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Analysis of trends of temperature and rainfall variations and tea yields from 1995 to 2019 in Kisii County, Kenya

Research article

Norah Moige Nyaiyo[1], **Dennis Mabeya Mamboleo**[2] & **Daniel Nyantika**[3]
Department of Geography, Kisii University, Kenya
Correspondence: norahmoige@yahoo.com
https://orcid.org/0000-0002-3812-4354

Abstract
The study examined the trends of temperature and rainfall variations and tea yields from 1995 to 2019 in Kisii County. The study targeted Kisii Meteorological Department, and three Kenya Tea Development Agency factories of Kisii County. Purposive sampling was used to choose tea factories and the meteorological Department. The study used document analysis was used to collect secondary data. Interview schedules were used to collect data from the field service coordinators who were key informants. Mann-Kendall (MK) test was used to detect trends of meteorological variables and tea yields. The results indicated that there was significant negative rainfall trend for January where rainfall has 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 ($p<0.05$). With regard to tea production levels, there were significant though negative trends in the months of February, March, June, July and December.

Keywords: climate variability, rainfall trend, tea yields, temperatures, tea farmers

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Public Interest Statement

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). 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.

Introduction

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 (Attavanich & Mc Carl, 2014; Di Falco & Veronesi, 2013; Kabubo- Mariara & Karaja 2007; Serdeczny et al., 2016; Pereira, 2017; Somboonsuke et al., 2018; Yamba et al., 2019). IPCC, (2019), has observed that food security in the world have 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 (Intergovernmental Panel on Climate Change, IPCC, 2019).

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 (Bore, 2015; Owour et al., 2011). 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). 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 hence 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 (Mendelsohn, 2008; Muema, et al., 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)

In Kenya climatic variability and change has always presented a threat to 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; Government of Kenya, GOK, 2018; Sagero, Shisanya & Makokha, 2018). A study conducted by Ochieng 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 the 1990s, Kenya has been affected by the droughts of 1983-4,1991-3, 1995-6, 1998-2000, 2004, 2008-9, 2014 and 2017, the *El-Niño* rains that resulted in the floods of 1985,1997-1998, 2000,2007, 2015and 2018 (Republic of Kenya, ROK, 2004; Orindi & Ochieng, 2005; GOK, 2018).

Literature Review

Trends of Temperature and Rainfall Variation and Tea Yields

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

Evidence of Temperature Variations

The temperature range of a given region is influenced by locations, for example in the ocean area. The temperature characteristic of the tea-growing area in continental climates is different. The elevation of the soil also has a major effect on the tea growth temperature. Coupling the location of a region and altitude, the temperature variations can have a major impact on tea growth. For example, in Sri Lanka's upland districts, which are 450 meters higher and have similar temperature ranges to that of the Kenyan highlands. The Kenya Tea Research Foundation has observed that tea needs a temperature range between 19 and 29 degrees Celsius (Leshamta, 2014). 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 the human activities that release greenhouse gases 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. Global average surface temperatures have increased 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 human 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. In particular 2005 was an exceptionally warm year with an increase of above 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 the last about 100 years the average minimum temperature has increased by about 1.3 degrees Celsius in North East India and the annual average maximum temperature has also shown same the trends in tea growing areas (FAO, 2016; Kothawale et al., 2010; Deka et al., 2009). 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 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.

The 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.

Widespread changes in the instrumental record of extreme weather events such as droughts, heavy precipitation, heat 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 et al., (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 et al., (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 et al., 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 $0.5^{o}c$ and $0.8^{o}c$ 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 has been observed for countries bordering the western Indian Ocean between 1961 and 2008 (Niang, et al., 2014; Vincent et al., 2011). 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 by Christy and co-authors on climate for 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 a warming trend in observed maximum, minimum and mean temperatures during between 1979 and 2001 in Kericho.

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 attributed to the warming 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. Also, the minimum temperatures have shown an increasing trend of about 0.6 degrees Celsius over the same period (Leshamta, 2017). These changes in temperatures therefore may have drastic effects on tea growth and production.

Evidence of Rainfall Variability

The most important factor in rain-fed agriculture is the availability of water to maintain crop production. Even if there is a drought -resistant trait, there is no water in the soil sufficient for crops. The variability of plumage between seasons significantly influences the availability of soil water for crops and thus poses a risk to crop production. 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 tea. 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.

Han et al., (2016) reported that the intensity of climate variations and extreme weather events such as prolonged drought, heavy rainfall 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. Analysis of ninety-six years of annual total rainfall data of the South bank region for Assam indicated that the rainfall in this region has declined by more than 200 mm (FAO, 2016a). This is attributed to anthropogenic activities which have led to global warming. In Africa rainfall variability has also been reported. 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 to the above, a 10 percent increase in annual rainfall along the Guinean coast during the last 30 years has also been observed (Nicholson et al., 2000).

Climate instability and severe weather extremes, including droughts, floods, and severe storms, have affected agricultural systems of the world (IFPRI, 2011). Agricultural productivity is adversely affected by climate variability, and this has a direct effect 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 intensity and length of rainfall, the link between annual precipitation and potential evapotranspiration and annual rainfall variation are the main climate factors affecting weed growth (Kabubo-Mariara & Karanja, 2007).

Research on the influence 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 demonstrates that tea yield is greatly determined by the microclimatic parameters of a region especially rainfall, temperature, moisture and light period. Irrigation is also rarely used on tea plantations, and scanty curiosity caused irreparable losses. Heavy rains, on the other hand, erode high soils and remove fertilizers and other chemical substances. A weather data analysis 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.

An analysis of the effects of rainfall on crop production, as well as suggestions for adaptation, was carried out in Japan by Ndamani and Watanabe (2015). The findings showed moderate annual rainfall amounts in the seasons which varied irregularly. In general, precipitation begins in May in the district, nevertheless, in June, until peaking in July and August, the number of rain days and volume in millimeters continues to decline. For all the crops examined, including tea, sorghum, millet and groundnut, the association between annual rainfall and crop production was negative.

Ahmed et al. (2014) in Pakistan conducted a review of the impact of water on the growth and functional quality of tea and pest pressure (*Camellia sinensis*), and found that higher water availability and jasmonic acid (JA) have significantly increased new leaf growth. The availability of water and JA varied with individual secondary metabolites on tea consistency. The availabilities of higher water considerably increased the overall concentrations of methylxanthine tea leaves but the JA treatments and the water interaction and the JA had no major effects.

In comparison, increased water supply led to substantially reduced concentrations of 3-gallate Epicatechin but there was no substantial influence of JA and the interactive effects of Water and JA. These results point to the interesting complexities of the impact of climate change on therapeutic plants that offset the interactions between precipitations and the pesticide pressure within agroecosystems.

A study on the effect of rainfall on tea yield and crop distribution was carried out by Hossain et al. (2015). The findings from the study 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.

Elbehri et al., (2015) has shown a poor 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. Therefore, a warm wet season is favorable for tea growth. The situation in Magura Tea Estate was however different, where yields and precipitation were in a poor 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 Production Authority provided the tea yield data for the period 1995 to 2012 and climate data were obtained from Kenya Meteorological Department. The study found in Murang'a County, that rainfall variability and tea yields had a positive relationship.

The agricultural sector, which relies heavily on predictable rainfall and temperatures, suffers most from climatic fluctuations, according to Kakubo-Mariara (2007), thus affecting the livelihoods of most households who depend on rain-fed agriculture. 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, Neufeldt, Mowo, Abdelkadir, Muriuki, Dale, Asetta, Guillozet, Kassa, Dawson, Luedeling & Mbow, 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.

Kisii Central Sub County households are primarily small-scale farmers, and the main forms of farming are tea, coffee, maize, bananas, milk, and intensive land use systems for grazing (Maobe, Wanyama, Njue & Mogaka, 1994). Pressured by food insecurity, increased poverty, and water scarcity, these smallholder households are already functioning (Mutekwa, 2009; Regassa, Givey & Gina, 2010). Kisii County is a high population density area with high potential (GoK, 2009) and increased land fragmentation has been observed. Thus, households practice subsistence farming that is already susceptible to the effects of fluctuations in rainfall (Irungu, Ndirangu & Omiti, 2009) coupled with continuous cultivation of the same land plots and loss of soil fertility due to erosion.

In addition to the production of staple crops such as maize, rainfall variability also affects cash crops such as tea and coffee (Herrero et al., 2010; Badege et al., 2013), thus raising the vulnerability of Kisii Central Sub County households. Growth, production, and subsequent yields of crops depend on seasonal temperature, quantities of rainfall, and distribution. Changes in rainfall during the season lead to fluctuations in crop yields with marked effects on quality and quantity. Kabuto- Mariara & Karanja, (2007); Karukulasariya & Mendelsohn., (2007) carried a research on the impact of changing climate on arable agriculture. Qualitative modeling is a dominant discourse in these studies, and the results are crop-modeled simulations that are run for biophysical adaptations to water and temperature stress. They believe that farmers do not make any adaptations or adapt entirely and are therefore not responsive to farmers' socio-economic characteristics. This study sought to address this gap by researching the link between household characteristics and the adoption of rainfall variation adaptation strategies.

Barrios et al., (2008) found a major effect on farm production in 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). 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).

Therefore, changes in long and short rainfall patterns have had significant effects on agricultural production (IPCC, 2007). Seasonal precipitation is characterized by delayed onset, decreasing number of rain days, and increased intensity, altering agricultural calendars with adverse effects on yields. Policymakers and agricultural practitioners have discussed the effect of variations and changes on small-scale rain-fed agricultural production (Jokastah, Leahl Filho & Harris, 2013). Although there have been several studies on climate change and variations, not all regions have been covered to note the effects of these variations on small-scale farming. 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. This knowledge of the perceived effects of rainfall variability on small -scale crop production will inform scholars and agricultural policymakers to establish policies and introduce adaptations for specific agro-ecological zones that fit the present and future agricultural enterprises.

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. New et al., (2006) and Usman and Reason, (2004) have also noted that in Southern Africa, floods, droughts and prolonged rainfall have been experienced. It has been noted that 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 is also 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). 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 year-to-year 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 the long rains (March-May) decreased annually by 10 millimeters while the short rains (October-December) decreased annually by 2millimeters for 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 Hillel & Rosenzweing (2002) who found out that changes in the intensity and precipitation patterns in Africa have led to reduced agricultural outputs.

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 pronounced effects on tea production (Leshamta, 2017).

Evidence Tea Yield Variations

From the above discussion, it can be concluded rainfall and temperature variability may cause changes in tea 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. Majumder. 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.

Designs and Methods

This study adopted a correlational research design. As it is used to examine 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 decreasing. No relationship occurs when there is no identifiable pattern (Thompson et al., 2005; Slavin, 1992). This design was important for this study because it was used to examine the relationship between rainfall and temperature variations and tea production. Both quantitative and qualitative approaches were used in collecting and analyzing data. The study targeted six Kenya Tea Development Agency (KTDA) factories and six field service coordinator personnel from the six factories, 120,000 small scale tea farmers (KTDA, 2017) who supply their tea to the six factories, and personnel from the meteorological department of Kisii County to provide information on monthly tea production totals from 1996 to 2019 and monthly rainfall and temperatures from 1995 to 2019 respectively.

Data Collection Instruments

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 the KALRO's Kisii Meteorological Department and tea yields from KTDA factories for the years 1996 to 2019. Two research assistants were used to administer questionnaires to the farmers and interviews were administered to the field service coordinators by the researcher.

Results and Discussion

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

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, on the other hand, 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.

Temperature Trends in Kisii County

To test the temperature 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.

Mann Kendall's trend analysis compared the temperature data from 1995 to 2019. The data was grouped in months therefore comparison was done for each month in the various years during the study period.

Table 1: Temperature Trend Analysis

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

The results indicate that there were no temperature trends detected for most months with an exception of January and July. This was informed by the significant p-values (less than the alpha value of 0.05). Also, the results showed that temperature has been increasing over time (positive Kendall's tau) except for November and December where they have been decreasing.

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 2: Sen's Slope Analysis for Temperature in January

	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 points from one year to the other. From the figure below, 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).

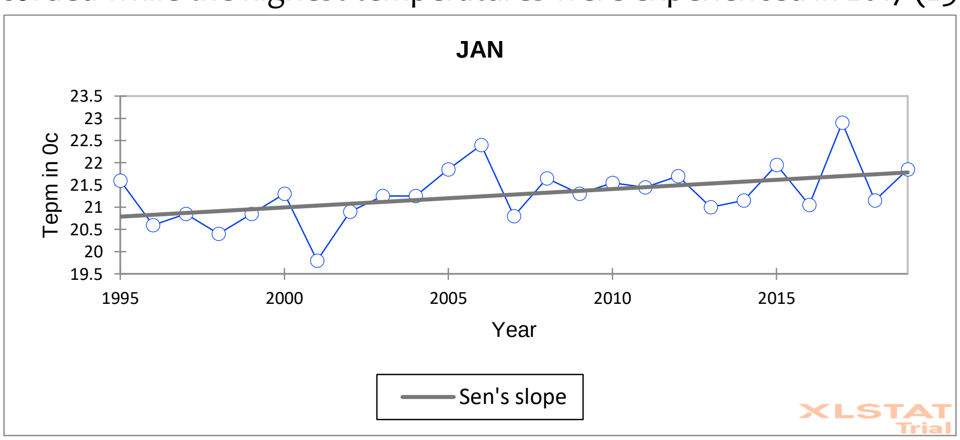

Figure 1: Graph Showing Sen's Slope for Temperature in January

Source: Field data, 2020

Table 3: Sen's Slope Analysis for Temperature in July

	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.

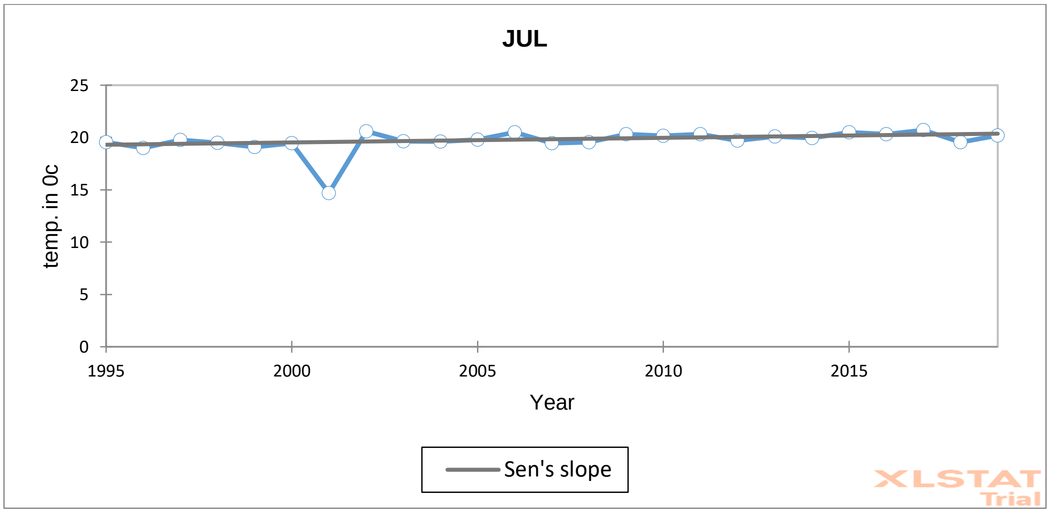

Figure 2: Graph Showing Sen's Slope for Temperature in July
Source: Field data, 2020

The results from the study revealed that there were no temperature trends detected for most months with an exception of January and July. This was informed by the significant p-values (less than the alpha value of 0.05). Also, the results showed that temperature has been increasing over time (positive Kendall's tau) except for November and December where they have been decreasing. The results support those of Attri & Tyagi, (2010), which revealed that temperatures have increased by about 0.71°c in India from 1901 to 2007 with accelerated warming after 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 Christy and co-authors (2011) and Wachakala et al. (2015) on climate for 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 was included. This is in consistency with Omumbo, et al, (2011) who found a warming trend in observed maximum, minimum and mean temperatures during the period of 1979-2001 in Kericho. In addition, according to Tea Research Foundation of Kenya, TRFK, (2011); Ongoma, et al, (2013) and Funk et al, (2010 that both minimum and maximum temperatures have a rising trend in Kenya. This also is in agreement with a study conducted by Samwel et al., (2018) which found that temperatures were on an increasing trend in Kisii County from 1983 to 2013.

Rainfall Trends in Kisii County

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 H0, and accept the alternative hypothesis Ha.

Table 4: Rainfall Trend Analysis

	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

Based on Table 4, it was only the month of January that had a positive significant trend. This was informed by the significant p-value (less than 0.05). generally, 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.

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

Table 5: Sen's Slope Analysis for January for Rainfall

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 during the observation period. The lowest amount of rainfall recorded was in 2002 when there was an average of 6mm while the highest was 2007 (281mm).

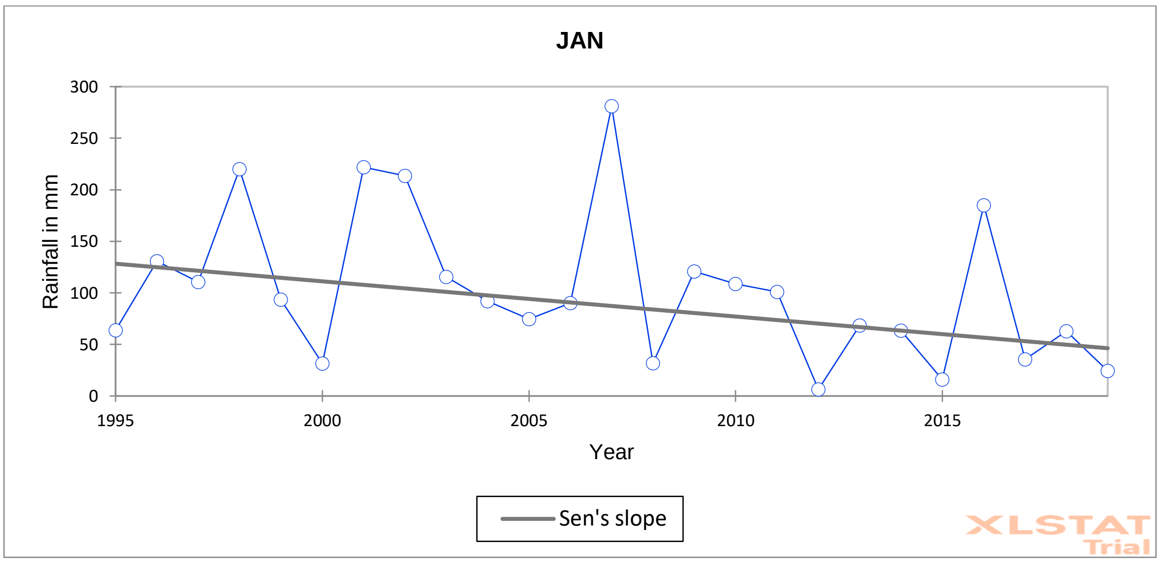

Figure 3: Graph Showing Sen's Slope for Rainfall in January

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 (less than 0.05). generally, 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 the months of April, August, September, October, November and December over time. 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 South bank region in an analysis done for 96 years in areas.

Furthermore, according to 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. 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 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.

Tea Yields Trends

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.

Table 6: Tea Production Trend Analysis

	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

As evidenced in Table 6 above, a significant trend in tea production was observed in February, March, June, July and December. 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 the Sen's slope as follows;

Table 7: Sen's Slope Analysis for Tea Production in February

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

Source: Field data, 2020

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

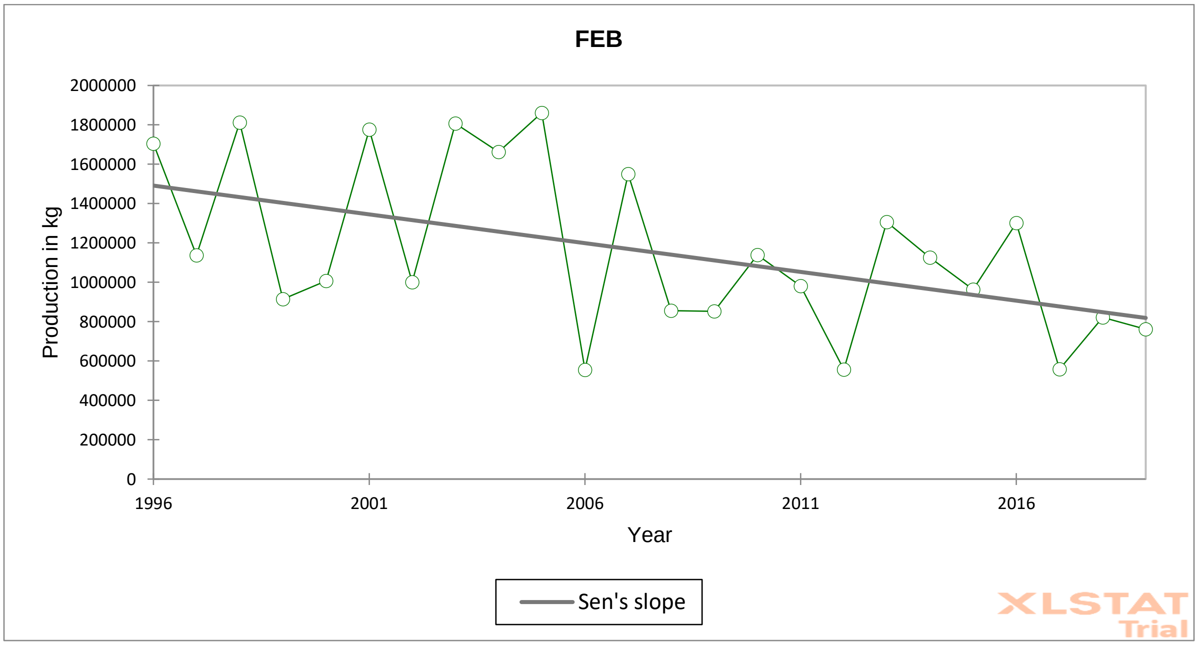

Figure 4: Graph Showing Sen's Slope for Tea Production in February

Source: Field data, 2020

Table 8: Sen's Slope Analysis for Tea Production in March

	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 kilos per year. The highest and lowest yields recorded were 2200712 kilos and 553069 kilos in 2004 and 1998 respectively.

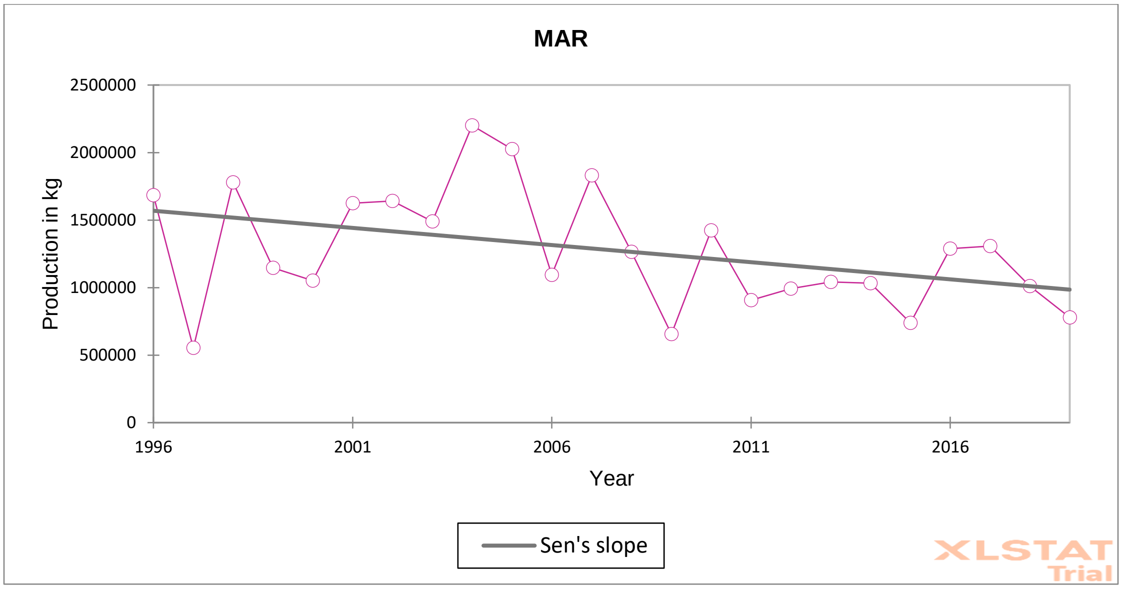

Figure 5: Graph Showing Tea Production for March

Source: Field data, 2020

Table 9: Sen's Slope Analysis for Tea Production in June

	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 kilos 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).

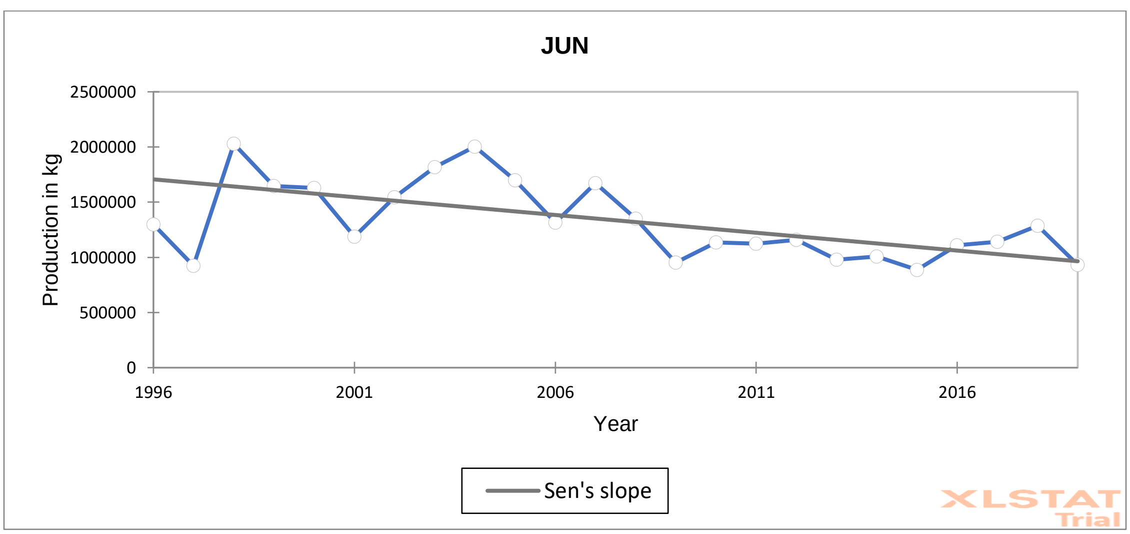

Figure 6: Graph Showing Tea Production for June

Source: Field data, 2020

Table 10: Sen's Slope Analysis for Tea Production in July

	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.

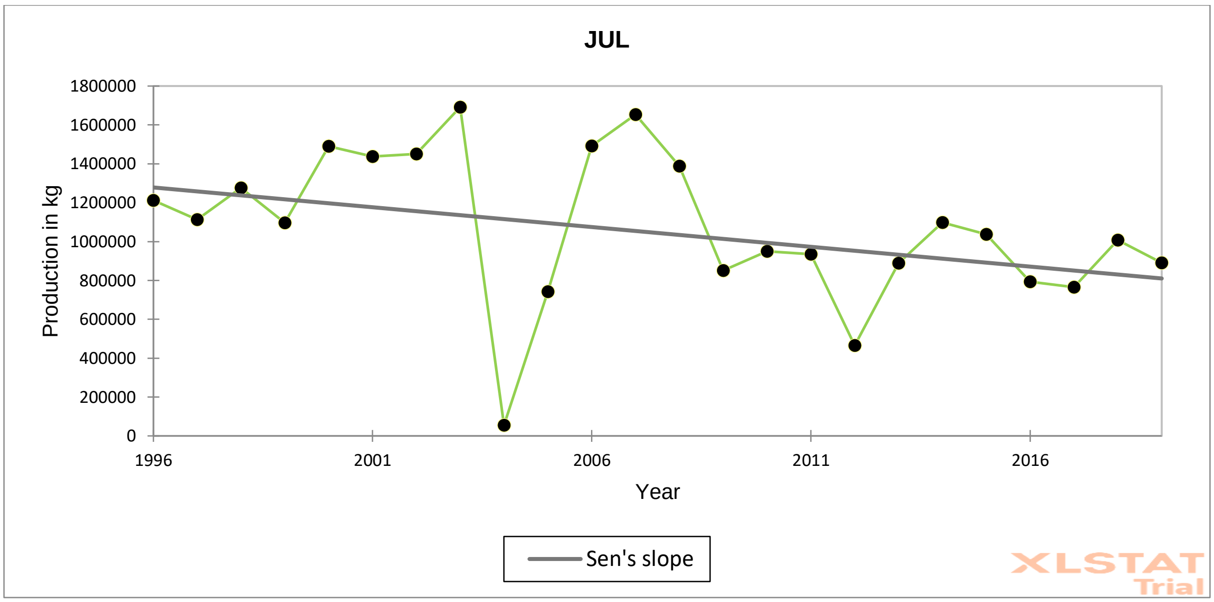

Figure 7: Graph Showing Tea Production for July
Source: Field data, 2020

Table 11: Sen's Slope Analysis for Tea Production in December

	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.

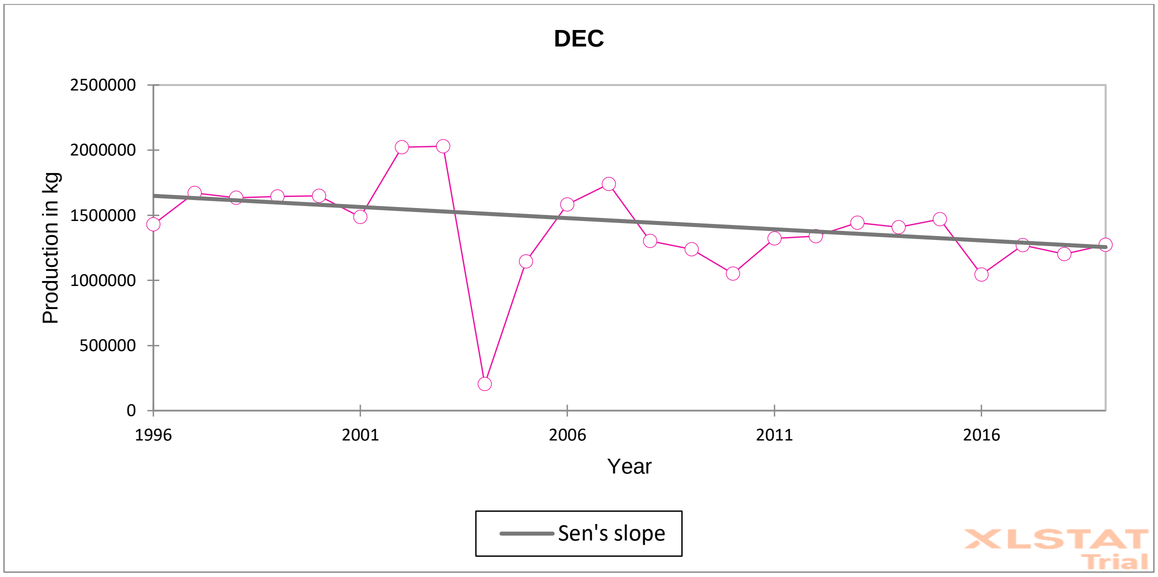

Figure 8: Graph Showing Tea Production for December
Source: Field data, 2020

Analysis of tea yields showed a significant trend in the months of February, March, June, July and December. 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, according to researches by AFFA (2014) and Tea Directorate (2019) in Kenya, have shown that tea yields have been fluctuating over time even though area under production is steadily increasing.

Conclusion

The results of the study concluded that there were no temperature trends detected for most months with an exception of January and July. There was also conclusion that temperature has been increasing over time except for the months of November and December where they have been decreasing. The study further concluded that trends of rainfall showed 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 the months of April, August, September, October, November and December over time. Furthermore, concerning trends of yields of tea, the study concluded that tea yields trend has 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.

Recommendations

The results showed that rainfall, temperature, and tea yields have inverse associations, hence the study recommends farmer 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.

Bionote

Norah Moige Nyaiyo is a PhD student in the Department of Geography, Kisii University. She holds MA Geography from Kenyatta University and Bachelor of Education Arts (Geography and Mathematics) from Moi University. Currently, she is working at the Department of Geography, Kisii University as a tutorial fellow. Her research interests include climate and agriculture.

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