. Development of agricultural policies, reduction of global warming and research moderates the effect of rainfall and temperature variability on tea production for continued sustainable outputs.

1.13 Operational Definition of Key Terms

Adaptation: Act of getting used with variations in climate by moderating negative effects and exploiting benefits attached to the variations. These include activities that reduce a population's vulnerability to climate variability and change.

Anthropogenic emissions: Release of green house gases to the atmosphere as a result of human activities such cutting of trees, animal husbandry, industrialization and burning of fossil fuel.

Climate change: Refers to increase in global temperatures that to has triggerd changes in rainfall patterns

Climate variability: refers to climate variability refers to fluctuations of rainfall and temperature over a given period of time.

Coping capacity: The means by which a population use available resources and abilities to face adverse climatic conditions that can be hazardous to their wellbeing. It involves the management of resources sustainably thus building resilience to overcome the effects caused by climate variation.

El Niño-Southern Oscillation (ENSO): This is a climatic event with three phases (El Nino, Lanina and Nuetral) which is caused by fluctuations of the inter-tropical surface pressure patterns and wind circulations over the Indian and Pacific Ocean. El Nino is the warming phase of the ocean surface, La Nina is the cooling phase of the ocean surface and Neutral the Tropical Pacific Sea surface temperatures (SSTs) are near to the average (IPCC, 2007).

Heat waves: A period of abnormally hot weather

Rural livelihood: Means of securing the necessities of life in the rural areas.

Small-scale: Tea acreage below four acres

Temperature Variability: Fluctuations in temperature amounts at a given location across a region for a specific time interval.

Rainfall Variability: Fluctuations of rainfall amounts from the mean in a given location across a region for a specific time interval.

Perception: It refers to the opinion of farmers towards climate variation and its impact on agriculture

Production: refers to the green tea harvested from the farms.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This section presents literature review related to the effects of climate variability and tea production. This chapter first discusses about tea production and climate variability. The second part discusses on the literature related to the study objectives on temperature, rainfall and tea variations; effects of temperature and rainfall variation on tea production; perception of farmers on climate variability; coping and adaptive strategies to climate change and variability.

2.1 Tea Production in Kenya

The tea plant is a slagging tree of the flowering plant genus of the *Camellia*, which is in the group of the Theaceae family (*Camellia Sinensis*). The shrub/tree grows to around 2-2.5 metres in height. According to Agriculture, Forestry and Fisheries (2016) there are three major types of tea in the world which are Chinese (*C.s Sinensis*), Assam (*C.s assamia*), and Cambodian (*C.s lasiocalyx*). In Kenya, the Assam variety is widely planted due to the production of high yields (Rwigi et al., 2009). Many clones have been developed vegetatively to suit the climatic conditions in Kenya by the Tea Research Foundation of Kenya (TRFK). Through this, high yield and well-fitted 50 varieties have been developed to fit specific areas (Tea Board of Kenya, 2012).

Kenya's Tea Board (2012) stated that tea is among the highest foreign exchange earner in the country. Tea exports account for twenty percent of total Kenyan exports, globally, twenty-six percent of tea exports and ten percent of tea output worldwide following China and India with thirty-four percent and twenty-four percent of world tea output respectively. Currently 62 percent of tea is produced by the Kenya Tea Development Agency (KTDA) Limited, which processes and sells its crop. KTDA is operated by small farmers, making it the world's largest single tea producer. The 38 percent balance is generated by the large estates, controlled by major multinational corporations. The tea sector employs directly and indirectly, about five million people. Tea cultivation and production primarily take place in rural areas of Kenya and contribute greatly to rural communities as it is a source of income to many people

According to a study by Rwigi et al. (2009), tea grows well worldwide at an altitude of 1200 meters above sea level and above in the subtropics and highland regions in which the tea growing regions of Kenya lie. It is grown in, the Great Rift Valley, the Hoods of Aberdare, Nyambene Hills, Nandi Hills, Kericho, Mount Elgon, and the Kisii highlands. These areas lie between 1500 and 2700 meters above sea level with a favorable climate for tea growing. Tea grows best in areas with well drained tropical volcanic soil of ph 4 to 5.6, rainfall ranging between 1200 millimeters and 1400mm, which should be well distributed throughout the year (Kamunya et al., 2019; Rwigi et al., 2009). These conditions encourage the growth of tea in Kenya.

Ochieng et al. (2016) stated that tea growing is dependent on air and soil temperature, precipitation, humidity, soil water, radiation, sunshine and evaporation hours. Seasonal shifts in climate parameters such as precipitation, temperature, solar radiation and moisture have a major impact on tea production (Biggs et al. 2018; Marx et al. 2017). The climatic requirements of the growth of tea plants are rainfall that is well distributed throughout the year, minimum temperature between 13 degrees Celsius and 14 degrees Celsius and a maximum temperature between 18 degrees Celsius and 30 degrees Celsius in order to obtain to optimal shoot growth. Extreme temperatures affect the rate of shoot development which in turn affects tea yields negatively.

High temperature coupled with low humidity result in osmotic stress which induces biochemical and physiological effects on the quality and amount of tea yields (Cheserek, 2013). Furthermore, higher temperatures result to high evapo-transpiration rates which leads to reduction of soil water required for tea growth, thereby reducing the quality and amount of tea produced. Likewise, theoretically, low air temperatures on high altitudes can cause growth rates to drop hence reduction of yields. Although events like droughts, floods, hailstorms, frost and landslides cause harvest damage and failure, changing precipitation patterns create uncertainty as to when fertilizers are to be applied (Cheserek et al., 2015; Ng'etich, 1995).

It has been noted that tea growing areas in Kenya experience a dry spell between December and March which affects tea yields. (FAO, 2015). These effects of climate change and variation differ from region to region in relation to the period and severity of the climate change effect. Certain areas that grow tea which include Nandi, Kericho and Gucha, may not be suitable for tea growing because of expected rises in precipitation and variability of temperature and farmers may have to shift to planting alternative crops. By 2050, these areas are projected to decrease by about 40 percent as a result of increase in temperature and rainfall in the cold season. Other areas that will remain stable, including Bomet, Kisii and Nyamira because of increase of rainfall in the wet season. Further, it has been noted that by 2050, areas around Kenya's Mountain and higher altitudes could see the potential rise by around 15 to 20 percent in suitability in planting the tea crop, (CIAT, 2011).

2.1.1 Climate Variability in Kenya

In Kenya, the most extreme episodes are ElNiño (1997/98) and La Niña (1999/2000) and complex cycles of climate variability have occurred (Stockholm Environment Institute, SEI, 2009). Since the 1960s Kenya has typically experienced an increase in average temperatures by 0.21 degrees Celsius, with trends in minimum and high temperatures reflecting global warming over time. The highest annual precipitation events are showing a decline in the 24-hour rainfall and the long rain season recorded between 1960 and 2014 (ROK, 2016; Osbahr &Viner, 2006).

Temperature and rainfall variations in coffee and tea cultivation areas were determined by the use of data from meteorological stations of Kisii, Kabete, Kericho, Nyeri, Kakamega, Meru and Embu Counties. The annual average temperature variation for the period from 1970 to 2014 suggests that the temperature have varied significantly, with variations up to minus 2.8 degrees Celsius and more than one degree Celsius. These meteorological stations are situated in regions where tea is grown. The disparity in precipitation levels from the average annual rainfall from 1970 to 2014 indicated that droughts and flooding conditions affected crop production. These changes were a result of variations in the amount of sunshine hitting the earth's surface and circulations in the atmosphere and oceans. The weather conditions vary from season to season depending on the atmospheric-ocean circulations. The fluctuations reflect the events of serious weather in Kenya. For instance, in 1971/73, 1983/84, 1991/92, 2004-2006, and 2008-2010, according to Rarieya et al. (2009) and KIPPRA (2013) there have been severe droughts and flooding, that are closely connected to the events of El Nino. These El Nino phenomena are also linked to the 2012 frost, which also occurred in 1997/98 and 2002 and had profound effects on crop production.

According to a study by Mutua and Runguma (2020) episodes of prolonged drought occurred in the twenth century along the Kenyan uplands and regions along the coast. IPCC (2007) has futher indicated that weather and climate has varied from the normal means with temperature increasing and extreme precipitation occurring frequently. These changes have affected agricultural production in Kenya. These changes have exposed the Kenyan population to hunger and poverty (Ochieng, Kirimi & Mathenge, 2016)

2.1.2 Agricultural Sector and Climate Variability in Kenya

The agrucultural sector play a pivotal role in the Kenyan economy. It contributes 26% to the national GDP and through other linkages with other sectors 27% of the GDP. The sector employs 40% of the total population and more than 70% of the rural population (ROK, 2020; FAO, 2021). The rain-fed agricultural sector accounts for about 98% of the farm produce in Kenya (UNEP, 2010). It heavily relies on predictable rainfall and temperatures, suffers most from climatic fluctuations thus affecting the livelihoods of most households who depend on rain-fed agriculture (Kakubo-Mariara 2007). In Kenya, climate change is already evident in shifting precipitation patterns and severe events such as floods, droughts, and heatwaves that are more frequent and unpredictable (Badege et al., 2013). It is estimated that the increased frequency of these events has impacted the region's local crop production (IPCC, 2007). Kenya's agricultural sector is especially vulnerable to weather adversity, not just because it is rain-fed but also because it is subsistence-oriented.

Empirical findings indicate the current climate instability caused by regular floods and droughts, increases the cost of production and mitigation (SEI, 2009). The effects of changes of climate in Kenya were examined by Downing et al. (1997) and findings showed that high temperatures would have a positive effect in highlands, but a negative effect in the lowlands and semicircular regions. Also, with the rise in temperatures and rainfall, theoretically food production will increase, but yields would decrease due to low precipitation in semi-tropics. The overall effect of global climate change on Kenya's food production was indicated by Fischer and Van Velthuizen (1996). The study concluded that production increases would result from a rise in carbon dioxide and temperature if, precipitation also increases.

According to Adger (1999), the fundamental cause vulnerability is the central feature of a vulnerability constitution, which is social vulnerability to climatic change. This encompasses the ability of people to externalities. In Kenya smallholder farmers diversify into off-farm work, to respond to climatic extremes (Downing et al., 1997). In adaptive micro-level adaptation interventions, market reactions, technological developments and structural improvements, demonstrated their broad capacity to reduce the impact of global warming and climate changes (Mariara & Karanja, 2007),

Short-term climate change in Kenya has been experienced with the majority of farmers witnessing increased temperatures by taking some measures to accommodate demands and adaptations in various sectors (Ndukhu et al., 2012). The effect on medium and low possible areas of climate change will be more negative (Kabubo- Mariara & Karanja, 2007). The farmers also predicted that Kitui County would dry up and that rainfall would drop to 34 mm annually (Oremo, 2013). The Oremo studies examined the ratio of rainfall to maize yields through cross-sectional data for the region, without taking equal temperature variations affecting maize productivity into consideration.

Although Kabubo-Mariara and Karanja's (2007) survey presents the most detailed survey of climate change impacts in Kenya, there still remain several important gaps in the current study to resolve. First, without taking time into account, Ricardian's study estimates climate effects on crop net space revenues. The TAPRA Data Panel Package takes account of adjustments to household revenues (Muyanga & Jayne, 2017) and will contribute to the debate, precipitation and temperature over time and space and allowing for evaluation of any fluidity over time in these primary indicators. The results for select main crops in Kenya, maize and tea are further evaluated, although most studies of climate model research only have an impact on crop income. The breakdown of revenue in crop types illustrates more the effects on tea, a leading foreign-exchange earner, that contributes about 20 percent of Kenya's overall foreign currency revenue, of variability and change in climate.

About 98 percent of agricultural activities in Kenya are accounted for by rain-fed agriculture (Turral, Burke & Faurs, 2009; UNEP, 2008; 2010), which makes the industry extremely vulnerable to rising temperatures, droughts, floods, and shifting patterns of rainfall. The consequences endanger farmers' livelihoods and are likely to impact the decisions of farming. The output of the sector of agriculture depends primarily on the production of crops, which is largely dependent on the environment. As stated by Alila and Otieno, 2006; KIPPRA, 2013; the Republic of Kenya, ROK, (2016), the rate of growth of the sector have fluctuated in the last decades. This is due to over-dependence on un-irrigated agriculture, that is highly vulnerable to unpredictable climatic conditions and increased costs in agricultural inputs.

The output of the sector fell dramatically from 4.7 percent in the 1980s to less than two percent in the 1990s, this led to a negative rate of growth in 2000 by negative 2.4 percent. Moreover, there was an increase of 4.3 percent in 2008 and 2.3 percent in 2009 in the sector's added value. The sector also registered a 1.5 percent growth rate in the year 2011, far below 6.4 percent in 2010, and growth decelerated from 5.2 percent growth in 2013 to 3.5 percent in 2014. According to the Government of Kenya, (2014), cultivation and animal production in several regions of the country were adversely affected by poor long plumage, with the North Rift region, which serves as the grain basket of Kenya, being the worst hit. As a result, the output of maize decreased, but the yields of certain food crops such as Irish potatoes rose, partially compensating for the negative effects of decreased production in maize in the sector.

According to (UNDP (2002) Alila and Otieno (2006), agricultural activities are minimally diversified in Kenya with farmers depending majorly on maize, tea, coffee, dairy, wheat and horticulture production as a source of livelihood. Furthermore, maize is the country's main staple and important for food security. Decreases in agriculture's growth among the growing population have far-reaching implications for the country on food safety, jobs, revenue generation and trade balance. It thus hampers the achievement of sustainable development Goals and Vision 2030 (Government of Kenya, 2018; UNDP, 2002; 2015). This study focused on the tea crop, given that it is important in the Kenyan economy and the livelihoods of most rural inhabitants.

2.2 Trends of Temperature and Rainfall Variation and Tea Yields

Temperature and rainfall have varied in different areas at different times over decades. This section shows evidence of temperature and rainfall variability over time.

2.2.1 Evidence of Temperature Variations

The temperature range of a given region is influenced by locations, for example on the land or in the ocean area. It has been noted that in the recent decade there has been variation in mean temperatures of many regions of the world which have led to the occurrence of droughts and floods (IPCC 2013; Ayugi et al. 2016; Alexander 2016). According to WMO, (2019), the years from 2010 up to 2019 were warmer as compared to the records of the 1980s. This is attributed to anthropogenic emmissions into the atmosphere which have led to increased temperatures. This has further triggered other changes in the global climatic systems like changes in precipitation. Over the past two million years ago, observational climatic records from weather stations on the earth's surface have shown drastic changes in climate. The average surface temperatures worldwide have rose by about 5 to 7 degrees Celsius (IPCC, 2007; Christensen et al., 2007).

According to WMO records surface temperatures have risen drastically since 1860 by 0.6 degrees Celsius worldwide. Measurements have also shown that the mean air temperatures have rose by about 0.8 degrees Celsius since the 19th century as a result of anthropogenic activities (Ring et al., 2012). It has been noted that in the 20th-century temperatures had risen by 0.6 degrees Celsius. Analysis of climatic data for the Northern Hemisphere indicates that the late 20th century was warmer as compared to the past centuries. Over the same period, the 1990s were the warmest decade, the year 1998 was the warmest and the years 2002 and 2003 the second and third warmest, respectively. However, in the Arctic area, 2005 was the warmest year with an increase of over two degrees Celsius (Przbylak, 2007).

It has been noted that 1998 recorded the highest temperature since the start of industrialization in the world. An increase in temperatures was also observed between 1910 and 1945 in which temperatures rose by 0.14 degrees Celsius and between 1976 and 1999 temperatures rose by 0.17 degrees Celsius. In contrast, the period 1946 to 1975 the Northern and Southern Hemisphere experienced lower temperatures (Salinger, 2005). It has also been recorded that surface air temperatures (SAT) raised abruptly from 1995 to 2005 in the Pacific and the Canadian region above one degree Celsius while the lowest was the Siberian region by 0.82 degrees Celsius and the highest two degrees Celsius (Przbylak, 2007).

Lobell & Ortiz- Monasterio (2007a), have noted that temperature observations and model projections have shown greater warming of daily minimum temperatures relative to the maximum in wheat-growing areas. In India, minimum and annual average temperatures have shown a gradual rise (Punia, et al. 2015). It has been estimated that in North East India, the average minimum temperature has increased by about 1.3 degrees Celsius over the last century and the annual average maximum temperature has also shown same the trends in tea growing areas (Deka et al., 2009; Kothawale et al., 2010; FAO, 2016). Temperature patterns in Assam from 1993 to 2013 in tea growing areas revealed that there was a steady increase in minimum temperatures which had a profound effect on tea yields. This is in agreement with IPCC reports. In contrast to the above, it has been revealed that temperatures have increased by about 0.71 degrees Celsius per hundred years in India from 1901 to 2007 with accelerated warming after the 1970s (Attri & Tyagi, 2010). This is in agreement with World Bank (2016) and Department for International Development (DFID), (2004) who found out that between 1960 and 2006 the Malawian annual temperature increased by 0.9 degrees Celsius. Also, the number of hot days and nights had risen independently of the season. Between 1960 and 2003 the average annual hot days and nights had grown from 30 to 41 (Resilience Policy Team-Irish Aid, 2015).

In Sri Lanka, temperatures have increased over the last one and a half centuries and the warming rate has accelerated in recent years. For instance, the mean temperature increased at a rate of 0.016°C annually from 1961 to 1980 and 0.025degrees Celsius annually from 1987 to 1996 (Esham & Garforth, 2013). This, therefore, implies that trends in temperature have varied over time in different places. The variability in temperature is the short-term variation from the normal mean temperature, such as extreme occurrence. The frost condition damages tea leaves and the roots. It also lowers the efficiency of the workers responsible for picking the tea leaves as severe cold conditions are detrimental to their health. Extreme warmth will scorch the tea leaves leading to high transpiration, an infestation of insects and pests and emergence of diseases thereby reducing tea leaves both in quality and quantity.

Widespread changes in the instrumental record of severe atmospheric conditions such as prolonged dry spells, torrential rains, hot-waves and the intensity of tropical cyclones were noted in the IPCC's Fourth Assessment Report, with these changes showing discernable human influences (IPCC, 2007). This agrees with CARE, (2009); Muller, (2009); Stringer, et al. (2009) who have noted that extreme weather conditions such as drought and flood have been noted to affect agriculture and livelihood in many ways which may not be limited to total crop failure or reduced yields and severe livestock deaths. The IPCC's Fifth Assessment Report (IPCC, 2013) noted the substantial recent progress in the assessment of extreme weather and climate events, with the simulated global-mean trends in the frequency of extreme warm and cold days and nights over the second half of the 20th century have been generally consistent with observations. Changes in temperature variations caused by anthropogenic activities have been linked to global warming. The report noted that temperature has been steadily increasing over the years by 0.74 degrees Celsius during the 20th Century (Anju, 2011).

In the African continent, many parts have experienced an increase in the mean annual temperature since 1900 (Niang et al., 2014) which is about 0.5degrees Celsius per century according to Hulme, Doherty, Ngara, New and Lister (2001). This is in agreement with Hussein (2011) who found that the increase is about 0.7 degrees Celsius during the same period. In North Africa, Barkhordarian, Bhend and von Storch (2012a) found out that annual and seasonal observed mean near-surface temperatures generally showed a warming trend above the normal variations which was as a result on natural variability. Further, it was noted that in March- April-May and June-July-August there was a rise in near-surface temperature in Northern Algeria and Morocco due to anthropogenic activities (Barkhordarian, von Storch, & Zorita, 2012b). This is supported by Vizy and Cook, (2012), who have indicated that both annual minimum and maximum temperatures showed an upward trend in the same region. Similarly, a study by Collins (2011), in West Africa revealed statistically significant warming of between 0.5^0c and 0.8^0c from 1970 to 2010 using remotely sensed data.

Since the 1980, in Eastern Africa, areas around the equator and south parts have shown a rising trend in temperature (Anyah & Qiu, 2012). This is supported by Famine Early Warning Systems Network (FEWS NET) reports which have revealed that over the past 50 years mean temperatures have rose in Kenya, Ethiopia, South Sudan and Uganda (Funk et al., 2011; 2012; Williams et al., 2012). Besides, warming of the near-surface temperature and an increase in the frequency of extreme warm events have been observed for countries bordering the western Indian Ocean between 1961 and 2008 (Vincent et al., 2011; Niang et al., 2014). This is evidenced by the disappearance of the snow caps on Mount Kenya, Mount Ruwenzori and Mount Kilimanjaro peaks (UNICEF, 2006). In Uganda, temperature records have shown sustained warming in the southern parts with minimum temperatures increasing more than maximum temperature (Government of Uganda, GOU, 2002). This is also in agreement with Omondi et al. (2014), who found out that in Tanzania the frequency of warm days and warm nights increased and Lema & Majule (2009) who found a similar trend of increased in annual temperature over Manyoni district in Tanzania.

Further, an analysis conducted in East Africa on air temperature trends in 60 stations across Kenya found that there is a significant upward trend in minimum temperature in the Kenyan highlands where Kisii is included (Christy et al., 2011; Wachakala et al., 2015). This is in agreement with Omumbo et al. (2011) who found that mean temperatures had increased by 0.2^0 c for every ten years from 1979 to 2001 in Kericho.

Research on Kenya's climate change tea sector was conducted by Elbehri et al., (2015). The results of the study showed that the greatest effect on tea production is temperature variability. During dry spells, a negative association was observed between temperature and tea yield. Timbilil Tea Estate production was compared to the national average, showing a less than national monthly average. While national tea output includes outputs from small farms and large plantations that may influence output with various farm management practices, the results show that temperature and radiation may be a major factor influencing production even when soil moisture is not restrictive. Research on the correlation between extreme temperature and tea production has been conducted in Kisii in Kenya's Lake Basin Region in Leshamta (2014).

The results showed that seasonal and inter-annual air temperature fluctuations have a major effect on tea outputs. Additionally, in each tea growing area there was a relationship between temperature and tea yields. Further, Hatfield and Prueger (2015) found that temperature has more influence than precipitation on yield outcomes and that temperature thresholds, which severely restrict yields, may have already been met in a study of climate change effects in Kenya. In addition, Rwigi and Otengi (2009) found out that the average minimum, mean maximum temperature and terrestrial radiation are the three main climate parameters that influence tea outputs in Kiambu County.

According to the Tea Research Foundation of Kenya, TRFK, (2011), the observed temperature changes have shown a rise by 0.016 degrees Celsius per year for 52 years totaling nearly one degree Celsius (TRFK, 2011). This agrees with Ongoma et al. (2013) who noted that in Kenya, temperatures had increased over the last three decades. It has been noted that from 1960 to 1969, temperatures have risen at an average of 0.21 degrees Celsius annually with both maximum and minimum temperatures showing an increasing trend over time (World Bank, 2014). In Central Kenya, a study done by Funk et al., (2010) has shown an increase of temperature by one degree Celsius between 1960 and 2009. The increase in temperature can be allotted to the rise in temperature of the Indian Ocean with the drying impacts of the warm ENSO- events (Skogseld, 2017) and anthropogenic activities which have led to the increase of greenhouse gases in the troposphere hence leading to global warming. It has also been noted that Kisii County has also experienced increasing trends of daily temperatures by 0.5 degrees Celsius from 1976 to 2014. Further, the minimum temperatures have shown an increasing trend of about 0.6 degrees Celsius over the same period (Leshamta, 2017, KMD, 2020). These changes in temperatures therefore may have drastic effects on tea growth and production. Based on the above literature, it is evident that temperature variations have differed from place to place over time.

2.2.2 Evidence of Rainfall Variability

Climate instability and severe weather extremes, including droughts, floods, and severe storms, have affected agricultural systems of the world (IFPRI, 2011). Agricultural productivity is negatively impacted by climate variability, and this has candid effects on smallholder farmers, who depend mainly on rain-fed agriculture for their production. This is because, mainly depending solely on rain-fed agriculture, smallholder farmers, the main contributors of domestic food, have a restricted means of coping with this adverse weather variability (Nganga, 2006; Molua, 2002; Moula & Lambi, 2007). The strength and length of rainfall, the link between annual precipitation and potential evapotranspiration and annual rainfall variation are the main climate factors affecting tea growth (Kabubo-Mariara & Karanja, 2007).

The United States Environmental Protection Agency (2016) found out that in USA, most states have experienced an increase of rainfall by 0.08 inches after every ten years while some few areas such as South West rainfall decreased. This agrees with an analysis on rainfall that was done in China by Touseef, Chen, Yang and Chen (2020). Findings revealed that over the last fifty years, rainfall had declined but, in the Monsoon and winter season there were increasing trends.

Han et al., (2016) reported that the intensity of climate variations and severe weather events such as prolonged dry spell, torrential rains and late spring cold spells had increased in tea-growing areas in China. Trend analysis of rainfall from North East India's tea growing regions have shown a steady decline in the annual rainfall. This supported by a study in Japan on the effect of precipitation on crop production which found that annual rainfall amounts were on a decline and varied irregularly from season to season (Ndamani &Watanabe, 2015). Analysis of ninety-six years of annual total rainfall data of the South Bank region for Assam indicated that the rainfall in this region had declined by more than 200 mm per decade (FAO, 2016a). This is attributed to anthropogenic activities which have led to global warming though Yang et al. (2014) it is due to the variation of sea surface temperatures over the Pacific Ocean.

In the torrid zone from 1960 to 1998, it has been noted that mean annual rainfall had decreased by about 4 percent in West Africa, 3 percent in North Congo and 2 percent in South Congo (Malhi & Wright, 2004). In contrast, it has been observed that along the Guinean Coast the annual rainfall rose for the last thirty years rose by ten percent (Nicholson et al., 2000).

In SSA, food production which is a source of income to the large population is majorly influenced by the annual precipitation received in these countries. (UNEP, 2007; 2008). An analysis done by Omondi, et al. 2014, on rainfall in individual stations of the greater Horn of Africa from 1980- 2010 has revealed a decreasing trend in the total precipitation in Southern Sudan, Western Ethiopia and areas around Lake Victoria. Usman and Reason, (2004) have also noted that in Southern Africa, floods, droughts and prolonged rainfall have been experienced. Further, the seasonality of rainfall and recurrent droughts demonstrated in most parts of Sub-Saharan Africa (SSA) countries pose many constraints on agriculture (Rakgase & Norris, 2015; Stringer et al., 2009). It has been projected that SSA countries will experience decreased precipitation of about 20 percent. Overall crop yields in many parts of Africa will fall by 10 to 20 percent up to 2050 because of global warming and droughts (Bergamaschi, 2004; Durand, 2006; Parry et al., 2004).

Research by Schreck and Semazzi, (2004), found out that in Eastern Africa, precipitation increased in the Northern part while it decreased in the Southern parts over the past 30 years. This seasonality of rainfall patterns is controlled by the Northwards and Southwards movement of the Inter-Tropical Convergence Zone (ITCZ). The Northeast trade and the Southeast trade winds bring moisture from the surrounding regions, allowing the rains to be formed (Mtongori, 2016). In Tanzania, from 1980 to 2010 Mwanza, Bukoba and Dar es Salaam had shown a declining trend in rainfall while Mbeya and Dodoma had an increasing trend (Omondi et al. 2014). Further a study by Gebrechorkos, Hulsmann and Bernhofer (2019) found that rainfall has declined in the Eastern part of Ethiopa by one hundred millimeters and in Eastern Kenya by fifty millimeters from 1981 to 2016. But the study noted high inter-seasonal variability with long rains decreasing by 10mm while short rains by 2mm annually.

This, therefore, shows a clear indication that rainfall variability trends are different from one region to another.

A study done in semi-arid areas of Eastern Kenya has revealed that there were negative anomalies and high yearly variation in rainfall with forty-nine percent for the long rains and fifty eighty percent for the short rains (Gichangi et al. 2015). This also agrees with a study by Muhati, Olago & Olaka, (2018) which was done in Marsabit Forest Reserve of Kenya. The study revealed that mean rainfall declined annually at a rate of 6 millimeters from 1961 to 2014. Further, the study revealed that from March to May rainfall decreased annually by 10 millimeters while the short October to December it decreased annually by 2 millimeters in the same period.

Further, reports have shown that in Kenya, severe weather anomalies characterized by a rising trends in temperature, increasing incidences of frost and heavy rainfall coupled with hailstorms over a short period followed by prolonged dry periods have been experienced (Bore & Nyambundi, 2016). In Marsabit, trends have shown reduced rainfall for the last forty-three years from 1961 to 2014 with high variability (Muhati, Olago & Olaka, 2018) which is in agreement with Funk et al., (2010) who did a study on the general trend of Kenya's spatio-temporal rainfall distribution which has led to a drastic decrease in crop production. In addition, a study which was done in the Great Rift Valley of Kenya has shown that rainfall has been reducing annually with great variations within seasons (Wakachala et al., 2015) and this affects production and farmers in decision making.

Studies by Liwenga et al., (2007), Kangalawe and Liwenga, (2005) have revealed that extreme weather events have led to food insecurity. This is further supported by Rosenzweing et al.,

(2002) who found out that changes in the intensity and precipitation patterns in Africa have led to reduced agricultural outputs.

Astudy done on the spatio-temporal patterns for twenty-six stations in Kenya from 1971 to 2010 revealed that maximun mean annual rainfall of 2087 mm and the highest in observed value of 3673.6mm were recorded in Kisii weather station. It was also observed that the long rains declined by 95.5 mm and short rains rose by 65.3 mm. Kisii County experiences two rainy seasons; the long rains from March to April (MAM) and short rains from October to December (OND) This bimodal rain is associated with the annual movement of the Inter-Tropical Converge Zone (ITCZ) (Gitau et al., 2015). However, it has been noted that there have been rainfall variations within different seasons which may have affected tea production in the County (Leshamta, 2017).

Therefore, changes in long and short rainfall patterns have had significant effects on agricultural production (IPCC, 2007). Seasonal precipitation which is characterized by delayed onset, decreasing number of rain days, and increased intensity, altering agricultural calendars with adverse effects on yields (Jokastah, Leahl Filho & Harris, 2013). Although there have been several studies on climate change and variations, not all regions have been covered. Furthermore, the link between household characteristics and the way they perceive the effects of climate variation, especially rainfall fluctuations, has been little emphasized. Therefore, this study sought to develop the relationship between household characteristics and the perception of the effects of rainfall variability on Kisii County tea farming.

2.2.3 Evidence Tea Yield Variations

From the above discussion, it can be concluded rainfall and temperature variability may cause changes in crop yields. It has been noted that tea yields have been fluctuating in different tea-growing regions of the world. FAO, (2015), has reported declines in tea production in tea-growing areas in Asia and Africa. Further, this has been supported by Chang, (2016) who has noted that the trend of world tea production has been fluctuating over time. In 1991, the production was 2631.5 million kilograms which remained almost the same till 1997 even the acreage increased slightly. In 1998 it increased to 3026.13 million kilograms and dropped to 2928.67million kilograms in 2000 (Majumder, 2010). This is a clear indication that indeed there are fluctuations in tea yields which calls studies to be done.

Studies done by Thasfiha et al., (2020) and Thushara, 2015 in Sri Lanka have shown that tea production is low and fluctuating from time to time due to different factors such as age, management and climate variability. This agrees with a study done by Dutta (2011); Gupta and Gey, (2010) who found that tea yields have also been fluctuating in India. It has been noted that tea yields in North East India had stagnated from 1999 to 2007. This agrees with Liu and Shano, (2016) as quoted by Das and Zirmire, (2017), who found out that tea production had fluctuated and this led to periodical variations in export prices. In contrast to the above, a comparative study done in China has shown a low tea yield increase which is not commensurate to an increase in acreage over the past ten years. (FAO, 2015). But, production of black tea in China decreased from 1998 to 2003 but rose in 2004 (Zongmao, 2010).

In Kenya, researchers have shown that tea yields have been fluctuating over time even though the area under production is steadily increasing (AFFA, 2014; Tea Directorate, 2019). It is on this basis that this study assessed whether these fluctuations were the result of climate variability or due to other factors.

2.3 Effects of Temperature and Rainfall Variations on Tea Production

The quantity of tea leaves harvested is a function of its weight and acreage under cultivation. Usually, tea leaves are harvested after seven to ten days depending on the prevailing weather conditions. (De Costa et al., 2007). Various studies have found out that variations in rainfall distribution, amounts and temperature variations affect crop growth in different geographical areas including tea plants (Schepp, 2009; Decision and Policy Analyses Group, 2011). This section examined the effects of temperature and rainfall on crop production.

2.3.1 Effects of Temperature Variations on Crop Production

Temperatures have been noted to affect crop production in the present world. In Australia, a rise in night temperatures led to the increase of yields of wheat but reduced when frequent frosts were experienced (Nicholls, 1997). In Germany, Chmielewski et al., (2004) found that from 1961 to 1990 the rise of mean annual temperature by 0.368 degrees per every ten years led to the shift of planting season by 2.3 days. Further, higher temperatures enhanced the growth of rye by 2.9 days and cherry tree by 2.2 days after every ten years. This is supported by Peng et al., (2004) who found that increasing temperatures in the tropics had affected crop production negatively. In the Philipines, it was noted that between 1979 and 2002, a mean temperature rose by 1.8 degrees Celsius reduced yields of rice by fifteen percent.

It has also been observed that an increase in temperatures above the required mean initiates agricultural drought causing wilting of plants hence leading to low crop yields (Mati, 2000; Tao & Zhang, 2011; Nianthi, 2018). This is because vapor saturation rises with the rise in temperature hence more water vapor is needed in the atmosphere. In response to this, the crop plant closes the stomata as a response to reduce transpiration and this reduces the photosynthesis process leading to low yields (USAID, 2017; Lobell & Field 2007). Also heat stress during crop development leads to fewer and small organs, reduced light interception and altered carbon- assimilation process including transpiration, photosynthesis and respiration (Stone, 2000) and this reduce yields drastically if it coincides with the reproductive stages even if it is for a shorter period (Teixeira et al., 2013).

Further, Dahlsten and Garcia, 1989 and Surtherst (1990), noted that weeds may spread out to high elevations as temperature rise beyond the optimal requirement. These weeds are known to compete for nutrients with the plants leading to low yields. Also, higher temperatures enhance the multiplication of disease-causing organisms leading to an increase in their population. It has also been noted that some insect species thrive well in environments with increased temperatures. Some of these insects may become deep-rooted and develop resilience to the effects that emanate from variations and changes in climate. Research done by Sawe et al., (2018) revealed that an increase in crop pests and diseases are mostly associated with to increase in temperatures. This is in agreement with Adhikari et al, (2015); Barros et al, (2014) and Vrieling et al., (2013), who found out that water stress is caused by the increase in temperatures in Africa, which inturn increases crop pests and diseases. In India, it has been noted that temperature variability is the most serious factor affecting tea yields in South India (Raj, et al, 2019). A study done in the Assam region in India in 2016, revealed that drought increases the susceptibility of tea plant pests (Biggs et al., 2018; Reay, 2019).

According to Kathasiri et al., (2018); Wijeratne, et al., (2011) and Carr, (1972) temperature above or below the optimal temperature of 22 degrees Celsius may affect tea yields either positively or negatively. Extreme temperatures such as frost and heat stress also affect the tea crop which will result in fluctuation of yields. But a daily temperature range between 13 degrees Celsius and 30 degrees Celsius is considered as being favorable to the leaf growth of the tea plant. Temperatures below or above this range probably reduce the growth of the plant or may harm it (Bhagat et al., 2010). It has been found out that crop phenology and productivity are affected by warmer climates. Increased temperature causes early flowering and maturity which results in a reduction in crop growth and yields in many crops (USAID, 2017; Craufurd & Wheeler, 2009; Talukder et al., 2014).

Lobell, et al., (2011) reported a reduction in maize yield by 1.7 % was due to an increase of temperatures above 30 degrees Celsius in some days of the growing period. Increased night temperature can also reduce crop yield. Serious effects have been reported for rice where an increase in night temperature from 27 degrees Celsius to 32 degrees Celsius caused a 90 percent yield reduction (Mohammed & Tarpley, 2009). It has also been noted that an increase in average temperatures during the growing season makes plants use more energy for respiration for their maintenance and less to support growth. With an increase of one degree Celsius in average temperatures, crop yields for food and cash crops can reduce by five to ten percent (Lobell & Field, 2007; Chaung et al., 2017). Temperature variability can also modify grain quality since high temperature during grain filling affects the protein content of wheat (Hurkman et al., 2009). Pittock, (2003) concluded in their findings that the frequency of extreme events will increase due to global warming which affects crop production.

A study done by Kang & Banga (2013) on factors influencing climate variation revealed that global warming had a greater contribution and this, in turn, affected agricultural production. Food and Agriculture Organization (FAO) experts reported that each one-degree Celsius rise in temperature would cause annual wheat yield loss of about 6 million tons. An IPCC projection anticipates that 2 degrees Celsius increase in temperature may lead to a 20 to 40 percent fall in cereal yield mostly in Asia and Africa (Lele, 2010). In contrast to the above, some reports have indicated that global warming might increase plant growth because of increased levels of temperatures and atmospheric carbon dioxide beyond the optimal level. But increased atmospheric temperatures caused by elevated concentrations of carbon dioxide also cause heat injury and physiological disorder to some crops which will decrease production (USAID, 2017).

A study done in Sri Lanka revealed that tea production correlated negatively at higher levels in warmer months and lower temperatures in colder months (Nijamdeen et al., 2018). This was due to agricultural droughts and high rate of transpiration which were a result of higher temperatures and effects of frost caused by lower temperatures. It was also found out that high temperatures increase evaporation losses of soil moisture and accelerate the burning of organic matter from soils. This agrees with FAO, (2016b), which has also noted that higher daytime temperatures during the reproductive stage led to the decline of crop yields.

A study conducted in India on Assam tea revealed that a monthly temperature greater than 26.6^{0} c reduced tea yields. Further, it was noted that one-degree warming at an average monthly temperature of 28 degrees Celsius resulted in a 3.8% reduction in tea yields (Duncan et al., 2016). In tropical regions, an increase in minimum and maximum temperature by 1 to 2 degrees Celsius reduces crop yields because of inadequate soil moisture. Increased temperatures result in rising levels of water loss from the soil and the plant leading to stunted growth and decline in yields (Parry et al., 2005; FAO, 2008; Bals et al., 2008; Chijioke et al., 2011; Abu et al., 2018).

Further, temperatures more than the average, make plants complete their cycles more rapidly (Hatfield et al, 2011) and this leaves the plant with less time to reproduce leading to lower yields (Craufurd &Wheeler, 2009). Experiments on the analysis of the known responses of tea shoots to temperature have indicated that differences in mean temperatures of only 2 degrees Celsius were sufficient to cause differences in length of the shoot growth cycle of up to 20 days in the clones (Ng'etich et al., 2006). It has also been noted that in higher elevations, stunted plant growth and reduced yields is experienced due to lower temperatures. Plants growing in warm environments produce higher amounts of dry matter than those in cooler areas and shoot growth increases with an increase in altitude (Ng'etich, 1995).

Higher night temperatures are perceived to increase dark respiration of plants which lowers biomass production globally while very low season temperatures retard plant growth thus leading to low yields. Furthermore, rising temperatures may result in making arable land less favorable for farming (Bals et al., 2008; Chijioke et al., 2011).

A study by Adhikari et al., (2015), has noted that tea and coffee exports will drop by 40 percent due to the reduction of suitable tea growing areas in East Africa due to temperature increase. According to Cheserek et al., (2015) extreme temperature beyond the optimal requirement affects tea production negatively. Even though higher temperatures improve tea quality, maximum temperature beyond 30^{0}C affects tea leaves because of high transpiration rates and thus lower yields. On the other hand, lower temperatures inhibit tea clone growth, eventually resulting to reduced output and lowers the morale of the smallholder tea farmers. It has been noted that temperatures below 14 degrees Celsius slow the rate of shoot growth hence leading to reduced yields (Carr &Stephens, 1992; Cheserek et al., 2015).

Frost incidences in Kenya have also become a common phenomenon (Bore, 2015; Cracknell, 2015; FAO, 2012). In early January 2012, a severe frost incident that affected all tea-growing regions was experienced across Kenya. This affected tea production reducing green tea leaves yields by about 20 million kilograms (Gachenge, 2012) which caused the reduction of yields by 30 percent (Bore, 2015). Frost damage the tea clones especially the leaves causing the plant to take two to three months to regain hence reduction in yields. Increased temperatures on the other hand can cause soils to dry if mulching is not applied thus reducing the yields. All these changes bring great losses to small-scale farmers who depend on tea as a source of earning a living.

A more serious problem, however, is the increased incidence of new pests and diseases that attack tea bushes (FAO, 2015; Murugan et al, 2012). Due to water stress, the stressed plants are more susceptible to pest attacks. Research conducted in India has revealed that large areas in Assam and North Bengal have suffered great crop losses due to the outbreak of looper caterpillar, mosquito bugs and red rust disease of tea leaf (FAO, 2016). This affected tea production drastically. A study conducted in Kisii County has revealed that temperatures have varied over time and affected crop production (Samwel et al., 2018). This research examined the effect of these temperature variations on tea yields.

2.3.2 Effects of Rainfall Variability on Crop Production

The most important factor in rain-fed agriculture is the availability of water to maintain crop production. The variability of plumage between seasons significantly influences the availability of soil water for crops and thus poses a risk to crop production. Barrios et al., (2008) found that major factors influencing farm production are rainfall and temperature. However, rainfall is the main climate factor and influences the distribution of plants' spatial yields (Makenzi et al., 2013). Agricultural practices in tropical regions, in particular, follow precipitation trends (Huho et al., 2012).

The amount of rainfall in which tea maintains robust growth does not seem to be a definitive upper limit. Some areas of Sri Lanka receive up to 5100 mm of rain but this does not affect tea growth and productivity. Regarding the smaller range, the precipitation below 1300 mm per year is expected to have a detrimental impact on the growth of tea. Different studies, however, show different rainfall effects on tea production (Kamunya, et al., 2019).

Rainfall availability is the most crucial factor for sustaining crop production in rain-fed agriculture. Rainfall amounts, distribution, seasonality and timing are of paramount importance to crop production. Inter-seasonal variation of rainfall leads to a deficit of soil moisture available for the plants thereby causing danger on crop growth and subsequent yields (USAID, 2017). Climate change and variability have increased inter-annual rainfall variability and increased the frequency of extreme events such as floods and droughts which have affected crop production, tea included. This has led to total crop failure or reduced harvest (CARE, 2009; McSweeney, 2006; Stringer et al., 2009).

It has been noted that rainfall patterns have been shifting and the occurrence of extreme events such as droughts and floods have become common as a result of global warming (Zoellick, 2009 as cited by Enete et al., 2011). In Africa, these have had profound effects on yields, thereby making farmers more vulnerable (UNFCCC, 2007). It has also been projected that increased surface temperature is expected to increase spatial and temporal variations in patterns of precipitation which will affect crop production (FAO, 2016). Variability in rainfall between and within seasons (Rowhani, et al., 2011), prolonged dry spells and occurrence of extreme rainfall events (Moriondo et al., 2011; Laux et al., 2010) may have great effects in crop production and yields. A study by Cheruiyot et al (2007), has documented that droughts account for 14 to 20 percent loss in tea yields and 6 to 19 percent tea mortality. In addition to these, reduction in seasonal mean precipitation is perceived to have drastic effects on degraded soils with low levels of organic carbon as they cannot be able to retain water for plant usage

(Mohotti, 2015). Further, as rainfall becomes variable, farmers may no longer rely on their knowledge of the seasonality of climatic variables. Shifting planting seasons and weather patterns make it harder for farmers to plan and manage the production (Smith et al., 2014).

It has been noted that in the Pacific Region of Central America, hurricanes have had significant effects on smaller holder farmer’s livelihoods with strong winds and torrential rainfall destroying coffee plantations and farms (Philpott et al., 2008; Cruz-Bello et al., 2011; Eakin et al., 2012). Additionally, the hurricanes damage roads, bridges and farm infrastructure (Philpott et al., 2008; Ruiz Meza, 2015) which disrupt crop harvest transportation and processing.

Research on the impact of climate variability on the production of tea leaves in the different tea estates was conducted by Ali et al. (2014) in Bangladesh. The research demonstrated that tea yield was greatly determined by the microclimatic parameters of a region especially rainfall, temperature, moisture and light period. Heavy rains, on the other hand, erode high soils and remove fertilizers and other chemical substances. Data analysis on weather found that the highest yield of tea leaves per hectare increases when the rainfall ranges between 4000mm and 4600mm precipitation. The growth and yield of tea were affected adversely by heavy or low or delayed precipitation. The production of tea leaves was observed to increase marginally, with the average yearly precipitation increasing.

A study on the effect of rainfall on tea yield and crop distribution was carried out by Hossain et al. (2015). The findings revealed that tea yields from various parts of the Sylhet district increased marginally due to increased precipitation. Results also showed that maximum rainfall with maximum rainy days is required for maximum output tea. Research on the effect of plumage variability of production of agricultural products and welfare of households was conducted in rural Malawi by Moylan (2012). The results showed that households with extreme negative rainfall shocks were experiencing substantially lower crop outputs, agricultural value, a per-capita intake per capita over the wettest quarter of 2008/2009 and 2009/2010.

Research conducted at Darjeeling Tea Research Development Centre on the effect of climate change on tea production revealed that there was reduction of yields by 41% in 2012. There was a strong positive and significant correlation between green leaf yield and total rainfall (r =0.78) (Patra et al., 2013). Projections by 2050 in Africa reveal that tea yields crop yields will decline by 10-50 % (Jones & Thornton, 2003, Nelson et al., 2009). This is because African agriculture is majorly rainfed and hence fundamentally dependent on the vagaries of weather. These changing rainfall patterns and the rise in the intensity of severe weather events may increase in the prevalence of crop pests and diseases (Barrios et al., 2008; Rarieya & Fortun, 2009).

Han, (2012) and Yang, (2015) have noted that for optimal tea growth, annual rainfall of between 1500 to 2000 millimeters or monthly rainfall from 223 to 417 millimeters which is well distributed is required. However, as noted in Carr (1972), the distribution of rainfall throughout a growing season is as important to tea growth as total annual rainfall. It has been noted that rainfall during the early part of the growing season has a greater positive impact on yield than precipitation falling during the rainy season (Adams et al., 1998). There are also reports that rains in excess of 500 mm per year could affect tea growth success (Carr, 1972). Research that was done in the tropical regions has shown that extreme rainfall can negatively affect tropical plant growth and development (Reyer, 2013, Ahmed et al., 2014).

In China, a study analysis done using provincial-level data of tea production to identify the effect on monsoon dynamics and weather on tea production found out that a retreat date of the monsoon and an increase in monsoon precipitation was associated with a decrease in tea yield (Boehm, et al., 2016). This agrees with a study done on observing climate impacts on tea yields in India which revealed that there were decreasing returns to tea yields with increasing monthly precipitation (Duncan, et al., 2016). Further, it has been noted that tea production is lower during the long rains as compared to short rains due to long rainy periods reducing sunshine and photosynthesis of tea leaves (Han, 2018). In contrast to the above, Ahmed et al., (2014) argue that increased water availability increases tea plant growth and growth of new leaves of tea bushes. From the above discussion, it is evident that the tea plant is affected by both excesses and shortages of water as long as it more or less the required optimum. Water excesses may lead to the leaching of soil nutrients and low water levels will affect the tea plant nutrient uptake which in turn will affect production.

In Sri Lanka, research done on the series of analysis of monthly tea yield (kg/ha) and rainfall of tea estate, revealed that there was a polynomial relationship between these two parameters when lag period of one month is considered, that is rainfall of the previous month relates to the productivity of the current month. According to Wijeratne et al., (2007), very high rainfall reduces yields because of lack of sunshine. Also, a study done in Sri Lanka indicated that monthly decrease in rainfall by one hundred millimeters leads to a decline by 30-80 kilograms of made tea for every hectare (Wijeratne et al., 2011).

Further studies done in India and Sri Lanka have also revealed that heavy rainfall causes damage on the tea plantations through soil erosion, poor growth due to lack of sunlight and increased disease incidences (Duncan et al., 2016, Wijeratne, 2011). In Sri Lanka, tea yield losses were experienced in May to July in 2013 as a result of excessive rains and low sunlight (Prematilake, 2014). It has been noted that rainfall reduction by 100mm reduces tea yields by 30 to 90 kilograms per hectare per month (Wijeratne et al., 2007). Further, it revealed that the impact on yield loss due to erosion was higher in high elevation areas as compared to low elevation areas (Mohotti, 2015). This was attributed to higher rates of erosion on elevated areas which carried away the soil nutrients. Loss of soil fertility leads to reduction of retention capacity of water in the soil, exposes the root system and reduces microbial activities due to loss of organic matter (FAO, 2016; Talukdar, 2016; Prematilake, 2014). This eventually leads to lower yields. It was also noted that landslides caused by heavy rains affected the tea plantations and endangered the lives of laborers on hilly slopes (Wijeratne, 2011).

In contrast to the above, a study done in Assam in India found out that drought does not affect tea yields (Duncan et al., 2016), but other research suggests that it increases the susceptibility of tea plants to pests and diseases (Biggs et al., 2018) such as tea mites and wood rot respectfully.

A study conducted on tea production in Uganda showed that there were tea losses of 1.1 billion in 2011 due to rainfall variability. Tea plantations were sensitive to the temporary unavailability of water for their growth and respond through lower unit yields and quality of the harvested product (Bigirimana, 2010/2011). Intense rains lead to soil erosion, landslides and waterlogging which damage root development in tea farms and reduces yields of the tea plants (Nowogrodzki, 2019). In Kenya, a study by Cheruiyot et al., (2007) has shown that climate variability has led 14-20% tea losses especially in the dry season.

Temperature increases coupled with changes in reliability, distribution patterns and predictability of rainfall have been observed to have adverse effects on tea yields and quality

(Ahmed et al., 2014; Boehm et al., 2016; Bore, 2015; Cracknell, 2015; Elbehri et al., 2015) particularly in Kenya (Cheserek, 2013; Cheserek et al., 2015). The rise in temperature trends were projected to continue (Eitzinger et al., 2011) and therefore impacting tea production if precautionary measures are not put in place. While the volume of annual precipitation is on the rise in Kenya, torrential rains, floods and mudslides have become a common occurrence. These have damaged the tea clones and removed the top soil which is rich of nutrients. Unreliable rainfall further impedes decisions along the value chain, from the timing of fertilizer application to the regulation of leaf moisture during processing. Research has also revealed that crop response to fertilizers highly depends on the seasonal distribution of rainfall as it influences the soil water content (Talukdar, 2016). Therefore, rainfall variability affects the decisions of farmers on when to apply fertilizers in the farms.

Projected changes in the precipitation rates in the future suggest a strong variability as well as more frequent extreme climatic events such as heavy rainfalls or droughts and thus implying a high vulnerability of tea production (Asfaw et al., 2014; Nkomwa et al., 2014). The occurrence of droughts reduces soil moisture content which affects the photosynthesis process and plant growth thus reducing yields (Cheserek et al., 2015). In support of the above, Ahmed, et al., (2014) has noted that tea clones experience more stress during droughts because of their shallow root. Although leaf quality can be retained during a drought, research has confirmed that droughts can cause yield loss by 12 to 20 percent per annum which is dependent on the severity of the drought and type of clone grown (Ahmed et al., 2014; Bore, 2015). The reduction in yields leads to low income at farm-level foreign exchange earned in a country (Bore, 2015; Chang & Brattlof, 2015 Nyaoga et al., 2015).

Hailstones also damage the tea leaves and stem of the clones leading to high losses in some tea-growing areas. As a result, yields fall subsequently as the tea plant's effectiveness and speed of recovery from hail destruction take several years to recover. Further, the situation is worsened if the plant is infested with pests and diseases (Willson, 1992). In Kenya, an estimated loss of 2 million kilograms of green tea per year has been incurred in the tea-growing counties of the Western region which includes Kericho, Sotik and Nandi due to hail (Bore, 2015). The Kenyan tea sector is already facing recurrent hail episodes (FAO, 2012) and climate change schemes predict substantial rise of hailstorms damage in subsequent years (Botzen et al., 2010).

Elbehri et al., (2015) has shown a weak negative relationship between tea yields and precipitation (1,4 Kg ha-1 mm-1) at Timbilil Tea Estate in a study focusing on Kenya's climate-change tea sector. This is because the rainy season and the depressing crop yields follow low temperatures. The situation in Magura Tea Estate was however different, where yields and precipitation had a positive relation (5.5 kg ha-1 mm-1). The warm temperatures in the area were responsible for this relationship. Frostbite has tremendous potential for a 3-month reduction in tea yields by up to 30 percent. The net loss of green tea leaves from hail was estimated at 2.7 million kilograms per year in areas such as the Kericho, the Sotik and the Nandi Hills.

Furthermore, Juma (2014) conducted a study in Murang'a County on the influence of rainfall variability on tea production. The Kenya Tea Development Authority provided the tea yield data for the period 1995 to 2012 and climate data were obtained from Kenya Meteorological Department. The study in Murang'a County found out that rainfall variability and tea yields had a positive relationship.

2.3.3 Climate Variability and Its Impacts on crop production

Empirical studies have confirmed recent changes and climate fluctuations in agricultural development globally have affected crop production (Skoufias et al., 2011). Global weather is unpredictable and this has created uncertainities that have affected agricultural productivity. The main consequence of climate variability is that extreme weather conditions such as drought, hail, and frost have affected agricultural systems and livelihoods in general (Bore et al., 2011). Past research has shown that the main factor which has led to annual tea yield fluctuations is climate variability. The tea yields have been strongly affected by a region's microclimate, especially rainfall, temperature, humidity and light durations, in a study done in Bangladesh (Ali, et al., 2014). A study carried out in Sri Lanka on the susceptibility of tea production to global climate change found that temperature rises, soil moisture deficits and low-level saturation vapour pressure have had negative effects on tea growth and performance (Wijeratne, 2014).

The average tea plantation productivity in Sri Lanka has increased overall since the 1930s despite fluctuations between years. Currently, the production of national tea is more than 300 million kilograms per year, generally as the amount of processed or 'created' tea. It has been noted that rainfall and temperature have had a strong influence on tea production. Certain crop models were developed to predict tea output in different weather conditions. Increasing global warming and reduction of rainfall have harmed tea production and hence fluctuations in yields (Wijerante & Fordham, 1996). Informed by these findings this study used econometric models to study the effect of temperature and rainfall variability on tea production in Kisii County.

A comparative analysis on the impact of climate change on supply and output variability of major crops was carried out by Chen et al. (2004) in the United States of America where maize, cotton, sorghum, soya and wheat were the principal crops. The study showed that the rainfall had a positive influence on crop yields and that temperature had a negative effect on crop yields using the panel data technology with magnitudes differing according to the estimated form of activity. For example, Maize returns were observed with a linear specimen decrease of 0.24 percent and a decrease of 2.98% due to a temperature increase of one percent using Cobb-Douglas's specimens.

The study also found that increasing precipitation decreased maize and cotton yield but enhanced sorghum yield. At the very same time, the increase in temperatures reduced cotton and sorghum differently, but the variability in maize yield increased. The observations were done in various places in which the plants were grown and the cultural conditions. The goal of this research was also to derive quantitative estimates for the effect temperature and precipitation variability on tea yields in Kenya.

Seo et al., (2005) evaluated climate change and its impact on agriculture with the application of the method of Ricardian and five experimental models of AOGCM in Sri Lanka. They studied the effects of rainfall and temperature on the net income of tea, rice, rubber, and cocoa. The findings indicated that rainfall benefited all the selected plants under study, with gains of between eleven and twelve percent of crop revenues. Temperature on the other hand had a negative effect of between eighteen to fifty percent loss. This research, informed by the results, considers rainfall and temperature as the main variables affecting the development of tea in Kenya and sought to use a different set of econometric methods to assess their effect.

Using computer simulation and experiments, Porter & Semenov, (2005) demonstrated climate variability and its effects on the development of crops. The results of the study showed that rising temperature and precipitation variability contributed to increased yield risks. Various crop processes are influenced both by changes in mean and annual temperatures which have different effects on crop growth and development. This study combined the variability of rainfall and temperature to take account of the impacts on crop production by extreme events to capture climate risk. But as in Porter & Semenov (2005), this review takes an approach that is more quantitative than experimental.

In South West Ontario, Canada, Cabas et al. (2010) measured climate and non-climate effects of the mean and variance between maize, soya and wheat. Three models were estimated in this analysis. The first model contained economic properties (change to input and location characteristics) as independent variables (change in the planted area). The second model featured, in addition to the economic and site elements, overviews of seasonal climate indicators. The seasonal climate variables were daily, seasonal average, seasonal precipitation, precipitation variation coefficient and temperature variation coefficient.

To capture the influence on the yield of extreme events, the rainfall and temperature variables were combined. Instead of seasonal overview indicators in the second model, the third model used monthly weather variables. The variables used were mean monthly minimum temperature and total monthly precipitation. Squared precipitation values and temperature values for non-monotonicity were used. The findings revealed that climatic elements under study had a significant influence on plant distribution. Crop returns were affected by the season of the year with temperature and precipitation variances largely explained the variation in yield.

In spring and autumn, there have been temperature shifts that raise concentrations at a higher rate but in the summer months at a lower rate. At the beginning of the growing season, precipitation rises and summer yields also increase. The study found out that there was nonlinear correlation between rainfall, temperature and plant yields (Cabas et al., 2010). In addition, the study included environmental and economic variables in the evaluation of their effect on production supply. This study, however, goes one step further and takes into account the effect of rainfall and temperature variations on tea

Basak et al, (2009), using the simulation model of the Decision Supporting Framework for Agrotechnology Transfer (DSSAT), assessed the effects of potential climate change on rice production in Bangladesh. Results show that production of rice decreased dramatically by 13.5 % and 28.7 % respectively, with a rise in maximum temperature of 2 degrees Celsius and 4 degrees Celsius. The model results also show that dropping at minimum temperatures decreases yield, but more dramatic damage is caused by the increase in maximum temperatures.

While applying a case study research design in the study, the effects of climate change on the production of food crops using bivariate Chi-square and ANOVA in Ibadan were investigated by Agboola & Ojeleye (2007). A sample of 325 farmers were interviewed to test the hypothesis on the effects of climate variability on food crop production. The study showed that farmers have seen improvements in climatic conditions over the last two to three decades. Furthermore, farmers noted that the yield of food crops was affected by an increase in temperature, a decrease in precipitation, and a decrease in relative humidity. However, the study found that climate change had no major impact on crop production, using chi-square, and correlation analysis. The regression outcomes did not foster the perception of farmers. The study, therefore, assumes that farmers' understanding of climate change affects their decision-making processes for crop production and therefore affects the availability of crops. The research tries nevertheless to use a well-constructed set of econometric models to evaluate the effect on crop production of climate change, provided that the Chi-square approach is restricted as not much information is given about the intensity of the connection or the substantive value of this relationship within the population.

In contrast, Benhin (2008) showed that both temperatures rise and precipitation would cause the farm income to fall, using the Ricardian method for estimating the effects of climate change on farm income in South Africa. The studies provide a logical connection between climate and crop productivity. To identify the effect of climate variables and crop yields in Kenya, this study integrates rainfall and temperature variability as well as seasonal precipitation and temperature means used in Kabubo-Mariara & Karanja (2007) and Benhin (2008). Furthermore, the study uses 23-year time-series data to capture the influence of time variations.

The impacts of climate change on tea productivity in Sri Lanka were assessed in Wijeratne et al. (2007). The results of the study showed that low and medium altitude tea-growing regions were more vulnerable to climate change compared to higher altitude areas. The optimal temperature required for tea growth was 22 degrees Celsius, while optimal rainfall ranged from 223 to 417 millimeters a month in different regions. Reduced monthly rainfall by 100 millimeters would reduce output per hectare of "Made Tea" by 30 to 80 kilograms. The rise from 370 ppm to 600 ppm of environmental CO_2 concentration increased the production of tea by 33 percent to 37 percent, depending on altitude. Projections from the crop model showed that increased temperatures and decreasing rainfall in most tea-growing regions in Sri Lanka, except for upland wetlands, led to a reduction in tea yields. Moreover, the study projected that returns will possibly increase at high altitudes but decline at low altitudes due to climate change. Therefore, the research recommended sustainable adaptation measures to mitigate these adverse effects. In relation to the above findings, this study used monthly temperature and rainfall variations to assess their impact on tea production in Kisii County of Kenya. It used a statistical approach to determine their impact. This study, however, did not examine the effects of changes in atmospheric CO2 concentration.

The impact of climate variability on the yield of major cereals in the Dadeldhura district, western development region of Nepal was assessed by Bhandari (2013). The research utilized an exponential model of the growth curve and used data from the time series. Temperature and precipitation were shown to have a substantial influence on the cereal yield. Precipitation was found to have a significant influence on maize and barley yield whereas it was not significant for rice, wheat and millet. The temperature had a significant influence on the yields of the five cereal crops. High temperature and rainfall favored maize and rice growth hence high yields. Precipitation increases and temperature variations had a significant influence on crop production. The study shows that variations in precipitation and temperatures have heterogeneous effects that can harm or gain the plant, depending on height above sea level, plant type and season of the year.

In Veracruz, Mexico, Gay et al., (2006) reported the effects of climate change on coffee production. A multiple regression model was used in the analysis that combined environment and economic explanatory variables. The model contained linear and quadratic terminology for seasonal climatic indicators and seasonal variation of climatic variables. Extreme events that influence crop production have been captured by seasonal variances in climate variables. Economic variables used as explanatory variables: coffee prices of state, international coffee prices, population, the index of producers and coffee stocks in the USA. The model predictions have shown that coffee production negatively reacts to seasonal temperature more so, changes of the average winter temperature more adversely. Study estimates also have shown that rainfall and temperature changes could cause coffee production to decline by 34 percent by 2020. This research incorporates both economic variables and climatic variables, according to Gay et al. (2006) in modeling the response from maize, tea and coffee to climate variability. The analytical model also requires taking account of extreme events and the threats to the precipitation and temperature variations to the farmer.

In the US historical data used by Huang et al. (2010) to estimate the effect of environmental and technological change on corn, soybeans and wheat yields from 1978 to 2007 using county-level panel data, a general crop yield model. Climate variables included: annual monthly rainfall and quadruple conditions, increase in seasonal grade days and monthly variation in temperature (MVT). The study found that for all three crops, climate variables have a major effect on yields, and high temperatures led to decreased crop yields, whereas more precipitation would only increase the yields of maize and soybeans. The findings are inconclusive about the effects of precipitation on wheat yields. Thus, shifts in precipitation from the analysis may theoretically increase or decrease crop yields.

The multi-regression model Hamjah, (2014) has been developed to quantify the climate impacts on Bangladesh tea and cotton. The analysis also calculated climate-based output efficiency using a stochastic border model. The estimates showed that tea production was negative and significant only during sunshine hours and wind speed during the summer. These climate changes account for 92 percent of Bangladesh's variations in tea production. Based on the results, the purpose of this study was to evaluate how climate change affects the production of tea in Kenya using a statistical approach. However, the effects of changes in sunshine and wind speeds were not reported in this report.

Kumar (2014), while using a simple regression model, Cobb Douglas model, and Ricardian productivity regression, estimated the effects of climate change on sugar cane productivity. The study found that precipitation and temperature had a big effect in different seasons on sugarcane production. Similarly, the impacts of climate change on agricultural productivity have been studied by Mahmood et al. (2012), Nastis et al. (2012), and Lee et al. (2012) who estimated the production function of Cobb Douglas. These researches have shown that rainfall and temperature have a significant influence on agricultural development. Concerning crop yields with climate variables, this study adopted the Cobb Douglas model.

Using a climate scenario of a rise in temperature of about 2.8 degrees Celsius and an increase in precipitation of 8 percent, under the crop model, land prices have been expected to decline, while the land values under the crop revenue model are forecast to increase. Due to the various weights and crop models allotted to different geographic areas, the results were different. According to Mendelsohn, the market value of production reflects the growth of a particular parcel of land, which means that variation in the spatial environment contributes to variation in productivity in the land. The study environment allows the assessment of climate and agricultural productivity and their rational relationship using a model of multivariable regression (Parry et al., 2004). The research used time-series data to test the effects of climate variables on crop production by using regression models, capturing the effects of climate change on crop productivity. The same climate scenario and identical weights were used by Reinsborough (2003) and Schlenker et al. (2005) as Mendelsohn et al. (1994). A similar conclusion was drawn by Schlenker et al. (2005) as Mendelsohn et al. (1994).

However, under the two-crop soil model, Reinsborough, (2003) projected a rise in the value of farmland in Canada, concluding that global warming is supposed to favor Canada.

Deschenes & Greenstone (2011), on the other hand, argued that Schlenker et al., (2005).'s conclusions were not strong and suggested that weights be used in agricultural areas. Their conclusions were not strong. While the impact of these weights was lower, the value of farmland was projected to decrease. The effects of Climate Change on 59 crops were studied in Taiwan in 2002. The study used an econometric model incorporating climate and economic variables. In this analysis, the independent variables of climate included the seasonal average of the average monthly temperature and the average of monthly precipitation and the variance of average seasonal temperature and the mean variation of long-term average 20-year seasonal rainfall. The effect of optimal temperature and precipitation on yields was implemented with a linear term and a quadratic term for each climatic variable. The results of the study showed that rising temperatures and changes in rainfall have a major non-monotonic effect on yields. The positive effects of climate change on vegetables and the negative impacts on cereals and pulses have been observed. This research also uses econometric approaches. In assessing their effect on the supply of maize, tea, and coffee crops in Kenya, the models incorporate economic variables and climate variables, using data spanning 45 years. The study also considered a non-monotonic relationship between climate variables and crop yields in estimating the impact of climatic temperature and rainfall on yields of the crop (Mendelsohn, 2009).

Maddison, (2006) has surveyed farmers and conducted a Ricardian study using land prices, in eleven countries in Africa, as farmers consider them as being against market values. The study showed that African agriculture is highly susceptible to climate change in countries with hotter climatic conditions projected to experience severe losses. The value of providing water, which is highly affected by temperature and precipitation, has been confirmed, rendering it particularly vulnerable to climate change. Similarly, Kurukulasuriya and Mendelsohn (2006) use the Ricardian cross-cutting approach to identify the connection between net crop revenues and the environment through farm-level data on a survey carried out in 11 countries. The results have shown that net revenues are dropping with a decline in precipitation or temperature rise. The study predicted hotter and higher temperatures would be disadvantageous for dryland regions. The studies create a logical connection between climate and agricultural productivity.

In South Africa, the effect of moderate temperature and precipitation on maize yield was investigated by Akpalu et al. (2008). A generalized maximum entropy estimating method was used to estimate cross-partial findings. Increase in rainfall and temperature led to an increase in maize yields. In return, Moula (2010) found that one percent standard deviation from the long-term mean of precipitation and temperatures had a negative effect on crop production when analyzing the effects of Cameroonian farming with time series data for 40 years. The key variables influencing crop production were stated in the study by Akpalu et al. (2008) and Moula (2008) were rainfall, temperature and deviations from median values. The study, however, used data from time series over 45 years and not from cross-sectional data as used in Akpalu et al. (2008).

A detailed assessment of the impacts of climate change on crop development in Sub-Saharan Africa was conducted by Blanc (2011). Maize, cassava, millet, and sorghum were among the crops under research. The study estimated the productivity of crops and the response of supplies to climate change. The first collection of econometric analyses estimated the impact on crop yield from changing weather. The forecasts revealed a major effect on crop yields from temperature, precipitation, evapotranspiration, floods, and droughts. In countries with less favorable agricultural conditions, temperatures and rainfall have had greater impacts. The accumulation of CO_2 has only had a noticeable impact on millet.

The second series of economic analyses examined the effect of climate change on farmers' decision-making. Estimates of regression showed that temperature and rainfall variation influenced supply options for farmers who were more sensitive to exports of crops. Temperature and precipitation variations had an adverse impact on the availability of soil water available for crop growth. The outcome showed that farmers invest in other practices or diversify into other crops as climate risk increases. The study, therefore, establishes a connection between climate change and the decision-making process of farmers. Thus, as followed in this report, Blanc (2011) reports on projections of the response to production supplies to climatic variables shifts. In addition, this analysis also takes cash crops into account in assessing the impact of changes in climate variables on tea crops.

The impact of climate variability on the development of maize in Nigeria was examined by Sowunmi & Akinola (2010). The study used the 2-way ANOVA and coefficient of variation (CV) to investigate the complex connection between climate changes and agronomic variables for maize production. Seven ecological zones and data for the period from 1980 to 2002 were used in the study. The results showed that in most parts of Nigeria, with ample water availability and negligible temperature variation maize can be grown throughout the year. The study showed that in the development of maize, water is a crucial input. Since Kenya relies highly upon the development of rain-fed crops, the study was carried out using national data and a set of economic methods to determine the effects of rainfall and temperature variability on tea production.

While using an Error Correction Model, Eregha et al. (2014) investigated the effect of climate change on crop development in Nigeria. The study assessed the impact on the production of maize, rice, beans, cassava, cocoa, groundnuts, millet, potatoes, sorghum, and yams of temperature, rainfall, and carbon emissions on production. The study found that maize, rice, beans, cocoa, and sorghum production was adversely affected by temperature. The temperature, however, had a positive effect on groundnut development. Rainfall had a positive impact, but had a negative impact on sorghum production, on beans, cocoa, potato, cassava and rice production. The adverse impact on the production of maize, millet, rice and sorghum has been shown to carbon emissions. As pointed out by Bhandari (2013), rainfall and change of temperature can have a variety of harmful or beneficial effects depending on the crop type. This study, therefore, examined the effects of temperature and rainfall variation on a different crop, tea.

The mean temperature in Ethiopia increased over the past 20 years, and plaster patterns and quantities dramatically changed, with crops accounting for over 45% of GDP being generated (Abera, 2011). It has been observed that climate variability is a major factor affecting agriculture in Zambia, and has been projected to reduce its annual GDP growth rate by 0.4 percent per annum. Long-term climate data study in East Africa shows that the climate is changing certainly (Mendelsohn et al, 2000) with an all-embracing tendency to raise temperatures and rainfall. It is estimated that the rising temperatures of many countries such as Kenya, Uganda, Ethiopia, Brazil, Peru, Mexico, and Nicaragua would have disastrous impacts on tea and coffee as an important export (McDonald, 2009).

Providing more regular and severe weather, evidence of rising climatic variability in East Africa emerges. Uganda has seen a substantial rise in the intensity and severity of droughts and floods. The records of dry and wet years in Uganda from 1943 to 1999 have shown that the frequency of very dry years has increased significantly over the last 30 years in the northern and western areas of the country which have negatively affected agricultural productivity (Orindi & Eriksen, 2005). In Tanzania, it has been observed that intra- and inter-season temperature variations, as well as precipitation, have affected cereal yields (Rowhani et al., 2011). Increasing the seasonal temperature by 2 degrees Celsius on their model reduced the average yields of maize, sorghum, and rice by 13percent by 8.8 percent, and by 7.6 percent.

Research by Omumbo, et al., (2011) was performed using the Golden Standard weather observations to demonstrate a warming trend of the maximum, and minimum temperatures observed in Kericho from 1979 to 2009. The study revealed that there was an upward trend in temperature by 0.2 Celsius per decade which would affect crop production in the area. As noted by previous studies climate variability and its effects vary from place to place over time. Informed by the study of Omumbo et al. (2011), this study examined the effects of monthly rainfall and temperature variations from 1995 to 2019 in Kisii County on tea production.

Kenya has also suffered several droughts and floods, as did its neighbours, that have devastating effects on the farming sector. In several eastern African countries, climate change influences weather patterns. There are already proven climate changes in Kenya that have been postponed, decreased and damaging precipitation and increased temperatures that have a significant effect on the production of tea. The key source of income for many families is endangered because the population depends on tea production (Adapcc, 2010). More than 70 percent of Kenya's natural disasters are weather-related, with drought and floods being the most severe over the years (Omambia et al., 2009). It was observed that over the past decades, the erratic variations in rainfall patterns have been evident and sometimes long dry spells have become a common phenomenon, impeding tea growth substantially and thus leading to low production and consequently low profitability (Soy et al., 2009).

In a detailed study from scientific research, Tubiello et al, (2007) investigated the reaction of of different species of plants in relation to climatic changes. Results showed that hurricanes, flooding, cross-year and climatic change over decades as well as large-scale traffic like the Southern Oscillation of El Nino impact crops, pastures and the development of forests tremendously. Performance losses can also be greater than those measured through regressors which are medium variables only. The results of the study showed that while previous studies have shown that crop biomass and yield appear to increase dramatically as CO2 increases, change in climate will alter and minimize the direct effects on crop growth and yields. During the stage of flowering of the crop, higher temperatures will have a direct reduction on the positive yield effects by reducing the quantity, size, and quality of the grain and, indirectly, by raising the water demand, thereby altering the positive effects of increased carbon dioxide. Moreover, changes in the ratio of evapotranspiration to precipitation alter the productivity and function of the ecosystem, especially in marginal areas. High water efficiency under high CO2 can ease or mitigate the effects of drought.

Bukhari, (2009) conducted an econometric analysis of climate change effects on the growth of Gambia's cash and food crops. The study determined the reaction of soil, paddy rice, sorghum, millet and maize to climate change. A random time effect data system was used in the study. Depending on last season's production, last season rates, current plant and precipitation levels and current seasonal usage of the land, the current season production was expressed. All the other variables were considered important, other than rainfall variability, whose effect was negligible. Rainfall had the greatest effect on crop production and the most important justification variable for crop yield in Gambia was the climate impact over the period studied. Further the study noted that there was need to incorporate economic and climate variables in the modeling of maize's responses to climate variation, the main foodstuffs, tea crops and coffee crops in Kenya. Moreover, precipitation and temperature variations are considered for extreme events and the danger to farmers in the empirical model.

Using the statistical approach in Tanzania, the impacts on cereal yield of both seasonal climate and variability of climate were examined by Rowhani et al. (2011). The study results showed that cereal yields in Tanzania were affected by both intra-seasonal and inter-seasonal changes in temperature and precipitation. With a temperature rise of 2 degrees Celsius, the seasonal temperature had the most effect on production, decreasing the yield of maize, sorghum, and rice by 13, 8.8, and 7.6 % by 2050, respectively. Maize, sorghum, and rice are expected to decrease by 4.2, 7.2, and 7.6 percent respectively by 2050, with a 20 percent rise in inter-seasonal precipitation. The study also shows that if climate variability is ignored and the focus is confined to climate media, climatic implications for maize, sorghum, and rice, are below the estimated at 3.6,8.9, and 28.6 percent. The research focused on seasonal precipitation and temperature methods, and also the variations in precipitation and temperature, to obtain robust estimates. Using a longer data set, this analysis uses different estimation techniques than Rowhani et al., (2011) to estimate the effects of rainfall and temperature variations on tea production.

In addition, in a different physical area, this study estimates the response of a food and cash crop. According to the location analysis and the option of explanatory variables used in the study, it is predicted that the impact on crop yields of climate change would distinguish. The effects of climate change on rice production were calculated by Kawasaki and Herath (2011) by calculating the production function of Cobb Douglas. The study found that crop position, solar radiation and temperature influenced the rice yield. Precipitation had little effect on rice production since farmers who cultivated drought-tolerant rice varieties had prudence with management practices in water. The survey shows that climate changes lead to changes in the level of decision-making, transformation and development.

Using a time series analysis, Tesso et al. (2012) used co-integrated VAR and ECM for climate variability and its effect on dietary development in Ethiopia. Information spanning three decades was included in the analysis. The results of the study suggested that improved technology, the region under irrigation, the use of manure, the Meher rain, and the average temperature significantly affect food production. Meher rain, mean temperature, Belgian rainfall and irrigated area, manure usage per hectare and led to change in yields which accounted for about 90% of the productivity fluctuations. Precipitation and temperatures are therefore expected to have different effects in various seasons on crop production. The study also investigates the effect of seasonal variations of temperature and rainfall on the distribution and tea yields.

The links between weather and tea productivity in Kenya were studied by Cheserek et al. (2015). The authors used Timbilil tea farm, Magura tea estate, and Kangaita farms to carry out the research. Data analysis found that land temperatures had increased, precipitation amounts and distribution had varied over time. The study revealed tea thrives well when soil moisture is not inhibitory in warm temperatures. A substantial positive link between average air temperature and tea production was observed in all study sites where soil moisture does not restrict. The study used a series of econometric techniques to analyze the impact on tea production of climate variability based on a different approach to the one used by Cheserek et al., (2015). While Cheserek et al., (2015) considered three farms' data, this data cannot be used for generalization to all tea growing regions since the climate is not static as it varies from region to region over time. Evidence of climate change exists in tea-growing areas, according to Wachira (2009). There has been evidence of reduced precipitation, decreased soil water, and elevated temperatures since 1958. The rainfall in Kericho decreased by 4.82 millimeters annually in the 52 years covered by the report, while the temperature rose by 0.016 degrees Celsius annually. Temperatures in the area of tea growing have increased from 0.1 to 2.9 degrees Celsius. There is a high correlation between tea production and precipitation with the number decreasing with drought periods and an increased deficit in soil water.

Rwigi and Oteng'i (2009) were also evaluating the effect of climate parameters in the Mount Kenya region on tea yields in tea-growing regions. Linear and various regression models were employed in the analysis. The research used five climatic variables: mean daily minimum temperature, mean daily maximum temperature, mean daily relative humidity, total weekly radiation and weekly tea yield. The results show that the weekly tea production is highly influenced by the mean minimum daily temperature and relative humidity. In this investigation, the results inform, the main variables that influence Kenya's tea production include precipitation, temperature and the variability thereof. However, this study expands the scope of the climate variability and examines the effects of total tea production on the national level. Further for econometric estimation analysis uses a specific range of techniques to determine the effect on tea production.

In Kiambu County, Kenya, Wangui (2010) investigated the effect of temperature and rainfall variations on large-scale coffee production in the estates of the county. Using the Pearson correlation method, the study revealed that in the study area, fluctuation of precipitation and temperature increase led to the reduction in coffee yields. This research, informed by the results, considers rainfall and temperature variability as the main variables affecting the production of coffee in Kenya. However, this research extends the scope, taking into consideration the national influence on total coffee production of the rainfall and the medium temperature and their deviation from the mean. Further for econometric calculation, the study uses a specific set of techniques.

For testing of data from 227 farms irrigated by rice in 6 countries in many seasons, Welch et al. (2010) used the Multiple Regression Model. The model included environmental variables for the farm and agricultural variables and economic variables for the particular area. Economic variables were introduced to make the forecasts more accurate compared to modeling using only weather variables. From the approximate coefficients, temperature and radiation had statistically more effects on both the vegetative and ripening phases of the rice plant. In order to minimize yield, high minimum temperatures and moderate maximum temperatures increased yields. The study prediction suggested a decrease in the yield of rice from mild warming over the next few decades. With the probability that during the study period, rainfall did not restrict irrigation levels, rainfall had no significant effect. The results of the study showed that the effects of precipitation and temperature on crops depend on the crop plant's growth and development stage.

However, according to Gay et al. (2006), the seasonal means are more precisely significant than the annual values in relation to climatic variables and plant phenology. This research, therefore, deals with seasonal climate data on crop growth and crop output. The ties between climate change and crop production in Uganda have been observed by Mwaura & Okoboi (2014). The research used the period that ranged from 1981 to 2008 for the ARCH model. The projections of the model showed that the fluctuations in rainfall and temperature from long-term means significantly influence crop production. The increase in the temperature difference produced a higher crop production difference, while the exponential increase in precipitation had a detrimental effect on crop output. The results showed that climatic instability affects crop production. However, in the research, the study did not include monthly means.

The potential effect of future climate change on tea production in Kericho County, Kenya, was assessed by Okoth (2011), using Kapkatet tea estate. The analysis was based on regional climate model outputs from PRECIS. The research was carried out using tea production data collected from the Kapkatet tea factory, rainfall and temperature data to examine the seasonal production cycles using the simulation method. Further research by Bett (2018), on the effect of climate variability on tea production in Kericho County was carried out. The study used, James Finlay's (k) limited tea yield data, rainfall and temperature data from the Kenya Meteorological department. Using multiple regression, the study found out that rainfall variability had a positive significant influence on tea production. the study showed rising patterns in maximum and minimum temperatures. The study indicated that climate changes in Kericho County have occurred and are likely to change in the future. This research used econometric techniques to analyze the effects of climate variability on the production of tea, using a different methodology from the simulation process employed by Okoth (2011). Given that climate varies from region to region, this study cannot be used to generalize the effects of climate to all regions of the nation. Therefore, this study used correlational analysis and sen's slope to determine the strength of the slope which was not used by Bett, (2018) and Okoth, (2011). It further examines the perception and adaptation to climate change by tea farmers.

A study was conducted by Leshmta (2017) on the suitability of tea-growing zones in Kenya under changing climate where Kisii was included. The study used tea production data for a period of ten years that from 2006 to 2015, monthly rainfall and temperature from 1976 to 2014. But this study used tea production data, monthly rainfall and temperature from 1995 to

2019 to examine the effects of climate variability on tea yields. The study by Leshmta, (2017), did not give a detailed inquiry on the effect of climate variability on tea yields in respect to the period in question. Therefore, the current research examined the effect of climate variability in each year in line with tea yields.

Samwel, Abutto and Otieno (2018), assessed the impacts of climate variability on food security in Kisii County. The study examined the effects of rainfall and temperature on food crops such as maize, beans, potatoes and bananas from 1983 to 2014. Given that climate affects different crops differently, this study examined the effect of climate variability on tea yields from 1995 to 2019.

2.4 Perception of Farmers on Climate Variability

Different population groups have different perceptions on climate variability (Haque et al., 2012). Some perceive it in terms of rainfall and temperature variations, others perceive it from extreme climatic events such as floods and droughts and others from crop failure, reduced crop yields and reduced water resources. Many farmers worldwide have been experiencing climatic changes as reported through rising temperatures, unpredictable and reduced rainfall which has led to reduced yields (Karki, 2019). It has been noted that assessing different levels of farmers' perception is paramount for successful efforts to curb negative effects of climate variability and change on Agriculture. Further, perception of the severity of climate variability and change in agriculture and water resources is an important prerequisite in coping and adapting to these changes since they influence the farmer's responses (Patt &Schroter 2008; Ochenje, et al., 2016). Adaptation at the farm level will not take place unless farmers perceive variations in the climatic elements.

Most researchers such as Roncili et al., (2002); Vogel & O' Brien, (2006) and Thomas, et al., (2007), have argued that environmental perceptions are among the lead factors that influence the adoption of adaption strategies, planning and management of agricultural activities taken by farmers. Maddison (2006) described that adaptation to climate change requires the perception of farmers that there has been a spatial variation of climate over time and then choose useful adaptations and implement them. Sledgers (2008) as cited by Moyo et al., (2012) has also indicated that an important factor that shapes a farmer's perception is experience. In terms of seasonality, bad experiences of the seasons, when extreme climatic conditions such as droughts affected agricultural production, can be remembered. In agreement to the above, a review done on the experiences and perceptions of farmers about climate change and variability on research articles up to 2016, revealed that farmers worldwide have been experiencing climate changes mainly regarding rising temperature, unreliable and reduced rainfall which have led to the reduction of the agricultural produce (Karki, Burton & Mackey, 2020; Hitayezu, Wale & Ortmann 2017).

Research done in Songkhla Lake Basin in Thailand on farmers' perception of the effect of climate variability on crop production revealed that change in temperature and rainfall had led to reduction of crop production and these affected farmers involved in fruit production, and fisheries adversely (Somboonsuke et al., 2018). This is in agreement with a study conducted on perceptions of farmers on climate change and variability in Central America which revealed that smallholder farmers perceived that climate has been changing with most of them reporting the rise in temperatures, low annual rainfall and seasonality of the rain season (Harvey et al., 2018). A study done in North West Ethiopia, on the perception of farmers to climate variability showed that there were crop failures in the past, changes in temperature and precipitation significantly influenced farmers' perception on climate variation in wet lowland parts of the study area. In dry lowland conditions, farming experience, climate information, duration of food shortage, and the number of crop failures experienced determined farmers' perception of climate change (Paulos & Belay, 2018).

A study that was done using participatory research techniques in two semi-arid regions of Zimbabwe on farmers perception on climate variability and the correspondence of these perceptions with historical climate data revealed that farmers perceived that there were variations in climatic and weather patterns over the past decade. Further, it was indicated that there were erratic rainfall patterns, decreased rainfall and temperature increases, which led to a decline in crop production and increased livestock morbidity and mortality (Mvumi et al., 2012). This agrees with a study of South African farmers' adaptation to climate variability and change (Bryan et al., 2009), where it was observed that 95 percent of the farmers perceived that temperature had changed over time while 97 percent of them thought there has also been a change in rainfall. Extreme weather events had been projected to increase in the Southern Africa region which is frequently affected by frequent drought occurrence due to its characteristic low rainfall index and variability (Rakgase & Norris, 2015; Stringer et al., 2009). In contrast to the above, a study conducted in a semi-arid Basin by Shimola and Krishnaveni, (2017) on farmers perception on climate variability revealed that the majority of the farmers reported that rainfall had been decreasing and they had experienced high incidences of droughts that forced them to opt for other sources of income.

A comparison of farmers' perception of climate variability with climatological data was made in South Africa. The response of the farmers was consistent with that of the climatological data which revealed that there was a decrease in the total annual rainfall from 2006-2015 (Rapholo, 2020). This study is in agreement with the one conducted in the semi-arid highlands of Northern Ethiopia where 92 % of the farmers perceived that annual rainfall had decreased from 1983 to 2015 (Kahsay, Guta & Gidey, 2020). In South Africa, a study was conducted in the rural Limpopo Province on the perception of smallholder farmers on climate variability and crop production and household livelihood by Ubisi, et al., (2017). The study found out that 56.4 percent of the smallholder farmers perceived prolonged droughts as the main factor affecting crop productivity. This is in agreement with a study done in the Central River Region of Gambia where most farmers perceived an increase in the occurrence of extreme events. Almost all farmers that is 90 percent considered drought as the main factor affecting agricultural activities in the area (Begagnan, Ouedraogo & Fonta, 2019).

A review was done by Sani and Chalchisa (2016) on farmers' perceptions on impact and adaptation strategies to climate change among small-scale farmers in Sub- Saharan Africa. It was revealed that most farmers were aware of climate change and variability which was manifested in changes in precipitation patterns. This agrees with a study conducted in five Counties of Eastern Province in Kenya on farmers' perception on rainfall variability and its associated risks. Farmers were aware of the rainfall variability and its effects on crop production but were not able to recognize the long-term trends (Rao, et al., 2011).

In Kisii Sub County, a study done on the perception on the effects of rainfall variability on crop production and household security, results showed that farmers perceived that it led to reduced yields, reduced water availability and increased crop and animal diseases (Otiso, 2016).

2.5 Mitigative Measures to Climate Variability

The global nature of climate variation is demonstrated by efforts to address its impacts. Addressing these impacts requires technological innovations in farming systems. This makes it compulsory for both farmers and policymakers all over the world to consider taking efforts and developing policies, which, in turn, will be translated into domestic contexts and implemented (UNFCCC, 1992). This requires building and adjusting indigenous understanding with modern knowledge gained from field research operations (FAO, 2008; 2014). In developing countries, most countries are faced with high population growth. Therefore, their agricultural systems and food security are required to come up with coping strategies as uncertainties in climate variability and change have become a common occurrence (Kogo, Kumar & Koech, 2020).

According to the cultural theory for climate change adaptation, the way people perceive climate change risk is informed by the social interactions and cultural worldviews comprising fundamentals beliefs about society and nature. This in turn influences the feasibility and acceptability of climate adaptation planning, policy-making and implementation (McNeeley, & Lazrus, 2014). In agreement with the above, Herrero et al., (2010) argues that adaptations to climate variability and change should include all relevant sectors from the crop -farm level, community, national regional and global levels in enacting policies that sustain agricultural investment.

Therefore, adaptation requires the involvement of multiple stakeholders, including policymakers, extension agents, Non-Governmental Organizations (NGOs), researchers, communities, and farmers. Potential strategies will include infrastructural investment, water management reform, land-use policy, and food trade. Climate change and variability can no longer be considered to be secondary or long-term reactions. For those communities already vulnerable to the effects of current climate threats, initiatives are normal, imperative and urgently needed (Cooper, 2013). Adaptation strategies are long-term (within a single precipitation period), which are required to respond farmers to a new set of unprecedented changing climate conditions. This should be clearly distinguished from coping policies, which are interventions that have evolved through farms' long-term experience in dealing with the natural weather variation they expect in and between seasons.

In response to climate variability and changing conditions, Pathak et al., (2012) have identified several adaptation strategies available for crop farming. These include technical alternatives (for example, more drought-tolerant crops), behavioral responses (for example, improvements in dietary choices), management changes (for example, various animal feeding practices) and policy options (including the planning and infrastructure growth regulations) (Thornton et al. 2006). A four-pronged approach to embracing and controlling the climate fluctuations in the agricultural and specifically crop-producing sector is suggested: drought, floods, frost, extreme storms and hailstones.

In Lake Victoria, where the Central Sub Company is based, most households depend heavily upon the cultivation and rearing of the cattle, according to Dida et al., (2013). However, as climatic conditions do not seem to be favorable in most areas of the region, and knowledge building and changing farming practices are therefore important. East African farmers still had high variability in rainfall during or between seasons and were not static in their farm systems (Cooper et al., 2011).

A study by Bryan et al. (2011), found that farmers are more concerned with increased uncertainty and seasonal changes that prevent their ability to forecast planting trends and to schedule their agricultural activities accordingly. Weather patterns have already changed, and therefore, various mechanisms have been employed (Kuria, 2009; Macharia, Lugadiru, Wakori, Ng'ang'a & Thuranira, 2010; Kristjansen et al., 2012). Changes and modifications to various agricultural strategies reflect evidence of the changes perceived by households (Meze-Hausken, 2004). Climate variability and change modification require various responses, including crops and animals, land use, and land management and livelihood strategies (Bryan et al., 2011).

Practices to cope with plant variability in local communities include crop diversification, fish farming adoption, kitchen planting, hay staking, and bio-intensive farming (FAO, 2016b; 2017a; GOK, 2010; 2013). The fluctuations of precipitation and declining land size have resulted in farmers adopting various agricultural practices to increase productivity in an environment that is worsening. Farmers move away from traditional farming practices based on the cultivation of one or two or three cash crops for household living. New crops are introduced, the number of livestock has fallen, zero-grazing has been included, as well as agroforestry (Muriuki, Kirumba & Catacutan, 2011; Elbehri & Sadiddin, 2016) is now widely practiced. Comprehension of household choices of crop-livestock can generate important information on how farm households change the risk of their crop composition in response to variability in rainfall. It has been noted that a crop management adaptive system includes; early planting, planting of cultivars that are resistant to climate variability and irrigation (FAO, 2016b). In agreement with the above, Ixchel et al. (2019) in their study found out that crop management can increase crop yields by 7 to 15 percent, though these results depend entirely on the region and crop in consideration.

The efficacy of these adaptation approaches depends on a variety of factors which include the knowledge base of farmers, capital, technology, the physical and social environment as well as support programs made available for farmers that make such adjustments possible (Assan et al., 2018; Zizinga et al., 2017). This agrees with FAO, (2011) which argues that raising crop productivity requires sustainable intensification which lowers the cost of production and steadily increase in yields while preserving the environment thus minimizing the negative effects. The approach of sustainable crop production intensification uses the model "save and grow" which promotes productive agriculture that conserves and enhances natural resources. It also uses an ecosystem approach that draws on nature's contribution to crop growth such as soil organic matter, water flow regulation and natural predation of pests.

In response to rainfall variabilities, Selvaraju, Subbiah, Baas and Juergens (2006) found adaptation methods widely used by farmers were; water harvesting, early planting, deep plantation, cover crop planting, application of mulch to preserve moisture, planting of drought-tolerant crops, early planting and farming of alleys and business diversifications. Various studies (Yamba, 2019) suggest the promotion of appropriate/indigenous farm adaptation technologies. Though several studies have been carried out in developing countries on adaptation to climate change (Selvaraju et al., 2006; Nhemachena, 2007; Badi, 2010; Ojwang et al., 2010; Huho et al., 2012), they have not done their studies at group or household coping strategies for high potential regions and at how they respond to variation in rainfall.

The analysis must, therefore, concentrate on high potential regions and how the different populations view the effects and adaptations of the rainfall variability. This is because societies are inclined to adapt successfully to their traditional information structures (UNEP, 2006; 2010). Therefore, what is taking place in a high potential region like the Kisii Central Sub County at the household level is relevant for us to understand. The explanation is the households are the most vulnerable group to climate change.

The instability of expected precipitation is one of the ongoing stresses faced by rural communities. For the population which is dependent on rainfed farming for their survival, the seasonality, quantity, distribution, and timing of rainfall are especially important. During this study, several studies were conducted in order to study the effect of plant variability (Klein & Roehing 2006; Ojwang 2010; Shisanya, Recha & Anyamba, 2011; Recha, 2011; Bezabih, Défalcao & Yesuf, 2011; Huho et al., 2012) in view of the prevalence of weather instability and the virtually exclusive dependence on cropland for production. However, most of these studies have concentrated on dry and semi-arid areas and medium potential areas. While farmers seem to have a wide range of practices that give much productiveness, adaptation and mitigation benefits, the degree to which farmer practice the adaptation is varied according to farm household characteristics, biophysical and socio-economic conditions (IPCC, 2007; IFPRI, 2011; Ambasa, 2015).

Agricultural technology adoption is regarded as synonymous with farmers' adaptation strategies to combat the negative influences of change in climate (Nhemachena & Hassan, 2007) and as a consequence, adoption literacy can be applied in adaptation studies on climate change. A number of variables, including age, gender, education level, income levels and agro-ecological areas, are known to affect household response strategies to climate change. Adesina & Forson (1995) and Gbetibouo (2009) studies of agricultural technology observe that there is no consensus in the literature on the accurate impact of age on the adoption of agricultural technologies since the age impact is generally unique to localization or technology or thus an empirical concern.

For the sake of older farmers' being more risk-averse and thus less agile than younger farmers, age might have a negative impact on decision making to implement new farming technologies. On the contrary, age will have a positive impact on a farmer's decision to adopt as older farmers are better able than younger farmers to determine the characteristics of new agriculture. These researches have not concentrated on how perception is affected by age. Future events may be influenced by experiences and interpretations of previous events (Smelton et al., 2011). Thus, this research aimed to find out how age affects the understanding of rainfall variability effects and adaptation choices.

Concerning gender, Asfaw & Admassie (2004) note that male-headed households are more likely to obtain information on new farming technologies and are more likely to pursue riskier projects than in the households headed by females. The same observation was made by Tenge & Hella (2004), who pointed out that the risk of women-headed households is less high because women may be limited by traditional social barriers to knowledge, land, and other resources. Contrary, households that are headed by women follow strategies for adjusting to climate change than men (Nhemachena & Hassan, 2007). These studies did not show how gender and the influence of rainfall variability are related.

Norris & Batie (1987) argue in terms of education that farmers with more education have more chance than farmers with less education that can have increased access to technical knowledge. Igoden, Ohoji & Ekpare (1990) and Lin (1991) also noted a positive correlation between household education and improved technology adoption and adaptation to climate change. Farmers with a higher educational standard are also more likely to understand and respond to climate change. Linked to Nhemachena and Hassan (2007) study shows that farming experience, as the education level of farmers, is increasing the chances of implementing climate change adaptation steps.

Farmers' innovation and decision-making normally involve a process under which farmers themselves can develop ways of doing practices that improve their farming activities as well as coping and adapting to any changes that may seem threatening their farming activities and so, their livelihoods. This also implies that climate variability and change action should be informed by Traditional Ecological Knowledge (TEK) in areas where environmental change has been experienced, adaptations options, land use, and natural resource management have been employed (Aswani, Lemahieu & Sauer, 2018; Saylor, 2018; Alsharif & Torres, 2017; Yamba et al., 2019; Vinyeta & Lynn, 2013).

Over decades, small-scale farmers have coped with external stressors through changing their agricultural operations. Past climatic observations coupled with traditional knowledge were of great importance in coping with environmental changes (Altieri &Koohafkan, 2008). Farmers have used community-based tested methods and practices to cope-up with these changes thus enhancing food security. According to Shaw et al., (2009), local and traditional knowledge should be valued in coping with climate variation. This is because place-based memory of vulnerable areas, knowledge for responding to recurrent extreme events and detection of abnormal environmental events manifest in the power of local knowledge (Cutter et al., 2012). The people at the grassroot in regard to climate change and variation conserve resources when they perceive changes in weather patterns and therefore adapting to these changes (Salik & Ross, 2009; Turner & Clifton, 2009).

Different people use different methods depending on the vulnerability of the extreme event and their culture. Some of the methods used include mountain rice terrace systems in Madagascar; multiple cropping systems in Chinampas, Mexico; ancient irrigation, soil and water management systems in Iran, Afghanistan and Mali; and complex multi-layered home gardens with wild and domesticated plants for foods, medicines, ornamentals and others in China and India (Fussel, 2007, Koohafkan & Altieri, 2011).

In China, soil and water conservation measures have been put in place to increase soil water holding capacity to reduce the impact of droughts so as to maintain tea productivity. Some farmers have employed organic farming which has contributed to climate mitigation and sustainable agriculture. Studies have revealed that organic tea production can enhance soil carbon sequestration (Han et al., 2016) through increasing soil organic matter levels. This increases plant nutrients, increases water retention capacity and hence increased productivity. According to the High-Level Panel of Experts, HLPE, (2015) and Oweis, (2014) water and soil conservation in Sub- Saharan Africa are used to increase production and reduce losses incurred during the dry period. Supplemental irrigation using water harvested during the rainy season is a prime approach for growth and increase of crop yields in rain-fed agriculture.

In Ethiopia research done by Nzuma et al., (2010) and Yamba et al., (2019), have revealed that adaptation practices to climate variability and change include: reducing the amount of food consumed daily, gathering of wild game, engaging in trading activities and migration to other areas if the effects are severe. This is in agreement with a study conducted in Ghana which has revealed that adaptations to climate variability include on-farm practices such as timely planting, mulching, digging of canals to divert water to the farms, harvesting water during the rain season for irrigation, afforestation and agricultural diversification such animal farming (Antwi-Agyei, Fraser, Dougill & Simelton, 2013; Asante & Amuakwa-Mensah, 2014; Mohamed, Kwaghe, Abdulsalam, Aliyu & Dahiru, 2014). All these practices are aimed at either improving the water retention capacity of the soil, reducing evapotranspiration, removing flood water, or enhancing the hydrological cycle.

The tea ecosystem is unstable because the tea plant is a mono perrenial crop. With climate change and variation, more complex and integrated ecosystems should be considered to maximize the use of natural resources such as hot weather, water and enriched carbon dioxide, while minimizing stress conditions. Proper shade management and mixed farming cropping, such as animal husbandry which provides biogas slurry fertilizer for tea growth and other vegetation provide green manure. Biogas slurry is a liquid that is discharged from a biogas digester that is dried and composted to get solid organic fertilizer that is rich in nitrogen, phosphorous, potassium, calcium, magnesium and Sulphur needed for plant growth (Bouten et al., 2014). According to SNV (2011) when tea is treated with slurry, it improves in quality and yields increase by 11 percent. Conservation agriculture, precision agriculture, organic agriculture and other sustainable farming systems have been integrated to adapt to climate change (FAO, 2016). In response to climate variability and change conservation agriculture involves minimal disturbance of soil, permanent soil cover and regular crop rotations.

Among the adaptation strategies listed include: improving crop varieties through careful selection of seed, harvesting rainwater, soil conservation measures as well as changing farming practices (Briggs, 2018; Reij & Waters-Bayer 2001; Critchley & Mutunga, 2002; Chinkhuntha, 2004; Ojwang', et al, 2010; Wood, et al., 2014). Creative traditional irrigation by many local ethnic groups in many developing countries, for example, use of trenches by Wachagga and Wasonjo in Tanzania and Qantas in Iran (Shemsanga, 2010); use of biological methods to control crop pests (O'Neil, 1995); use of concotions to produce new pestcides (Minja et al., 2003); planting of leguminous and cover crops to conserve and improve the fertility of the soil (Wickama & Mowo, 2001).

Diversification is also another important adaptation to climate variability and change as it helps to spread the risk of climate variability damaging livelihood (Chandra, 2017). It reduces the impacts of climatic blow on income and provides a wider variety of alternatives for managing subsequent threats. Agricultural diversification means adding plant varieties and species or animal breeds to farms. It involves landscape diversification with different crops and cropping systems interspersed over space and time. It has been noted that farmers look for different means of earning a living such as employment in Malawi, but in Zambia, farmers variegate to animal husbandary. Where the climatic impacts are high, mixed farming is preferred as animals are treated as assets that can be sold anytime to provide income in Sub-Saharan Africa (Herrero et al., 2013; Braudron et al., 2013). Further, mixed farming systems provide manurethat is used in crop production which reduces input costs (Liu et al., 2010; Herrero et al., 2013).

Adaptations to adverse climatic changes are numerous in Kenya and include crop management practices (choice of fields, planting densities, crop varieties and planting dates), land use and management (fallowing, tree planting or protection, irrigation and water harvesting, soil and water conservation measures, and tillage practices and soil fertility management), livelihood practices (mix of crop and animal production, permanent or temporary migration and agricultural and non-agricultural activities) (Bryan et al., 2011). This agrees with a study done in Trans- Mara East Sub-County on climate adaptive capacity and smallholder farming which found out that farmers diversified crop their varieties and used improved drought-tolerant varieties (Simotwo et al., 2018). The Tea Research Institute of Kenya (TRIK) has also developed clones that are resistant to frost damage and are recommended for the areas that suffer from frost (Maina, et al., 2013). From the above literature, it evident that different regions of the globe adapt to differently to climate variation depending on the agricultural activity and the vulnerabilities. Though many reseasrches have been done on measures of curbing climate variability on crop production, no known research has been done on small-scale tea farmer in Kisii County. To fill this gap, the study examined climate variability and its effects on small-scale tea production in Kisii County.

It was evident from the literature review that climate change and variability have adverse effects that affected tea production. Table 2.1 summarizes climate variability and its effects on tea yields.

Table 2.1: Climate Variability Effects on Tea Production

Climate Variable Problem	Effect
Increased temperatures	Increased evapo-transpiration leading to drying of soil causing reduced water content in the soil leading to reduced tea yields and negative impact on quality Emergence of pests and diseases which not previously present in these areas Changes in suitability of existing tea growing areas. Sun burns and destroys leaves, leading to decreased yields and low quality
Variation of rainfall patterns	Uncertainty in when to apply fertilizers
Increase in extreme weather events such as drought, hail, storms, floods, frost and landslides	Leaf damage and Crop failure Susceptibility of tea plants to pests and diseases Erosion washes away the soil fertility Frost damage the leaves Increased financial vulnerability of tea farmers Increased reliance on irrigation due to reduced precipitation

Source: Summary of literature Review

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter discusses various sections such as the study area, research design, sample size and sampling techniques, data collection instruments, data collection procedures and methods of data analysis and presentation.

3.2 Study Area

3.2.1 Geographical location

This study was conducted in Kisii County which is situated in former Nyanza Province in South Western Kenya. The County is inhabited mostly by the Abagusii people. The area lies between latitude 0^0 30ˈ and 1^0 00″ S and longitude 34^0 38ˈ and 35^0 00″ E. It has an area of 1,317.9 square kilometres with a population of 1,266,860 according to the 2019 census (KNBS, 2019).

Kisii County is bordered by the following Counties: Homabay and Migori to the West, Nyamira County to the North East and Narok County to the South. The administrative divisions of Kisii County are; Keumbu, Kisii town, Marani, Masaba, Mosocho and Suneka. Kisii County comprises of the following nine sub-counties: Masaba South, Gucha, Nyamache, Kenyenya, Sameta, South Gucha, Kisii Central, Kisii South and Marani (Kisii County Government, 2018).

3.2.2 Physiology

In physiology, it is characterized by undulating and hilly landscapes with several ridges and valleys that lie approximately 1500m above sea level (GOK, 2009a). The overall slope of the area is towards the west; therefore, the general drainage is in that direction. Topographically, it is divided into three classes; those that lie below 1,500m above sea level that are located on the western boundary of the County which includes parts of Suneka, Marani and Nyamarambe Divisions. Secondly, areas that lie between 1,500 -1,800m above sea level are located in the Western parts of Keumbu and Sameta Divisions, Eastern Marani and Gucha River basin. The last category covers areas lying above 1,800m above sea level in parts of Eastern and Southern Keumbu, Masaba and Mosocho Divisions.

The hills that are found in Kisii County include; Nyamasibi (2170m), Sameta (1970m), Kiamwasi (1785m), Kion'ganyo (1710m), Kiongongi, Kiombeta, Sombogo, Taracha, Nyanchwa and Kegochi among others. The slope of the land is generally from the East to the West where there are many depressions and valleys.

In drainage, rivers Gucha, Mogusii, Riana, Mogonga, Iyabe and Chirichiro cross the County Westwards flowing into Lake Victoria (Kisii County Government, 2017).

3.2.3 Climate and Soils

The County experiences a highland equatorial climate which has long and short rainfall patterns with an average annual rainfall of 1500mm and 60 percent reliability (800 mm in the short rains and 1200 mm in the long periods). Temperature ranges between 16^{0}c and 27^{0}c, with the coldest months being June, July and August while the hottest months are December and January (GOK, 2009a).

Soils found in the County include; red volcanic soils which cover 67% and clay soils, red soils and sandy soils. The soils favor the growth of cash crops such as tea, coffee, pyrethrum and subsistence crops such as maize, beans, bananas and potatoes among others (Kisii County

Government, 2017). The existence of natural vegetation is limited as ninety percent of the total land is under cultivation and homesteads (Mironga, 2006).

3.2.4 Economic Features

The County's economy is dependent on rain-fed agriculture with tea, coffee and sugar being the main cash crops while maize, beans, potatoes and finger millet being the key food crops. Bananas act both as food and cash crop. Other economic activities include dairy farming, soapstone carving and trade. In the transport sector, the County is served by a network of roads that connect to various counties such as Migori, Homabay, Nyamira and Narok. It has Suneka Airstrip which is the only mode of air transport.

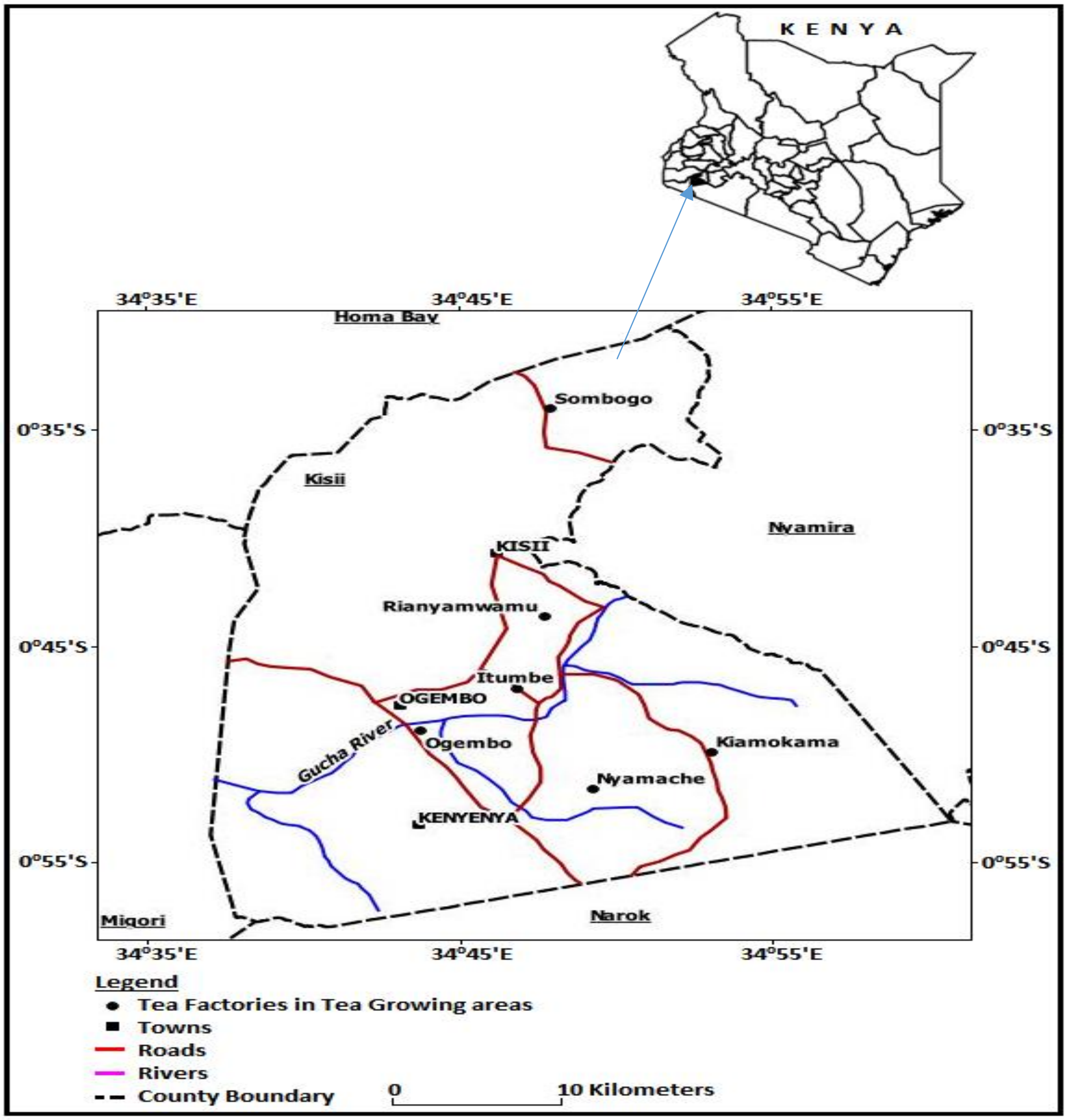

Figure 3.1: Map of Study Area

Source: Softkenya.net, 2021

3.3 Research Design

A research design is an outline of how to collect, measure and analyzes data (Kothari, 2004; Bariragi & Munot, 2019). It includes procedures adopted in collecting, analyzing, interpreting and reporting data in research (Creswell, 2007). This study adopted a correlational research design. The design examines a relationship between two concepts (Walliman, 2011).

Correlational research design explores the relationship between variables and measures the intensity of the relationship. Whenever variables change in the same direction, the relationship is said to be positive while a negative relationship occurs when one variable increase while the other is decreases. No relationship occurs when there is no identifiable pattern (Thompson et al., 2005; Slavin, 1992). This design was important for this study because it examined the relationship between rainfall and temperature variations and tea production. The study used quantitative and qualitative approaches.

3.4 Target Population

A target population is a group of participants who have particular attributes of interest for a research study (Creswell, 2003). It is a group of elements to which inference is made by the researcher. The study targeted six Kenya Tea Development Agency (KTDA) factories and six field service coordinators; 120,000 small scale tea farmers (KTDA, 2017) who supplied their tea; and personnel from the meteorological department of Kisii County. This study collected data on monthly tea production totals from factories for the years 1995 to 2019 and monthly rainfall and temperatures from the meteorological department from 1995 to 2019.

3.5 Sample Size and Sampling Techniques

There are six KTDA factories in Kisii County, but using inclusive and exclusive criteria only three were chosen based on their longevity in business. A typical inclusion criterion includes demographic and geographic characteristics. On the other hand, exclusion criteria are defined as characteristic participants of the study who meet the inclusion criteria but may have additional characteristics that can distort the success of getting credible information (Patino & Ferreira, 2018). All the factories could be included in the study to provide the required data but, because the tea production data required was from 1995 to 2019, three were excluded based on the length of service. The factories that were chosen included: Kiamokama, Nyamache and Ogembo. Data on monthly tea production from 1995 to 2019 was collected from field service coordinators of the three sampled tea factories. The head of the metorological department was purposively sampled.

The study used a sample size of 400 farmers as calculated by Yamane, (1967) at 95 % confidence level obtained from Yamane table (Appendix III).

$$n = \frac{N}{1 + N(e)^2}$$

(Yamane, 1967)

Where n = sample size

N= Total population

e =error term (0.05)

The sample size was distributed proportionately to three tea factories to obtain the sample size for each as shown in table 3.1 using the formula

n =x/N *400 where;

n = sample size for each factory

x = number of farmers for each factory

N = total number of farmers for the three factories

400 is the calculated sample size obtained from the target population

Table 3.1: Sample Size Distribution

Factory	**Number of farmers**	**Sample size (n/total *400)**
Kiaomokama	12937	113
Nyamache	15942	140
Ogembo	16720	147
Total	**45599**	**400**

Source: Field Data, (2020)

The three field service coordinators were purposively sampled each from the selected factories. They provided secondary data on the number of farmers and monthly tea production from 1995 to 2019 (Appendix VII).

The farmers supplying tea to the three factories were randomly selected. They provided information on perception and adaptation to climate variability. Three field service coordinators, one from each selected factory served as key informants. The head of the Kenya Meteorological Department (KMD) provided climatic data on monthly rainfall and temperature measurements over the stipulated period, 1995-2019.

3.6 Data Collection Instruments

To collect data and test hypotheses, the study used interview schedules and questionnaires to collect primary data from field service coordinators and small-scale tea farmers respectively. Document analysis for secondary data was used to collect monthly rainfall and temperature data from 1995 to 2019 from KMD and tea yields from KTDA factories for the years 1996 to 2019. Two research assistants administered questionnaires to the farmers and interviews were administered to the field service coordinators by the researcher.

3.6.1 Questionnaires

A questionnaire is a data collection instrument that consists of a series of questions and other prompts to gather information from respondents. According to Kothari (2004) a questionnaire is commonly used by many researchers to collect data because it is cost-effective and precise way of collecting extensive information within a short period (Orodho, 2008). Open-ended and structured questions were used to collect data on the perceptions and coping strategies from smallholder KTDA farmers. Two research assistants were distributed and collected the questinnaires.

3.6.2 Interview Schedule

An interview schedule is a list that contains structured questions prepared by the researcher, to serve as a guide for interviewers and researchers in collecting information about a specific topic. It is used by the interviewer to fill the questions with answers received during the actual interview (Luenendonk, 2016). Interview schedules allow the interviewers and researchers to get more information since they can ask follow-up questions and clarifications to the questions asked. The interviews were specifically used as a complement to the responses obtained from questionnaires to reduce ambiguity in responses and give a clarification of the responses given. The interviews were administered to the field service coordinators who were the key informants.

3.6.3 Document Analysis

Document analysis is a systematic procedure for reviewing or evaluating documents. It requires that data be examined and interpreted to get meaning and develop empirical knowledge (Bowen, 2017). Monthly data on rainfall and temperature were collected from

Kisii Meteorological Department and monthly tea production were collected from the three selected factories.

3.7 Data Collection Procedure

After submitting the research proposal to the Board of Post Graduate Studies of Kisii University, the National Commission of Science and Technology Innovation (NACOSTI) gave a research permit. The researcher then sought permission from the County Commissioners and County education officer. The area chiefs were informed that there was a study done in their areas of jurisdiction. Further, the researcher assured the participants that the information collected was purely for academic purposes and was treated with a lot of confidentiality.

3.8 Pilot Study

A pilot study is important in ensuring that the study reasonably adopts a plan and approach that will significantly guarantee the purpose of investigation (Gay, 1987). It is meant to identify potential problem areas and deficiencies in the research instruments (Hassan, et al., 2006; Kraemer, et al., 2006; Murray 2003). A pilot study was done before the commencement of data collection to test the suitability of instruments. The pilot study was conducted in Nyakoba Tea Factory in Nyamira County. A field service coordinator of Nyakoba Tea Factory was interviewed and one small-scale farmer was given a questionnaire to fill and return. The pilot study enabled the researcher to review the suitability of the instruments and where there were ambiguities, corrections made with the help of the supervisors.

3.8.1 Validity of the Instruments

The validity of an instrument refers to how best it can measure what it intends to (Kimberlin & Winterstein, 2008; Pruzan, 2016). A test is said to be valid for measuring an attribute if the attribute exists and that variations in the attribute produce variation in measurement (Borsboom, et al., 2004; Kupar, 2018; Pandey, & Pandey, 2015). To determine the content validity of the instrument items, the supervisors corrected and ensured that the instruments were in line with the proposed study objectives. Based on their comments, the wordings of the instrument were modified and others made simpler.

3.8.2 Reliability of the Instruments

Reliability refers to the degree to which a measurement of a certain event gives a steady and consistent outcome (Carmines & Zeller, 1979; Bairagi& Monut, 2019). Reliability is also concerned with repeatability. It refers to the consistency or trustability of a measurement tool (Marczyk et al., 2005; Bairagi& Monut, 2019). For instance, a test is said to be dependable, if when the same measurement is done under the same circumstances will give the same outcome (Moser & Kalton, 1989).

Reliability testing is crucial as it shows the consistency across the whole tool of measurement (Huck, 2007). A scale is said to have high internal consistency reliability if the items of a scale "hang together" and measure the same construct (Huck, 2007, Robinson, 2009). Robinson, (2009), argues that many researchers use the Cronbach Alpha coefficient but, Whitley, (2002), disagrees by saying that the most suitable method of measuring reliability is the use of the likert scale. They further advise that there no perfect law that exists for internal uniformity but agrees that the lowest coefficient for measuring internal consistency is 0.70.

In this study, the test and re-test method was adopted to assess the reliability (Mugenda and Mugenda, 2003). Test-retest reliability refers involves repeating the same test on the same respondent more than once (Marczyk et al., 2005). Using this approach, the same questionnaire was administered twice to the same farmer in June 2020. Then the correlation coefficient of reliability calculated was 0.9. This showed that the instrument was highly reliable because any value which is equal to 0.68 and above shows that the instrument is reliable and therefore can be used in the actual data collection process (Orodho, 2009).

3.9 Ethical Considerations

In research there is need to protect the research participants, develop a good relation and trust in them and follow the right procedure in the data collection process (Fouka, & Mantzorou, 2011). The researcher sought authority to conduct the study from the School of Post Graduate Studies of Kisii University and the National Council of Science and Technology Innovation (NACOSTI) before proceeding to the field to collect data. Consent to visit the field was also sought from the County Commissioner and County Education Officers. During field activities, the reseaercher informed the respondents that the data collected was for academic purposes and their responses would be confidential.

3.10 Methods of Data Analysis

To detect trends for temperature, rainfall and tea yields, Mann Kendall and Sen's slope were used.

3.11 Mann Kendall Test

Mann-Kendall (MK) test also known as Kendall tau, was used to detect trends of meteorological variables. Mann- Kendall is the most commonly non-parametric test used for detecting climatic changes in a time series and trend analysis (Mann,1945; Kendall, 1955; Gocic & Trajkovic, 2012). It was used to analyze data for temperature, rainfall and tea yields for 25 years to detect the consistency of increasing or decreasing trends (monotonic trends). It was used because it is a non-parametric statistic that is less affected by the presence of outliers and other forms of non-normality (Kendall, 1975). It is also able to detect spatial significant trends in climatological time series data (Moddarres& Sarhadi, 2009). It was used to test the null hypothesis of no trend and the alternative hypothesis that there is a trend in the two-sided test or there is an increasing or decreasing trend in the one-sided (Gocic & Trajkovic, 2012).

For the time series x_1, .., x_n, the MK Test uses the following statistic:

$$S = \sum_{i=1}^{n-1} \sum_{j=k+1}^{n} sign\left(x_j - x_i\right)$$

(1)

Where Sign(x) 1 if x > 0

0 if x = 0

−1 if x < 0

where n is the length of the sample, x and x are from k=1, 2, , n-1 and j= k+1, , n.

If n is bigger than 8, statistic S approximates to normal distribution. The mean of S is 0 and the variance of S can be acquired as follows:

$$\mathrm{var}(S) = \frac{n(n-1)(2n+5)}{18} \quad (2)$$

Then the test statistic Z is denoted by Eq. (3).

$$Z = \begin{cases} \frac{S-1}{var(S)}, & if\ S > 0 \\ 0, & if\ S = 0 \\ \frac{S+1}{var(S)}, & if\ S < 0 \end{cases} \quad (3)$$

If Z>0, it indicates an increasing trend, and vice versa. Given a confidence level α, the sequential data would be supposed to experience statistically significant trend if $|Z|>Z(1-\alpha/2)$, where $Z(1-\alpha/2)$ is the corresponding value of $P=\alpha/2$ following the standard normal distribution. In this study, 0.05 and 0.01 confidence levels were used.

3.12 Sen's Slope Estimator

Besides, the magnitude of a time series trend was evaluated by a simple non-parametric procedure developed by Sen. Sen's slope estimator was used to detect linear trend present in the time series (Wilcox, 2001). According to Sen (1968), where a linear trend is present in a time series, then the slope can be estimated using non parametric procedure, that is the Sen's slope. The trend is calculated by

$$Sen's\ slope = Median\left\{\frac{x_j - x_i}{j - i} : i < j\right\}$$

The function is also used to compute the upper and lower confidence limits for Sen's slope.

sens. slope (x, conf. level = 0.95) for *(1 <= i < j <= n)*, where,

x denotes the variable,

n is the data size,

i, j are indices.

X_i and X_j are the sequential data values, n is the data set record length.

Data analysis was undertaken using Statistical Package for Social Science (SPSS) version 25 and XLSTAT.

3.13 Karl Pearson Coefficient of Correlation

Karl Pearson Coefficient of Correlation was used to evaluate the effect of rainfall and temperature variation on tea production.

Karl Pearson Coefficient of Correlation (r) $=\sum (x_i - \bar{x})(y_i - \bar{y}) / n (\sigma_x . \sigma_y)$

Where:

x_i = i^{th} tea yields

$\bar{x}$ = mean of x

y_i = i^{th} Rainfall, Temperature

$\bar{y}$ = mean of y

σ_x = standard deviation of x

σ_y = Standard deviation of y

The r value lies between ± 1.

Positive value of r indicates positive correlation between the two variables and a negative value indicates a negative relationship while zero, shows no relationship (Kothari, 1996, Shaw and Wheeler 1985).

Data collected by the use of questionnaires and interview schedules was analyzed using thematic analysis and measures of central tendency. The results were presented using line and bar graphs, tables and pie charts.

Table 3.1: Operationalization of variables

Objective	Data Required	Measurable Variable	Methods of Data Analysis
i). To examine the trends for temperature, precipitation and tea yields from 1995 to 2019 in Kisii County	Rainfall Temperature Tea yields	Rainfall Temperature Tea yields	Mann-Kendall test, Sen's slope
ii). To evaluate the effects of temperature and rainfall variations on tea yields from 1995 to 2019 in Kisii County	Rainfall Temperature Tea yields	Rainfall Temperature Tea yields	Karl Pearson Coefficient of Correlation
`iii). To assess the perception of tea farmers on the effect of temperature and rainfall variation on tea production in Kisii County	Perceptions	Perceptions	Percentiles Mean
iv). To evaluate mitigative measures put in place by tea farmers to curb the effects of climate variability in Kisii County	Mitigative measures	Mitigative measures	Mitigative measures

Source: Summary of methods of data analysis

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Introduction

This chapter presents results and discussions on response rate, demographic characteristics, temperature, rainfall and tea trends from 1995 to 2019; effect of temperature and rainfall on tea production; perception of tea farmers on effect of temperature and rainfall variation on tea farming, adaptive and coping strategies. Data was analyzed and presented using pie charts, line graphs, bar graphs and frequency tables. Table 4.1 shows the response rate.

4.2. Response Rate

Table 4. 1: Response Rate

	Frequency	**Percentage %**
Responded	352	91.7
Did not respond	32	8.3
Total	**384**	**100**

Source: Field data, (2020)

A total of 352 dully filled and usable questionnaires out of 384 were obtained from farmers in the study. This represented 91.7% response rate and a non-response rate of 8.3%. According to Mugenda and Mugenda (2003), this was sufficient for doing the analysis. Table 4.1 shows the response rate. Therefore, all the tables and graphs presented in this chapter have a sample size of 352 tea farmers.

4.3. Demographic Information

This section presents demographic information of the tea farmers namely: age of tea farmers, level of education, size of land under tea cultivation in acres, duration of tea cultivation as well as respondents' knowledge on climate variability.

4.3.1 Age of Farmers

The study sought to establish the ages of tea farmers in Kisii County. This was useful as it helped the researcher to gauge the experience of the respondents on matters about tea production. The results were as presented in Figure 4.1.

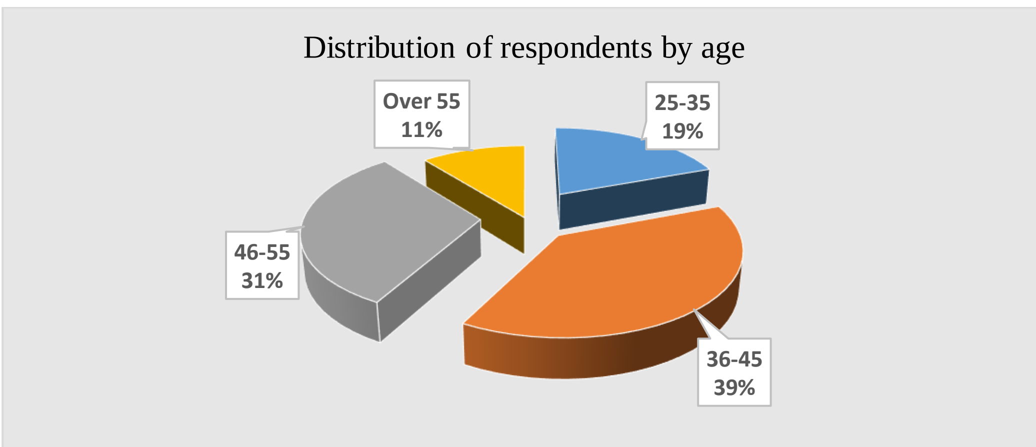

Figure 4. 1: Distribution of farmer's age

Source: Field data, 2020

The majority of the tea farmers, 285 (81%) were old people while 67 (19%) were youths. For instance, 39 percent were aged between 36-45 years, 31 percent were aged between 46 and 55 years while 11% were over 55 years old. Age was considered as it was used to gauge the period farmers had engaged in tea farming and therefore understood the changing patterns in matters of temperature and rainfall variability.

4.3.2 Level of Education

Level of education was assessed to gauge the tea farmers' understanding on matters of climate variability.

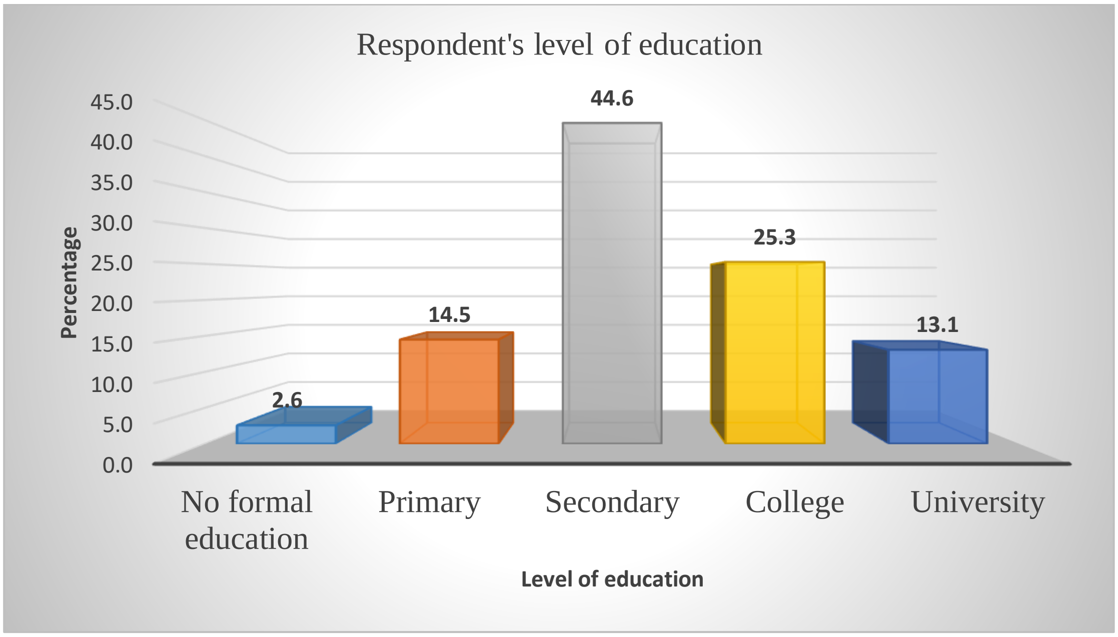

Figure 4. 2: Farmer's Level of Education

Source: Field Data, 2020

Based on the results, most of the tea farmers 292 (82.9%) had at least completed secondary school education while only 9 (2.6%) had never went to school (informal education). For example, 13.1% had university degrees, 25.3% had completed college and 44.6% completed secondary school. This shows that majority of the respondents were able to understand the questions and subject under investigation. For the few who had no basic education, questions were translated to them in vernacular since the research assistants were locals who understand the local language.

4.3.3 Size of Land under Tea Cultivation

Table 4. 2: Size of Land under Tea Cultivation in Acres

Descriptive Statistics

	N	Minimun	Maximum	Mean	Std. Deviation
Size of land under tea cultivation	352	.25	4.00	1.4607	.79533
Valid N (listwise)	352				

Source: Field Data, (2020)

Farmers were asked to state the acreage of land under tea cultivation. Using descriptive statistics, the average size of land under tea plantation was 1.46 acres. However, the minimum land on tea cultivation was a quarter of an acre while the maximum size was 4 acres.

4.3.4 Duration of Tea Farming

The tea farmers were asked to state how long they have been planting tea. This was used to gauge their experience on matters related to tea farming and their knowledge on weather dynamics.

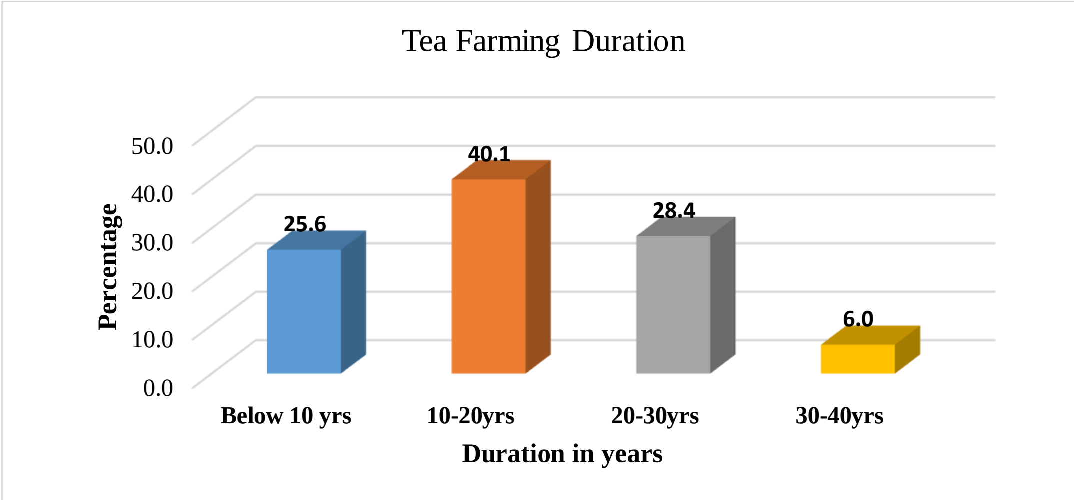

Figure 4. 3: Farmer's responses on duration on Tea Farming

Source: Field Data, (2020)

As evidenced in Figure 4.3,141, (40%) of the tea farmers had grown tea for between 10 and 20 years, 100, (28.4 %) had grown tea for between 20 to 30 years while 90, (25.6%) had grown tea for less than 10 years. This implies that majority of the respondents had adequate experience and were better placed to give information concerning tea farming.

4.3.5 Knowledge on Temperature and Rainfall Trends

Tea farmers' level of knowledge on temperature and rainfall trends in Kisii varied from no knowledge to expert knowledge. This was based on the variations experienced over time that affected tea production.

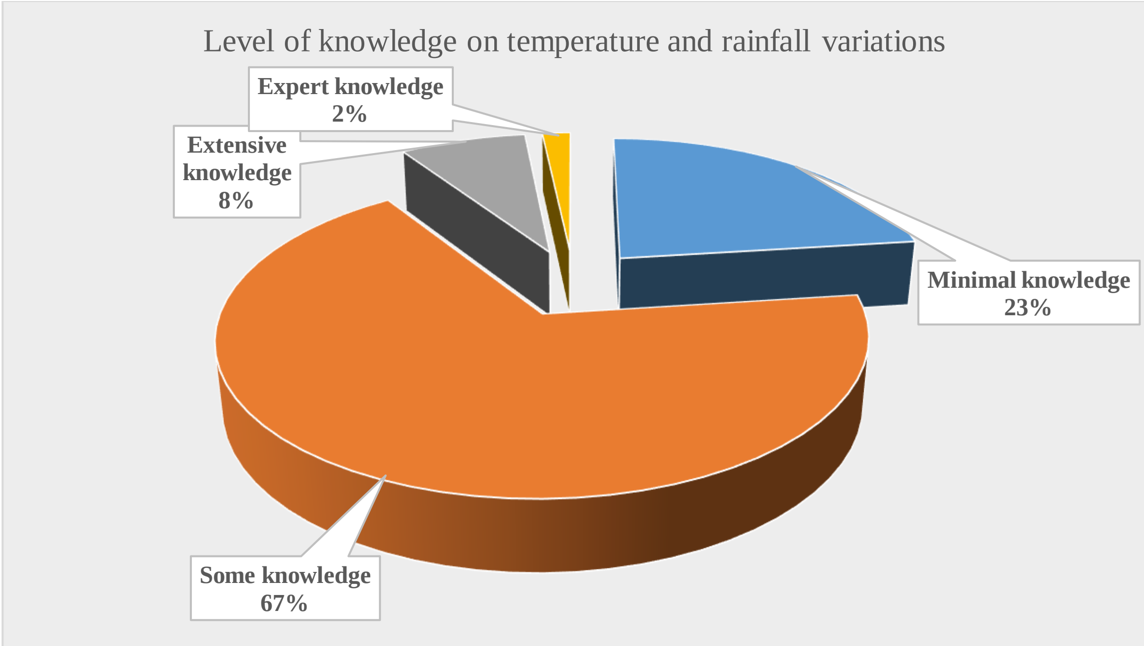

Figure 4. 4: Level of Knowledge on Temperature and Rainfall Variations

Source: Field Data, (2020)

Results on figure 4.4, revealed that, 67% (236) of the tea farmers indicated that they only had some knowledge on temperature and rainfall variations. Only 2% (7) reported expert knowledge while 8% (28) had extensive knowledge on these trends.

Further, the tea farmers were asked whether there have been changes in temperature and rainfall on their tea farms for the last ten years. The results were as presented in figure below.

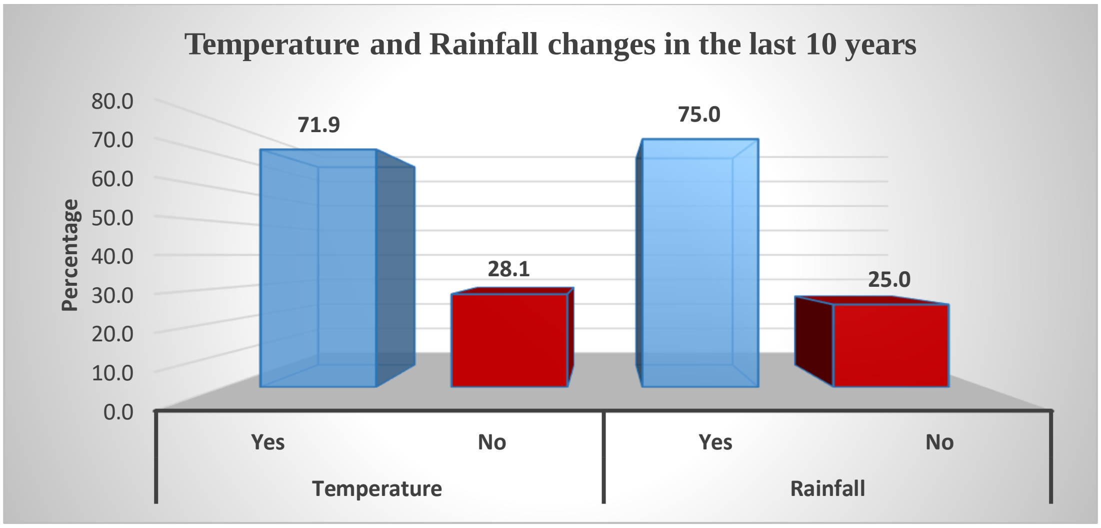

Figure 4. 5: Temperature and Rainfall changes in the last 10 years

Source: Field Data, (2020)

Based on results in Figure 4.5, 72% (253) of the tea farmers perceived that there had been temperature changes in the last ten years. On the other hand, rainfall changes in the last 10 years were reported by three out of every four (264) of the tea farmers who participated in the study.

4.4 Trends of Temperature and Rainfall Variations and Tea Yields from 1995 to 2019 in Kisii County

The first objective of the study sought to examine the trends of temperature and rainfall variations and tea yields from 1995 to 2019 in Kisii County. To effectively do this, both temperature and rainfall data were obtained from the Meteorological Department in Kisii County. Tea production data was obtained from three tea factories in Kisii County, namely; Kiamokama, Nyamache and Ogembo. Both the temperature, rainfall and tea yield trends were examined independently using Mann Kendall's Trend analysis and Sen's slope. The data for temperature, rainfall and tea yields are provided in appendix VII, VIII and IX respectively.

4.4.1 Temperature Trends in Kisii County

Information on temperature has been provided in appendix VII

To test the temperature trends over time, Mann Kendall test was used to test the following hypothesis.

H_0: There is no trend in the series

H_1: There is a trend in the series

When the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H_0, and accept the alternative hypothesis H_1.

Mann Kendall's trend analysis compared the temperature data from 1995 to 2019. The data was grouped in months from January to December for 25 years and comparison was done for each month in the various years during the study period using monthly means. Table 4.3 shows analysis of temperature.

Table 4. 3: Temperature Trend Analysis from 1995 to 2019 in Kisii County

Month	Kendall's tau	S	Var(S)	p-value		Interpretation
January	0.342	102.000	1829.333	**0.018**	Reject H_0	**Trend detected**
February	0.208	62.000	1829.333	0.154	Accept H_0	No trend detected
March	0.232	69.000	1828.333	0.112	Accept H_0	No trend detected
April	0.020	6.000	1829.333	0.907	Accept H_0	No trend detected
May	0.106	31.000	1817.000	0.482	Accept H_0	No trend detected
June	0.088	26.000	1824.667	0.558	Accept H_0	No trend detected
July	0.397	118.000	1826.667	**0.006**	Reject H_0	**Trend detected**
August	0.234	69.000	1823.667	0.111	Accept H_0	No trend detected
September	0.115	34.000	1822.000	0.439	Accept H_0	No trend detected
October	0.037	11.000	1823.000	0.815	Accept H_0	No trend detected
November	-0.075	-22.000	1820.000	0.623	Accept H_0	No trend detected
December	-0.054	-16.000	1826.667	0.726	Accept H_0	No trend detected

Source: Field Data, (2020)

Where:

S: is the test statistic

Var(s): is the variance of the statistic test

The results indicate that there were no temperature trends detected for most months with an exception of January (p-value 0.018) and July (p-value, 0.006). This was informed by the significant p-values (less than the alpha value of 0.05). Therefore, the null hypothesis that there was no trend for the month of January and July is rejected. Also, the results showed that temperature has been increasing over time (positive Kendall's tau) except for November (p-value -0.075) and December (p-value -0.054) where they have been decreasing. These results are supported by Ren, Ding and Tang (2017), who found that mean annual surface temperature had rose by 0.17^0c over the past sixty years in China.

Sen's slope: January

For the significant temperature trends in January and July, Sen's plots were as illustrated below. Generally, Sen's slope shows the magnitude of the trend.

Table 4. 4: Sen's Slope Analysis for Temperature in January from 1995 to 2019

Observation	Value	Lower bound (95%)	Upper bound (95%)
Slope	0.041	0.010	0.071

Source: Field data, (2020)

The gradient of the Sen's slope shows that in the month of January, temperature levels have been increasing by 0.041^0 c from one year to the other. From the figure 4.6, it was evident that there was a positive trend with varying temperature levels for the different years studied. For instance, the lowest temperatures recorded for January were in the year 2001 where an average of 20°C was recorded while the highest temperatures were experienced in 2017 (23°C). This result is supported by Macharia and Raude (2017), who found that in Thika River Basin, trend from Sen's slope showed that temperature in the past 30 years increased by 2.14^0 c

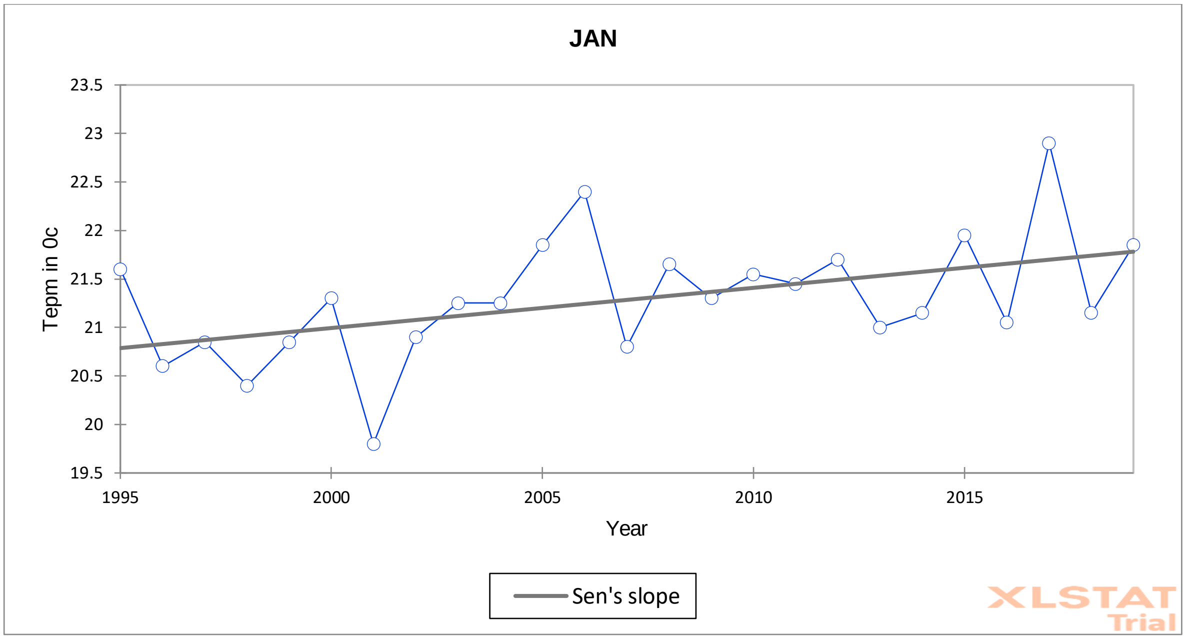

Figure 4. 6: Graph Showing Sen's Slope for Temperature in January from 1995 to 2019

Source: Field data, 2020

Table 4. 5: Sen's Slope Analysis for Temperature in July from 1995 to 2019

Observation	Value	Lower bound (95%)	Upper bound (95%)
Slope	0.044	0.012	0.070

Source: Field data, (2020)

Similarly, there was a positive temperature trends for the month of July with a slope value of 0.044. The lowest temperatures for July were recorded in 2002 (15°C) whilst the highest values recorded were 21°C. The variations were very minimal across the years.

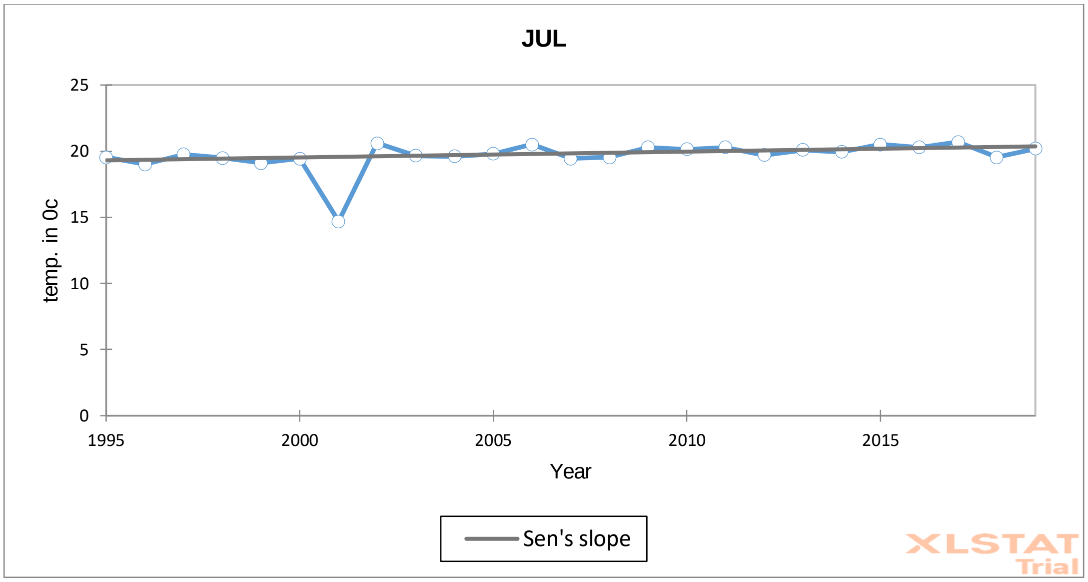

Figure 4. 7: Graph Showing Sen's Slope for Temperature in July from 1995 to 2019

Source: Field Data, (2020)

The results from the study revealed that there were no temperature trends detected for most months February, March, April, May, June, August, September, October, November and December as revealed by p- values greater than 0.05 in table 4.3. Temperature trends were detected for January (p-value 0.018) and July (p-value 0.006) where there were significant p-values less than 0.05. The results also showed that temperature has been increasing over time (positive Kendall's tau) except for November and December where they have been decreasing. This is in agreement with the anthropogenic global warming theory which asserts that temperatures are on the rise. The results support those of Attri & Tyagi, (2010), which revealed that temperatures have increased by about 0.71^{0}c in India from 1901 to 2007 with accelerated warming after the 1970s. This also agrees with World Bank, (2016) which found out that between 1960 and 2006 the Malawian annual temperature increased by 0.9°c.

Further, this agrees with an analysis conducted by Gebrechorkos, et al, (2019); Ongoma and Haishan, (2017), on long-term trends in temperature for East Africa. They found that there were significant increasing trends in maximum temperature by 1.9^0c and minimum temperature by 1.2^0c from 1979 to 2010. This is in agreement with Omumbo, et al, (2011) who found increasing trend by 0.2^0c for every 10 years in observed maximum, minimum and mean temperatures from 1979 to 2001 in Kericho. Also, according Daron (2014), temperaures have increased by 1.5^0 c to 2.0^0 c in the greater Horn of Africa for the last fifty years. This also is in agreement with a study conducted by Samwel et al., (2018) which found that temperatures were on an increasing trend shown by the p-value 0.001 in Kisii County from 1983 to 2013.

4.4.2 Rainfall Trends in Kisii County

The study sought to examine if there were rainfall trends from 1995 to 2019 using Kendall's trend analysis. The following results in table 4.6 were computed using the means of each month for 25 years. Rainfall data is provided in appendix VIII

Table 4. 6: Rainfall Trend Analysis from 1995 to 2019 in Kisii County

	Kendall's tau	S	Var(S)	p-value		Interpretation
January	-0.333	-100.000	1833.33	**0.021**	**Reject H_0**	**Trend detected**
February	-0.277	-83.000	1832.33	0.055	Accept H_0	No trend detected
March	-0.110	-33.000	1832.33	0.455	Accept H_0	No trend detected
April	0.127	38.000	1833.33	0.388	Accept H_0	No trend detected
May	-0.093	-28.000	1833.33	0.528	Accept H_0	No trend detected
June	-0.100	-30.000	1833.33	0.498	Accept H_0	No trend detected
July	-0.250	-75.000	1832.33	0.084	Accept H_0	No trend detected
August	0.180	54.000	1833.33	0.216	Accept H_0	No trend detected
September	0.180	54.000	1833.33	0.216	Accept H_0	No trend detected
October	0.144	43.000	1832.33	0.327	Accept H_0	No trend detected
November	0.040	12.000	1833.33	0.797	Accept H_0	No trend detected
December	0.160	48.000	1833.33	0.272	Accept H_0	No trend detected

Source: Field Data, (2020)

In the same way, to test the rainfall trends over time, the following hypothesis was tested.

H_0: There is no trend in the series

H_1: There is a trend in the series

When the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H_0, and accept the alternative hypothesis H_1.

Based on Table 4.6, it was only the month of January that had a positive significant trend. This was informed by the significant p-value of 0.021 which was less than 0.05. the null hypothesis that there was no trend is rejected for the month of January Generally, rainfall was seen to be decreasing during January (-0.333), February (-.0.277), March (-0.110), May (-0.093), June (-0.100) and July (-0.250) as shown by Kendall's tau in table 4.6. These results are supported by research done by Ren, Ding &Tang, (2017) who found out that during the twentheth century, from 1950 to 2000 the total annual precipitation had declined in China.

On the other hand, there was an increase in rainfall for April (0.127) August (0.180), September (0.180), October (0.144), November (0.040) and December (0.160) over time. This agrees with the analysis done by Yue, et al, (2002), who found in Thika catchment areas annual precipitation had increased by 7.8mm for the past thirty years.

The Sen's slope for January (which revealed a significant trend) was as shown on table 4.7.

Table 4. 7: Sen's Slope Analysis for January for Rainfall from 1995 to 2019

Observation	Value	Lower bound (95%)	Upper bound (95%)
Slope	-3.415	-8.225	-0.682

Source: Field Data, (2020)

Rainfall has been decreasing in the January at an average of 3.415mm from 1995 to 2019.The lowest monthly rainfall recorded was in 2002 when there was an average of 6mm while the highest monthly mean in 2007 (281mm).

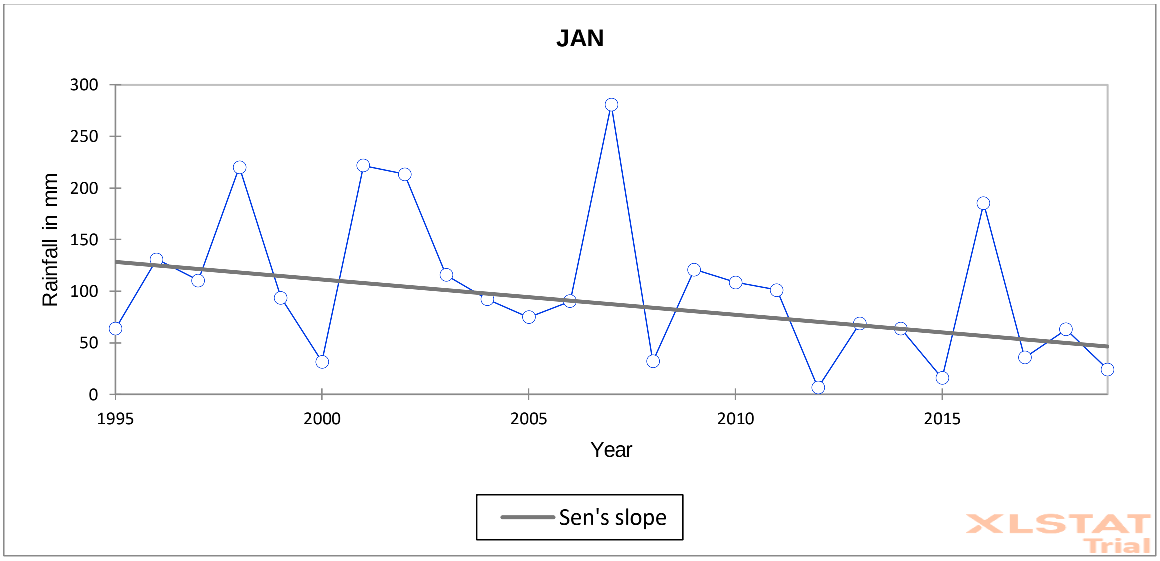

Figure 4. 8: Graph Showing Sen's Slope for Rainfall in January from 1995 to 2019

Source: Field Data, (2020)

Results on the trends of rainfall showed it was only the month of January that had a positive significant trend. This was informed by the significant p-value =0.021 (less than 0.05) as shown on table 4.6. Generally, rainfall was seen to be decreasing as shown in tale 4.6 by Kendall tau values during January (- 0.333), February (-0.277), March (-.0.110), May (-0.093), June (-0.100) and July (-0.250) while there was an increase in rainfall for April (0.127), August (0.180), September (0.180), October (0.144), November (0.040) and December (0.160), over 25 years. The results are in agreement with FAO (2016a), which indicated that rainfall had shown a steady decrease in North East India's tea-growing regions. Further, the total annual rainfall had decreased by more than 200mm in the South Bank region in an analysis done for 96 years.

Furthermore, according to an analysis done by Omondi, et al. (2014), the rainfall in individual stations of the greater Horn of Africa from 1980- 2010 has revealed a decreasing trend in the total precipitation in Southern Sudan, Western Ethiopia and areas around Lake Victoria. In addition, a study by Wakachala et al. (2015), which was done in the Great Rift Valley of

Kenya has shown a decreasing trend in annual rainfall with high variability within seasons, which affects production and farmers in decision making. These results contrast with a study done on the Guinean Coast by Nicholson et al. (2000), which found that there was a ten percent rise in annual rainfall for the last thirty years. Moreover, in Kisii, according to Leshamta (2017) has been noted that there have been rainfall variations within different seasons which may have pronounced effects on tea production. This also agrees with a study by Samwel et al., (2018) which found out that in Kisii County rainfall had a decreasing trend from 1983 to 2013.

4.4.3 Tea Yields Trends

The study sought to examine trends on tea yields from 1995 to 2019. The following table 4.9 provides the analysis on total yields using Kendall trend analysis. Data on tea yields is provided in Appendix IX.

Table 4. 8: Tea Production Trend Analysis from 1996 to 2019 in Kisii County

	Kendall's tau	S	Var(S)	p-value		Interpretation
January	-0.261	-72.000	1625.333	0.078	Accept H_0	No trend detected
February	-0.355	-98.000	1625.333	0.016	Reject H_0	Trend detected
March	-0.290	-80.000	1625.333	0.050	Reject H_0	Trend detected
April	-0.232	-64.000	1625.333	0.118	Accept H_0	No trend detected
May	-0.181	-50.000	1625.333	0.224	Accept H_0	No trend detected
June	-0.399	-110.000	1625.333	0.007	Reject H_0	Trend detected
July	-0.290	-80.000	1625.333	0.050	Reject H_0	Trend detected
August	-0.283	-78.000	1625.333	0.056	Accept H_0	No trend detected
September	-0.072	-20.000	1625.333	0.637	Accept H_0	No trend detected
October	-0.239	-66.000	1625.333	0.107	Accept H_0	No trend detected
November	-0.181	-50.000	1625.333	0.224	Accept H_0	No trend detected
December	-0.326	-90.000	1625.333	0.027	Reject H_0	Trend detected

Source: Field Data, (2020)

The following hypothesis was tested when determining tea production trends in Kisii.

H_0: There is no trend in the series

H_1: There is a trend in the series

When the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H_0, and accept the alternative hypothesis H_1.

As evidenced from Table 4.8, a significant trend in tea production shown by p-value less than 0.05 was observed in February (0.016), March (0.050), June (0.007), July (0.050) and December (0.027). The null hypothesis that there is no trend is rejected since there was a significant trend. Nevertheless, there has been decreasing yield in tea over the years as this is informed by the negative coefficient (Kendall's tau).

The significant trends were further illustrated using Sen's slope as follows;

Table 4. 9: Sen's Slope Analysis for Tea Production in February from 1996 to 2019

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-29234.756	-56203.288	-3361.050

Source: Field Data, (2020)

Tea production for February has been decreasing at an average of 29,234.756 kilograms per year from 1996 to 2019. The highest yield recorded in February was in 2005 where 1,861,106 kilograms of green tea were harvested while the lowest production was in 2006 where only 555,111 kilograms were recorded.

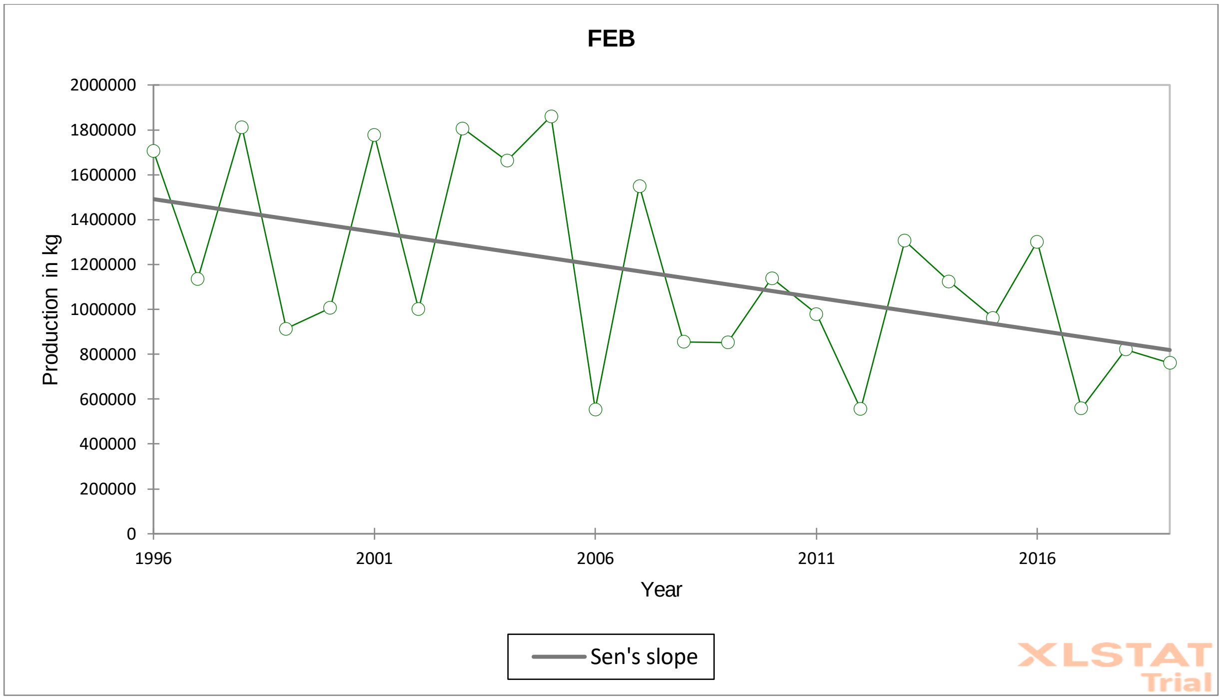

Figure 4. 9: Graph Showing Sen's Slope for Tea Production in February from 1996 to 2019

Source: Field data, (2020)

Table 4. 10: Sen's Slope Analysis for Tea Production in March from 1996 to 2019

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-25389.659	-50787.360	-844.077

Source: Field Data, (2020)

Similarly, in March, tea production showed a decreasing trend at a rate of 25,389.659 kilograms per year. The highest and lowest yields recorded were 2200712 kilograms and 553069 kilograms in 2004 and 1998 respectively. These results expose farmers to the reality of tea fluctuations and will enable them to plan on how to adapt to these changes. The results are in agreement with AFFA, (2014) which showed that there were tea fluctuations over the years even though the land under acrearge was increasing.

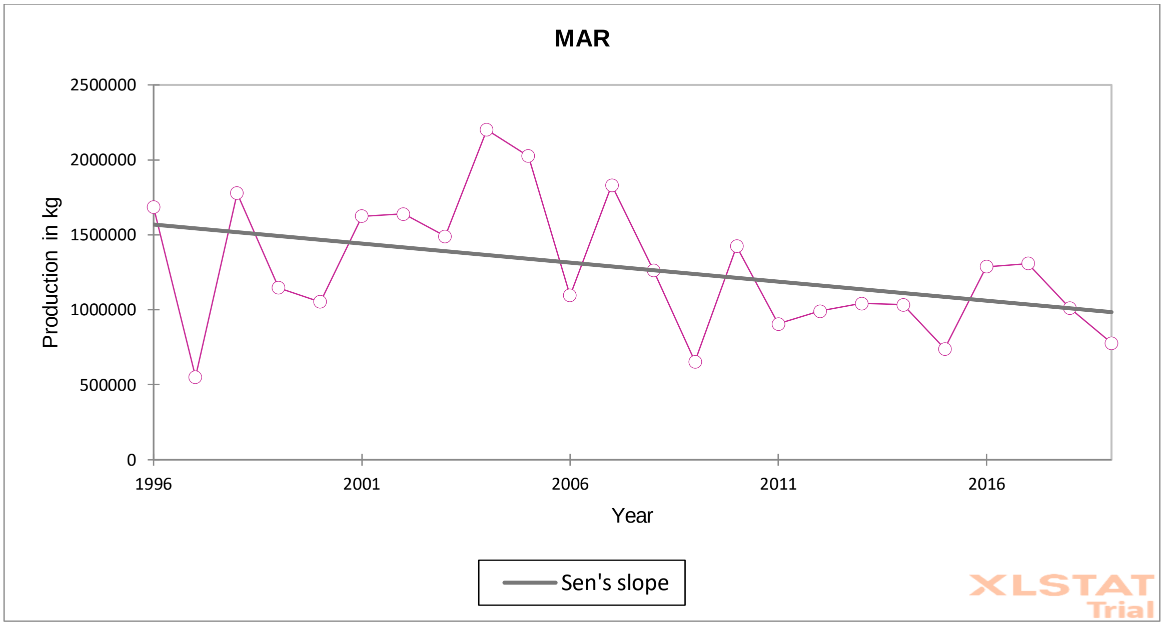

Figure 4. 10: Graph Showing Tea Production for March from 1996 to 2019

Source: Field data, (2020)

Table 4. 11: Sen's Slope Analysis for Tea Production in June from 1996 to 2019

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-32263.969	-47713.921	-7589.183

Source: Field Data, (2020)

In June, a decreasing trend was revealed where tea production declined by an average of 32,263.969 kilograms with each passing year. The lowest production was recorded in 2005 (887,020 kgs) and the highest production was in 2004 (2,004,515 kgs).

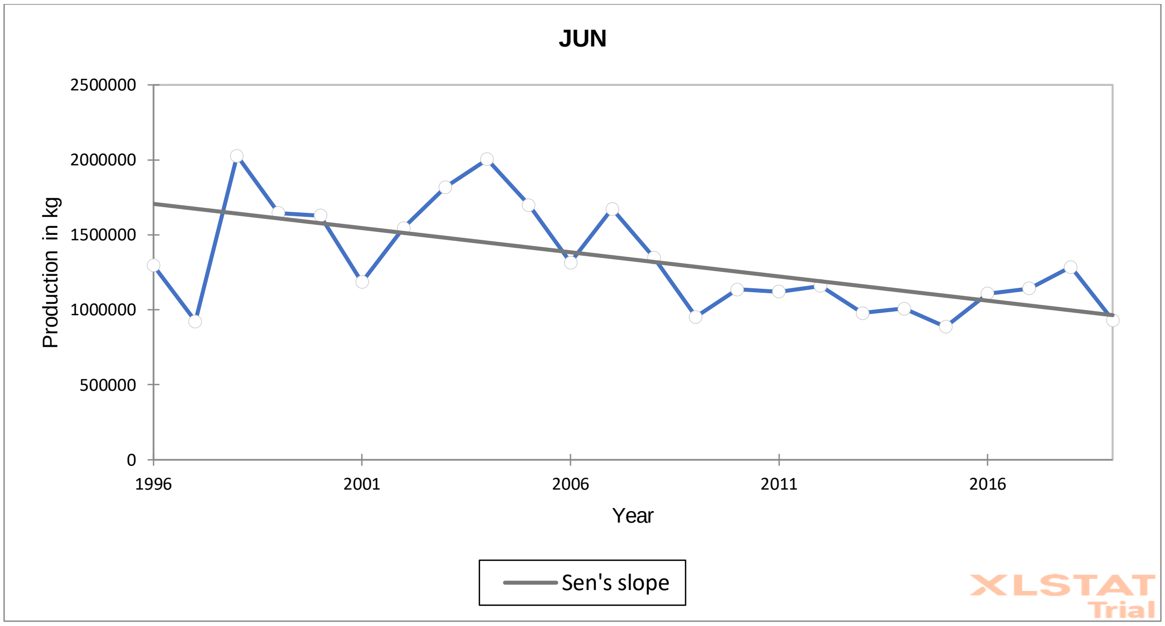

Figure 4. 11: Graph Showing Tea Production for June from 1996 to 2019

Source: Field data, (2020)

Table 4. 12: Sen's Slope Analysis for Tea Production in July from 1996 to 2019

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-20352.267	-41988.381	-903.000

Source: Field Data, (2020)

A similar trend was detected in July where yields declined annually at an average of 20,352.267 kgs. The highest production for July was recorded in 2003 (1,691,681 kg) while the following year (2004) recorded the lowest production at 55,554 kgs.

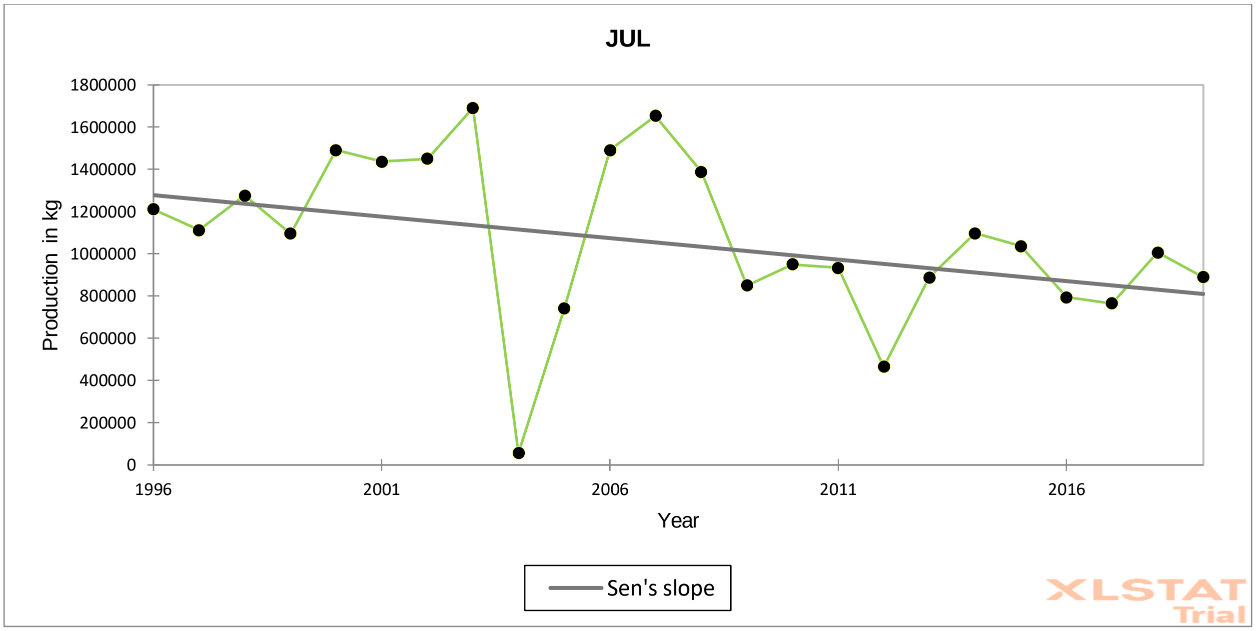

Figure 4. 12: Graph Showing Tea Production for July from 1996 to 2019

Source: Field data, (2020)

Table 4. 13: Sen's Slope Analysis for Tea Production in December from1995 to 2019

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-17108.786	-32984.789	-3716.083

Source: Field Data, (2020)

Moreover, a decreasing trend in tea production was manifested in December where the yields reduced by 17,108.786 kilograms on average. As also shown in July, subsequent years (2003 and 2004) recorded the highest as well as the lowest yields.

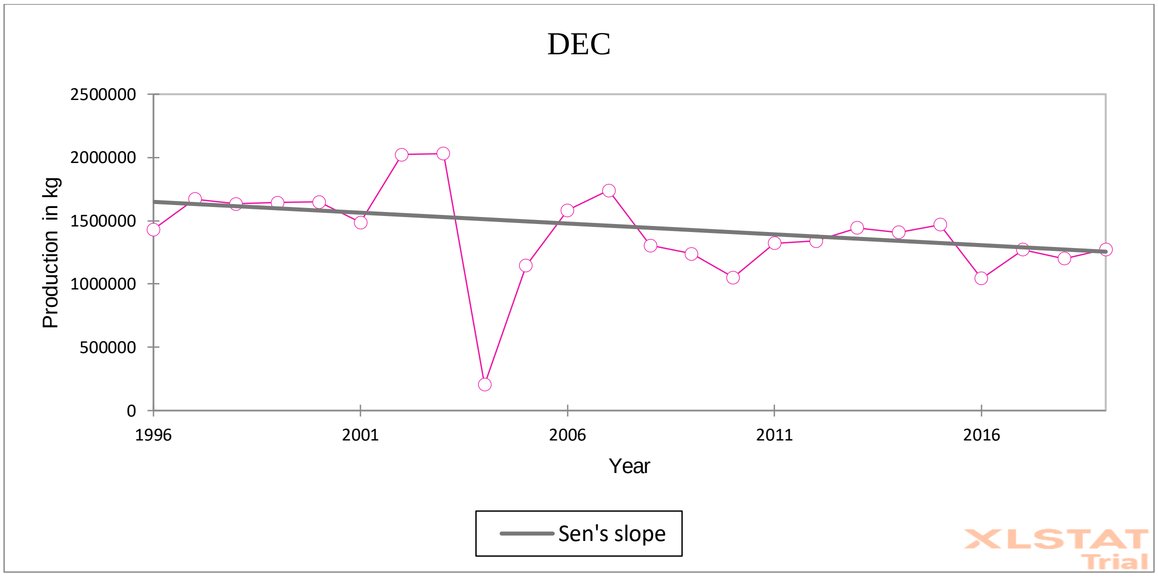

Figure 4. 13: Graph Showing Tea Production for December from 1996 to 2019

Source: Field Data, (2020)

Analysis of tea yields showed a significant trend p-value less than 0.05 in February (0.016), March (0.050), June (0.007), July (0.050) and December (0.027). Nevertheless, there has been decreasing yield in tea over the years as this is informed by the negative coefficient (Kendall's tau). The results are supported by Majumder, Bera & Rajan (2012), who noted that the trend of world tea production has been fluctuating over time. Similarly, Thasfiha et al., (2020) and Thushara, (2015) in Sri Lanka have shown that tea production is low and fluctuating from time to time due to different factors such as age, management and climate variability. This agrees with a study done by Dutta (2011); Gupta and Gey, (2010) who found that tea yields have also been fluctuating in India. It has been noted that tea yields in North East India had stagnated from 1999 to 2007.

This agrees with Liu and Shano, (2016) as quoted by Das and Zirmire, (2017), who found out that Indian tea in terms of production, exports and imports indicated fluctuations in the production which leads to cyclical fluctuation in prices, import and export. In contrast to the above, in China, there has been slower yield growth compared to the rate of area expansion over the last decade (FAO, 2015). Furthermore, researches by AFFA (2014) and the Tea Directorate (2019) in Kenya, have shown that tea yields have been fluctuating over time even though the area under production is steadily increasing.

4.5 Effect of Temperature and Rainfall Variations on Tea Production

The second objective of the study sought to assess the effect of both temperature and rainfall on tea production in Kisii County for the period between 1996 to 2019. Data was combined in terms of seasons and average figures were computed for each season as follows:

Rainy season 1: November, December and January

Dry season 1: February and March

Rainy season 2: April, May, June and July

Dry season 2: August, September and October

To assess the effects, Pearson's correlation analysis was carried out. The coefficient showed the relationship between tea production, rainfall and temperature. Monthly means for rainfall, temperature and rainfall were used.

4.5.1 Rainy Season 1

Table 4. 14: Correlation Analysis for Rainy Season 1 (November- January)

Variables	Prod_R1	Rainfall_R1	Temp_R1
Prod_R1	**1**	0.138	-0.343
Rainfall_R1	0.138	**1**	-0.318
Temp_R1	-0.343	-0.318	**1**

Source: Field Data, (2020)

During the rainy season 1 (the period between November and January of the following year), there was a positive though weak correlation (r=0.138) between rainfall and tea production. This implies that an increase in rainfall would lead to a slight increase in tea production and vice versa. The results are supported by the results of rainfall trend analysis in November and December rainfall increased as shown by positive Kendall tau values 0.040 and 0.160 respectively.

With regard to temperature, an inverse relationship was depicted. The correlation between temperature and tea production was moderate (r= -0.343). This relationship means that increase in temperature would result in to decrease in tea production and vice versa.

4.5.2 Dry Season 1

Table 4. 15: Correlation Analysis for Dry Season 1 (February and March)

Variables	Prod_D1	Rainfall_D1	Temp_D1
Prod_D1	**1**	0.110	-0.178
Rainfall_D1	0.110	**1**	**-0.480**
Temp_D1	-0.178	**-0.480**	**1**

Values in bold are different from 0 with a significant level alpha=0.05
Source: Field Data, (2020)

This period was represented by February and March just after rainy season 1 and before the onset of rainy season 2. During this period, there was a weak positive correlation between rainfall and tea production (r=0.110). This implies that an increase in rainfall would insignificantly lead to an increase in tea production and vice versa. These results are in agreement with trend analysis done in table 4.6 where rainfall decreased in February (-0.277) and March (-0.110) as shown by the negative Kendall tau. This led to decline in tea yields in February (-0.355) and March (-0.290) as revealed in table 4.8.

On the other hand, the temperature had a moderate negative relationship with tea production (r= -0.178). This relationship means that increase in temperature would result in decrease in tea production and vice versa though the change would not be significant. This is revealed in table 4.3, where temperatures were increasing as shown by the p-values greater than 0.05 hence led to a decrease in tea production as depicted by negative Kendall tau values in table 4.8 for February (-0.355) and March (-0.290).

4.5.3 Rainy Season 2

Table 4. 16: **Correlation Analysis for Rainy Season 2 (April to July)**

Variables	Prod_R2	Rainfall_R2	Temp_R2
Prod_R2	**1**	-0.079	0.054
Rainfall_R2	-0.079	**1**	-0.296
Temp_R2	0.054	-0.296	**1**

Source: Field Data, (2020)

During the rainy season 2 (period within April, May, June and July), there was a weak negative correlation (r=-0.079) between rainfall and tea production. This period is characterized by long rains and low temperatures. An increase in the amount of rainfall within this period resulted in a decline in tea production and vice versa.

Conversely, there was a positive though weak correlation between temperature and tea production r=.0.054 This implies that an increase in temperature led to an increase in production though with low magnitudes.

4.5.4 Dry Season 2

Table 4. 17: Correlation Analysis for Dry Season 2 (August to October)

Variables	Prod_D2	Rainfall_D2	Temp_D2
Prod_D2	**1**	-0.272	0.051
Rainfall_D2	-0.272	**1**	-0.162
Temp_D2	0.051	-0.162	**1**

Source: Field Data, (2020)

Dry season 2 covered the period within August, September and October. This is the period before the December rains and is usually characterized by high temperatures. Correlation analysis between rainfall and tea production during this period revealed a negative moderate relationship between the two variables (r= -0. 272). This implies that an increase in rainfall moderately decreased tea yields though the change was not statistically significant.

On the other hand, there was a positive weak correlation between temperature and tea production (r= 0.051), where increase in temperatures resulted in increased yields though marginally.

4.5.5 Overall Correlation Analysis between rainfall, temperature and tea yields

Table 4. 18: Overall Correlation Analysis between rainfall, temperature and tea yields from 1995 to 2019

Variables	Average Production	Average Rainfall	Average Temperature
Average Production	**1**	-0.232	-0.218
Average Rainfall	-0.232	**1**	**-0.458**
Average Temperature	-0.218	**-0.458**	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Source: Field Data, (2020)

In general, there was an inverse relationship between both rainfall and temperature and tea production in Kisii County for the period between 1996 to 2019. For instance, there was a weak negative correlation between rainfall and tea yields (r=-0.232). This means that tea production decreased with an increase in rainfall while tea production increased with a decrease in rainfall.

Temperature, on the other hand, depicted a weak negative correlation with tea production (r = -0.218). the correlation was however not statistically significant at 5% confidence interval. The implication here is that tea production decreased with an increase in temperature while it (production) increased with a decrease in temperature.

The study's findings are supported by those of Boehm, et al. (2016) who did a study analysis in China using provincial-level data of tea production to identify the effect of monsoon dynamics and weather on tea production. The study found out that a retreat date of the monsoon and an increase in monsoon precipitation was associated with a decrease in tea yield.

The results also agreed with a study done by Duncan, et al. (2016) on observing climate impacts on tea yields in India which revealed that there were decreasing returns in tea yields with increasing monthly precipitation. This was consistent with research on the influence of climate variability on the production of tea leaves in the different tea estates in Bangladesh (Ali et al., 2014). The research demonstrates that tea yield is greatly determined by the microclimatic parameters of a region especially rainfall, temperature, moisture and light period. Strong rains, on the other hand, erode top soils and remove fertilizers and other chemical substances hence lowering the tea yields.

Further, Han (2018) noted that tea production is lower during the long rains as compared to short rains due to long rainy periods reducing sunshine and photosynthesis on tea leaves. In contrast to the above, Ahmed et al., (2013) argues that increased water availability increases tea plant growth and growth of new leaves of tea bushes. The results contrasted with those of Patra et al. (2013) who noted there was a strong positive and significant correlations between green leaf yield and total rainfall (r =0.78). The results also contrast with research done by Hossain et al. (2015) on the effect of rainfall on tea yield and crop distribution. The findings revealed that tea production in distinct areas of Sylhet district increased marginally due to increased precipitation. Results also showed that maximum rainfall with maximum rainy days is required for maximum output tea. In contrast to the above, Ahmed et al., (2013) argues that increased water availability increases tea plant growth and growth of new leaves of tea bushes.

The above findings disagree with a study done in Assam in India which found out that drought does not affect tea yields (Duncan et al., 2016), but other research suggests that it increases the susceptibility of tea plants to pests and diseases (Biggs et al., 2018) such as tea mites and wood rot respectfully.

Results also showed that temperature, on the other hand, depicted a weak negative and insignificant correlation with tea production (r = -0.218). The implication here is that tea production decreased with an increase in temperature while it (production) increased with a decrease in temperature. The results were in agreement with Kathasiri et al., (2018); Wijeratne, et al., (2011) and Carr, (1972) who stated that temperature above or below the optimal temperature of 22^0c may affect tea yields either positively or negatively. Extreme temperatures such as frost and heat stress also affect the tea crop which will result in fluctuation of yields. Furthermore, a study done in Sri Lanka by Nijamdeen et al. (2018), revealed that tea production correlated negatively at higher levels in warmer months and lower temperatures in colder months. Similarly, a study conducted in India on Assam tea revealed that a monthly temperature greater than 26.6^0C reduced tea yields. Further Duncan, Saikia, Gupta and Biggs (2016) noted that one-degree warming at an average monthly temperature of 28^0C resulted in a 3.8% reduction in tea yields. Furthermore, the results were in agreement with research on the correlation between extreme temperature and tea production has been conducted in Kisii in Kenya's Lake Basin Region by Leshamta (2014). The results showed that seasonal and inter-annual air temperature fluctuations have a major effect on tea outputs.

The results on the relationship between temperature and tea production were consistent with those of Wijeratne (2014) who carried a survey in Sri Lanka into the susceptibility of tea production to worldwide climate change. They found that temperature rises and soil moisture deficits have negative effects on tea growth and performance. Furthermore, according to Okoth (2011) who assessed the potential effect of future climate change on tea production in Kericho County, Kenya, the research was carried out using tea production data collected from the Kapkatet Tea Factory on seasonal production cycles with two high periods and two low periods. In most seasons, the study showed rising patterns in maximum and minimum temperatures. Study forecasts show that the rise in rainfall would increase production by 2070, although an increase in maximum temperature has been found to produce a possible production decrease. The study indicated that climate changes in Kericho County have occurred and are likely to change in the future.

Similarly, these findings are supported by those of Cheserek et al. (2015) who determined the links between the weather and tea productivity in Kenya. The authors used Timbilil tea farm, Magura tea estate, and Kangaita farm to carry out the research. Data analysis found that land has raised temperatures and that the distribution of precipitation has been unexpected which affected tea production.

4.6 Perceptions of Tea Farmers on the Effect of Temperature and Rainfall Variation on Tea Production

The third objective of the study sought to assess the perceptions of tea farmers on the effect of temperature and rainfall variation on tea production in Kisii County. To respond to this objective, the tea farmers were required to give their level of agreement with a statement regarding the effects of rainfall and temperature variability on tea production.

4.6.1 Results on effects of Rainfall Variability on Tea Production

Tea farmers' perceptions about rainfall variations were assessed by gauging their level of agreement on various statements. These statements used a likert scale of 1-4 where 1was strongly agree while 4 was strongly disagree. The results for the statements regarding the effects of rainfall variability on tea production are presented in table 4.19

Table 4. 19: Effect of Rainfall Variability on Tea Production

		Strongly agree	Agree	Disagree	Strongly disagree	Mean	Std. Deviation
Scanty rainfall reduces tea yields	N	269	65	14	4	1.30	0.598
	%	76.4	18.5	4.0	1.1		
Heavy rainfall causes erosion of top soil and washes away available fertilizer	N	116	216	1	19	1.78	0.708
	%	33.0	61.4	0.3	5.4		
Frostbites reduces tea yields and production significantly	N	73	268	9	2	1.83	0.477
	%	20.7	76.1	2.6	0.6		
Hailstones destroy the tea leaves and reduces tea yields drastically	N	102	218	14	18	1.85	0.717
	%	29.0	61.9	4.0	5.1		
Heavy rainfall destroys tea clones	N	47	113	188	4	2.42	0.732
	%	13.4	32.1	53.4	1.1		
Rainfall changes affects soil water availability to tea clones	N	66	84	177	25	2.46	0.876
	%	18.8	23.9	50.3	7.1		
Rainfall changes affects farmer's decision on when to apply fertilizers	N	55	109	134	54	2.53	0.933
	%	15.6	31.0	38.1	15.3		
Rainfall variability leads to emergence of pest which were never experienced before	N	79	30	75	168	2.94	1.209
	%	22.4	8.5	21.3	47.7		

Source: Field Data, (2020)

Based on results presented in Table 4.19, most of the tea farmers 334, (94.9%) generally agreed (reporting both agree and strongly agree) that scanty rainfall reduces tea yields. Moreover, 94.4% (332) of the tea farmers were in agreement that heavy rainfall causes the erosion of topsoil and washes away available nutrients thus affecting tea production. Further, 96.8% (341) of the tea farmers concurred that frostbites reduce tea yields and production significantly with 90.9% (320) ascertaining that hailstone destroy the tea leaves and reduce tea yields drastically.

Informed by the mean scores, the rainfall aspects that greatly affected tea production were Scanty rainfall (M=1.30), effect of heavy rainfall on the erosion of topsoil (M=1.78), the effects of frostbites (M=1.83) as well as the effects of hailstones (M=1.85).

On the effect of rainfall variability on tea, one of the field service coordinators (FSC) reported as follows:

> Tea yields have been fluctuating as a result of variations in rainfall. Indeed, during the season of heavy rainfall, tea yields reduce as a result of lack of sunshine. Low rainfall on the other hand is detrimental as the is no enough water to enhance shoot growth. This reduces the cycle of tea picking among tea farmers (FSC,2020)

However, 94.9 % (334) also reported that scanty rainfall reduces tea yields. The results agreed with Karki, Burton & Mackey, (2020); Hitayezu, Wale & Ortmann (2017) who found out that farmers worldwide have been experiencing climate changes mainly in regard to rising temperature, unreliable and reduced rainfall which have led to reduction of the agricultural produce.

Another field service coordinator reported the following:

> Hailstones experienced in the tea-growing areas have become a serious menace to the farmers over decades. Once this occurs, the tea plant is affected and this reduces yields drastically as it takes a longer period for the plant to regain. Indeed,

> we lack a solution for this. Further, as noted from farms where tea is grown on low lands waterlogging has also affected tea production leading to stunted growth hence reduced yields (FSC, 2020)

In agreement to the above results, research conducted by Somboonsuke et al., (2018) in Songkhla Lake Basin in Thailand on farmers' perception on the effect of climate variability on crop production revealed that change in temperature and rainfall had led to reduction of crop production and these affected farmers involved in fruit production, and fisheries adversely. This was in agreement with an investigation made by Harvey et al. (2018) on farmer's perceptions to climate change and variability in Central America which revealed that smallholder farmers perceived that climate has been changing with most of them reporting the rise in temperatures, low annual rainfall and seasonality of the rain season.

Moreover, heavy rainfall causes erosion of topsoil and washes away available fertilizer thus affecting tea production (94.4%.) Further, results showed that frostbites reduce tea yields (96.8%) and production significantly with 90.9% ascertaining that hailstone destroy the tea leaves and reduce tea yields drastically. The results support those of Otiso (2016) who carried a study in Kisii Sub County, on the perception on the effect of rainfall variability on crop production and household security, the results showed that farmers perceived that it led to reduced yields, reduced water availability and increased crop and animal diseases.

4.6.2 Indications of Rainfall Variations

Rainfall variations were indicated by various factors. These were the aspects that the tea farmers experienced to ascertain that indeed variations in rainfall had affected tea production. Further, the tea farmers were asked to give their level of agreement with statements regarding the various indications of rainfall variations. The findings were as shown in table 4.20.

Table 4. 20: Indications of Rainfall Variation

		Strongly agree	Agree	Disagree	Strongly disagree	Mean	Std. Deviation
Change of planting date to onset	N	268	56	26	2	1.32	0.634
of Rainfall	%	76.1	15.9	7.4	0.6		
Change of planting and	N	230	88	32	2	1.45	0.682
harvesting	%	65.3	25.0	9.1	0.6		
Unpredictable rainfall amounts	N	93	249	10	0	1.76	0.488
	%	26.4	70.7	2.8	0.0		
Crop failure due to drought	N	38	300	14	0.0	1.93	0.379
	%	10.8	85.2	4.0			
Short rainy season	N	57	258	37	0	1.94	0.514
	%	16.2	73.3	10.5	0		
Rainfall delays	N	112	50	182	8	2.24	0.932
	%	18.8	23.9	50.3	7.1		
Early onset of rainy season	N	64	89	197	2	2.39	0.784
	%	18.2	25.3	56.0	0.6		
Early exit of rainy season	N	54	91	42	165	2.90	1.156
	%	15.3	25.9	11.9	46.9		

Source: Field Data, (2020)

As evidenced in the table 4.20, the majority of the tea farmers 342, (97.1%) were in agreement that rainfall variation was indicated by the unpredictable rainfall amounts and 324 (92%) that the change of planting date to onset of rainfall. This was followed by change of planting and harvesting seasons as reported by (318) 90.3% of the tea farmers, crop failure due to drought 338 (96%), short rainy seasons 315 (89.5%), rainfall delays 162 (46%), early onset of the rainy season 153 (43.5%) and early exit of the rainy season 145 (41.2%).

From table 4.20, results and based on the mean scores, were as follows, change of planting date to onset of rainfall (1.32), change of planting and harvesting seasons (1.45), and unpredictable rainfall amounts (1.76) were the main indicators of rainfall variations in Kisii County.

The above results are in agreement with Amadou et al., (2015) who found that about 99% and 98% of interviewed farmers reported that there is a long-term change in the start and end of the rainy season respectively. In terms of the date of the onset of the rainy season, 97% of respondents reported that the late dates of onset have been shifting from April to June during the last 20 years while only 2% of them reported that the dates of the onset are early. Further, 96% of the farmers reported that the dates of the end of the rainy season are early and have shifted from November to October over the last 20 years. The findings are also in agreement with Maddison, (2006) and Thornton et al., (2006) who found out that temperatures are continuously increasing while rain has become more variable and duration shortened. Further, Mugalavai et al., (2008) noted that there was high variability in the onset and cessation of the rainy season. But the results contrast with climatological data which showed that the rainy seasons in Ghana end late (Amadou et al., 2015).

During the interview one of the field service coordinators reported the following:

> Indeed, there have been variations in the amount of rainfall and temperature received in the tea-growing areas over the past decades. The onset and intensity of rains have been varying over time. Also, the night temperature has increased as evidenced by the great heat experienced during the night (FSC, 2020).

The above statement supports Resilience Policy Team-Irish Aid (2015), who found that the number of hot days and nights had increased independent of the season. Between 1960 and 2003 the average annual hot days and nights had grown from 30 to 41 in Sri Lanka.

4.6.3 Effect of Temperature Variability on Tea Production

Similarly, the study also sought to determine the effect of temperature variability on tea production and the results shown in table 4.21 were responses from the tea farmers.

Table 4. 21: Effect of Temperature Variability on Tea Production

		Strongly agree	Agree	Disagree	Strongly disagree	Mean	Std. Deviation
High temperatures cause high transpiration rates leads to reduced yields	N	259	93	0	0	1.26	0.442
	%	73.6	26.4	0.0	0.0		
High temperatures cause high evaporation from the soil leading to stunted growth, hence reduced yields	N	115	230	7	0	1.69	0.503
	%	32.7	65.3	2.0	0.0		
High temperatures lead to wilting and drying of tea	N	30	286	4	32	2.11	0.671
	%	8.5	81.3	1.1	9.1		
	N	32	99	220	1	2.54	0.661

Cold conditions damages tea leaves and roots leading to low productivity	%	9.1	28.1	62.5	0.3			
Hot conditions may add heat stress, increase pest infestation and disease prevalence thus reducing both quality and quantity of tea leaves	N	94	44	35	179	2.85	1.298
	%	26.7	12.5	9.9	50.9		

Source: Field Data, (2020)

In table 4.21, there was a unanimous agreement that high temperatures cause high transpiration rates leading to reduced yields. It was also evident that high temperatures were responsible for the high evaporation from the soil thus leading to stunted growth, hence reduced yields as was reported by 98% (345) of the tea farmers. Besides, other effects of temperature on tea production were the notion that high temperatures lead to wilting and drying of tea wasreported by 89.8% (316), the assertion that cold conditions damage tea leaves and roots leading to low productivity 27.2% (96) and the allegation that hot conditions may add heat stress, increase pest infestation and disease prevalence thus reducing both quality and quantity of tea leaves was the least effect temperature.

One of the field service coordinators reported the following during the field interviews:

> Temperature variations have affected tea production negatively. The increase of temperature has led to high evapotranspiration leading to low yields. Low temperatures, on the other hand, affects tea leaves leading to reduced yields mostly in June and July (FSC, 2020).

The above results support those of Adhikari et al, (2015); Barros et al, (2014) and Vrieling et al., (2013), who found out that water stress caused by the increase in temperatures in Africa, increases crop weeds, pests and diseases. In India, it has been noted that temperature variability is the most serious factor affecting tea yields in South India (Raj, et al, 2019). A study done in the Assam region in India in 2016, revealed that drought increases the susceptibility of tea plant pests (Biggs et al., 2018; Reay 2019).

4.6.4 Indications of Temperature Variations

The tea farmers were asked to give their level of agreement with statements regarding the various indications of temperature variations. The results were as presented in Table 4.22.

Table 4. 22: Indications of Temperature Variation

		Strongly agree	Agree	Disagree	Strongly disagree	Mean	Std. Deviation
Switch to drought resistant crops	N	241	79	30	2	1.41	0.669
	%	73.6	26.4	0.0	0.0		
Disappearance/ reduction of water sources/ points due to high evaporation	N	93	253	6	0	1.75	0.470
	%	26.4	71.9	1.7	0.0		
Longest months with high day time temperatures	N	57	116	179	0	2.35	0.743
	%	16.2	33.0	50.9	0		
Frost that affects crop leaves	N	36	130	184	2	2.43	0.680
	%	10.2	36.9	52.3	0.6		
Frequent occurrence of heat induced crop pest and diseases	N	55	73	53	171	2.97	1.149
	%	15.6	20.7	15.1	48.6		
Frequent occurrence of heat induced animal diseases	N	34	83	69	166	3.04	1.046
	%	9.7	23.6	19.6	47.2		

Source: Field Data, (2020)

On the count of indications of temperature variations, results showed the majority of the farmers (90.9%) agreed that farmers have shifted to drought resistance crops in order to mitigate the problem of drought. Another major sign of temperature variability was the disappearance and/or reduction of water sources/ points due to high evaporation as reported by 98.3% of the respondents. Other indicators of variations in temperature were experiencing the longest months with high daytime temperatures, presence of frost that affects crop leaves, frequent occurrence of heat-induced crop pests and diseases as well as frequent occurrence of heat-induced animal diseases as shown in Table 4.22.

These findings support a study done in Sri Lanka which revealed that tea production correlated negatively at higher levels in warmer months and lower temperature in colder months (Nijamdeen et al., 2018), which was due to agricultural droughts and high rate of transpiration. It was also found out that high temperatures increase evaporation losses of soil moisture and accelerate the burning of organic matter from soils. This agrees with FAO, (2016b), which has also noted that higher daytime temperatures during the reproductive stage led to the decline of crop yields.

One of the field service coordinators reported the following during the field interviews on pests and diseases:

> Pests such as aphids, mites and diseases such as armillaria root rot and stem canker are common. Mites appear during the seasons when there is high temperature, dry conditions and absence of shade. Root rot disease usually occurs during the wet season where the soils are poorly drained which leads to the death of the tea plants (FSC, 2020).

The above response agrees with Sawe et al., (2018) who found out that an increase in crop pests and diseases is mostly associated with increase in temperatures. It further supports Adhikari et al, (2015); Barros et al, (2014) and Vrieling et al., (2013), who found out that water stress is caused by increase in temperatures in Africa, the increases crop weeds, pests and diseases in India, (Raj, et al, 2019).

4.7 Adaptive and Coping Strategies to Curb the Effects of Climate Variability

The study also sought to examine the adaptive and coping actions to curb the effects of climate variability and the results are as shown in the figure below;

4.7.1 Fertilizer Application

Farmers were asked whether they use fertilizers as one of the ways of adapting to climate variability. All the tea farmers ascertained that they indeed used fertilizers in their tea farms and the figure 4.14 shows the frequency of application in a year.

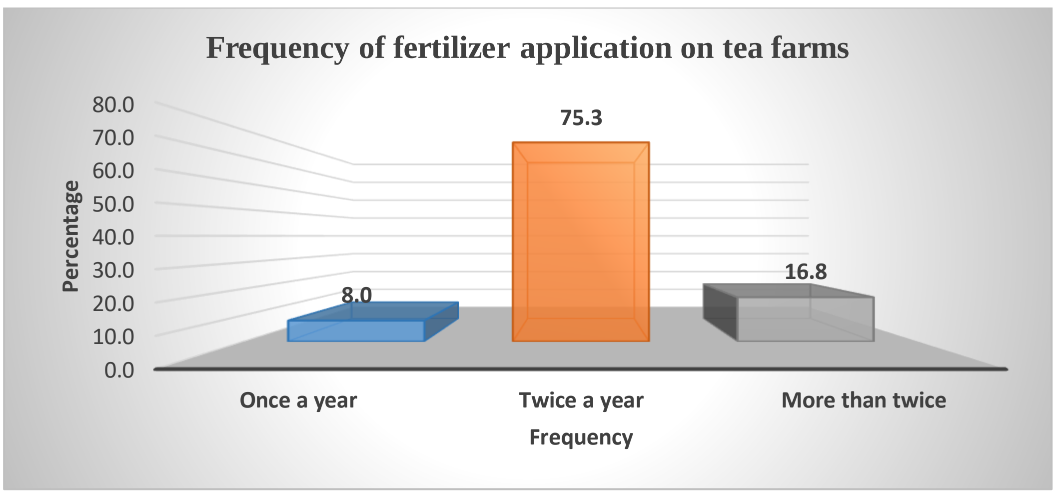

Figure 4. 14: Frequency of Fertilizer Application on Tea Farms

Source: Field Data, (2020)

One of the strategies employed to counter effects of climate variability was the application of fertilizers. The results showed that the majority of the tea farmers 265 (75.3%) applied fertilizer twice a year, 59 (16.8%) applied fertilizer more than two times a year while only 28 (8%) of the tea farmers reported applying fertilizer on their tea plantations once per year.

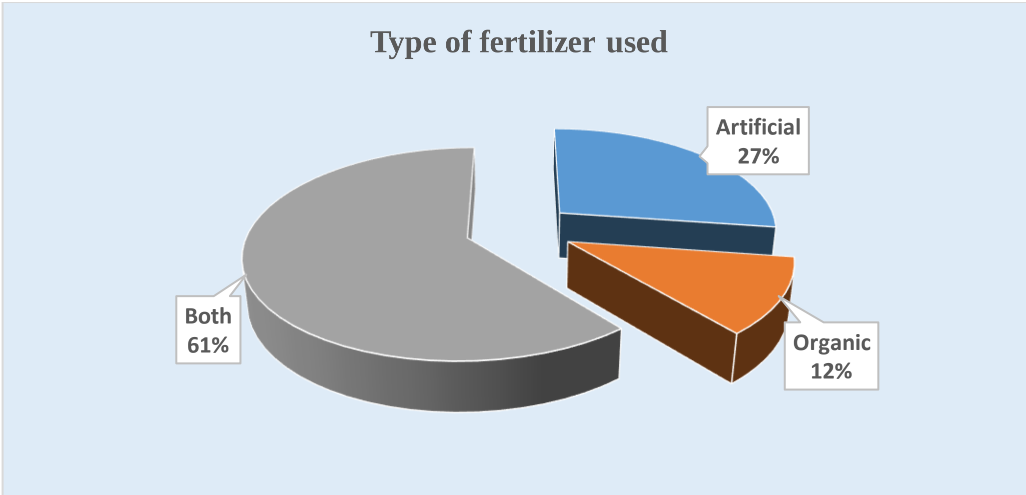

Figure 4. 15: Type of Fertilizer Used

Source: Field Data, (2020)

Findings revealed that 215 (six out of ten) tea farmers indicated that they applied both organic and inorganic fertilizers. Nevertheless, 95 (27%) reported the use of artificial (inorganic) fertilizers whilst (42) 12% used organic fertilizers only.

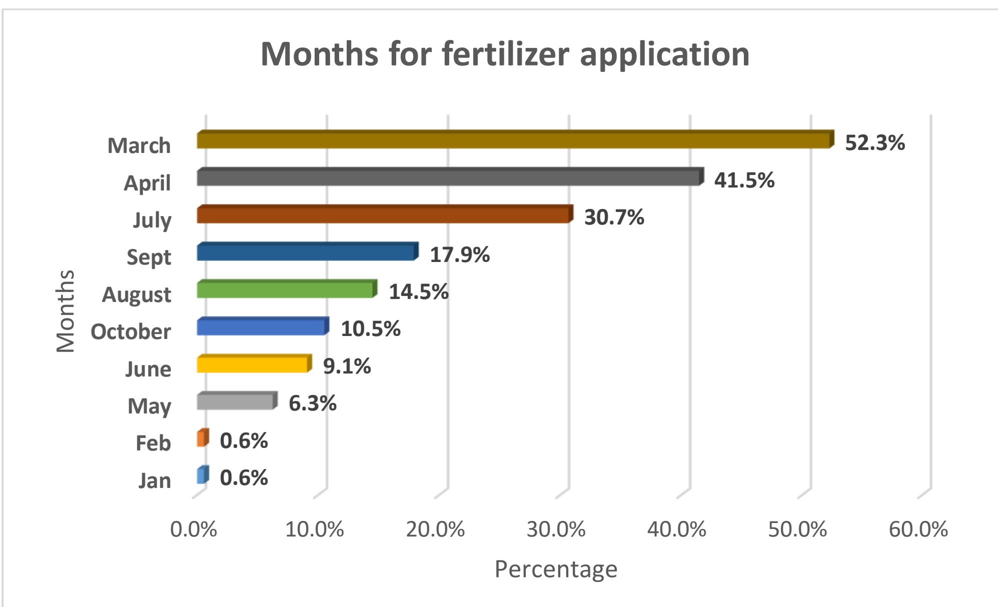

Figure 4. 16: Months for Fertilizers Application

Source: Field Data, (2020)

The tea farmers were asked the months which the applied fertilizers to ascertain whether they were applied at the right time. Results showed March was the month that most farmers applied fertilizers in their farms as reported by 52.3% (184). This was followed by April 41.5% (146), while July came third. February and January were the least months with 0.6% each.

Table 4. 23: Effect of Fertilizer on Tea Production

	Frequency	Percent
Increase	343	97.4
No difference	9	2.6
Total	**352**	**100.0**

Source: Field Data, (2020)

Further, tea farmers were asked whether the application of fertilizers had any effect on tea yields. The results showed that after the application on the tea farms, the yields increased as reported by 97.4% (343) of the tea farmers whereas 2.6% (9) did not realize any difference. As evidenced from figure 4.16 41.5% (146) applied ferilizers in the month of April which experiences high rainfall and therefore much of the ferilizers may be washed through erosion. This result agrees with Pathak and Ladha (2007) who argued that fertilizer applicationis one of the ways of conserving soils but, timing is key in realizing the required results.

4.7.2 Weed, Pest and Disease Control

Further, the tea farmers were asked about the frequency of weed, pest and disease control in their tea farms. This is because climate change and variability, is associated with the emergence of pests and diseases that affect tea growth and subsequent years. The results are shown in table 4.24

Table 4. 24: Frequency of Weed, Pest and Disease Control

	Frequency	Percent
Regularly	7	2.0
When they appear	298	84.7
Twice a year	39	11.1
Not sure	8	2.3
Total	**352**	**100.0**

Source: Field Data, (2020)

From the study, the results showed that tea farmers controlled weed, pest and diseases when they appear which was represented with 84.7% (298), followed by twice a year with 11.1% (39), while regularly was represented by 2.0% (7). Figure 4.17 shows the varous stragegies used by the tea farmers to adapt to climate variability in Kisii County

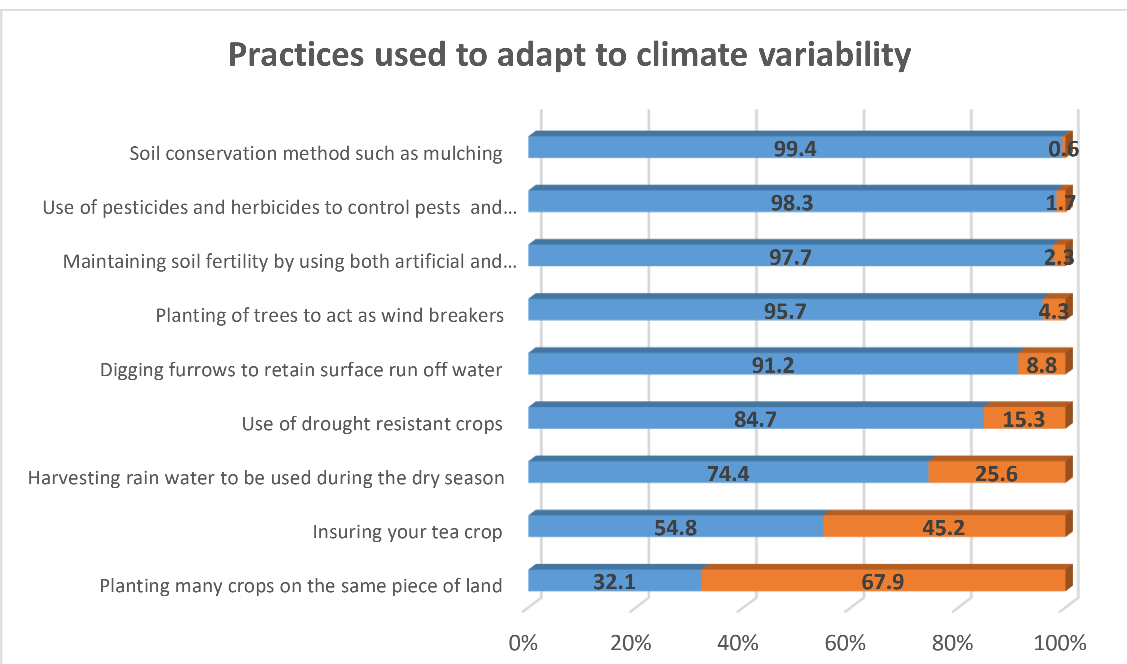

Figure 4. 17: Practices Used to Adapt to Climate Variability

Source: Field Data, (2020)

The study also was designed to determine the practices to adapt to climate variability and the results from the figure above showed that soil conservation method such as mulching was the most adaptive practice with 99.4% (350), followed by the use of pesticides and herbicides to control pests and weeds with 98.3% (346), planting of trees to act as windbreakers came fourth with 95.7% (337). Insuring the tea crop for compensation if the crop fails as a result of climate variability and change was reported by193 (54.8%) tea farmers. These findings agree with theaction theory of climate adaptation where farmers where farmers adjust and maximize the benefits accrued from climate variability.

On mitigative measures put in place to climate variability, one field service coordinator reported the following:

> We have advised farmers to do agroforestry on their tea farms by planting indigenous trees. This will reduce the rate of evapotranspiration from the tea farms. Also, we have produced tea cultivars like TN14 that are more resistant to climate change. Further, the farmers have been advised to diversify their farming activities (FSC, 2020).

The above findings are supported by findings of Muench et al, (2020) who found out that in Nepal tea farmers use crop diversification, agroforestry, planting resistant tea plant variaties and soil conservation methods to adapt to climate change.This is also in agreement with a study conducted by Simelton et al. (2013); Asante & Amuakwa-Mensah, (2014); Mohammed, Kwaghe, Abdulsalam, Aliyu., & Dahiru, (2014) in Ghana who found that farmers used on-farm practices such as creating or improving the drainage system, early planting and waterway, irrigation or dry season farming, planting more trees and cover crops, planting drought-resistant and early yielding crops, early planting, improved farm management practice, diversification into livestock rearing and mulching to adjust to variations in climate.

The results also concur with those done in China, where soil and water conservation measures have been put in place to increase the water holding capacity of the soil and reduce the impact of droughts so as to maintain tea productivity. Furthermore, research by Han et al. (2016) shows that organic tea production can strengthen soil carbon segregation through increasing soil organic matter (carbon) levels. Further, the results are consistent with those of Bryan et al. (2011) who stated that adaptations to adverse climatic changes are numerous in Kenya and include farm management applications such as mixed cropping, crop rotations, water harvesting and irigation, minimum tillage and increasing the fertility of the soil through the use of organic and artificial fertilizers.

The results also concur with those done by Simotwo et al., (2018) in Trans- Mara East Sub-County on climate adaptive capacity and smallholder farming which found out that farmers diversified crop varieties and used improved drought tolerant varieties. Similarly, Pathak et al. (2012) have identified several adaptation strategies available for crop farming in response to climate variability and changing conditions. Climate variability is dealt with by a wide range of adaptive responses. These include technical alternatives (for example, more drought-tolerant crops), behavioral responses (for example, improvements in dietary choices), management changes (for example, various animal feeding practices) and policy options (including the planning and infrastructures growth regulations).

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the summary of the findings, conclusions, recommendations and suggestions for further research.

5.2 Summary of the findings

The purpose of the study was to examine climate variability and its effects on small-scale tea production in Kisii County. The study also assessed the trends of temperature and rainfall variations and tea yields from 1995 to 2019 in Kisii County, evaluated the effect of temperature and rainfall variations on tea production from 1995 to 2019 in Kisii County and relate it to tea yields, assessed the perceptions of tea farmers on the effect of temperature and rainfall variation on tea production and evaluated the adaptive and coping strategies put in place by tea farmers to curb the effects of climate variability in Kisii County. The study was triggered by the fact that tea production in Kenya is dependent on the stability of weather and therefore is being affected by variations and changes of climate which have become a global threat with no spatial boundary. This has affected crop production from region to region in different ways. Since studies have indicated that Kenya has been experiencing increasing temperatures and decreasing trends in annual rainfall with high variability within seasons in many parts of the country, there was the need to research so as to suggest possible solutions to the rising challenges in tea production.

The research used a correlational research design to explore the relationship between variables and measured the extent to which two variables were related. Both qualitative and quantitative approaches were used to obtain and analyze data. Simple random sampling procedure was used to select farmers while purposive sampling used to select tea factories and the meteorological department. In addition, three field service coordinators, one from each selected factory were key informants. The head of the Kenya Meteorological Department provided climatic data on monthly rainfall and temperature measurements over the stipulated period, 1995-2019.

Findings revealed that there were no temperature trends detected for most months with an exception of January and July. The results also showed that temperature has been increasing over time) except for November and December where they have been decreasing. Results on the trends of rainfall showed it was only the month of January that had a positive significant trend. Generally, rainfall was seen to be decreasing during January, February, March, May, June and July while there was an increase in rainfall in April, August, September, October, November and December over time. Results also showed that tea yields trend showed a significant trend in tea production which was observed in February, March, June, July and December. Nevertheless, there has been decreasing yield in tea over the years. In other results, the study revealed that there was an inverse relationship between both rainfall and temperature and tea production in Kisii county for the period between 1996 to 2019. The perception of the farmers concerning the effects of temperature showed that that scanty rainfall reduces tea yields. Moreover, heavy rainfall causes erosion of topsoil and washes away available fertilizer thus affecting tea production. Further, the tea farmers concurred that frostbites reduce tea yields and production significantly with the majority ascertaining that hailstone destroy the tea leaves and reduce tea yields drastically. Furthermore, results showed that soil conservation method such as mulching was the most adaptive practice, followed by use of pesticides and herbicides to control pests and weeds with, planting of trees to act as windbreakers.

5.3 Conclusions of the study

Findings from this study were informed by the following conclusions.

The study to examined climate variability and its effects on small-scale tea production in Kisii County. The first objective sought to assess the trends of temperature and rainfall variations and tea yields from 1995 to 2019 in Kisii County. The results of the study concluded that there were no temperature trends detected for most months with an exception of January and July. Findings showed that temperature has been increasing over time except for November and December where they have been decreasing. The study further concluded that for the trends of rainfall, it was only the month of January that had a positive significant trend. In general, rainfall was seen to be decreasing during the months of January, February, March, May, June and July while there was an increase in rainfall for April, August, September, October, November and December over time. Furthermore, concerning trends of yields of tea, the study concluded that tea yields trend had a significant trend in tea production which was observed in February, March, June, July and December. Nevertheless, in general terms, there has been decreasing yield in tea over the years.

The second objective was designed to find the effect of temperature and rainfall variations on tea production from 1995 to 2018 in Kisii County and relate it to tea yields. Effects are the positive or negative outputs gotten from the variable that is affecting another variable. From the results, the study concluded that there was an inverse relationship between both rainfall and temperature and tea production in Kisii county for the period between 1995 to 2019, that's whenever rainfall or temperature increased above the optimal requirement, the tea yields decreased.

The third objective was designed to assess the perceptions of tea farmers on the effect of temperature and rainfall variation on tea production in Kisii County. Perceptions are how people believe that something has enacted or caused a change in another thing. Perception of tea farmers on the effect of temperature and rainfall is the farmers' feelings on whether rainfall and temperature have contributed either negatively or positively to the changes in tea yields. From the results, the study concluded that the perception of the farmers concerning the effects of rainfall that; scanty rainfall reduces tea yields, heavy rainfall causes erosion of topsoil and washes away available fertilizer thus affecting tea production, and frostbites reduce tea yields and production significantly since hailstones destroy the tea leaves and reduce tea yields drastically. On the other hand, increase in temperatures reduced yields due to high transpiration rates low temperaturedamaged the leaves and roots hence low yields.

The fourth objective sought to evaluate the adaptive and coping strategies put in place by tea farmers to curb the effects of climate variability in Kisii County. Adaptive and coping strategies are ways and means in which farmer engage themselves so that they maintain crop yields. The current study concluded that soil and water conservation methods most adaptive practices that were used by many tea farmers.

5.4 Recommendations

To address climate variability and its effects on small-scale tea production in the whole of Kisii County, the study recommends the following based on objectives: The study recommends the the Government, KTDA and tea farmers to be observant with the changing monthly trends in rainfall and temperature, this will help in determining when the yields are at peak and thus provide balance in tea production.

i) The results showed that rainfall, temperature, and tea yields have inverse associations, hence the study recommends farmers to keep records on monthly tea yields. This will help them to know the best method to use in adapting to climate change and variability and the best time to apply fertilizers so as to increase production without loss of inputs.

ii) The study showed the effect precipitation such as regular drought and floods, on tea production in Kisii County. In order to avoid water loss from the soil, the study suggests that tea growers follow adaption strategies such as water and soil conservation. During the rainy season farmers can harvest rain water to irrigate the farms in the dry season.

iii) Because of the uncertainty associated with more recurring extreme conditions (drought, hailstorms and frost) than in the past, the study suggests that farmers take note of climatic extreme risk with regard to insurance covers.

iv) In the analysis, severe heat conditions, frost and hailstoms affect both the quality and quantity of tea leaves harvested. The study thus indicates that farmers should use integrative methods to curb the effects of climate variability. The study found that extreme cold conditions decrease the effectiveness of staff responsible for picking tea leaves. Small-scale farmers to use protective clothing, gloves, overalls and caps to keep warm.

5.5 Suggestions for Further Research

The study focused on climate variability and its effects on small-scale tea production in the whole of Kisii County in Kenya. Researches can be conducted on the same topic in other tea-producing counties in Kenya, for example, Nyeri, Kirinyaga, and Bomet to make comparisons. The study was conducted during the COVID -19 pandemic period where there were restrictions of public gatherings and limited meeting many people. Therefore, researchers can increase the sample size and conduct the same study in the same study area to compare the perception of farmers on climate variability effects on tea yields. Further, research can be conducted on other factors affecting tea production other than climate.

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APPENDICES

APPENDIX I: RESEARCH PERMIT

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NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

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Date of Issue: **05/October/2020**

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This is to Certify that Ms.. Norah Moige Nyaiyo of Kisii University, has been licensed to conduct research in Kisii on the topic: CLIMATE VARIABILITY AND ITS EFFECTS ON SMALL- SCALE TEA (CAMELLIA SINENSIS) PRODUCTION IN KISII COUNTY, KENYA for the period ending : 05/October/2021.

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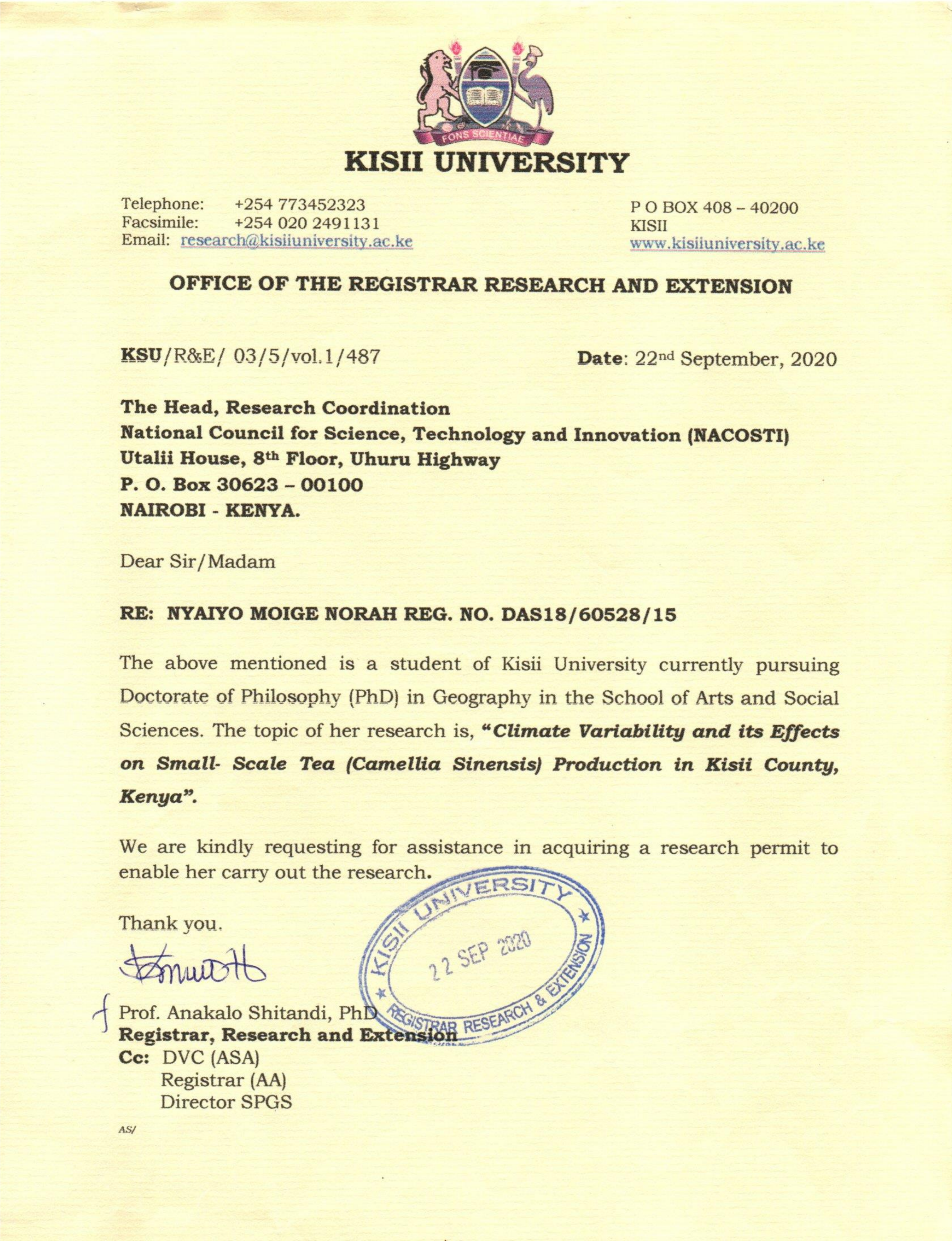
APPENDIX III: AUTHORIZATION BY THE UNIVERSITY FOR RESEARCH PERMIT



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OFFICE OF THE REGISTRAR RESEARCH AND EXTENSION

KSU/R&E/ 03/5/vol.1/487

Date: 22nd September, 2020

The Head, Research Coordination
National Council for Science, Technology and Innovation (NACOSTI)
Utalii House, 8th Floor, Uhuru Highway
P. O. Box 30623 – 00100
NAIROBI - KENYA.

Dear Sir/Madam

RE: NYAIYO MOIGE NORAH REG. NO. DAS18/60528/15

The above mentioned is a student of Kisii University currently pursuing Doctorate of Philosophy (PhD) in Geography in the School of Arts and Social Sciences. The topic of her research is, ***"Climate Variability and its Effects on Small- Scale Tea (Camellia Sinensis) Production in Kisii County, Kenya".***

We are kindly requesting for assistance in acquiring a research permit to enable her carry out the research.

Thank you.

KISII UNIVERSITY
22 SEP 2020
REGISTRAR RESEARCH & EXTENSION

Prof. Anakalo Shitandi, PhD
Registrar, Research and Extension
Cc: DVC (ASA)
Registrar (AA)
Director SPGS

AS/

APPENDIX IV: SAMPLE SIZE CALCULATION

Sample size for ±5%, ±7% and ±10% Precision Levels Where Confidence Level is 95% and P=.5, by Yamane, 1967

Population size	5%	7%	10%
500	222	145	83
600	240	152	86
700	255	158	88
800	261	163	89
900	277	166	90
1000	286	169	91
2000	333	185	95
3000	353	191	97
4000	364	194	98
5000	370	196	98
6000	375	197	98
7000	378	198	99
8000	381	199	99
9000	383	200	99
10000	385	200	99
15000	390	201	99
20000	392	204	100
25000	394	204	100
50000	397	204	100
100000	398	204	100
Above 100000	400	204	100

APPENDIX V: FARMER'S QUESTIONNAIRE

My Name is **Norah Moige Nyaiyo** from **Kisii University**. I am conducting a research on CLIMATE VARIABILITY AND ITS EFFECTS ON SMALL-SCALE TEA PRODUCTION IN COUNTY, KENYA. This research is purely for academic purposes. I kindly request for your cooperation as you answer the questions with honesty. The information you give shall be treated confidentially and will only be used for academic reasons. I appreciate for taking your time to answer his questions.

1. Demographic information

i) Factory-------------------------------------

ii) No basic education [ ]Level of education [ ] Primary [ ] Secondary [ ] College [ ] University

Iv) Age bracket in years: [ ] 25-35 [ ] 36-45 [ ] 46-55 [ ] Over 55

v)Size of land under tea cultivation …………………………………..

vi)For how long have you planted tea [ ] Below 10 yrs [ ] 10-20yrs [ ] 20-30yrs [ ] 30-40yrs [ ] Over 50yrs)

2. Knowledge on temperature and rainfall trends

a) Please circle the number from 1 to 5 that you feel best represents your knowledge on temperature and rainfall variations

1. Minimal knowledge

2. Some knowledge

3. Extensive knowledge

4. Expert knowledge

b) Has there been changes in temperature on your tea farm for the last ten years?

[ ] Yes [ ] No

If yes, which months of the year---

c) Has there been changes in rainfall on your tea farm for the past ten years?

[ ] Yes [ ] No

If yes, which season?

[ ] March, April and May (long rains) [ ] October, November and December (short rains)

[ ] both [ ] all the year

3. Effect of rainfall and temperature variation on tea production

i) Effect of rainfall variability on tea production

To what extent do you agree the following statements on rainfall variability and tea production? (Key; 1=strongly agree, 2= agree, 3= disagree, 4= strongly disagree)

Statements	**1**	**2**	**3**	**4**
Heavy rainfall destroys tea clones				
Scanty rainfall reduces tea yields				
Rainfall changes affects soil water availability to tea clones				
Rainfall changes affects farmer’s decision on when to apply fertilizers.				
Heavy rainfall causes erosion of top soil and washes away available fertilizer				

Hailstones destroy the tea leaves and reduces tea yields drastically				
Frostbites reduces tea yields and production significantly				
Rainfall changes leads to emergence of pest which were never experienced before.				

ii) **Effect of temperature variability on tea production**

To what extent do you agree the following statements on temperature variability and tea production? (Key; 1=strongly agree, 2= agree, 3= disagree, 4= strongly disagree)

	1	2	3	4
High temperatures cause high water/ moisture loss which leads to reduced yields				
Cold conditions damages tea leaves and roots leading to low productivity				
Hot conditions may add heat stress, increase pest infestation and disease prevalence thus reducing both quality and quantity of tea leaves				
High temperatures cause high evaporation from the soil leading to stunted growth, hence reduced yields				
High temperatures leads to wilting and drying of tea				

4. Indicators that justify farmers' perception of temperature rainfall variability

(Key; 1=strongly agree, 2= agree, 3= disagree, 4= strongly disagree)

Indicators of temperature variation

	1	2	3	4
Longest months with high day time temperatures				
Frequent occurrence of heat induced crop pest and diseases				
Frequent occurrence of heat induced animal diseases				
Disappearance/ reduction of water sources/ points due to high evaporation				
Planting drought resistant crops				
Frost that affects crop leaves				

Indicators of rainfall variability

	1	2	3	4
Short rainy season				
Change of planting date to onset of rainfall				
Early onset of rainy season				
Early exit of rainy season				
Unpredictable rainfall amounts				
Rainfall delays				
Crop failure due droughts				
Change of planting and harvesting seasons				

5. Management and adaptive practices

i) How often do apply fertilizers? Once a year [ ] Twice a year [ ] more than twice [ ]

Not sure [ ]

ii)What type of fertilizers do use?

[ ] Artificial [ ] Organic [ ] Both [ ] None

iii) In what months of the year do you apply these fertilizers?

[ ] Jan [ ] Feb [ ] March [ ] April [ ] May [ ] Jun [ ] July [ ] Aug [ ] Sept [ ] Oct [ ]Nov [ ] Dec

iv) How does the use of fertilizers influence your tea production?

[ ] Increase [ ] Decrease [ ] No difference

v)How often do you control weeds pests and diseases?

[ ] Monthly [ ] When they appear [ ] Twice a year [ ] Never

vi)Which of the following practices have you employed in your farm to adapt toclimate variability. Tick appropriately. Use (No or Yes)

FARMING PRACTICE	YES	NO
Planting of trees to act as wind breakers		
Harvesting rain water to be used during the dry season		
Soil conservation method such as mulching		
Digging furrows to retain surface run off water		
Planting many crops on the same piece of land		
Maintaining soil fertility by using both artificial and farm yard manure		
Use of drought resistant crops		
Use of pesticides and herbicides to control pests and weeds respectively		
Insuring your tea crop		

Thank you

APPENDIX VI: INTERVIEW SCHEDULE FOR FIELD SERVICE COORDINATOR

My Name is Norah Moige Nyaiyo from Kisii University. I'm conducting a research on CLIMATE VARIABILITY AND ITS EFFECTS ON SMALL- SCALE TEA PRODUCTION IN KISII COUNTY, KENYA. This research is purely for academic purposes. I kindly request for your cooperation as you answer the questions with honesty. The information you give shall be treated with a lot of confidentially. I appreciate for taking your time to answer these questions. Tick where possible and give details where required

1. From your own observation, has there been changes in temperature and rainfall in the tea growing areas? [ ] Yes [ ] No

   If yes give details --

   ----

2. Has rainfall variation affect tea yields? [ ]Yes [ ] NO

   If yes, How ---

   Which months of the year --

3. Has temperature variations affected tea yields? [ ] Yes [ ] No

   If yes, How ---

   Which months of the year --

4. Are there pests that have affect the tea clones? [ ] Yes [ ] No

   If yes, which ones,?---

   Which season --

5. Are there diseases that have affect the tea clones? [ ] Yes [ ] No

6. If yes, which ones, ---

---Which season?----------------

----

7. How to tea farmers cope with climate variability? --

Thank you

APPENDIX VII: ANALYSIS OUTPUT

Significance level (%): 5

Continuity correction: Yes

Confidence interval (%) (Sen's slope): 95

Summary statistics: Temperature

Variable	Observati Ons	Obs. With missing	Obs. Without	Minimum	Maximum	Mean	Std. deviation
JAN	25	0	25	19.800	22.900	21.302	0.640
FEB	25	0	25	20.300	23.500	21.996	0.801
MAR	25	0	25	19.900	23.100	21.582	0.846
APR	25	0	25	19.750	22.400	20.722	0.649
MAY	25	0	25	19.950	21.400	20.522	0.351
JUN	25	0	25	14.700	20.900	19.550	1.629
JUL	25	0	25	14.700	20.700	19.678	1.135
AUG	25	0	25	15.200	24.900	20.130	1.437
SEP	25	0	25	20.250	21.950	20.794	0.371
OCT	25	0	25	19.800	25.000	20.892	0.950
NOV	25	0	25	19.550	20.800	20.276	0.333
DEC	25	0	25	15.400	21.850	20.406	1.185

Mann-Kendall Trend Test / Two-Tailed Test (JAN):

Kendall's t	0.342
S	102.000
Var(S)1829.333	
p-value (T	0.018
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The continuity correction has been applied.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope:

	Value	Lower Bound (95%)	Upper Bound (95%)
Slope	0.041	0.010	0.071
Intercept	-61.863	-121.258	1.210

JAN

Mann-Kendall trend test / Two-tailed test (FEB):

Kendall's t	0.208
S	62.000
Var(S)	1829.333
p-value (T	0.154
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

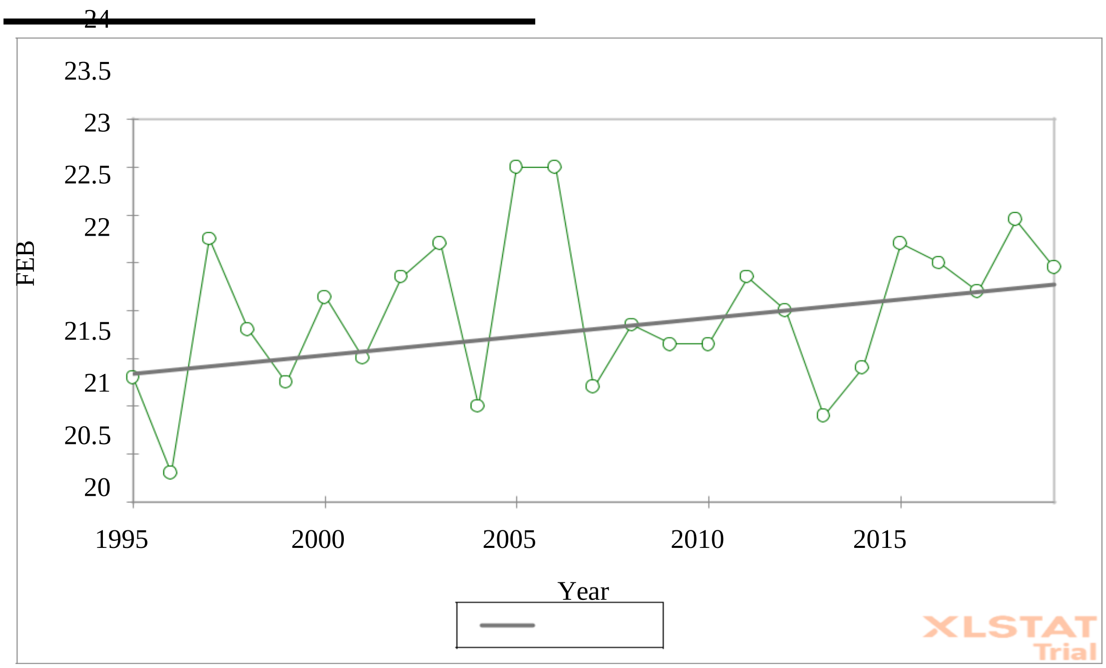
The continuity correction has been applied.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope:

	Value	Lower Bound (95%)	Upper Bound (95%)
Slope	0.039	-0.013	0.086
Intercept	-56.239	-150.093	47.140

FEB



Sen's slope

Mann-Kendall trend test / Two-tailed test (MAR):

Kendall's t	0.232
S	69.000
Var(S)1828.333	
p-value (T	0.112
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

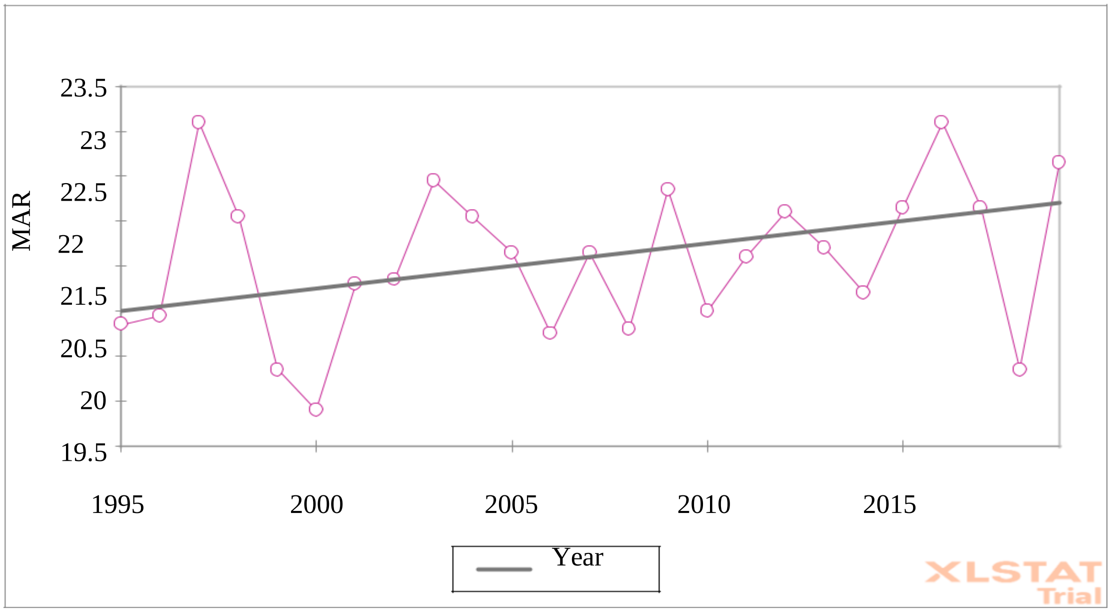
The continuity correction has been applied.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope:

	Value	Lower Bound (95%)	Upper Bound (95%)
Slope	0.050	-0.012	0.078
			46.737
Intercept	-78.750	-134.389	

MAR



Sen's slope

Mann-Kendall trend test / Two-tailed test (APR):

Kendall's t	0.020
S	6.000
Var(S)	1829.333
p-value (T	0.907
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

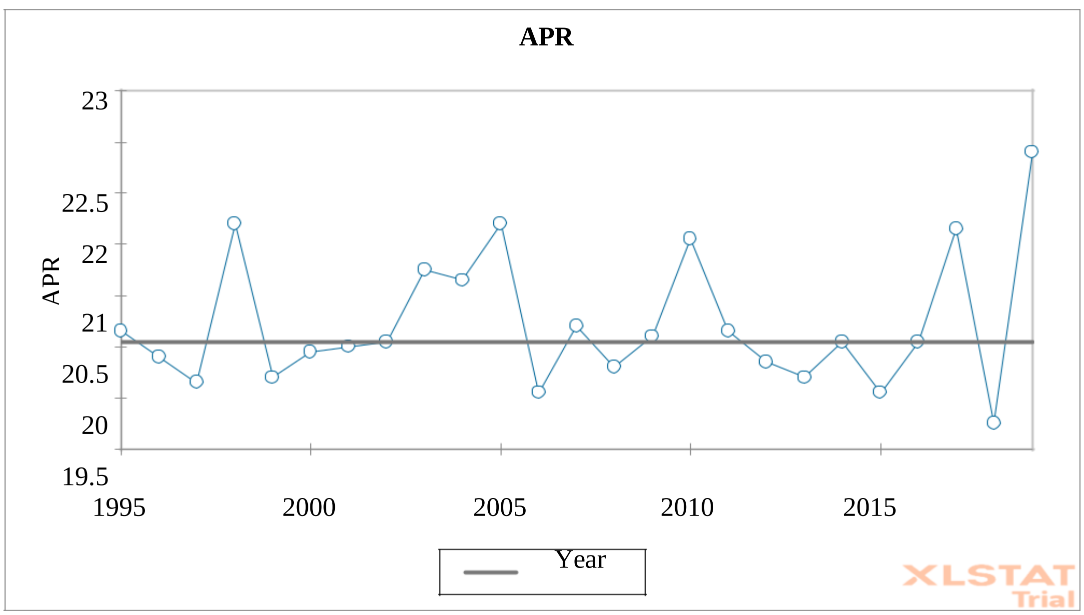
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	0.000	-0.027	0.036
Intercept	20.550	-50.979	74.519



Sen's slope

Mann-Kendall trend test / Two-tailed test (MAY):

Kendall's t	0.106
S	31.000
Var(S)	1817.000
p-value (T	0.482
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

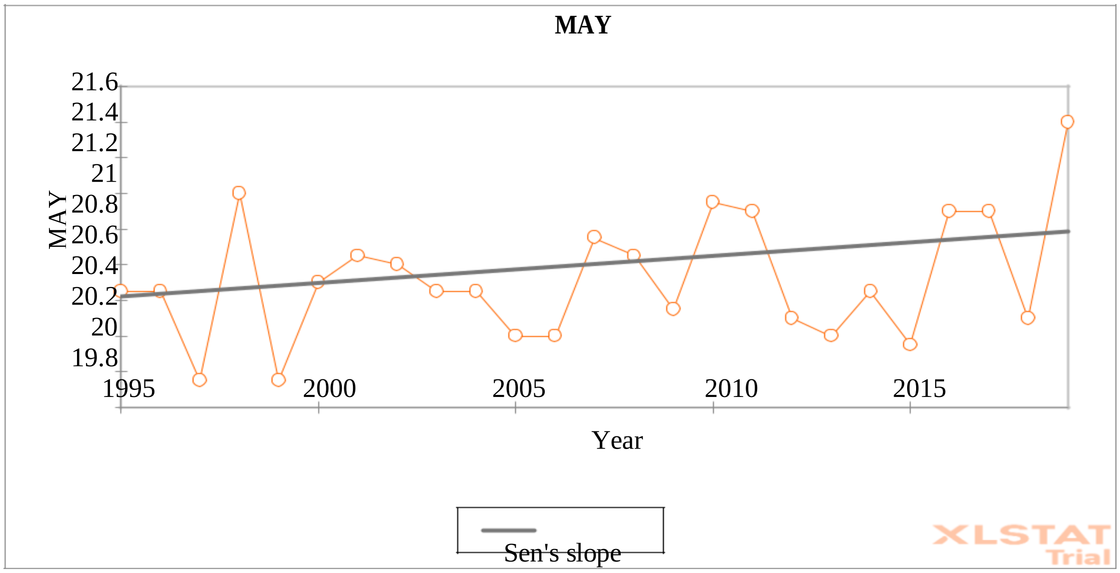
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	0.015	-0.008	0.032
Intercept	-9.885	-43.932	37.150



Mann-Kendall trend test / Two-tailed test (JUN):

Kendall's t	0.088
S	26.000
Var(S)	1824.667
p-value (T	0.558
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

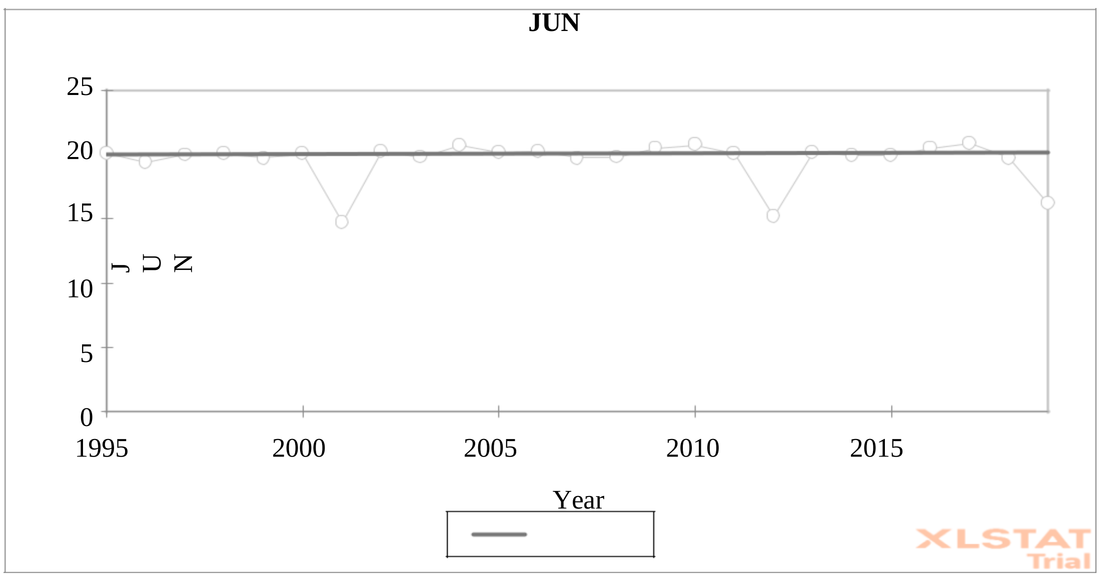
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	0.009	-0.018	0.037
Intercept	2.318	-53.395	56.441



Sen's slope

Mann-Kendall trend test / Two-tailed test (JUL):

Kendall's t	0.397
S	118.000
Var(S)	1826.667
p-value (T	0.006
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

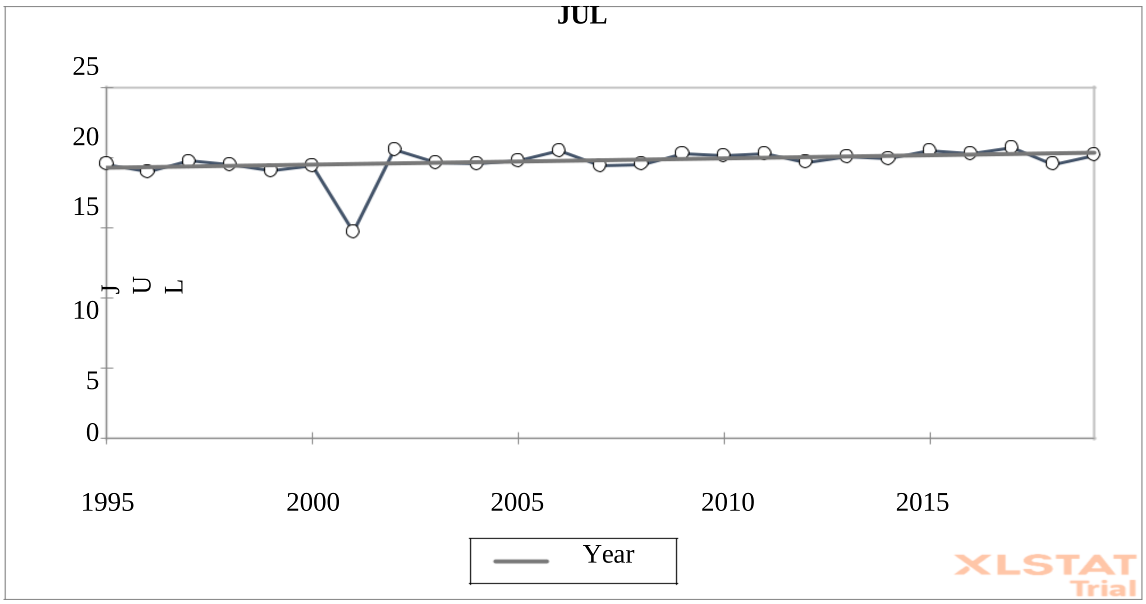
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The continuity correction has been applied.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope:

	Value	Lower Bound (95%)	Upper Bound (95%)
Slope	0.044	0.012	0.070
Intercept	-68.668	-120.560	-5.262



Sen's slope

Mann-Kendall trend test / Two-tailed test (AUG):

Kendall's t	0.234
S	69.000
Var(S)	1823.667
p-value (T	0.111
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

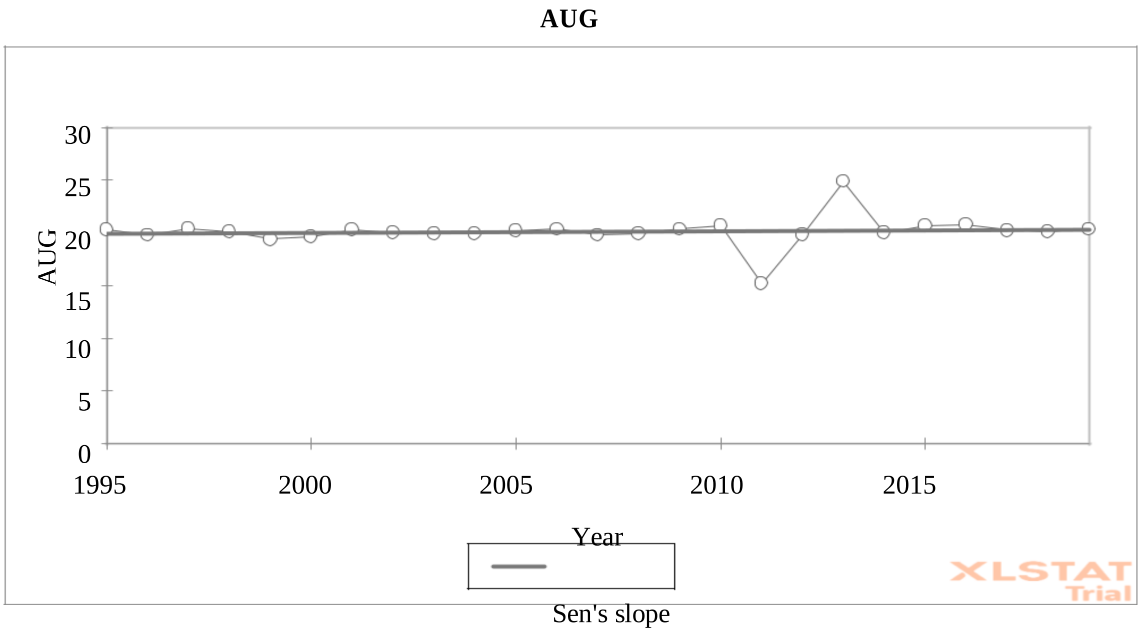
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	0.017	-0.003	0.044
Intercept	-13.317	-68.939	26.406



Mann-Kendall trend test / Two-tailed test (SEP):

Kendall's t	0.115
S	34.000
Var(S)	1822.000
p-value (T	0.439
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

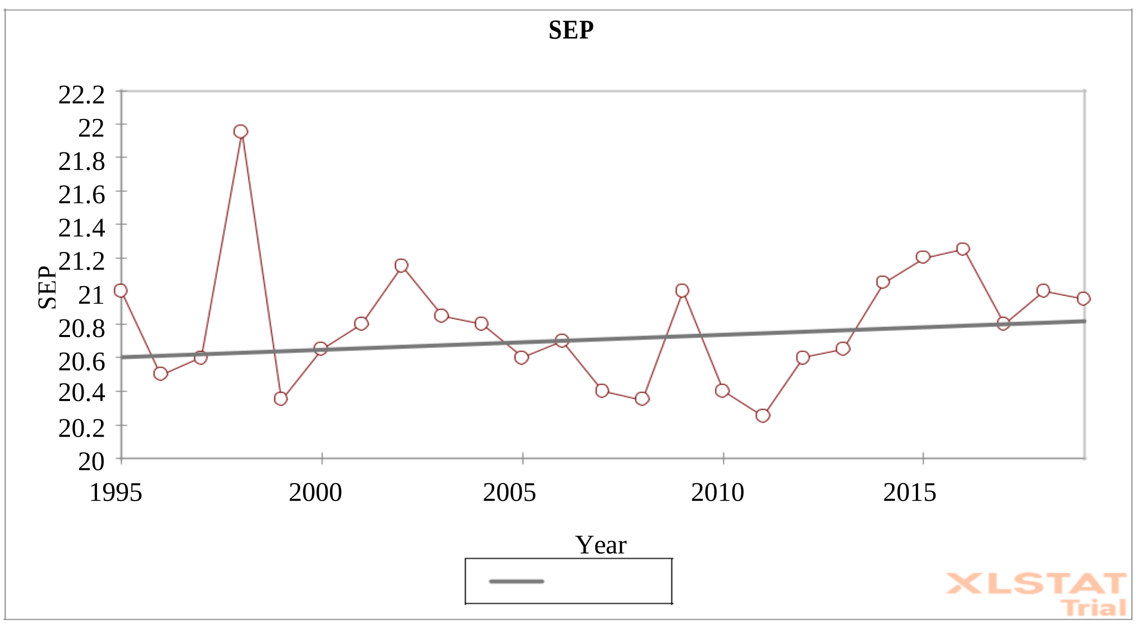
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	0.009	-0.017	0.029
Intercept	3.003	-37.717	54.200



Sen's slope

Mann-Kendall trend test / Two-tailed test (OCT):

Kendall's t	0.037
S	11.000
Var(S)1823.000	
p-value (T	0.815
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

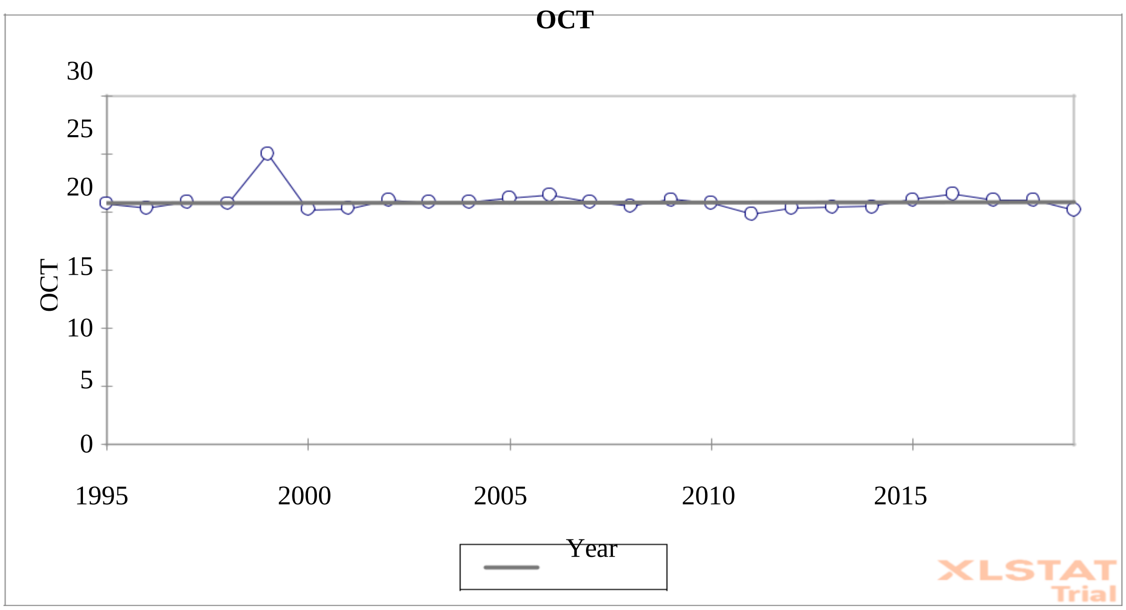
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	0.003	-0.031	0.029
Intercept	14.516	-36.521	83.394



Sen's slope

Mann-Kendall trend test / Two-tailed test (NOV):

Kendall's t	-0.075
S	-22.000
Var(S)	1820.000
p-value (T	0.623
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-0.004	-0.019	0.014
Intercept	27.511	-8.386	57.981

NOV

Sen's slope

Mann-Kendall trend test / Two-tailed test (DEC):

Kendall's t	-0.054
S	-16.000
Var(S)	1826.667
p-value (T	0.726
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

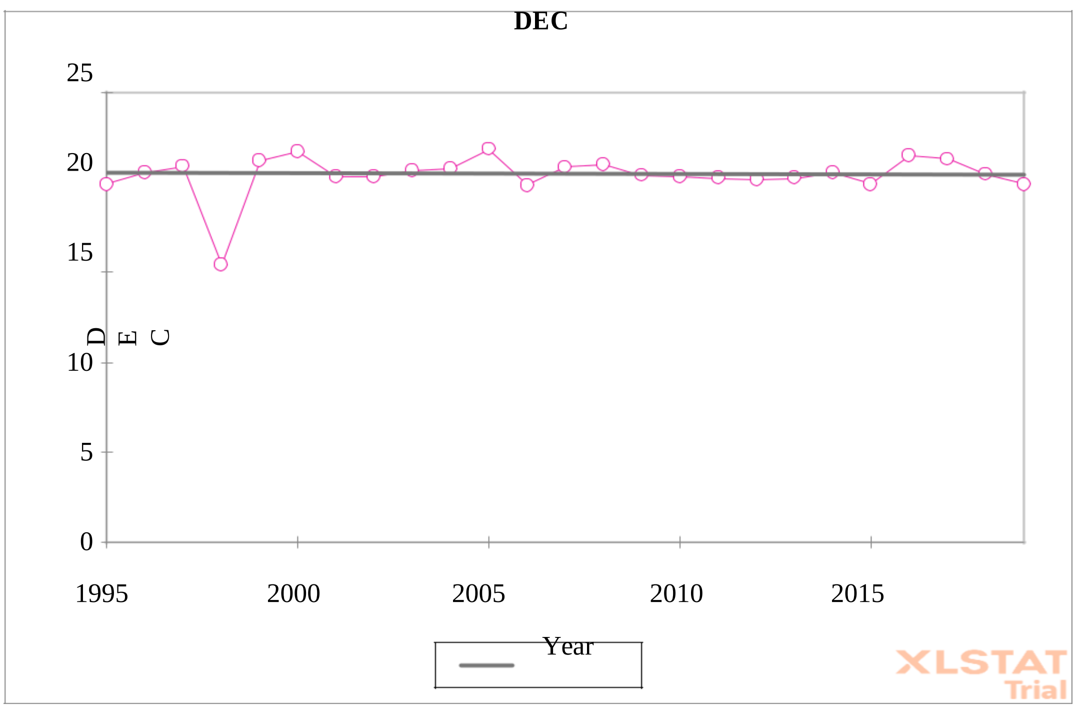
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-0.005	-0.044	0.033
Intercept	30.530	-46.433	108.281



Sen's slope

Significance level (%): 5

Continuity correction: Yes

Confidence interval (%)(Sen's slope): 95

Summary statistics: Rainfall

Variable	Observati Ons	Obs. with missing	Obs. without	Minimum	Maximum	Mean	Std. deviation
JAN	25	0	25	6.400	281.000	102.488	72.077
FEB	25	0	25	5.900	218.400	80.292	49.897
MAR	25	0	25	81.200	364.600	194.704	84.666
APR	25	0	25	139.200	399.600	261.656	63.181
MAY	25	0	25	118.500	388.600	265.796	65.978
JUN	25	0	25	94.400	267.700	165.796	47.462
JUL	25	0	25	33.300	220.600	101.660	40.564
AUG	25	0	25	66.700	414.600	190.124	85.182
SEP	25	0	25	31.100	299.400	187.864	68.142
OCT	25	0	25	65.900	390.000	196.316	78.362
NOV	25	0	25	97.500	345.900	203.500	76.297
DEC	25	0	25	32.000	365.800	163.039	95.210

Mann-Kendall trend test / Two-tailed test (JAN):

Kendall's t	-0.333
S	-100.000
Var(S)	1833.333
p-value (T	0.021
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

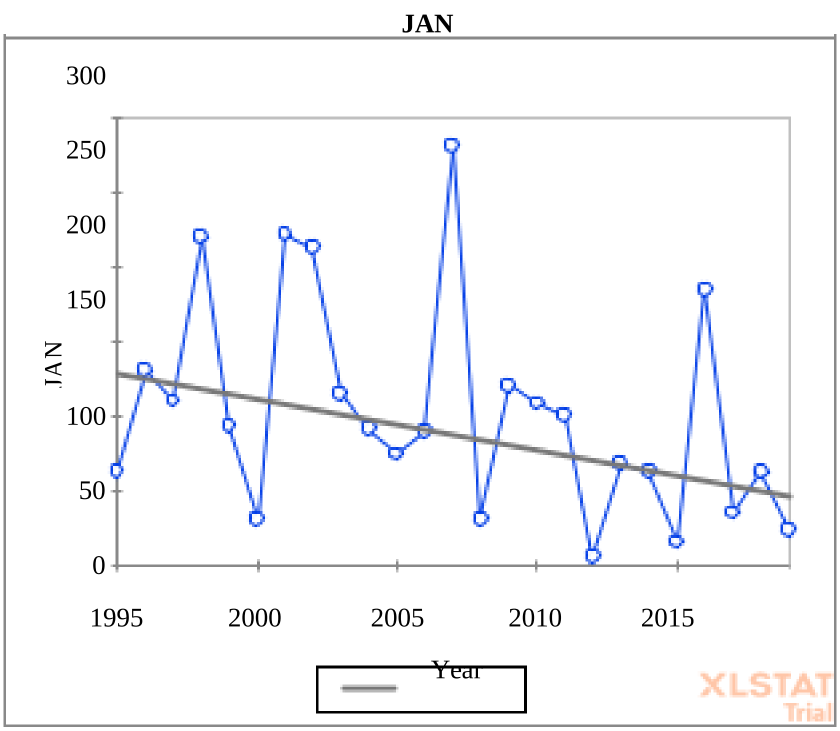
Ha: There is a trend in the series

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The continuity correction has been applied.

Sen's slope:

Observation	Value	Lower bound (95%)	Upper bound (95%)
Slope	-3.415	-8.225	-0.682
Intercept	6941.802	1457.827	16625.325



Sen's slope

Mann-Kendall trend test / Two-tailed test (FEB):

Kendall's t	-0.277
S	-83.000
Var(S)	1832.333
p-value (T	0.055
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

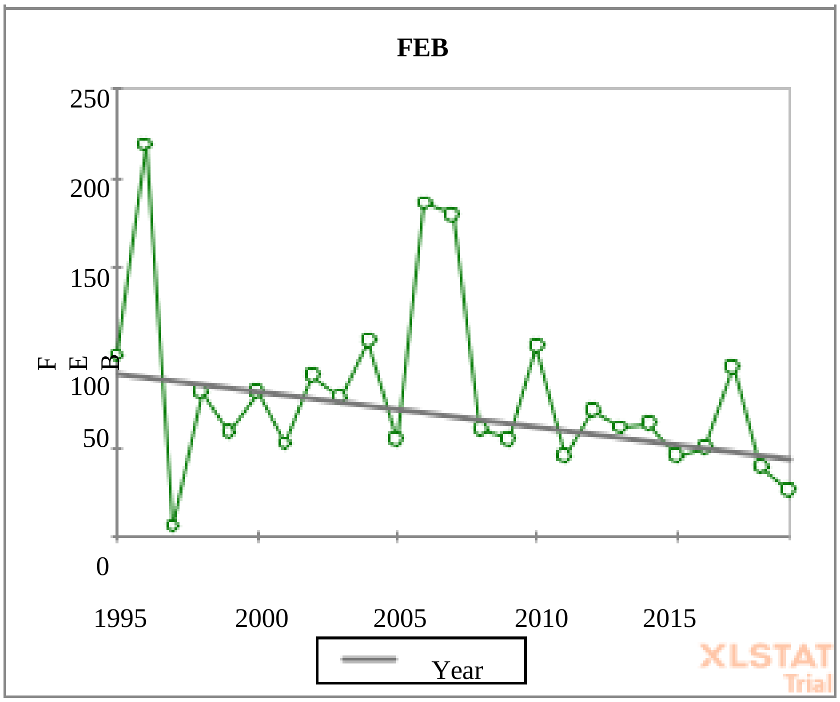
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope:

Observatio	Value	Lower bound (95%)	Upper Bound (95%)
Slope	-1.972	-3.580	-0.153
Intercept	4025.995	371.913	7257.060



Sen's slope

Mann-Kendall trend test / Two-tailed test (MAR):

Kendall's t	-0.110
S	-33.000
Var(S)	1832.333
p-value (T	0.455
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

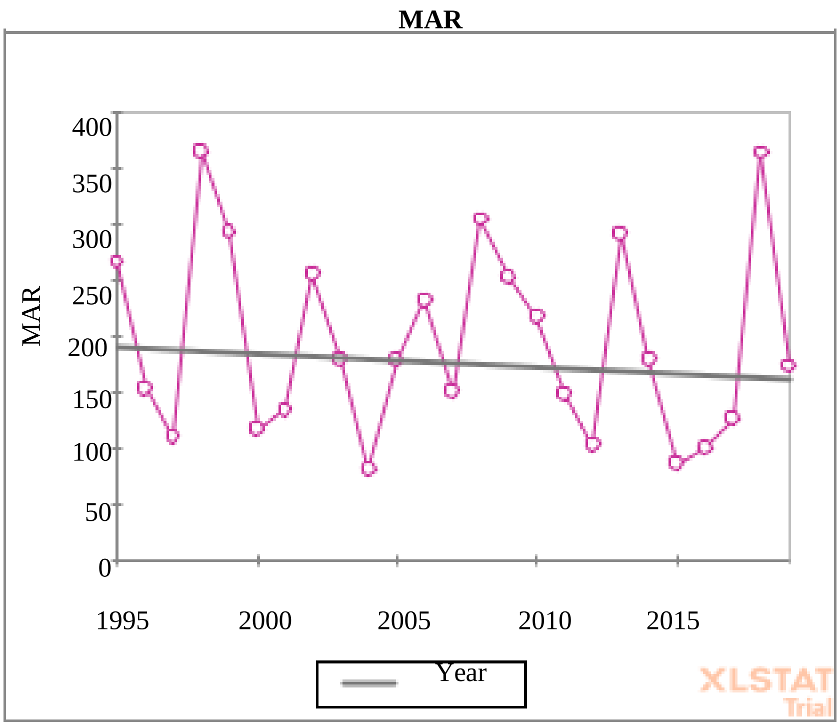
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope:

Observatio	Value	Lower bound (95%)	Upper Bound (95%)
Slope	-1.191	-7.150	3.438
Intercept	2566.421	-6715.315	14530.450



Sen's slope

Mann-Kendall trend test / Two-tailed test (APR):

Kendall's t	0.127
S	38.000
Var(S)	1833.333
p-value (T	0.388
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

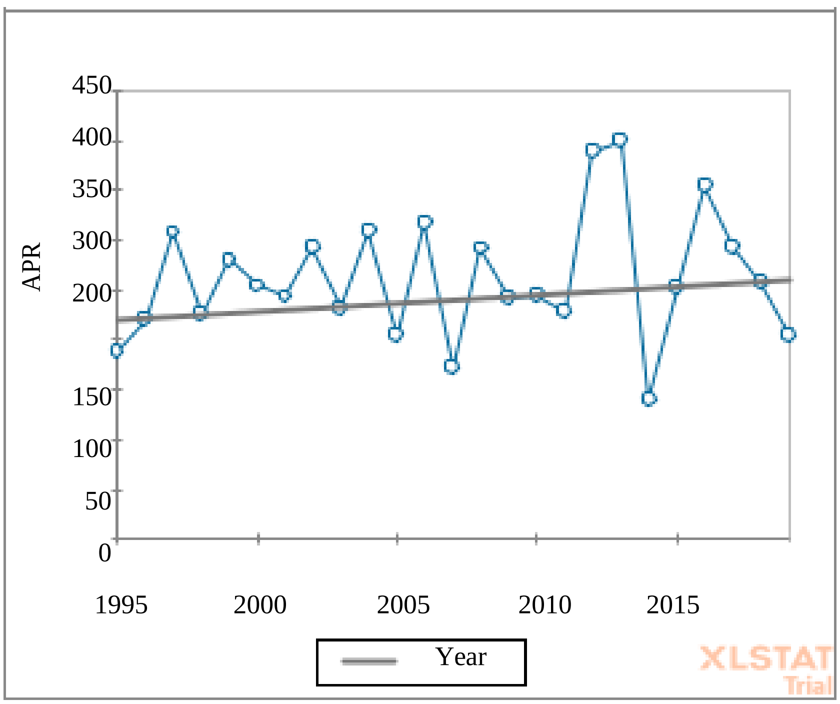
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Sen's slope:

Observatio	Value	Lower bound (95%)	Upper Bound (95%)
Slope	1.598	-2.532	5.257
Intercept	-2966.375	-10278.371	5333.074

APR



Sen's slope

Mann-Kendall trend test / Two-tailed test (MAY):

Kendall's t	-0.093
S	-28.000
Var(S)	1833.333
p-value (T	0.528
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

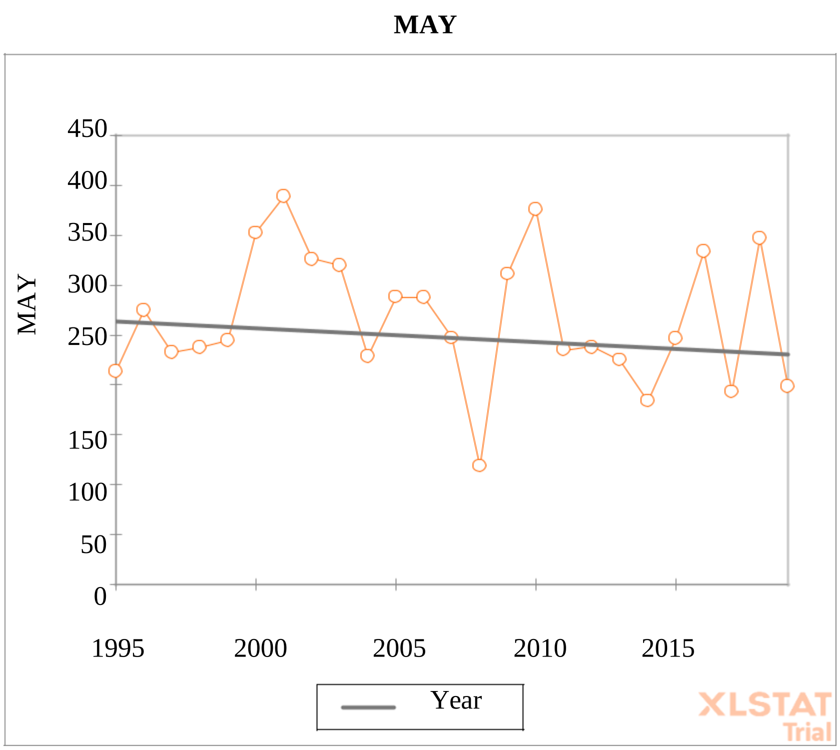
Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Sen's slope:

Observatio	Value	Lower bound (95%)	Upper Bound (95%)
Slope	-1.417	-6.117	2.800
Intercept	3090.250	-5357.200	12544.733



Sen's slope

Mann-Kendall trend test / Two-tailed test (JUN):

Kendall's t	-0.100
S	-30.000
Var(S)	1833.333
p-value (T	0.498
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

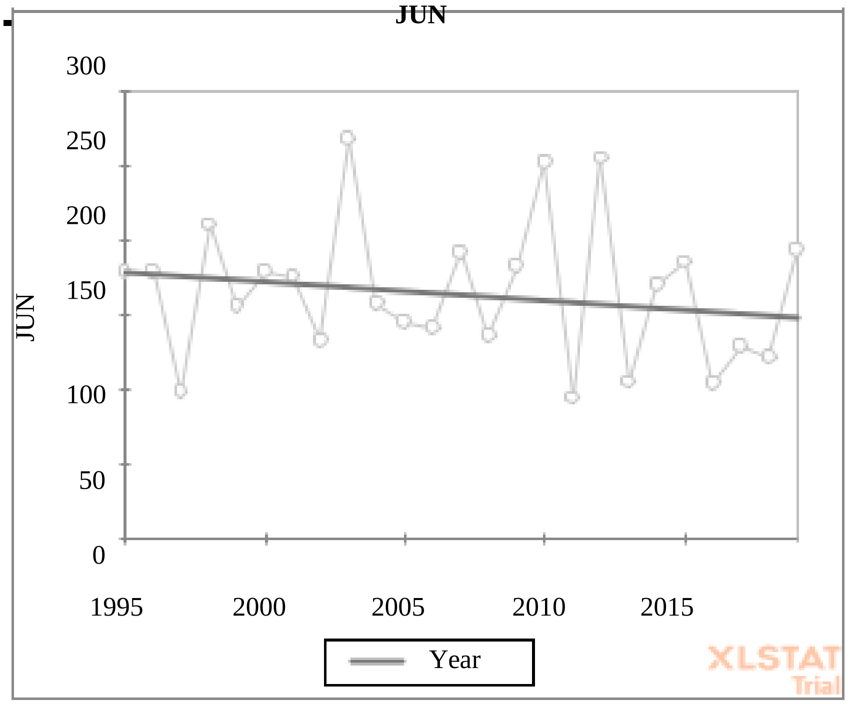
Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Sen's slope:

Observatio	Value	Lower Bound (95%)	Upper Bound (95%)
Slope	-1.259	-3.700	1.290
Intercept	2690.486	-2422.810	7578.700



Sen's slope

Mann-Kendall trend test / Two-tailed test (JUL):

Kendall's t	-0.250
S	-75.000
Var(S)	1832.333
p-value (T	0.084
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

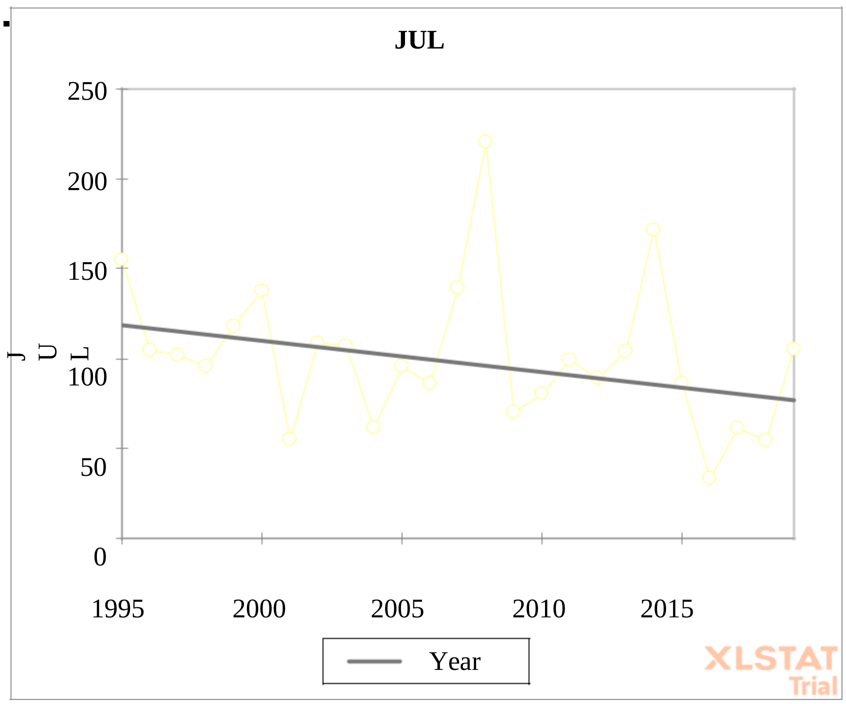
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope:

Observatio	Value	Lower Bound (95%)	Upper Bound (95%)
Slope	-1.724	-3.440	0.168
Intercept	3558.410	-239.114	6996.320



Sen's slope

Mann-Kendall trend test / Two-tailed test (AUG):

Kendall's t	0.180
S	54.000
Var(S)1833.333	
p-value (T	0.216
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

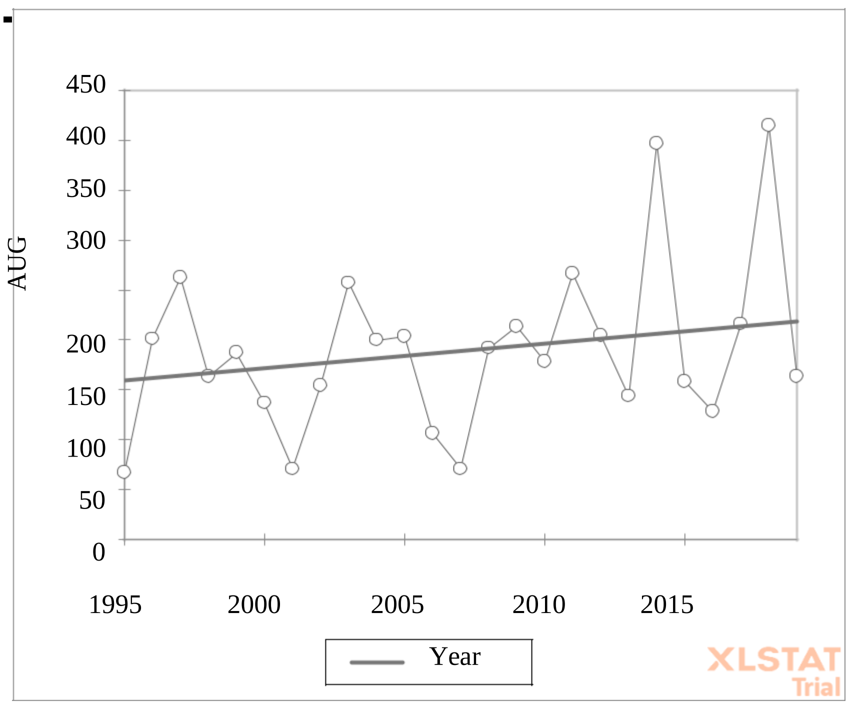
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Sen's slope:

Observatio	Value	Lower Bound (95%)	Upper Bound (95%)
Slope	2.468	-1.956	7.200
Intercept	-4763.040	-14263.500	4108.767

AUG



Sen's slope

Mann-Kendall trend test / Two-tailed test (SEP):

Kendall's t	0.180
S	54.000
Var(S)1833.333	
p-value (T	0.216
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

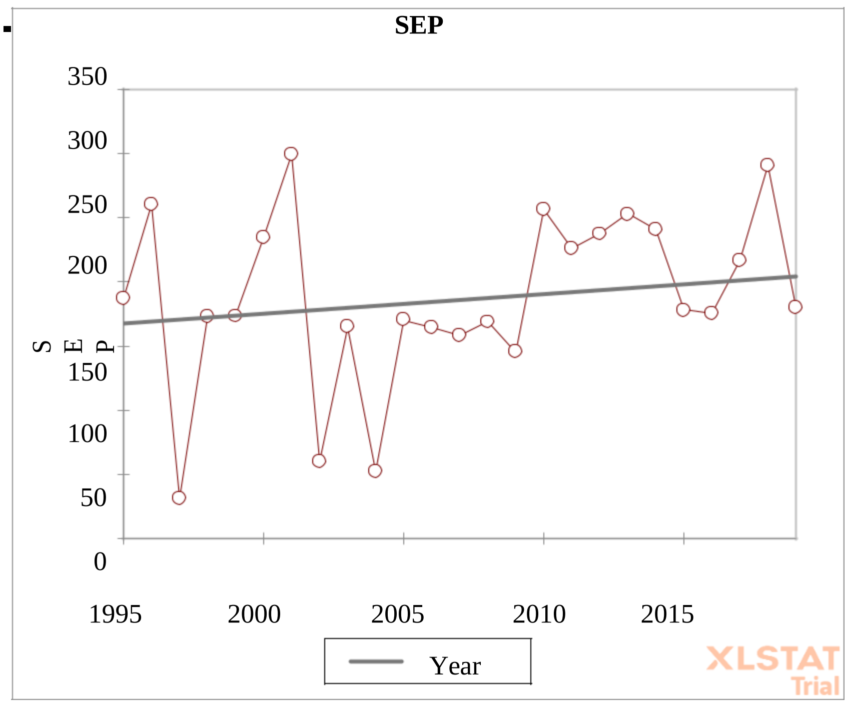
Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Sen's slope:

Observatio	Value	Lower Bound (95%)	Upper bound (95%)
Slope	1.542	-1.094	7.082
Intercept	-2908.392	-14023.259	2381.900



Sen's slope

Mann-Kendall trend test / Two-tailed test (OCT):

Kendall's t	0.144
S	43.000
Var(S)1832.333	
p-value (T	0.327
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

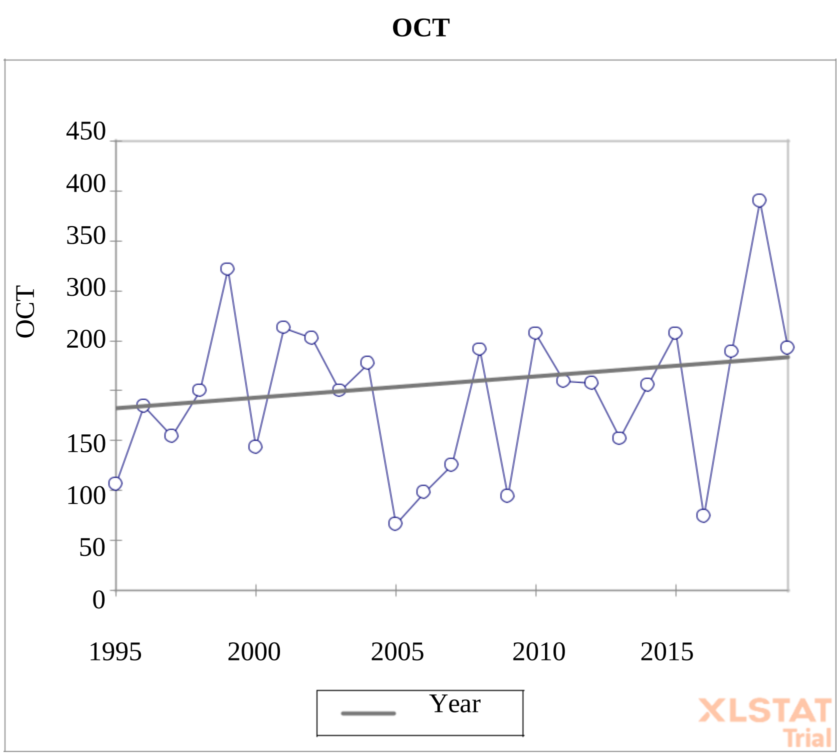
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Ties have been detected in the data and the appropriate corrections have been applied.

Sen's slope:

Observatio	Value	Lower Bound (95%)	Upper bound (95%)
Slope	2.141	-2.350	6.419
Intercept	-4090.041	-12694.300	4935.050



Sen's slope

Mann-Kendall trend test / Two-tailed test (NOV):

Kendall's t	0.040
S	12.000
Var(S)	1833.333
p-value (T	0.797
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

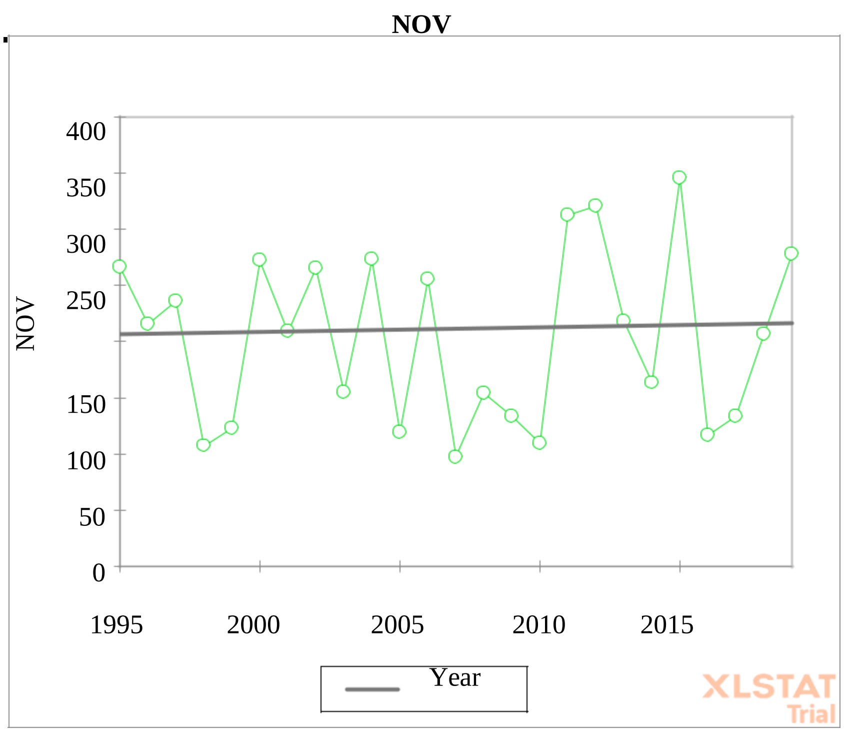
Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Sen's slope:

Observatio	Value	Lower Bound (95%)	Upper bound (95%)
Slope	0.399	-4.675	5.250
Intercept	-588.999	-10350.150	9571.875



Sen's slope

Mann-Kendall trend test / Two-tailed test (DEC):

Kendall's t	0.160
S	48.000
Var(S)1833.333	
p-value (T	0.272
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

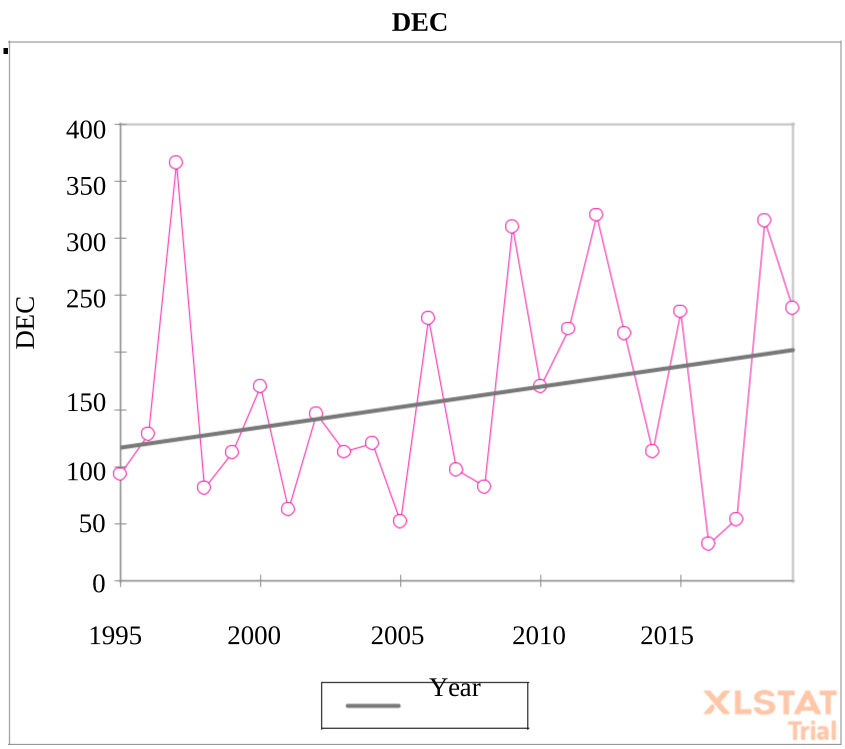
Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Sen's slope:

Observatio	Value	Lower Bound (95%)	Upper bound (95%)
Slope	3.581	-2.722	9.017
Intercept	-7028.740	-17934.100	5595.356



Sen's slope

Significance level (%): 5

Continuity correction: Yes

Confidence interval (%)(Sen's slope): 95

Summary statistics: Tea yields

Variable	Observations	Obs. with missing data	Obs. Without missing data	Minimum	Maximum	Mean
JAN	24	0	24	818230	2479729	1489435
FEB	24	0	24	555111	1861106	1166913
MAR	24	0	24	553069	2200712	1273408
APR	24	0	24	560630	6143035	1707435
MAY	24	0	24	543107	2009050	1399727
JUN	24	0	24	887020	2028533	1326072
JUL	24	0	24	55554	1691681	1074032
AUG	24	0	24	96572	1704485	1081345
SEP	24	0	24	5503	1818409	1047361
OCT	24	0	24	610058	2097759	1347281
NOV	24	0	24	775880	2025755	1292304
DEC	24	0	24	203946	2029999	1400280

Mann-Kendall trend test / Two-tailed test (JAN):

Kendall's t	-0.261
S	-72.000
Var(S)	1625.333
p-value (T	0.078
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

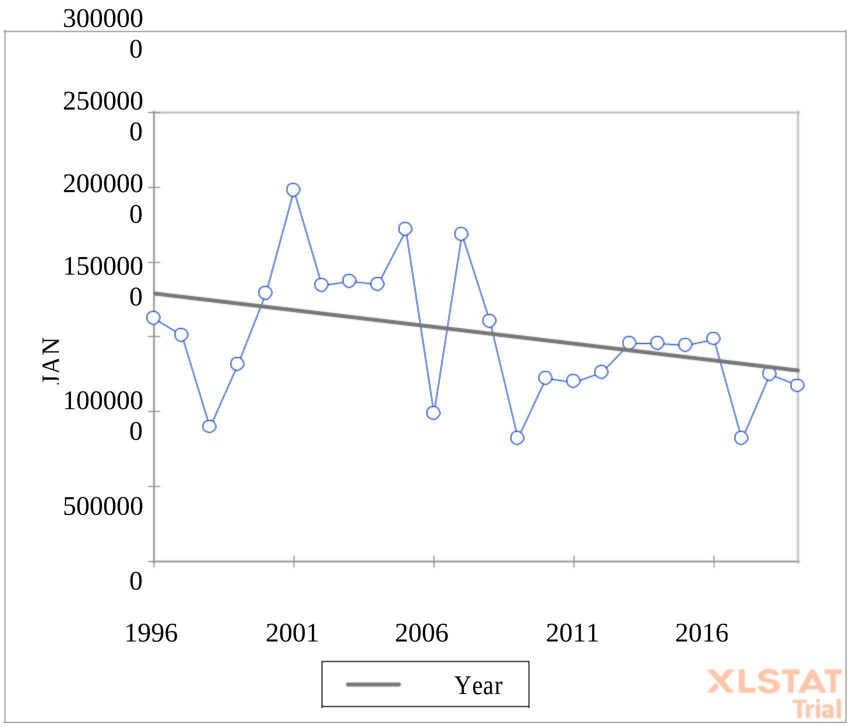
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-22380.262	-46968.929	7068.286
Intercept	46459201.100	16861896.008	71191384.722

JAN



Sen's slope

Mann-Kendall trend test / Two-tailed test (FEB):

Kendall's t	-0.355
S	-98.000
Var(S)	1625.333
p-value (T	0.016
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

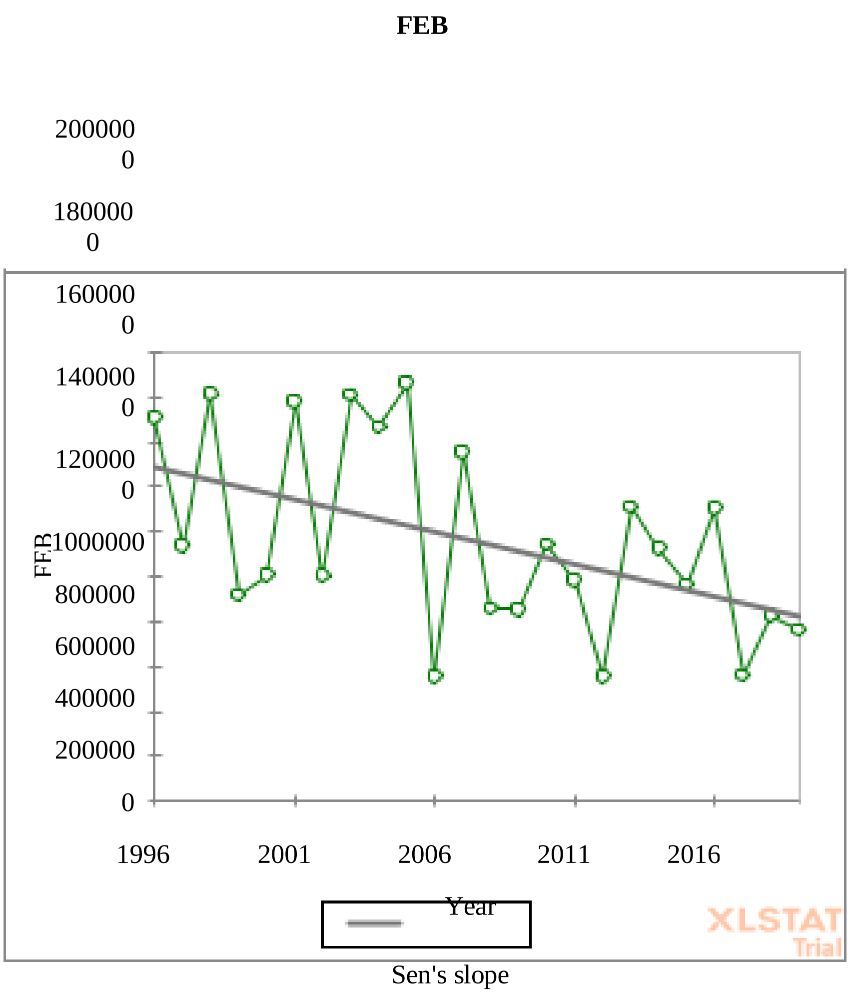
As the computed p-value is lower than the significance level alpha=0.05,

one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The continuity correction has been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-29234.756	-56203.288	-3361.050
Intercept	59843740.628	33804907.897	86988050.669



Mann-Kendall trend test / Two-tailed test (MAR):

Kendall's t	-0.290
S	-80.000
Var(S)	1625.333
p-value (T	0.050
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

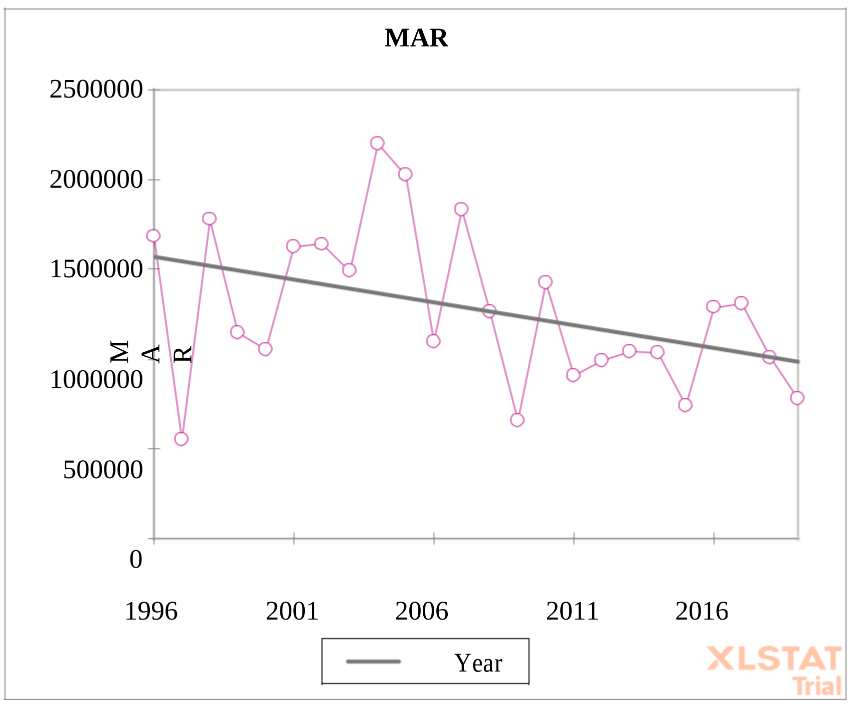
Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-25389.659	-50787.360	-844.077
Intercept	52246584.822	27540098.194	77748888.989



Sen's slope

Mann-Kendall trend test / Two-tailed test (APR):

Kendall's t	-0.232
S	-64.000
Var(S)	1625.333
p-value (T	0.118
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

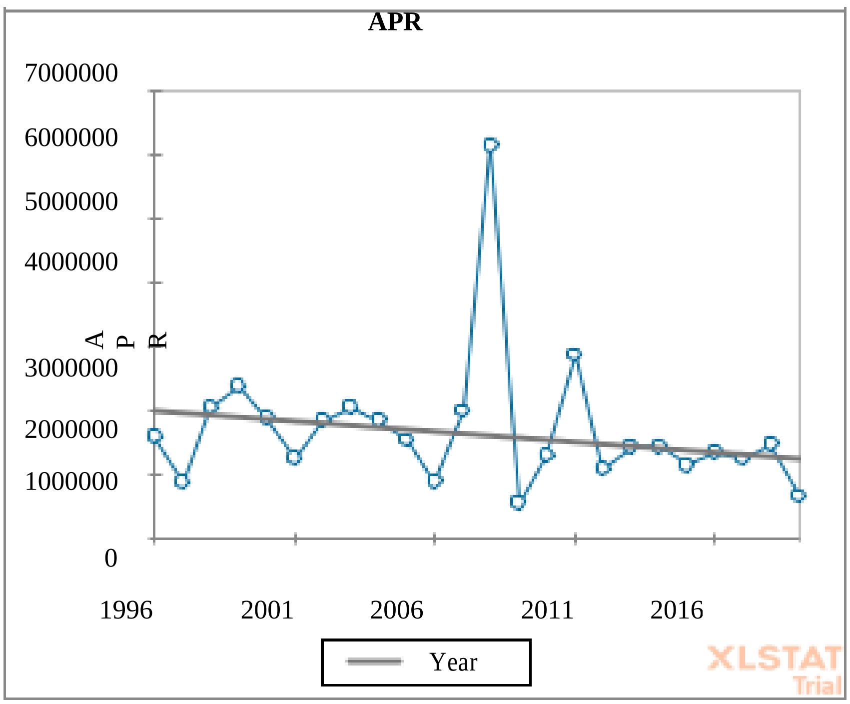
Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-31748.521	-62380.429	9352.500
Intercept	65357405.719	23987294.500	96045739.000



Sen's slope

Mann-Kendall trend test / Two-tailed test (MAY):

Kendall's t	-0.181
S	-50.000
Var(S)	1625.333
p-value (T	0.224
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

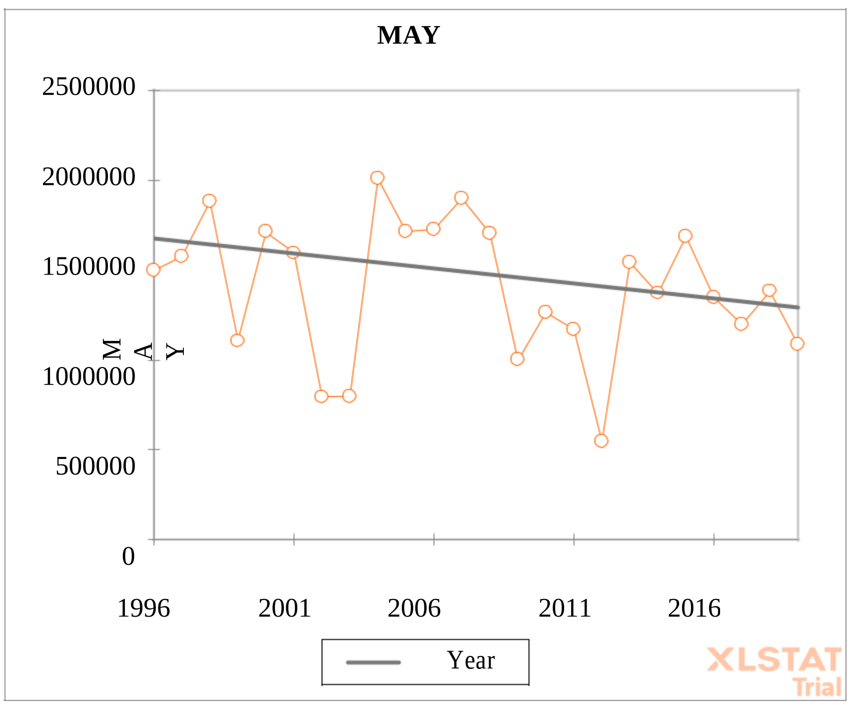
Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-16767.388	-37990.500	11663.000
Intercept	35143831.101	6514430.289	56467053.289



Sen's slope

Mann-Kendall trend test / Two-tailed test (JUN):

Kendall's t	-0.399
S	-110.000
Var(S)	1625.333
p-value (T	0.007
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The continuity correction has been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-32263.969	-47713.921	-7589.183
Intercept	66105402.688	41290236.592	81605419.121

Sen's slope

Mann-Kendall trend test / Two-tailed test (JUL):

Kendall's t	-0.290
S	-80.000
Var(S)	1625.333
p-value (T	0.050
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

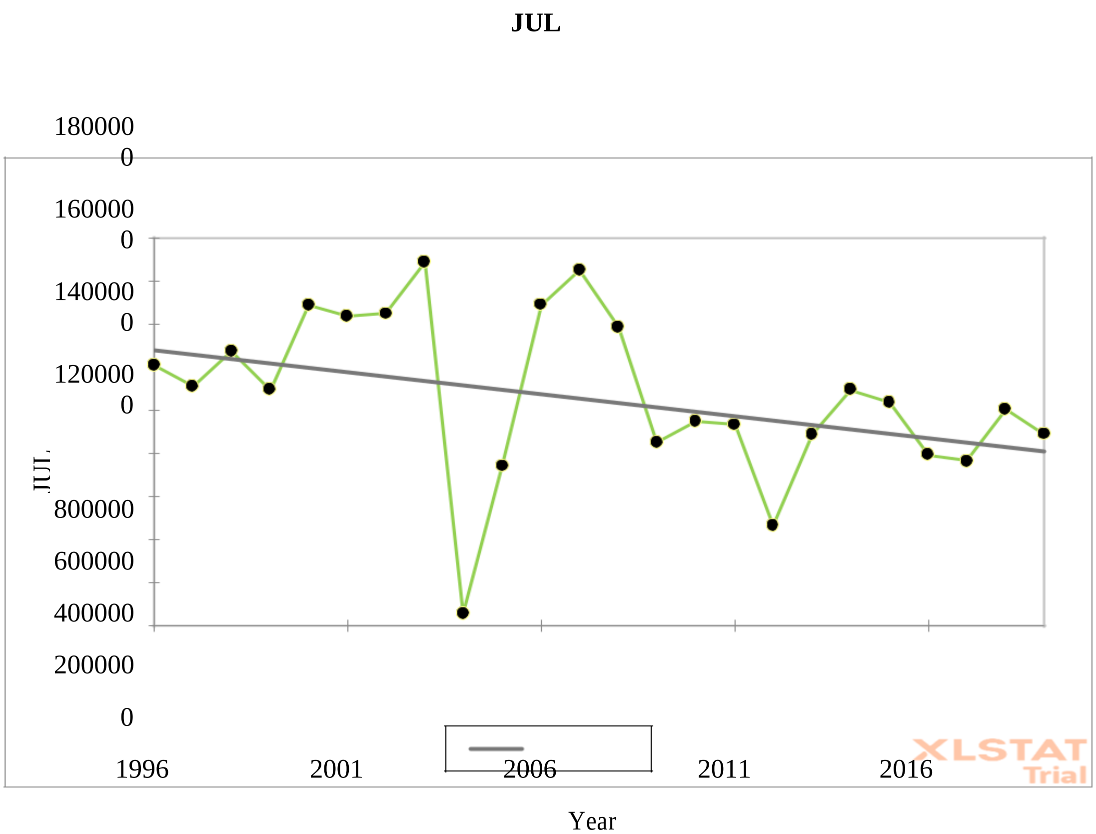
Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-20352.267	-41988.381	-903.000
Intercept	41901261.133	22398178.400	63690998.200



Sen's slope

Mann-Kendall trend test / Two-tailed test (AUG):

Kendall's t	-0.283
S	-78.000
Var(S)	1625.333
p-value (T	0.056
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

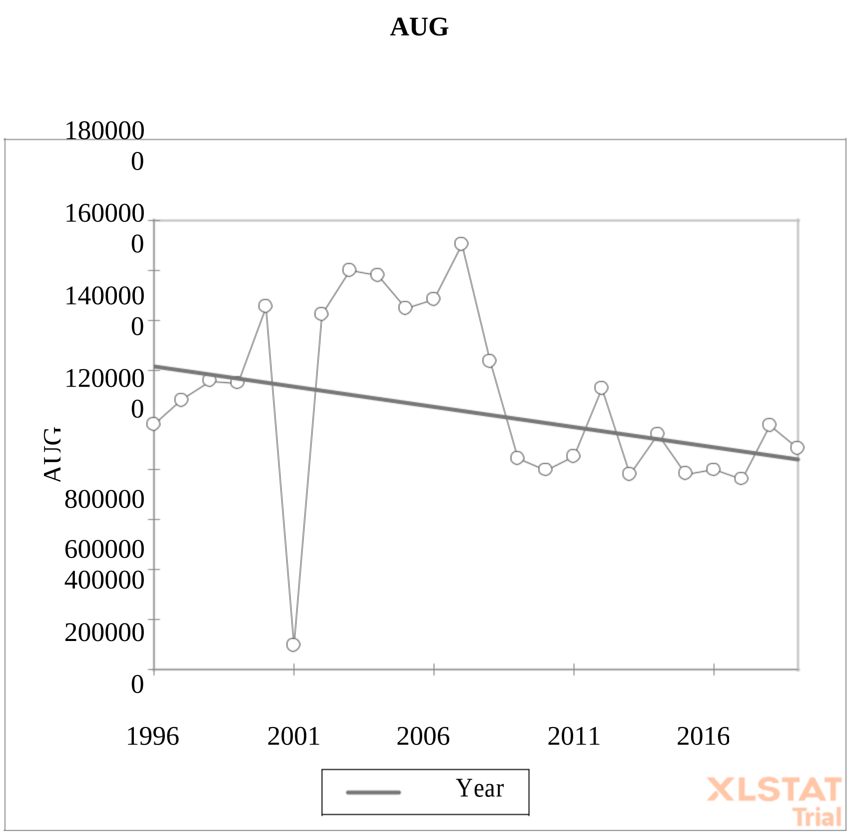
Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-16344.204	-40120.250	53.833
Intercept	33839654.809	17366587.879	57772623.671



Sen's slope

Mann-Kendall trend test / Two-tailed test (SEP):

Kendall's t	-0.072
S	-20.000
Var(S)	1625.333
p-value (T	0.637
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

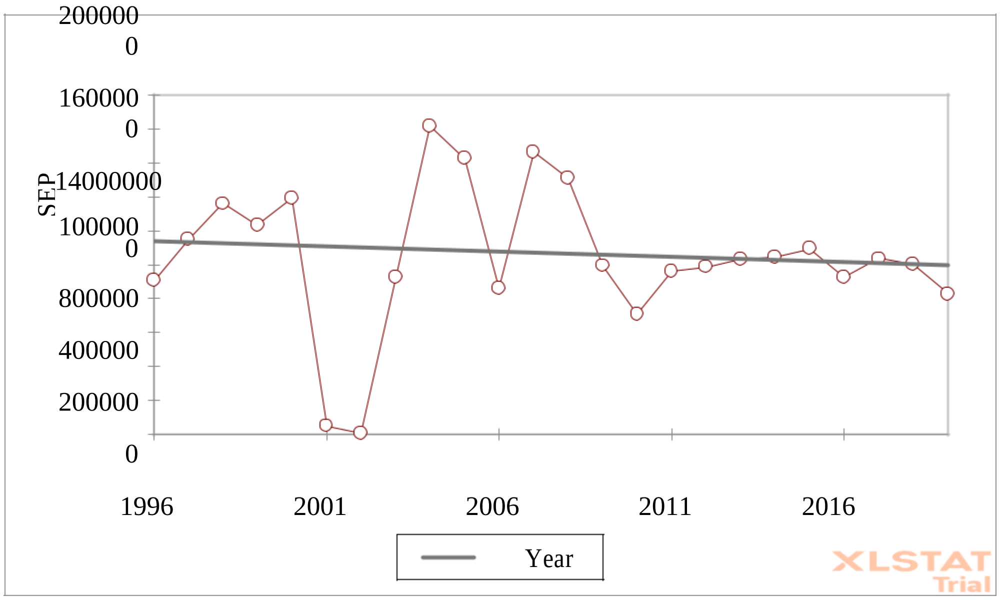
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-6245.965	-26714.450	13341.411
Intercept	13607539.865	-6107017.807	34172467.026

SEP



Sen's slope

Mann-Kendall trend test / Two-tailed test (OCT):

Kendall's t	-0.239
S	-66.000
Var(S)	1625.333
p-value (T	0.107
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

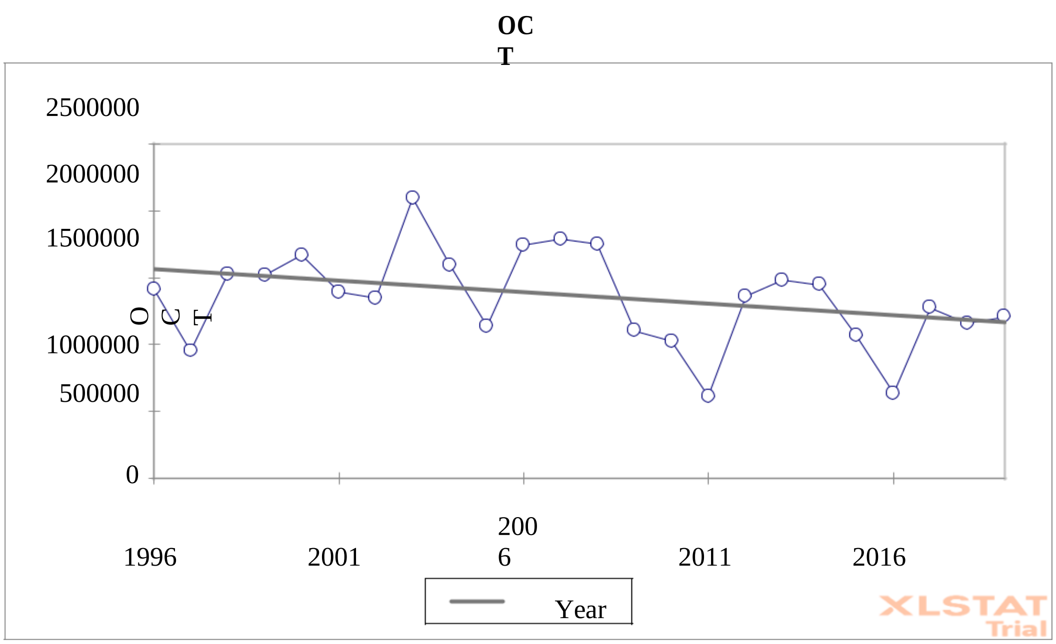
Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-17215.525	-44676.818	5089.929
Intercept	35929102.213	13545466.238	63477505



Sen's slope

Mann-Kendall trend test / Two-tailed test (NOV):

Kendall's t	-0.181
S	-50.000
Var(S)	1625.333
p-value (T	0.224
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

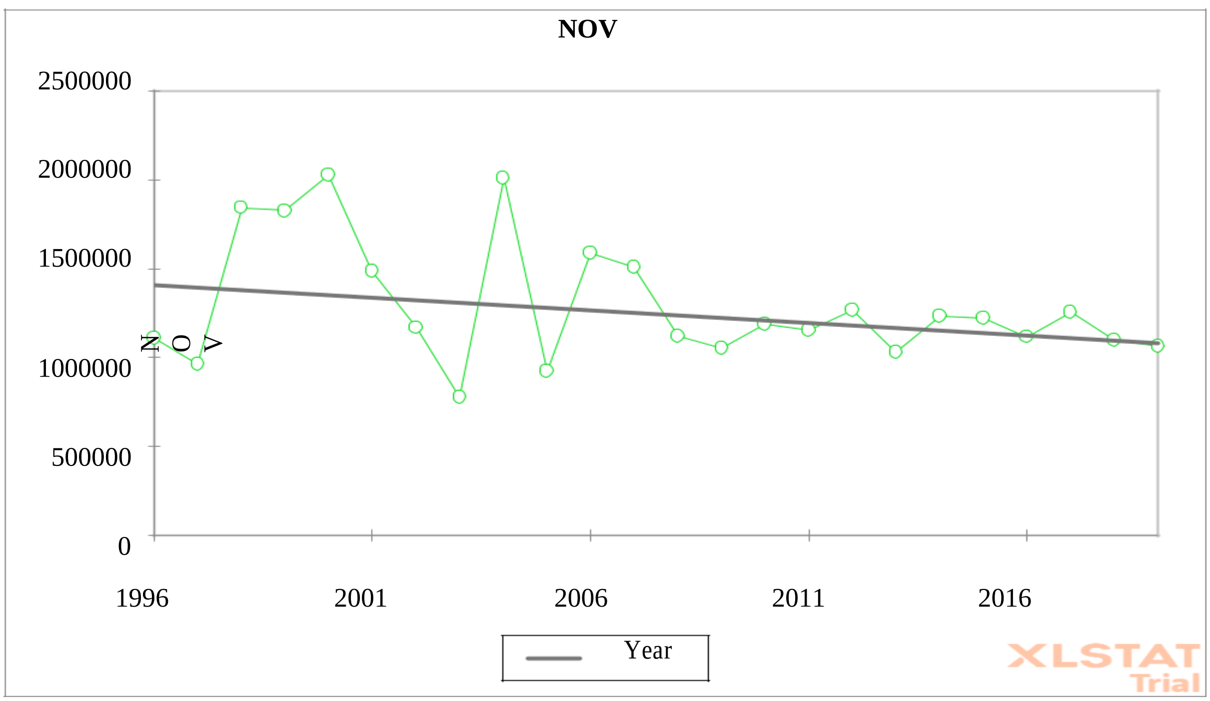
Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The continuity correction has been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-14376.601	-38087.083	5819.421
Intercept	30103905.601	9801563.390	54002794.434



Sen's slope

Mann-Kendall trend test / Two-tailed test (DEC):

Kendall's t	-0.326
S	-90.000
Var(S)	1625.333
p-value (T	0.027
Alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

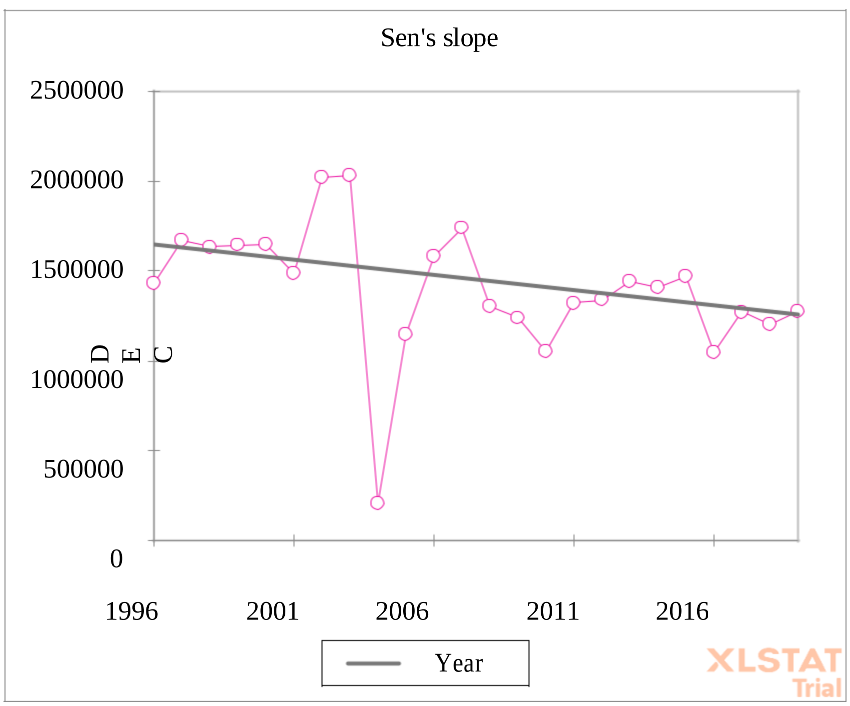
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The continuity correction has been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	-17108.786	-32984.789	-3716.083
Intercept	35798166.071	22332140.845	51717487.152

DEC



Type of correlation: Pearson

Summary statistics (Quantitative data):

Variable	Observations	Obs. with missing	Obs. without	Minimum	Maximum	Mean	Std. deviation
Prod_D1	24	0	24	753818.800	1942796.000	1199535.379	406416.617
Rainfall_D	24	0	24	58.450	222.700	135.577	48.487
Temp_D1	24	0	24	20.625	22.925	21.819	0.631

Correlation matrix (Pearson):

Variables	Prod_D1	Rainfall_D1	Temp_D1
Prod_D1	**1**	0.110	-0.178
Rainfall_D	0.110	**1**	**-0.480**
Temp_D1	-0.178	**-0.480**	**1**

Values in bold are different from 0 with a significance level alpha=0.05

p-values (Pearson):

Variables	Prod_D1	Rainfall_D1	Temp_D1
Prod_D1	**0**	0.609	0.406
Rainfall_D	0.609	**0**	**0.018**
Temp_D1	0.406	**0.018**	**0**

Coefficients of determination (Pearson):

Variables	Prod_D1	Rainfall_D1	Temp_D1
Prod_D1	**1**	0.012	0.032
Rainfall_D	0.012	**1**	0.231
Temp_D1	0.032	0.231	**1**

Type of correlation: Pearson

Summary statistics (Quantitative data):

Variable	Observati Ons	Obs. with missing data	Obs. without	Minimum	Maximum	Mean	Std. deviation
Prod_D2	24	0	24	513550.7	1720814.0	1158662.4	301330.3
Rainfall_D2	24	0	24	101.8	365.1	193.5	55.9
Temp_D2	24	0	24	18.4	22.0	20.6	0.6

Correlation matrix (Pearson):

Variables	Prod_D2	Rainfall_D2	Temp_D2
Prod_D2	**1**	-0.272	0.051
Rainfall_D2	-0.272	**1**	-0.162
Temp_D2	0.051	-0.162	**1**

Values in bold are different from 0 with a significance level alpha=0.05

p-values (Pearson):

Variables	Prod_D2	Rainfall_D2	Temp_D2
Prod_D2	**0**	0.199	0.812
Rainfall_D2	0.199	**0**	0.449
Temp_D2	0.812	0.449	**0**

Coefficients of determination (Pearson):

Variables	Prod_D2	Rainfall_D2	Temp_D2
Prod_D2	**1**	0.074	0.003
Rainfall_D2	0.074	**1**	0.026
Temp_D2	0.003	0.026	**1**

Type of correlation: Pearson

Summary statistics (Quantitative data):

Variable	Observations	Obs. with missing	Obs. without	Minimum	Maximum	Mean	Std. deviation
Prod_R1	24	0	24	993192.600	2051352.000	1387682.983	270555.256
Rainfall_R	24	0	24	61.467	273.900	157.695	65.390
Temp_R1	24	0	24	18.617	21.600	20.667	0.570

Correlation matrix (Pearson):

Variables	Prod_R1	Rainfall_R1	Temp_R1
Prod_R1	**1**	0.138	-0.343
Rainfall_R	0.138	**1**	-0.318
Temp_R1	-0.343	-0.318	**1**

Values in bold are different from 0 with a significance level alpha=0.05

p-values (Pearson):

Variables	Prod_R1	Rainfall_R1	Temp_R1
Prod_R1	**0**	0.521	0.100
Rainfall_R	0.521	**0**	0.130
Temp_R1	0.100	0.130	**0**

Coefficients of determination (Pearson):

Variables	Prod_R1	Rainfall_R1	Temp_R1
Prod_R1	**1**	0.019	0.118
Rainfall_R	0.019	**1**	0.101
Temp_R1	0.118	0.101	**1**

Type of correlation: Pearson

Summary statistics (Quantitative data):

Variable	Observations	Obs. with missing	Obs. without	Minimum	Maximum	Mean	Std. deviation
Prod_R2	24	0	24	813851.4	2646143.0	1376816.5	382105.2
Rainfall_R	24	0	24	164.3	242.9	199.4	21.7
Temp_R2	24	0	24	17.6	21.0	20.1	0.7

Correlation matrix (Pearson):

Variables	Prod_R2	Rainfall_R2	Temp_R2
Prod_R2	**1**	-0.079	0.054
Rainfall_R	-0.079	**1**	-0.296
Temp_R2	0.054	-0.296	**1**

Values in bold are different from 0 with a significance level alpha=0.05

p-values (Pearson):

Variables	Prod_R2	Rainfall_R2	Temp_R2
Prod_R2	**0**	0.713	0.804
Rainfall_R	0.713	**0**	0.160
Temp_R2	0.804	0.160	**0**

Coefficients of determination (Pearson):

Variables	Prod_R2	Rainfall_R2	Temp_R2
Prod_R2	**1**	0.006	0.003
Rainfall_R	0.006	**1**	0.088
Temp_R2	0.003	0.088	**1**

You are using the XLSTAT trial version. Number of days remaining until the trial expires

Type of correlation: Pearson

Summary statistics (Quantitative data):

Variable	Observations	Obs. with missing	Obs. without	Minimum	Maximum	Mean	Std. deviation
Average Production	24	0	24	936625.9	1708294.0	1280674.3	239882.3
Average Rainfall	24	0	24	117.2	235.9	171.5	23.7
Average Temp	24	0	24	20.0	21.5	20.8	0.3

Correlation matrix (Pearson):

Variables	Average Production	Average Rainfall	Average Temp
Average Production	**1**	-0.232	-0.218
Average Rainfall	-0.232	**1**	**-0.458**
Average Temp	-0.218	**-0.458**	**1**

Values in bold are different from 0 with a significance level alpha=0.05

p-values (Pearson):

Variables	Average Production	Average Rainfall	Average Temp
Average Production	**0**	0.275	0.306
Average Rainfall	0.275	**0**	**0.024**

Average Temp	0.306	**0.024**	**0**

Coefficients of determination (Pearson):

Variables	Average Production	Average Rainfall	Average Temp
Average Production	**1**	0.054	0.048
Average Rainfall	0.054	**1**	0.210
Average Temp	0.048	0.210	**1**

APPENDIX VIII: MONTHLY TEMPERATURE

REPUBLIC OF KENYA
MINISTRY OF ENVIRONMENT & FORESTRY

KENYA METEOROLOGICAL DEPARTMENT

KISII MET STATION P.O.BOX 30-40200, KISII

CELL PHONE: 0737052685

E -mail: kisiimet@meteo.go.ke

MONTHLY MEAN MINIMUM TEMPERATURES (◦C)

YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1995	16.3	15.9	15.9	16.2	15.8	15.8	14.9	14.9	15.4	15.5	15.4	14.6
1996	15.3	15.8	15.9	15.3	15.7	15.1	14.0	14.9	15.1	15.3	15.1	15.6
1997	15.6	16.9	16.8	15.6	15.1	14.9	15.0	15.1	15.8	15.8	15.7	15.7
1998	16.1	17.1	16.2	16.9	16.6	15.4	14.8	14.7	15.3	15.9	15.6	15.4
1999	14.9	16.0	15.5	15.0	14.7	14.3	13.6	14.2	14.4	14.4	14.5	14.7
2000	15.2	15.38	14.6	15.5	15.8	14.9	14.3	14.7	15.0	15.4	15.4	15.7
2001	15.5	15.7	15.5	15.7	15.9	14.7	14.7	15.1	15.4	15.6	15.4	15.7
2002	15.9	16.8	15.7	16.0	16.0	15.4	15.3	14.8	15.3	15.8	15.5	15.8
2003	15.9	16.9	16.5	16.4	15.9	15.1	14.8	15.0	15.5	15.7	15.4	15.6
2004	16.1	16.1	16.7	16.2	15.9	16.9	14.7	15.0	15.4	15.8	15.3	15.8
2005	16.4	17.3	16.1	16.7	16.1	15.5	14.9	15.1	15.3	15.8	15.5	15.8
2006	16.7	17.3	15.9	15.3	16.1	15.0	15.1	15.3	15.5	15.7	15.4	15.6
2007	16.0	16.3	16.1	16.3	16.1	15.5	14.8	15.1	15.4	15.8	15.3	15.8

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2008	16.0	16.1	15.8	15.5	15.7	15.1	14.7	15.2	15.7	15.9	15.7	16.1
2009	16.0	16.2	16.5	15.9	15.8	15.5	14.8	15.3	15.9	16.0	15.8	15.7
2010	16.3	16.3	16.1	16.7	16.5	16.1	15.2	15.5	15.4	16.0	15.7	15.5
2011	16.0	16.4	16.2	15.9	16.1	16.0	15.3	15.2	15.4	15.5	15.4	15.4
2012	16.1	16.2	15.9	15.5	15.8	15.2	15.0	14.9	15.4	15.2	15.4	15.3
2013	15.9	16.0	16.2	15.3	15.1	14.9	14.7	14.4	15.4	14.5	14.9	15.2
2014	15.3	15.7	15.2	14.7	15.2	14.9	15.0	15.0	15.5	15.6	15.4	15.6
2015	16.4	16.5	15.2	15.6	15.7	15.5	15.2	15.0	15.7	16.1	15.3	15.2
2016	16.3	17.2	17.2	15.0	16.7	15.6	15.3	15.8	15.3	15.9	15.6	15.8
2017	16.8	16.3	16.4	16.4	16.9	15.8	15.7	15.3	15.7	16.1	15.3	16.1
2018	16.2	17.3	15.9	15.9	16.0	15.4	14.6	15.1	15.9	15.8	15.7	15.7
2019	16.5	16.7	16.7	17.0	16.7	16.2	15.4	15.4	15.9	15.5	15.8	15.7

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DATE 14/7/20
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MINISTRY OF ENVIRONMENT & FORESTRY

KENYA METEOROLOGICAL DEPARTMENT

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MONTHLY MEAN MAXIMUM TEMPERATURES (◦C)

YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1995	26.9	26.7	25.8	25.1	25.1	24.39	24.2	25.7	26.6	25.9	23.7	25.2
1996	25.9	24.8	26.0	25.5	25.2	23.7	24.0	24.7	25.9	25.4	25.9	25.5
1997	26.1	28.6	29.4	24.7	24.8	25.1	24.5	25.7	25.4	25.9	25.0	26.1
1998	24.7	26.5	27.9	26.5	25.4	24.7	24.2	25.5	28.6	25.5	23.6	24.4
1999	26.8	26.5	25.2	25.4	25.2	25.2	24.6	24.6	26.3	25.0	26.2	27.7
2000	27.4	28.9	25.2	25.4	25.2	25.2	24.6	24.6	26.3	25.0	26.2	27.7
2001	24.1	27.3	27.1	25.3	25.4	24.4	24.4	25.5	26.2	25.0	25.0	24.9
2002	25.9	27.9	27.0	25.1	25.2	25.1	25.9	25.3	27.0	26.2	24.9	24.8
2003	26.6	28.5	28.4	26.1	25.0	24.5	24.5	24.8	26.2	25.9	25.8	25.7
2004	26.4	25.9	27.4	26.1	25.0	24.5	24.5	24.8	26.2	25.9	25.8	25.7
2005	27.3	29.7	27.2	26.7	24.3	24.9	24.7	25.3	25.9	26.6	25.5	27.9
2006	28.1	29.7	25.6	24.8	24.3	25.5	25.9	25.4	25.9	27.2	23.8	24.1
2007	25.6	26.1	27.2	25.1	25.4	24.0	24.1	24.5	25.4	25.9	25.4	25.9
2008	27.3	27.6	25.8	25.1	25.6	24.5	24.4	24.7	25.0	25.1	25.4	25.9

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2008	16.0	16.1	15.8	15.5	15.7	15.1	14.7	15.2	15.7	15.9	15.7	16.1
2009	16.0	16.2	16.5	15.9	15.8	15.5	14.8	15.3	15.9	16.0	15.8	15.7
2010	16.3	16.3	16.1	16.7	16.5	16.1	15.2	15.5	15.4	16.0	15.7	15.5
2011	16.0	16.4	16.2	15.9	16.1	16.0	15.3	15.2	15.4	15.5	15.4	15.4
2012	16.1	16.2	15.9	15.5	15.8	15.2	15.0	14.9	15.4	15.2	15.4	15.3
2013	15.9	16.0	16.2	15.3	15.1	14.9	14.7	14.4	15.4	14.5	14.9	15.2
2014	15.3	15.7	15.2	14.7	15.2	14.9	15.0	15.0	15.5	15.6	15.4	15.6
2015	16.4	16.5	15.2	15.6	15.7	15.5	15.2	15.0	15.7	16.1	15.3	15.2
2016	16.3	17.2	17.2	15.0	16.7	15.6	15.3	15.8	15.3	15.9	15.6	15.8
2017	16.8	16.3	16.4	16.4	16.9	15.8	15.7	15.3	15.7	16.1	15.3	16.1
2018	16.2	17.3	15.9	15.9	16.0	15.4	14.6	15.1	15.9	15.8	15.7	15.7
2019	16.5	16.7	16.7	17.0	16.7	16.2	15.4	15.4	15.9	15.5	15.8	15.7

OFFICER IN CHARGE
P.O. Box [illegible], KISII
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KISII METEOROLOGICAL STATION

REPUBLIC OF KENYA
MINISTRY OF ENVIRONMENT & FORESTRY

KENYA METEOROLOGICAL DEPARTMENT

KISII MET STATION P.O.BOX 30-40200, KISII

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MONTHLY MEAN MAXIMUM TEMPERATURES (◦C)

YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1995	26.9	26.7	25.8	25.1	25.1	24.39	24.2	25.7	26.6	25.9	23.7	25.2
1996	25.9	24.8	26.0	25.5	25.2	23.7	24.0	24.7	25.9	25.4	25.9	25.5
1997	26.1	28.6	29.4	24.7	24.8	25.1	24.5	25.7	25.4	25.9	25.0	26.1
1998	24.7	26.5	27.9	26.5	25.4	24.7	24.2	25.5	28.6	25.5	23.6	24.4
1999	26.8	26.5	25.2	25.4	25.2	25.2	24.6	24.6	26.3	25.0	26.2	27.7
2000	27.4	28.9	25.2	25.4	25.2	25.2	24.6	24.6	26.3	25.0	26.2	27.7
2001	24.1	27.3	27.1	25.3	25.4	24.4	24.4	25.5	26.2	25.0	25.0	24.9
2002	25.9	27.9	27.0	25.1	25.2	25.1	25.9	25.3	27.0	26.2	24.9	24.8
2003	26.6	28.5	28.4	26.1	25.0	24.5	24.5	24.8	26.2	25.9	25.8	25.7
2004	26.4	25.9	27.4	26.1	25.0	24.5	24.5	24.8	26.2	25.9	25.8	25.7
2005	27.3	29.7	27.2	26.7	24.3	24.9	24.7	25.3	25.9	26.6	25.5	27.9
2006	28.1	29.7	25.6	24.8	24.3	25.5	25.9	25.4	25.9	27.2	23.8	24.1
2007	25.6	26.1	27.2	25.1	25.4	24.0	24.1	24.5	25.4	25.9	25.4	25.9
2008	27.3	27.6	25.8	25.1	25.6	24.5	24.4	24.7	25.0	25.1	25.4	25.9

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2009	26.6	27.1	28.2	25.3	24.9	25.5	25.8	25.4	26.1	26.1	25.6	25.1
2010	26.8	27.0	25.9	26.4	25.4	25.4	25.1	25.8	25.4	25.5	25.2	25.1
2011	26.9	28.3	27.0	25.4	25.7	24.2	25.3	24.4	25.1	24.1	25.2	25.1
2012	27.3	27.8	28.3	25.2	24.8	24.4	24.4	24.8	25.8	25.5	25.5	25.0
2013	26.1	25.8	27.2	25.1	25.3	25.4	25.5	24.9	25.9	26.3	25.3	25.3
2014	27.0	27.1	27.2	26.4	25.7	25.0	24.9	25.1	26.6	25.3	25.0	25.5
2015	27.5	28.9	29.1	24.5	24.6	24.4	25.8	26.3	26.7	26.0	24.3	24.6
2016	25.8	27.8	29.0	26.1	25.1	25.4	25.3	25.8	27.2	27.2	25.2	27.2
2017	29.0	28.1	27.9	26.9	24.9	26.0	25.7	25.2	25.9	25.9	24.9	26.5
2018	26.1	28.6	24.8	23.6	24.6	24.1	24.5	25.1	26.1	26.2	25.1	25.2
2019	27.2	28.2	28.6	27.8	26.1	24.4	25.0	25.3	26.0	24.8	24.8	24.1

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APPENDIX IX: MONTHLY RAINFALL DATA IN MILLIMETERS

REPUBLIC OF KENYA
MINISTRY OF ENVIRONMENT & FORESTRY

KENYA METEOROLOGICAL DEPARTMENT

KISII MET STATION P.O.BOX 30-40200, KISII

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MONTHLY RAINFALL DATA IN MILLIMETRES (mm) FOR THE YEAR 1995 TO 2019

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1995	63.7	101.0	266.2	187.3	213.0	178.6	154.9	66.7	186.9	106.5	266.7	93.2
1996	130.7	218.4	154.1	220.5	274.8	179.0	104.6	201.0	260.3	184.1	215.9	128.1
1997	110.5	5.9	111.0	307.2	232.7	98.5	101.8	262.6	31.1	154.1	235.9	365.8
1998	220.0	80.8	364.6	225.4	237.2	210.3	95.6	163.5	172.7	199.6	107.2	81.0
1999	93.5	58.1	292.6	280.3	244.5	155.9	118.2	186.9	173.4	321.4	123.0	112.0
2000	31.5	80.8	117.5	254.1	352.3	178.7	137.7	136.5	234.3	143.2	272.2	170.2
2001	221.8	52.0	134.9	243.1	388.6	175.7	55.3	70.5	299.4	262.7	208.9	62.2
2002	213.4	89.9	255.5	292.1	326.1	133.3	108.4	154.0	59.7	252.3	265.3	145.8
2003	115.5	77.4	179.6	232.0	319.7	267.7	107.3	257.2	165.0	199.6	154.6	112.6
2004	92.0	109.5	81.2	309.2	228.5	157.7	61.4	199.7	52.2	227.1	273.1	120.2
2005	74.6	54.2	178.8	205.1	287.9	145.7	95.5	203.5	170.4	65.9	119.0	51.6
2006	90.1	185.6	232.4	317.1	287.5	141.2	86.1	106.1	140.4	97.5	255.4	229.6
2007	281.0	179.5	151.0	172.3	247.0	192.2	139.3	70.7	158.4	125.4	97.5	96.6
2008	31.8	59.5	304.1	291.1	118.5	136.0	220.6	191.7	168.9	241.0	154.3	82.1
2009	120.8	54.7	252.2	242.0	311.1	183.1	70.0	213.0	145.3	94.1	133.4	310.0
2010	108.6	106.5	217.7	244.6	375.7	252.3	80.3	178.1	256.7	256.9	109.3	170.3
2011	101.0	44.7	148.9	228.4	235.1	94.4	99.1	266.4	226.0	209.2	312.6	220.2

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2012	6.4	70.4	103.8	389.6	238.0	254.8	89.0	204.6	237.5	207.1	320.6	320.1
2013	68.4	60.8	291.2	399.6	224.9	105.2	104.3	143.6	252.8	151.9	218.1	125.9
2014	63.4	63.1	179.6	139.2	183.6	170.6	171.7	396.9	240.6	205.6	163.4	112.8
2015	15.9	45.0	86.7	252.3	246.3	19.6.6	86.1	158.0	178.0	257.3	345.9	235.5
2016	185.0	49.7	100.1	354.8	333.6	104.6	33.3	128.3	175.5	74.0	116.9	32.0
2017	35.5	94.8	126.9	292.8	192.9	128.9	61.1	215.7	216.4	238.9	133.5	53.7
2018	62.8	38.9	363.6	257.3	347.1	121.3	54.4	414.6	290.6	390.0	206.8	315.5
2019	24.3	26.1	173.4	204.0	198.3	193.9	105.5	163.3	180.1	242.5	278.0	238.7

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APPENDIX X: DATA FOR TEA PRODUCTION

OGEMBO TEA FACTORY CO.LTD.,

GREEN LEAF AND MADE TEA (1994 TO 2013)

MONTHS	1995-1996			1996-1997		
	GL	MT	OT	GL	MT	OT
JULY				1,211,558.00	275,303.00	22.72
AUGUST				980,875.00	232,822.00	23.74
SEPTEMBER				905,930.00	208,894.00	23.06
OCTOBER	1,301,827.00	299,354.00	23.00	1,413,974.00	328,371.00	23.22
NOVEMBER	1,489,940.00	335,636.00	22.53	1,110,087.00	249,403.00	22.47
DECEMBER	1,175,955.00	265,258.00	22.56	1,437,155.00	326,051.00	22.69
JANUARY	1,622,953.00	36,395.00	22.43	1,508,948.00	341,928.00	22.66
FEBRUARY	1,705,241.00	372,756.00	21.86	1,137,047.00	274,433.00	24.14
MARCH	1,683,705.00	378,632.00	22.49	553,069.00	143,320.00	25.92
APRIL	1,598,635.00	355,834.00	22.25	882,969.00	188,477.00	21.34
MAY	1,498,993.00	343,842.00	22.94	1,575,739.00	363,309.00	21.34
JUNE	1,296,679.00	284,478.00	21.94	922,740.00	210,483.00	22.36
TOTAL	**13,373,928.00**	**2,672,185.00**	**22.44**	**13,640,091.00**	**3,142,794.00**	**22.97**
	1997-1998			**1998-1999**		
	GL	MT	OT	GL	MT	OT
JULY	1,112,726.00	256,235.00	23.03	1,275,973.00	289,696.00	22.70
AUGUST	1,080,666.00	254,458.00	23.36	1,156,029.00	276,734.00	23.94
SEPTEMBER	1,151,176.00	284,013.00	24.67	1,361,787.00	331,016.00	24.31
OCTOBER	953,314.00	230,303.00	24.16	1,529,957.00	361,094.00	23.60
NOVEMBER	963,415.00	202,439.00	21.01	1,842,350.00	455,622.00	24.73
DECEMBER	1,671,713.00	357,791.00	21.40	1,634,406.00	419,591.00	25.67
JANUARY	895,856.00	258,371.00	22.07	1,315,576.00	333,317.00	25.34
FEBRUARY	1,811,472.00	395,496.00	21.83	913,633.00	259,227.00	28.37
MARCH	1,778,410.00	407,614.00	22.88	1,146,142.00	280,428.00	24.47
APRIL	2,042,557.00	439,418.00	21.51	2,379,571.00	559,793.00	23.32
MAY	1,882,088.00	407,056.00	21.63	1,105,325.00	255,288.00	23.10
JUNE	2,028,533.00	451,329.00	22.25	1,645,873.00	402,899.00	24.48
TOTAL	**17,371,926.00**	**3,944,523.00**	**22.48**	**17,306,622.00**	**4,224,705.00**	**24.50**
	1999-2000			**2000-2001**		
	GL	MT	OT	GL	MT	OT
JULY	1,096,593.00	270,209.00	24.64	1,490,974.00	358,825.00	24.07
AUGUST	1,147,493.00	278,188.00	24.24	1,453,300.00	356,903.00	24.56
SEPTEMBER	1,235,426.00	309,781.00	25.07	1,393,834.00	361,545.00	25.94
OCTOBER	1,517,800.00	361,938.00	23.85	1,669,739.00	427,225.00	25.59
NOVEMBER	1,825,011.00	431,825.00	23.66	2,025,755.00	467,228.00	23.06
DECEMBER	1,643,952.00	391,469.00	23.81	1,648,571.00	367,157.00	22.27
JANUARY	1,790,930.00	446,537.00	24.93	2,479,729.00	565,192.00	22.79
FEBRUARY	1,006,362.00	272,093.00	27.04	1,776,741.00	432,211.00	24.33
MARCH	1,052,458.00	266,371.00	25.31	1,625,526.00	412,751.00	25.39
APRIL	1,885,290.00	458,092.00	24.30	1,254,868.00	269,091.00	23.65
MAY	1,712,411.00	408,919.00	23.88	1,595,456.00	381,494.50	23.91
JUNE	1,627,888.00	391,029.00	24.03	1,186,225.00	276,051.00	23.35
TOTAL	**17,541,614.00**	**4,286,451.00**	**24.56**	**19,600,718.00**	**4,675,673.50**	**24.08**

OGEMBO TEA FACTORY CO.LTD.,
GREEN LEAF AND MADE TEA (1994 TO 2013)

MONTHS	2001-2002			2002-2003		
	GL	MT	OT	GL	MT	OT
JULY	1,436,876.00	346,558.00	24.12	1,450,632.00	357,411.50	24.64
AUGUST	1,196,572.00	291,680.00	24.38	1,422,762.00	364,447.50	25.62
SEPTEMBER	1,148,544.00	280,278.00	24.40	1,515,503.00	383,952.00	25.33
OCTOBER	1,395,536.00	335,272.00	24.03	1,349,335.00	349,725.00	25.92
NOVEMBER	1,486,315.00	338,745.00	22.80	1,677,614.00	385,777.50	23.00
DECEMBER	1,487,397.00	362,284.00	24.35	2,122,179.00	472,409.00	22.26
JANUARY	1,845,103.00	434,716.00	23.56	1,870,694.00	446,812.50	23.88
FEBRUARY	1,510,665.00	384,390.00	25.44	1,806,361.00	467,085.00	25.86
MARCH	1,640,456.00	399,747.00	24.37	1,490,066.00	376,013.50	25.23
APRIL	1,844,033.00	438,736.00	23.80	2,056,410.00	480,291.00	23.36
MAY	1,792,816.00	423,859.50	23.64	1,795,769.00	416,191.50	23.18
JUNE	1,545,446.00	373,315.50	24.16	1,818,315.00	424,505.50	23.35
TOTAL	**14,547,767.00**	**3,491,065.00**	**24.02**	**20,375,640.00**	**4,924,621.50**	**24.30**
	2003-2004			2004-2005		
	GL	MT	OT	GL	MT	OT
JULY	1,691,681.00	418,948.50	24.77	1,155,554.00	294,906.00	25.52
AUGUST	1,559,895.00	370,500.00	23.75	1,580,895.00	385,581.00	24.39
SEPTEMBER	1,927,602.00	475,436.00	24.66	1,818,409.00	471,388.00	25.92
OCTOBER	2,197,759.00	543,670.50	24.74	1,599,066.00	408,476.15	25.54
NOVEMBER	1,775,880.00	424,913.50	23.93	2,008,870.00	490,590.00	24.42
DECEMBER	2,029,999.00	474,319.00	23.37	2,103,946.00	476,108.00	22.63
JANUARY	1,849,390.00	437,570.00	23.67	2,216,317.00	541,144.00	24.42
FEBRUARY	1,662,080.00	404,849.00	24.36	1,861,106.00	481,421.75	25.87
MARCH	2,200,712.00	543,464.50	24.69	2,024,486.00	485,447.25	23.98
APRIL	1,853,562.00	445,013.50	24.01	1,538,241.00	365,874.00	23.79
MAY	2,109,050.00	485,080.50	23.00	1,713,556.00	394,721.25	23.04
JUNE	2,004,515.00	493,697.00	24.63	1,698,689.00	396,522.75	23.34
TOTAL	**22,862,125.00**	**5,517,462.00**	**24.13**	**21,319,135.00**	**5,192,180.15**	**24.41**
	2005-2006			2006-2007		
	GL	MT	OT	GL	MT	OT
JULY	1,241,124.00	305,321.00	24.60	1,495,856.00	355,561.25	23.77
AUGUST	1,418,966.00	341,735.75	24.08	1,442,936.00	359,105.25	24.89
SEPTEMBER	1,611,031.00	398,408.00	24.73	1,285,698.00	332,116.00	25.83
OCTOBER	1,732,248.00	443,619.50	25.61	1,553,576.00	389,124.00	25.05
NOVEMBER	1,914,057.00	461,387.25	24.11	1,511,726.00	363,215.75	24.03
DECEMBER	1,769,077.00	429,249.25	24.26	1,948,865.00	447,510.75	22.96
JANUARY	1,025,710.00	272,946.00	26.61	1,820,708.00	404,437.25	22.29
FEBRUARY	599,463.00	162,150.75	27.38	1,770,505.00	374,763.50	21.17
MARCH	1,705,810.00	408,768.50	23.96	1,523,471.00	348,954.75	22.91
APRIL	1,312,644.00	302,481.50	23.04	1,717,111.00	388,501.75	22.63
MAY	1,823,036.00	410,268.75	22.50	1,405,835.00	313,163.50	22.28
JUNE	1,764,373.00	424,676.00	24.07	1,436,429.00	321,609.25	22.39
TOTAL	**17,917,539.00**	**4,361,012.25**	**24.58**	**18,912,716.00**	**4,398,063.00**	**23.35**

OGEMBO TEA FACTORY CO.LTD.,

GREEN LEAF AND MADE TEA (1994 TO 2013)

MONTHS	2007-2008			2008-2009		
	GL	MT	OT	GL	MT	OT
JULY	1,534,763.00	369,646.75	24.08	916,736.00	220,477.00	24.05
AUGUST	1,580,492.00	364,572.00	23.07	821,584.00	200,910.00	24.45
SEPTEMBER	1,509,854.00	362,769.00	24.03	1,084,397.00	260,883.00	24.06
OCTOBER	1,408,384.00	355,319.50	25.23	1,226,001.00	296,392.00	24.18
NOVEMBER	1,105,766.00	276,676.50	25.02	1,110,634.00	261,430.00	23.54
DECEMBER	1,579,009.00	397,388.00	25.17	1,248,810.00	304,166.00	24.36
JANUARY	1,373,779.00	330,425.00	24.05	904,589.00	228,885.00	25.30
FEBRUARY	1,120,447.00	280,768.50	24.06	899,772.00	225,334.50	25.04
MARCH	885,470.00	221,804.00	25.05	1,114,470.00	271,662.00	24.38
APRIL	1,045,220.00	250,025.50	23.92	1,040,155.00	244,995.00	23.55
MAY	1,124,347.00	258,713.50	23.01	958,858.00	224,756.50	23.42
JUNE	970,262.00	223,973.00	23.29	973,232.00	231,923.00	23.83
TOTAL	**10,612,684.00**	**2,595,093.50**	**24.31**	**12,299,238.00**	**2,971,814.00**	**24.18**
	2009-2010			2010-2011		
	GL	MT	OT	GL	MT	OT
JULY	833,601.00	211,847.00	25.41	1,034,063.00	258,727.80	24.92
AUGUST	758,843.00	189,726.00	25	886,653.00	221,658.30	25.00
SEPTEMBER	1,002,312.00	246,394.00	24.58	706,829.10	167,065.50	25.23
OCTOBER	1,028,657.00	254,399.00	24.73	1,083,145.90	247,253.80	22.77
NOVEMBER	1,090,244.00	256,329.00	23.51	1,250,802.80	293,689.00	22.90
DECEMBER	1,272,045.00	295,434.00	23.23	1,190,841.00	268,550.00	22.55
JANUARY	1,188,027.00	285,088.00	24	1,223,726.70	283,770.00	23.19
FEBRUARY	1,207,424.00	287,961.00	23.85	982,532.20	235,770.00	24.00
MARCH	1,482,779.00	350,925.00	23.67	950,807.00	221,004.00	23.24
APRIL	1,348,686.00	321,426.50	23.74	1,502,775.50	349,069.00	23.23
MAY	1,352,065.00	314,824.00	23.01	1,293,195.60	296753.25	22.95
JUNE	1,193,290.00	314,347.00	23.68	1,344,430.90	298341	22.19
TOTAL	**13,757,973.00**	**3,328,700.50**	**24.03**	**13,449,802.70**	**3,141,651.65**	**23.51**
	2011-2012			2012-2013		
	GL	MT	OT	GL	MT	OT
JULY	920,084.60	210,498.00	22.88	1,211,182.70	267,801.50	22.01
AUGUST	938,213.60	214,142.00	22.79	1,221,033.40	271,983.00	22.27
SEPTEMBER	1,058,230.00	244,445.00	22.76	1,114,688.60	246,721.70	22.08
OCTOBER	1,421,105.90	317,442.00	22.3	1,587,463.90	350,456.25	22.04
NOVEMBER	1,352,094.90	276,842.00	21.42	1,480,481.70	322,122.00	21.27
DECEMBER	1,506,468.00	307,410.00	21.68	1,564,427.30	337,091.00	21.35
JANUARY	1,403,202.40	332,940.00	22.6	1,621,266.10	355,501.00	21.89
FEBRUARY	682,911.50	177,584.00	26	1,444,187.10	332,536.00	23.08
MARCH	1,159,431.30	282,840.00	24.39	1,227,517.00	279,687.00	22.78
APRIL	1,244,523.70	284,541.00	22.86	1,703,216.00	364,549.75	21.40
MAY	1,241,861.90	272,480.00	21.94	1,714,990.00	377,418.75	22.01
JUNE	1,298,442.00	286,342.00	22.05	1,182,146.70		
TOTAL	**14,226,569.80**	**3,207,506.00**	**22.81**	**17,072,600.50**	**3,505,867.95**	**22.02**

FIELD SERVICES CO-ORDINATOR
OGEMBO TEA FACTORY CO. LTD.
P. O. Box 1495 KISII
SIGN:........................
DATE:........................

OGEMBO TEA FACTORY CO.LTD.,

GREEN LEAF AND MADE TEA (1994 TO 2013)

	2013-2014			2014-2015		
	GL	MT	OT	GL	MT	OT
JULY	982,899.30	210,498.00	22.88	1,211,182.70	267,801.50	22.01
AUGUST	899,327.90	214,142.00	22.79	1,221,033.40	271,983.00	22.27
SEPTEMBER	1,165,967.60	244,445.00	22.76	1,114,688.60	246,721.70	22.08
OCTOBER	1,477,977.10	317,442.00	22.3	1,587,463.90	350,456.25	22.04
NOVEMBER	1,180,949.10	276,842.00	21.42	1,480,481.70	322,122.00	21.27
DECEMBER	1,578,944.50	307,410.00	21.68	1,564,427.30	337,091.00	21.35
JANUARY	1,484,609.40	332,940.00	22.6	1,621,266.10	355,501.00	21.89
FEBRUARY	1,224,304.70	177,584.00	26	1,444,187.10	332,536.00	23.08
MARCH	1,151,057.70	282,840.00	24.39	1,227,517.00	279,687.00	22.78
APRIL	1,571,278.40	284,541.00	22.86	1,703,216.00	364,549.75	21.40
MAY	1,543,590.90	272,480.00	21.94	1,714,990.00	377,418.75	22.01
JUNE	1,271,323.90	286,342.00	22.05	1,182,146.70		
TOTAL	**15,532,230.50**	**3,207,506.00**	**22.81**	**17,072,600.50**	**3,505,867.95**	**22.02**
	2015-2016			2016-2017		
	GL	MT	OT	GL	MT	OT
JULY	1,095,837.90			776,473.80		
AUGUST	852,141.10			893,711.60		
SEPTEMBER	1,195,503.30			1,096,398.70		
OCTOBER	1,127,425.70	257,443.10		1,178,511.40		
NOVEMBER	1,377,340.00	298,899.25		1,353,862.70		
DECEMBER	1,660,205.20	357,424.25		1,183,258.50		
JANUARY	1,590,287.70	345,888.75		975,520.10		
FEBRUARY	1,411,567.00	216,233.00		752,513.30		
MARCH	1,367,242.30	311,036.00		1,460,457.40		
APRIL	1,365,719.40	308,348.00		1,256,204.80		
MAY	1,410,460.20	310,630.25		1,406,452.50		
JUNE	1,166,632.70	255,916.50		1,265,818.40		
TOTAL	**15,620,362.50**	**2,661,819.10**	**#DIV/0!**	**13,599,183.20**	**-**	**#DIV/0!**
	2017-2018			2018-2019		
	GL	MT	OT	GL	MT	OT
JULY	870,411.00			970,915.55		
AUGUST	795,328.10			932,324.65		
SEPTEMBER	1,134,858.00			900,137.20		
OCTOBER	1,182,359.10			1,086,308.90		
NOVEMBER	1,235,603.30			1,285,107.90		
DECEMBER	1,317,456.80			1,234,817.45		
JANUARY	1,178,075.45			1,207,889.55		
FEBRUARY	742,280.08			812,160.55		
MARCH	1,030,262.91			796,087.85		
APRIL	1,563,718.60			1,054,114.65		
MAY	1,360,743.69			1,187,621.35		
JUNE	1,335,342.25			993,541.80		
TOTAL	**13,746,439.28**	**-**	**#DIV/0!**	**12,461,027.40**	**-**	**#DIV/0!**

OGEMBO TEA FACTORY CO.LTD.,

GREEN LEAF AND MADE TEA (1994 TO 2013)

	2017-2018			**2018-2019**		
	GL	**MT**	**OT**	**GL**	**MT**	**OT**
JULY	870,411.00			970,915.55		
AUGUST	795,328.10			932,324.65		
SEPTEMBER	1,134,858.00			900,137.20		
OCTOBER	1,182,359.10			1,086,308.90		
NOVEMBER	1,235,603.30			1,285,107.90		
DECEMBER	1,317,456.80			1,234,817.45		
JANUARY	1,178,075.45			1,207,889.55		
FEBRUARY	742,280.08			812,160.55		
MARCH	1,030,262.91			796,087.85		
APRIL	1,563,718.60			1,054,114.65		
MAY	1,360,743.69			1,187,621.35		
JUNE	1,335,342.25			993,541.80		
	13,746,439.28			**12,461,027.40**		
	2019-2020			**2020-2021**		
	GL	**MT**	**OT**	**GL**	**MT**	**OT**
JULY	943,662.55					
AUGUST	883,628.75					
SEPTEMBER	844,337.25					
OCTOBER	1,173,095.71					
NOVEMBER	1,069,287.35					
DECEMBER	1,313,103.10					
JANUARY	1,499,147.35					
FEBRUARY	1,238,179.60					
MARCH	1,603,760.70					
APRIL	1,470,182.75					
MAY	1,436,089.00					
JUNE						
	13,474,474.11					

FIELD SERVICES CO-ORDINATOR
OGEMBO TEA FACTORY CO. LTD.
P. O. Box 1495 KISII
SIGN:
DATE:

2019/2020

Year	RW	FW	no of farmers	bushes	acres
Jul-19	729332.3	736,199.95			
Aug-19	894367.7	90688.51			
Sep-19	782250.9	798549.34			
Oct-19	1315434.7	1333005.1			
Nov-19	1036425.7	1042129.05			
Dec-19	1157435.7	1175032			
Jan-20	1350521.15	1360344.96			
Feb-20	1033819.3	1026806.53			
Mar-20	1320330.5	1316924.78			
Apr-20	1388134	1385975.02			
May-20	1261544.9	1267910.08			
Total	**12,269,596.85**	**11,533,565.32**	**12947**	**13,969,565.00**	3487

2018/2019

july 202018	767211.7	926821.18			
Aug-18	872669.2	906796.4			
Sep-18	994835.6	1001625.9			
Oct-18	1040527.3	1044195.35			
Nov-18	902044	902424			
Dec-18	1148952	1154302			
Jan-19	1224094	1187978.93			
Feb-19	599926.7	608243.81			
Mar-19	684495.2	690390.05			
Apr-18	972389.1	976731.26			
May-19	1064841.5	1078404.8			
Jun-19	869004.1	870930.82			
Total	**11,140,990.40**	**11,348,844.50**	**12448**	**13,425,869.00**	3418

2017/2018

july 2017	578644.1	579001.85		

Aug-17	710636.9	710752.65			
Sep-17	957259.4	957550.9			
Oct-17	1411575	1412381.3			
Nov-17	1217844.8	1217463.8			
Dec-17	1147513.6	1147846.2			
Jan-18	1245673	1245842			
Feb-18	647299.3	648032.4			
Mar-18	796102.7	796461.4			
Apr-18	1514235.4	1514816.5			
May-18	1159986.1	1160523.95			
Jun-18	1094687.8	1094891.55			
Total	**12,481,458.10**	**12,485,564.50**	**11919**	**13,311,037.00**	3389

KIAMOKAMA TEA FACTORY CO.LTD

P.O BOX 374-KEROKA

2016/2017

Jul-16	788972	790151.8			
16-Aug	694263.3	695722.5			
16-Sep	288745.6	288865.7			
16-Oct	708022.2	708202.9			
16-Nov	1011109.5	1015756			
16-Dec	947367.8	943559.2			
17-Jan	671945.4	672742.8			
17-Feb	414005	414389			
17-Mar	1242806	1243981.8			
17-Apr	988977	993514.7			
17-May	951588.7	952402.2			
17-Jun	962190.8	964633.5			
Total	**9,669,993.30**	**9,683,922.10**	**1713**	**13,049,565.00**	3322

2015/2016

15-Jul	1021573.8	1033050.8			
15-Aug	808030.6	818765.7			
15-Sep	1039719.7	1050812.5			
15-Oct	1059576	1061735.1			
15-Nov	1011323.6	1009965.7			
15-Dec	1468006	1470223.2			
16-Jan	1440428.6	1444262.3			
16-Feb	1292254	1294424.9			
16-Mar	1198693.2	1201384.1			
16-Apr	1355830.7	1362702.5			
16-May	1281418.1	1284110.9			
16-Jun	976945.3	988538.4			
	13,953,799.6	**14,019,976.10**	**11554**	**12,855,410.0**	3273

2014/2015

14-Jul	902522.1	909720.6			
14-Aug	630930.3	638947.3			
14-Sep	962868.7	970507.6			
14-Oct	1369878.4	1382257			
14-Nov	1017645.4	1019665.3			
14-Dec	1345281.7	1349742.5			
15-Jan	1276208.5	1276645.7			
15-Feb	478680.8	485081			
15-Mar	252864.6	252114.6			
15-Apr	576087.6	585373.3			
15-May	1579996.5	1580043.5			
15-Jun	584694	588354.8			
Total	**10,977,658.6**	**11,038,453.20**	**11205**	**12,514,693.0**	3186

2013/2014

13-Jul	913701.1	913805.2			
13-Aug	811590.8	811700.9			
13-Sep	946990.6	947180			
13-Oct	1737488.1	1739851.6			
13-Nov	947807	947954			
13-Dec	1361069.5	1359524.8			
14-Jan	1562941.6	1563298.2			
14-Feb	1078101.7	1078251.1			
14-Mar	930020.9	933825.8			
14-Apr	1476250	1478475.5			
14-May	1162681	1174754.3			
14-Jun	707325.6	719847.4			
Total	**13,635,967.90**	**13,668,468.80**	**10659**	**12,054,183.00**	3069

2012/2013

12-Jul	953924.2	953500.5			
12-Aug	1259610.3	1295811.1			
12-Sep	1085194.3	1088641.3			
12-Oct	1323573.7	1334341.7			
12-Nov	1222379.1	1220652.95			
12-Dec	1246702.9	1267451			
13-Jan	1433153.7	1465608.9			
13-Feb	1172553.7	1183362			
13-Mar	890487.3	889463.2			
13-Apr	1402386.9	1430158			
13-May	1580915	1594680.4			
13-Jun	956921.3	957185.7			
Total	**14,527,802.40**	**14,680,856.75**	**10398**	**1,177,103.00**	2977

20111/2012

11-Jul	1163493.6	1172597		
11-Aug	1106029	1112773.4		
11-Sep	1155159.1	1162858.8		
11-Oct	1136721	1142949.8		
11-Nov	979334.7	980945.5		
11-Dec	1258237.4	1261097.3		
12-Jan	1199047.6	1200074.9		
12-Feb	401265.2	401280.9		
12-Mar	749799.6	761654.2		
12-Apr	928890.1	916796.1		
12-May	1073681.7	10707341		
12-Jun	1179143.2	1194307.6		
Total	**12,330,802.20**	**22,014,676.50**	**23694**	

2010/2011

10-Jul	1274445.5	1170027		
10-Aug	1117599.2	1092474		
10-Sep	1221843.2	1238979.8		
10-Oct	1601760	1613637		
10-Nov	1682252.3	1690008.6		
10-Dec	1556639.8	1564712.48		
11-Jan	1839022	1898838		
11-Feb	1516024	1517498		
11-Mar	1250230.1	1261291.8		
11-Apr	15833798	1589628		
11-May	1488036	1488777		
11-Jun	1244392.5	12444295		
Total	**31,626,042.60**	**28,570,166.68**	**23589**	

2009/2010

9-Jul	1039604.5	1100157		
9-Aug	989633	993800		
9-Sep	1194548.5	1198906		
9-Oct	1568332	1575224		
9-Nov	1359944	1362048		
9-Dec	1500468	1502370		
10-Jan	1705910	1611927		
10-Feb	1536579	1541463		
10-Mar	2030748	1912800		
10-Apr	1766895.5	1561690		
10-May	1668624	1506022		
10-Jun	1520587	1412463		
Total	**17,881,873.50**	**17,278,870.00**	**23499**	

2008/2009

8-Jul	1576809	1588861		
8-Aug	1309970	1327823		
8-Sep	1472230.5	1475903		
8-Oct	1656478	1651568		
8-Nov	1518483.5	1516096		
8-Dec	1679345.5	1701559		
9-Jan	906379	921602		
9-Feb	1010990	1015881		
9-Mar	1389702.5	1395267		
9-Apr	1191834.5	1193758		
9-May	1226648	1218538		
9-Jun	1058689.5	1064370		
Total	**15,997,560.00**	**16,071,226.00**	**22897**	

2007/2008

7-Jul		1521995		
7-Aug		1449349		
7-Sep		1379872		
7-Oct		1554330		
7-Nov		1311754		
7-Dec		1481931		
8-Jan		1326051		
8-Feb		1065964		
8-Mar		931391		
8-Apr		1770502		
8-May		1782333		
8-Jun		1354717		
	Total	**16,930,189.00**	**224614**	

2006/2007

6-Jul		1083491		
6-Aug		1135510		
6-Sep		978576		
6-Oct		1210204		
6-Nov		1328589		
6-Dec		1818495		
7-Jan		2101353		
7-Feb		1806201		
7-Mar		1418159		
7-Apr		1764792		
7-May		1798493		
7-Jun		1330115		
	Total	**17,773,978.00**	**22401**	

2005/2006

5-Jul		1104290		
5-Aug		1220909		
5-Sep		1376114		
5-Oct		1105185		
5-Nov		1269924		
5-Dec		1161479		
6-Jan		1152137.3		
6-Feb		414783		
6-Mar		1192608		
6-Apr		1444238		
6-May		1166540		
6-Jun		1162736		
	Total	**13,770,943.30**	22229	

key: RW raw weight FW: Factory weight **use factory weigh**

NYAMACHE TEA FACTORY COMPANY LIMITED
MONTHLY PRODUCTION SINCE 2005 TO 2018

YEAR		YEAR		YEAR		YEAR	
2017/2018		2016/2017		2015/2016		2014/2015	
JULY	706,317.30	JULY	811,923.70	JULY	982,040.40	JULY	1,032,280.80
AUG	743,652.50	AUG	731,711.20	AUG	709,845.20	AUG	741,914.10
SEPT	958,192.60	SEPT	912,388.80	SEPT	1,007,711.50	SEPT	997,441.40
OCT	1,338,364.70	OCT	1,175,811.10	OCT	1,016,685.30	OCT	1,328,558.40
NOV	1,281,570.70	NOV	904,314.30	NOV	1,116,306.10	NOV	1,043,009.40
DEC	1,255,610.00	DEC	931,153.40	DEC	1,279,884.30	DEC	1,268,527.60
JAN	1,321,570.10	JAN	698,334.30	JAN	1,391,006.20	JAN	1,305,022.60
FEB	943,786.60	FEB	400,743.30	FEB	1,193,855.80	FEB	601,603.40
MARC	1,044,138.80	MARC	1,171,847.10	MARC	1,231,287.50	MARC	372,908.00
APRIL	1,401,463.20	APRIL	1,304,964.60	APRIL	1,348,143.70	APRIL	753,391.60
MAY	1,461,180.90	MAY	1,047,269.00	MAY	1,296,142.30	MAY	1,684,957.90
JUNE	1,285,181.20	JUNE	1,063,102.10	JUNE	1,082,727.70	JUNE	667,473.80
	13,741,028.60		**11,153,562.90**		**13,655,636.00**		**11,797,089.00**
YEAR		YEAR		YEAR		YEAR	
2013/2014		2012/2013		2011/2012		2010/2011	
JULY	787,004.30	JULY	798,191.60	JULY	891,244.50	JULY	784,256.00
AUG	659,075.40	AUG	997,171.60	AUG	706,263.00	AUG	632,209.00
SEPT	925,019.80	SEPT	836,528.50	SEPT	814,211.60	SEPT	582,381.80
OCT	1,422,187.30	OCT	1,143,842.90	OCT	1,087,343.30	OCT	825,713.40
NOV	897,934.70	NOV	1,061,912.50	NOV	993,986.70	NOV	1,004,362.80
DEC	1,327,097.60	DEC	1,136,537.10	DEC	1,152,460.30	DEC	786,314.80
JAN	1,395,363.30	JAN	1,292,404.60	JAN	1,136,157.60	JAN	1,016,256.90
FEB	1,037,947.30	FEB	1,202,012.20	FEB	468,189.20	FEB	844,102.70
MARC	940,746.80	MARC	893,203.10	MARC	884,244.00	MARC	776,071.20
APRIL	1,319,227.40	APRIL	1,193,413.40	APRIL	968,258.00	APRIL	995,234.50
MAY	1,250,810.40	MAY	1,360,979.80	MAY	951,708.60	MAY	959,985.70
JUNE	819,403.40	JUNE	778,848.80	JUNE	1,016,583.20	JUNE	869,775.40

	12,781,817.70		12,695,046.10		11,070,650.00		10,076,664.20
YEAR		**YEAR**		**YEAR**		**YEAR**	
2009/2010		**2008/2009**		**2007/2008**		**2006/2007**	
JULY	820,297.50	**JULY**	1,811,886.50	**JULY**	1,905,059.00	**JULY**	1,589,171.00
AUG	895,524.00	**AUG**	1,632,298.00	**AUG**	1,992,261.00	**AUG**	1,613,058.00
SEPT	936,811.00	**SEPT**	1,948,947.50	**SEPT**	1,897,993.00	**SEPT**	1,406,248.00
OCT	1,064,863.00	**OCT**	2,297,173.00	**OCT**	2,230,620.00	**OCT**	2,074,812.00
NOV	938,569.00	**NOV**	1,029,149.50	**NOV**	1,959,474.00	**NOV**	1,725,761.00
DEC	1,138,722.00	**DEC**	1,264,520.00	**DEC**	2,064,115.00	**DEC**	2,154,843.00
JAN	1,131,557.30	**JAN**	709,833.00	**JAN**	2,202,311.00	**JAN**	2,568,148.00
FEB	971,288.90	**FEB**	766,234.00	**FEB**	1,536,577.00	**FEB**	2,266,592.00
MARC	1,213,113.80	**MARC**	1,111,535.50	**MARC**	1,725,657.00	**MARC**	2,243,305.00
APRIL	1,126,012.40	**APRIL**	962,303.00	**APRIL**	2,333,983.00	**APRIL**	2,320,364.00
MAY	1,072,466.60	**MAY**	983,467.00	**MAY**	2,263,800.00	**MAY**	2,418,604.00
JUNE	982,585.60	**JUNE**	904,208.50	**JUNE**	1,727,962.00	**JUNE**	1,996,781.00
	12,291,811.10		**15,421,555.50**		**23,839,812.00**		**24,377,687.00**
YEAR							
2005/2006			2018/2019				
JULY	1,371,578.00	JULY	1,102,309.1				
AUG	1,533,800	AUG	1,051,261.5				
SEPT	1,705,755.00	SEPT.	1,108,010.7				
OCT	1,550,654.00	OCT.	1,260,915.1				
NOV	1,757,403.00	NOV.	956,784.1				
DEC	1,519,414.00	DEC	1,182,508.9				
JAN	906,541.00	JAN	1,124,946.2				
FEB	615,842.00	FEB	750,009.2				
MARC	1,459,496.00	MAR	785,741.2				
APRIL	1,643,809.00	APR	1,252,846.3				
MAY	1,767,071.00	MAY	990,967.7				
JUNE	1,904,769.00	JUNE	886,978.9				
	17,736,132.00						
			12,453,280.1				

APPENDIX XI: PLATES

Plate 1: Tea pests in one of the farms in Kisii County

Plate 2: One of the Tea Farms where some tea trees had dried due to water logging

APPENDIX XII: PLAGARISM REPORT

CLIMATE VARIABILITY AND ITS EFFECTS ON SMALL-SCALE TEA PRODUCTION IN KISII COUNTY, KENYA

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