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Effects Of Climate Variability On Tea Production In Bomet County, Kenya

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***Abstract:** Changes in weather elements such as temperature and rainfall have a strong influence on tea production. The extent to which climate variability has impacted on tea production, the main source of livelihood in Bomet Central sub-County is still not documented. To bridge that gap, this study investigated the effects of climate variability on tea production and the adaptation strategies by smallholder farmers in Bomet Central sub-County, Bomet County. The data used in the study include: observed monthly rainfall and temperature for Bomet Central sub-County obtained from Kenya Meteorological Department for Bomet Water Supply Weather Station and monthly tea production data for Kapkoros and Tirgaga tea Factories obtained from Kenya Tea Development Agency from 1993–2013. The research was based on a descriptive survey design with a target population of 10,800 tea farmers with a sample size of 130 respondents. Regression analysis was used for time series rainfall, temperature and tea output data over the 21-year period The objective of the study was to evaluate the effects of rainfall and temperature variability on smallholder tea production in Bomet Central sub-County from 1993–2013. The results showed that Bomet County experienced a slight increase in rainfall and temperature trend by 6.471mm and about 0.029^{o}C respectively per year. Pearson correlation showed that there was a weak positive relationship between rainfall variability and tea production R=0.122 (R^2=0.015) but a strong positive relationship between temperature and tea production R=0.908 (R^2=0.825). The study recommends that farmers be advised to establish and manage shade trees in their tea farms so as to reduce ambient temperature around the tea bushes, add organic matter to soil and reduce drought effects.*

***Keywords:** Climate variability, Tea production, Smallholder Tea Farmers*

I. INTRODUCTION

A. BACKGROUND OF THE STUDY

Tea (*Camellia sinensis*) is widely cultivated as a rain-fed plantation crop and its productivity is greatly influenced by environmental conditions. Tea requires a temperature range of 18–25^{o}C and well-distributed annual rainfall of between 1400–2500 mm for optimum production (Nissanka, 2007). In India, unfavorable weather conditions for tea plantations owing to rainfall abrasions (too much and too little) have badly affected the tea plantations in various parts of Assam and North Bengal (Baruah and Bhagat, 2012). Irrigation which was not necessary some few years back has now become utmost essential for tea farms across states particularly in Brahmaputra Valley, the main tea producing region of Assam. Similarly, in Africa, there is a risk of reduced crop productivity associated with heat and drought stress, with strong adverse effects on regional, national and household livelihood and food security (IPCC, 2014).

Since the introduction of tea in Kenya in the early 20th century, the acreage under cultivation has steadily risen, with the land area under the crop totaling 147,080 hectares by 2007 (TBK, 2008). Tea growing areas in Kenya are divided into two regions defined by the Great Rift Valley, a natural geographical feature that divides the country almost asymmetrically into two major blocks. The East of Rift block comprises Mt. Kenya region, Nyambene hills, and the

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Aberdare highlands whereas the Kericho region, Mau highlands, Nandi Hills and Kisii highlands form the West Rift block (TBK, 2014). Over the years, tea production has increased through the development and release of cultivars with high yield and better beverage quality attributes (Republic of Kenya, 2016).

The tea industry is the second leading foreign exchange earner (accounting for about 20% of the total export earnings) amongst agricultural commodities after horticultural crops in Kenya (TBK, 2014). The tea sub-sector provides a source of livelihood to over 3 million people (about 10% of the total population) besides providing support to other sectors of the economy such as infrastructure development (TBK, 2004). Tea in Kenya is also expected to play a great role in achieving Vision 2030 (Kenya's development policy that aspires to achieve a 10% growth annually in gross domestic product from 2012). However, emerging reports indicate that growth in the sector may not be sustained probably due to the abiotic stress factors such as drought, hail, frost and low temperature (Kamunya, 2010; Cheserek, 2011). Prolonged drought periods are quite common nowadays. For instance, in 1997, 2000, 2003, 2011, late March, 2012 when tea yield losses of over 60 % were recorded (TBK, 2004, 2008; TRFK, 2012). Again, the green leaf deliveries by farmers dropped countrywide from 936.6 million kilogrammes in 2016 to 705.2 million kilograms in 2017 due to prolonged dry spell (TBK, 2018). Majority of the smallholder tea farmers in Bomet Central sub-County have planted most of their land with tea (Bomet County Government, 2013). Assam tea is widely grown by farmers in the area and the clones grown include C51, S15/10, TRFK 31/8, BB/35, TN14/3 and SFS 303/577 (TBK, 2008). Clones S15/10, TRFK 31/8 and BB/35 are susceptible to drought (TRFK, 2012). Hence, due to climate variability coupled with low returns from tea farms, some farmers face food insecurity.

The Tea Research Foundation Kenya (TRFK) has been monitoring climatic data in Kenya since 1958. TRFK observed changes in average temperature increase of 0.016^{o}C per year for 52 years which adds nearly to 1^{o}C, fall in annual rainfall at 4.82 mm per year totaling 250 mm over the same period and a greater soil water deficit (notably in January, February and March) resulting in significant reductions in tea productivity (TRFK, 2012). The occasional dry spells do not support the growth of tea and therefore lead to low productivity and hence poor profitability (Mose, 2012).

B. PROBLEM STATEMENT

Bomet County is experiencing changes in weather elements affecting both the quality and the quantity of tea produced (TRFK, 2012). The persistent cold weather conditions coupled with less rainfall in Bomet, Kisii, and Nyamira have led to a significant reduction of tea production over the years (TBK, 2012). For instance, tea production in Bomet dropped by approximately 9% from 27.1 million kilogrammes in 2005 to 24.6 million kilogrammes in 2006 (TBK, 2012).

Smallholder farmers in Bomet Central are more diverse across crops but tea remains to be the main rain fed-crop cultivated throughout the area. There is, however, a scarcity of information on effects of rainfall and temperature variability on the amount of tea produced in the area. To address that gap, this study was designed to evaluate the effects of climate variability on tea production in Bomet Central sub-County.

C. OBJECTIVE OF THE STUDY

To evaluate effects of rainfall and temperature variability on smallholder tea production in Bomet Central sub-County from 1993–2013.

D. RESEARCH QUESTION

What is the relationship between rainfall and temperature variability and amount of tea yield produced by smallholder tea farmers in Bomet Central sub-County?

E. STUDY HYPOTHESIS

The study was guided by the following null hypotheses;

There is no significant relationship between rainfall variability and the amount of tea produced by smallholder tea farmers in Bomet Central sub-County.

F. JUSTIFICATION AND SIGNIFICANCE OF THE STUDY

Climate variability poses a big threat to farmers in Bomet County because of their overwhelming reliance on tea farming. Rainfall in the County has become more variable, with increase in extremes (both lows and highs) from year to year, which has resulted in increase in drought and flood risk (MoALF, 2017). Food insecurity in the County can be attributed partly to the occurrence of weather related hazards such as intense rains, drought as well as increase in temperatures (MoALF, 2017). IPCC reports also indicate clearly that in developing countries, climate variability is the single most determining factor that endangers agricultural production and it is also predicted to increase further in Eastern Africa (IPCC, 2007). Therefore, it is important to carry out research to establish the effects of rainfall and temperature variability on tea production in Bomet Central sub-County. Rainfall and temperature are the preferred weather elements because they are the major factors that influence the tea yields globally more than any other factor (MoALF, 2017). The area has been purposely selected owing to its sensitivity to rainfall and temperature variability and also due to its accessibility and resourcefulness in terms information required in the study. This information could assist the policy makers, donors and researchers in coming up with appropriate research, innovations and development interventions that will improve the livelihoods of the smallholder tea farmers.

G. SCOPE AND LIMITATIONS

The study examined the effects of climate variability on smallholder tea production in Bomet Central sub-County. It focused on tea yields in Kgs, rainfall in mm and temperature in ^{o}C. Some of the limitations of this study included tea farmers' unwillingness to give the right information to the researcher.

II. LITERATURE REVIEW

A. INTRODUCTION

This chapter presents a review of literature that is related to climate variability and adaptation strategies that can be adopted. This enabled the study to develop new knowledge from the gaps identified which if bridged would lead to successful climate variability adaptation.

B. CLIMATE VARIABILITY AND TEA PRODUCTION

Global weather has become unpredictable and created uncertainty in agricultural production. Studies have shown that an important factor in the annual tea yield is climate variability (Ngetich, et al 2006 (b)). According to Wijeratne et al. (2007), tea production at low-and-mid altitudes is more vulnerable to adverse effects of climate variability than those at high altitudes in Sri-Lanka. The study established that optimum temperature for tea growing was about 22°C and the optimum rainfall varied from 223–417 mm per month. In addition, a drop of monthly rainfall by 100 mm could reduce productivity of processed tea by about 30–80 kg per hectare. The study also established that a rise in ambient carbon dioxide from 370–600ppm increased tea yield by 33%–37% depending on altitude. The study noted that, because of climate variability, yields are likely to decrease in low elevations but increase in high elevations. However, the study was carried out at the scale of country while the current study seeks to establish the effects of climate variability at sub-County level.

A study done by Bhagat, Baruah and Safique (2010) showed that apart from well-distributed rainfall and the attainment of certain optimum soil and air temperature; wind velocity, sunshine hours, vapour pressure of the atmosphere also influences the performance of the tea crop. In addition, daylength and change of seasons influences many important processes of the tea plant, such as initiation of flowering, induction of vegetative growth, abscission of leaves and fruits or dormancy and germination of seeds. A shift in any of the suitable climatic conditions as a result of climate change or otherwise may lead to poor crop performance. The study failed to capture how extreme weather events like frost and hailstorms affect tea yields.

CIAT (2011) carried out a study to predict climate change for tea growing areas using global models. The study found out that the change in conditions suitable for growing of tea is site-specific. In Uganda, for example, the study showed that the districts such as Bundibugyo, Kyejojo, Bushenyi, Bundibugyo, Masaka and Kanungu will become unsuitable for tea growing by 2050 and farmers will need to plant alternative crops. On the other hand, the districts such as Kisoro and Kabarole will remain suitable for tea but farmers need to adapt their agronomic management to the new climatic conditions that the area will experience. The study also noted that in Kenya, some areas such as Gucha, Kericho, and Nandi will gradually become unsuitable for tea while others like Nyamira Bomet and Kisii will remain stable. On the other hand, conditions of areas such as Meru, Kirinyaga, Embu, Muranga, Nyeri and Kiambu, could increase the probability of growing of tea. The study, however, focused on current and future suitability of tea production areas but the current study to the analyzed the effects of temperature and rainfall variability on tea yields.

According to Wachira, (2009), there is evidence of climate change in tea growing zones. Since 1958, there is evidence of reduced rainfall, decreased soil water and increased temperatures. In 52 years covered by the study (1958–2010), rainfall in Kericho dropped by 4.82 mm every year while temperature increased by 0.016^{o}C annually. Maximum and minimum temperatures were noted to have increased by between 0.1^{o}C and 2.9^{o}C in the tea growing areas. There was high correlation between tea production and rainfall with reduction in amount of tea produced coinciding with dry periods and increased soil water deficit.

A study done by FAO (2012) noted that the main crops grown in the West of Rift were tea, maize, and bananas while those grown in the East were maize, sweet potatoes, and bananas. The study observed that changes in rainfall patterns and distribution that reduced tea yields were tied to climate variability. Changes that were most notable were in wet and dry seasons which led to frost and shifts in planting season. The study concluded that tea producers may lose up to 30% in cash earnings due to climate variability. The current study provide more detailed information needed on the effects of climate variability on tea yield at a specific location particularly sub-County level and villages for effective adaptation options to be targeted.

Rwigi and Oteng'i, (2009) considered five climatic variables namely; daily mean relative humidity, total weekly radiation, daily mean minimum temperature, daily mean maximum temperature and weekly tea yields. The findings showed that mean minimum temperature and relative humidity highly influenced weekly tea yield. According to the study temperature, rainfall, and their variability are main variables influencing tea production in Kenya. The authors, however, didn't look at effect of extreme weather variables like frost and hailstorms on tea yields.

C. NON-CLIMATIC FACTORS INFLUENCING TEA PRODUCTION

A study by Dutta (2011) on the effects of age, pruning and fertilizer application on tea yield in Netherlands showed that the yield was influenced by fertilizer applications, age of tea plants, leaf area index and also pruning. Similarly, Hicks (2009) pointed out that the factors affecting global tea production were weather conditions, planted areas, population, age of tea bushes, labour, capital, price of inputs and yield risk. However, there is also need to evaluate climatic variables affecting tea yields in a specific area.

Additionally, Karanga and Bwisa (2014) cited poor road network, high cost of labour and low income from tea produced by farmers as factors which contributed to decline in the amount of tea produced in Abothuguci West Division. They concluded that greatest factor which negatively

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influences the quantity of tea reaching the factory is transportation. The current study seeks to establish the effects of weather variables on tea yield in Bomet central sub-county.

Soy (2010) established that the physical environment played a vital role in rainfall patterns and distribution in tea growing zones in Kenya. He further pointed out that factory production capacity which restricts inflow of green leaf from farmers at peak periods was the major bottleneck in the growing of tea. He argued that there was need for training of farmers and enhancement of production technology both in the field and factory. The author concluded that the poor profitability of the tea sub-sector is largely due to the degradation of the physical environment and low production capacity of both farmers and the factories. The current study seeks to establish the effects of weather variables on tea yield in Bomet central sub-county.

D. CONCEPTUAL FRAMEWORK

The study examined the effects of climate variability on tea production and the adaptation strategies adopted by smallholder farmers in Bomet Central sub-County, Bomet County. The conceptual framework that guided the study was adapted and modified from Bett (2018) as a strategic tool to better understand the interactions between climate variability, tea production and adaptation strategies used by smallholder tea farmers (Figure 2.1).

Independent Variables Intervening Variables Dependent Variables

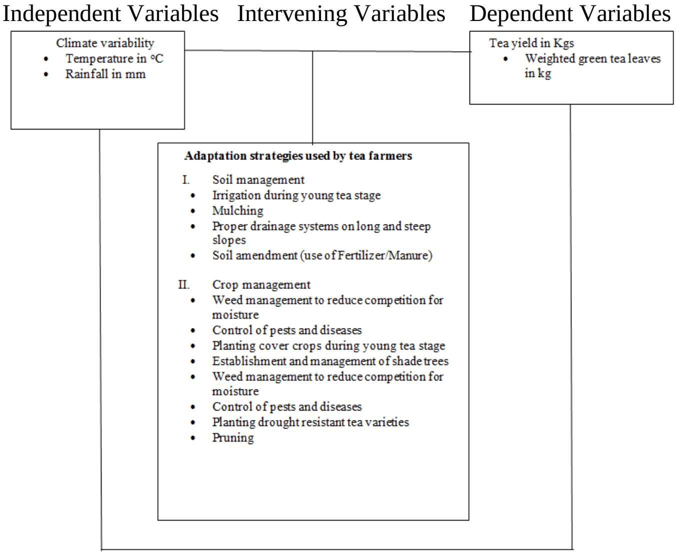


Figure 2.1: A Conceptual Framework Showing the Interactions of Independent and Dependent Variables (Adapted and modified from Bett, 2018)

III. RESEARCH METHODOLOGY

A. RESEARCH DESIGN

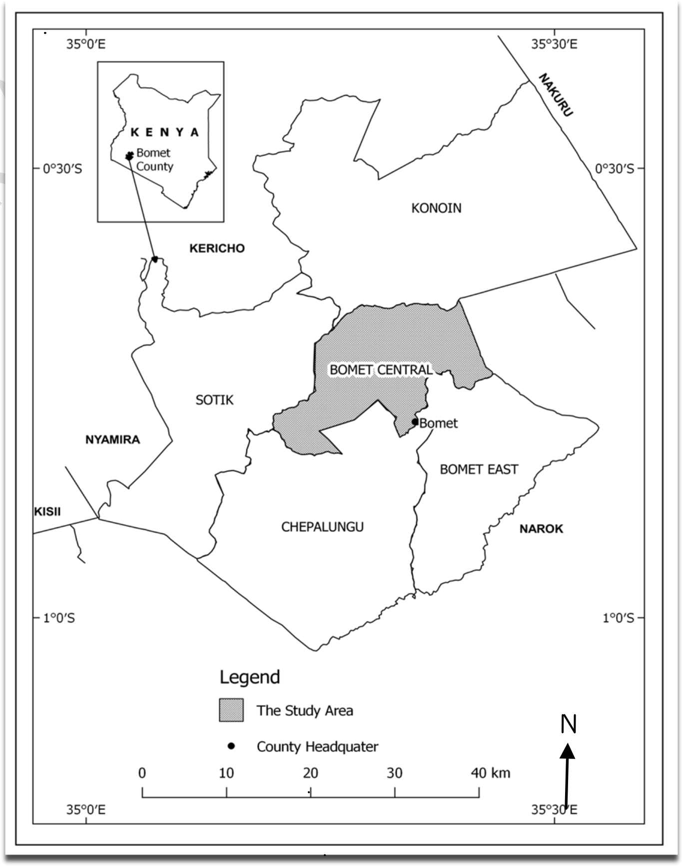
This study used descriptive research design. Descriptive survey designs are used when objectives are systematic or description of facts and characteristics of a given population or sample of the population or area of interest is factual and accurate (Kothari, 2007). According to Muganda, (2010), the goal of descriptive study is to offer the researcher a profile or to describe relevant aspects of phenomena of interest from an individual organization, industry, and some other perspective. Hence, the descriptive survey helped the researcher to get information on effects of climate variability on smallholder tea production and the adaptation strategies in the study area.

B. STUDY AREA

The study area was Bomet Central sub-County which is located in Bomet County. The following areas of the study area are examined;

a. LOCATION AND SIZE OF THE STUDY AREA

This study was conducted on smallholder tea farmers in Bomet Central sub-County, Bomet County. Bomet County lies between latitudes 0°29′ and 1°03′ South and between longitudes 35°05′ and 35°35′ East. It is bordered by four counties; Nakuru to the East, Kericho to the North-East, Nyamira to the West and Narok to the South (Figure 3.1). The County is divided into 5 Sub-counties, 25 wards, 66 locations and 177 sub-locations. Bomet Central is the smallest sub-County in Bomet County covering an area of 266 km^2 with five wards namely; Silibwet, Singorwet, Ndaraweta, Chesoen and Tarakwa.



Source: Bomet County Government, 2015

Figure 3.1: Bomet Central sub-County

C. SAMPLE SIZE AND SAMPLING TECHNIQUE

A sample size is a subset of the total population that is used to give the general views of the target population

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(Kothari, 2004). From the total population of 10,800 smallholder farmers in the area, the sample size was determined using a simplified formula provided by Yamane (1967) at 95% confidence level, 5% degree of variability and 9% level of precision. The formula is as shown in equation 1.

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

Where 'n' is the sample size, 'N' is the population size (total smallholder farmers), and 'e' is the level of precision. The above formula required a minimum of 123 but an additional 5% was included to cover for anticipated non-responses and to increase the power of the study giving a total of 130 farmers. Proportionate random sampling technique was employed to divide the number of tea farmers living within the study area into 5 sub-groups using the formula shown in equation 2. The sampling technique was used to ensure a fairly equal representation because number of tea farmers in the wards are not equal.

$$\text{Ward sample size} = \frac{130 \times \text{No. of smallholder farmers in the ward}}{10,800} \qquad \text{Equation 2}$$

Within each ward, the selection of tea farmers was done using simple random sampling. The Table 3.1 shows the sample sizes of the five wards.

Wards	No. of Tea farmers in the Ward	Ward Sample Size
Silibwet	1,859	22
Singorwet	2,760	33
Ndaraweta	3,090	37
Chesoen	2,790	34
Tarakwa	301	4
Total	10,800	130

Source: KTDA, 2015

Table 3.1: Sample sizes of the five wards

D. RESEARCH INSTRUMENTS

Secondary data on the trend of rainfall and temperature for the past 21 years was collected from KMD for Bomet Water Supply Weather Station while data on tea production was collected from KTDA so as to aid in comparison purposes.

E. DATA COLLECTION

Two organizations were targeted as the key sources of secondary data required for the analysis from 1993–2013. Rainfall data (mm) and temperature (^oC) were obtained from Kenya Meteorological Department for Bomet Water Supply Weather Station whereas tea yields (Kg) for Kapkoros and Tirgaga tea factories was obtained from Kenya Tea Development Agency for the twenty-one-year period under investigation. This period is long enough to compare the effects of climate variability and smallholder tea production in the area.

F. DATA ANALYSIS

Data obtained from KTDA on the amount of tea produced by smallholder tea farmers in the study area and data from the Kenya Meteorological Department was collated for further processing and analysis. Regression analysis was used for time series rainfall, temperature and tea output data over the twenty-one-year period. The Table 3.2 shows a summary of methodology used in this study.

Objectives	Variables	Data required	Source	Type of data	Data collection tools	Data analysis tools	Statistics required
To evaluate the effects of rainfall and temperature variability on smallholder tea production	-Rainfall -Temperature -Tea production	-Monthly rainfall in mm -Temperature in ºC -Monthly green tea leaves in kg	-KMD -TBK	Secondary time series data	summary check sheet	Regression analysis	Data on: Rainfall Temperature Monthly green tea leaves in kg

Table 3.2: Summary of data required and data analysis tools

IV. RESULTS AND DISCUSSION

A. INTRODUCTION

This chapter presents the results of the study based on the data collected from the field. The results are presented in four sections starting with rainfall, temperature, tea yields, adaptation strategies and determinant factors influencing adaptation strategies to climate variability in Bomet Central sub-County.

B. VARIABILITY OF RAINFALL, TEMPERATURE AND TEA YIELDS OVER BOMET CENTRAL SUB-COUNTY

This section described rainfall and temperature variability and their relationship with amount of tea yield produced in the study area.

a. RAINFALL VARIABILITY IN BOMET COUNTY

Data from Kenya Meteorological Station showed that the amount of rainfall in Bomet Central has been fluctuating between highs of 2172.7 mm in 1997 and lows of 955.0 mm in the year 2005. The rainfall descriptive analysis indicated high variation as in standard deviation from January to December over the years from 1993 to 2013. The maximum standard deviation of rainfall was 105.3 mm in April and minimum standard deviation was 46.1 mm in July. This fluctuation or variation does affect the tea yields as registered between 1993 and 2013. The affected months with large standard deviation of tea yields are April and November which are the peak months for first rains and second rains in the study area. The highest mean rains occurred in April for the first rains season with 440.3 mm followed by mean of the second rains which was 359.0 mm and 360.2 mm for November and December respectively (Table 4.1).

	N	Minimum	Maximum	Mean	Std. Deviation
January	21	.3	355.9	121.60	81.71
February	21	4.5	236.3	96.10	68.94
March	21	42.9	324.8	169.16	88.70
April	21	7.0	440.3	231.52	105.31
May	21	30.0	275.0	173.74	81.13
June	21	22.9	214.0	89.56	51.28

July	21	2.5	173.5	66.73	46.10
August	21	.0	269.1	106.62	73.00
September	21	26.2	259.1	111.65	60.46
October	21	23.0	288.9	111.59	74.58
November	21	43.7	359.0	162.56	97.54
December	21	17.5	360.2	117.92	89.58
Valid N (listwise)	21				

Source: KMD, 2015

Table 4.1: Rainfall variability in mm in Bomet Central sub-County

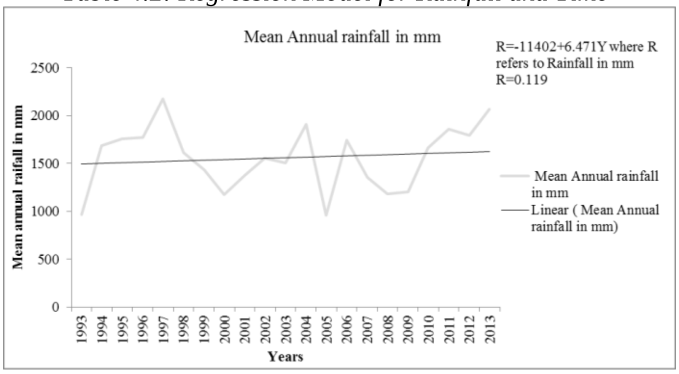
Further analysis was done on total rainfall from 1993 to 2013 and the results showed a major variation as shown in Figure 4.1. There was evidence of low rains in 1993, 1999, 2000 and 2005. High rains were recorded in 1997, 2004, 2011 and 2013. The time series analysis using regression model on annual rainfall and years indicated R = .119 (adjusted R^2 = 0.014). This means that only 1.4% of the change in the dependent variable (Annual rainfall) was as a result of the change in the independent/predictor variable (years) while 98.6% are related to other factors (Table 4.2). Linear regression analysis showed that there has been a slight increase of 6.471 mm in rainfall over the years in Bomet County (R = -11402 +6.471Y where R and Y refers to rainfall in mm and Years respectively) as in Figure 4.1.

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	-11402.469	24760.535		-.461	.650
	Years from 1993-2013	6.471	12.362	.119	.523	.607

a. Dependent Variable: Annual rain in mm

Source: Computed from field data, 2015

Table 4.2: Regression Model for Rainfall and Time



Source: computed from field data, 2015

Figure 4.1: Annual variability of rainfall from 1993–2013 for Bomet Central sub-County

The covariance on rainfall for the years under study was found to be 102.96 mm (Table 4.3). This shows that there was substantial change in rainfall patterns and if not taken into consideration will affect the tea farming in Bomet.

Model			Years from 1993–2013
1	Correlations	Years from 1993-2013	1.000
	Covariance	Years from 1993-2013	102.957

a. Dependent Variable: Annual rain in mm

b. Independent Variable: Years

Source: computed from field data, 2015

Table 4.3: Covariance for the year 1993–2013 on rainfall in mm

b. *TEMPERATURE VARIABILITY FROM 1993–2013 IN BOMET CENTRAL SUB-COUNTY*

Data from the Kenya Meteorological Station for Bomet water supply weather station showed that the minimum annual average temperature was 17.3°C while the maximum annual temperature was 19.0°C. The mean temperature was 18.4°C (Table 4.4).

Average Temperature (°C)	
Mean	18.4
Std. Deviation	.4158
Minimum	17.3
Maximum	19.0

Source: computed from field data, 2015

Table 4.4: Descriptive Statistics for Temperature

Further regression analysis showed that correlation co-efficient was R = .430 and R^2 = .185. This revealed that there was a positive relationship between time and the temperature. Thus as years increased from 1993–2013, there was a slight increase in temperature (Table 4.5).

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.430[a]	.185	.142	.38512

a. Predictors: (Constant), Years from 1993-2013

Source: computed from field data, 2015

Table 4.5: Correlation Co-efficient for Temperature with Time

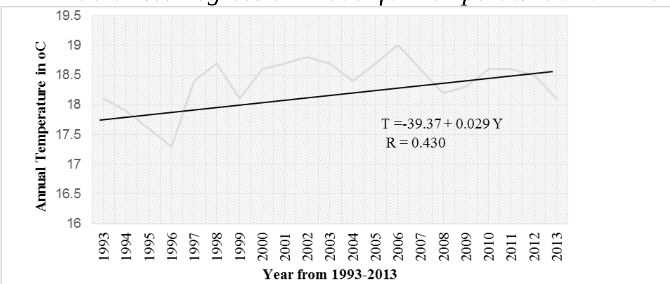
The time series analysis was T = -39.373 + 0.029Y where T and Y refer to temperature in °C and years respectively (Table 4.6). This showed that Bomet County experienced an increase in temperature trend of about 0.029°C per year from 1993–2013. The findings by TRFK (2012) in Kericho also corroborate with these findings. TRFK observed changes in average temperature rise at 0.016°C per year for 52 years totaling nearly 1°C. The regression model relationship can be presented as in Figure 4.2.

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	-39.373	27.799		-1.416	.173
	Years from 1993-2013	.029	.014	.430	2.077	.052

a. Dependent Variable: Average Temperature

Source: computed from field data, 2015

Table 4.6: Regression Model for Temperature and Time



Source: computed from field data, 2015

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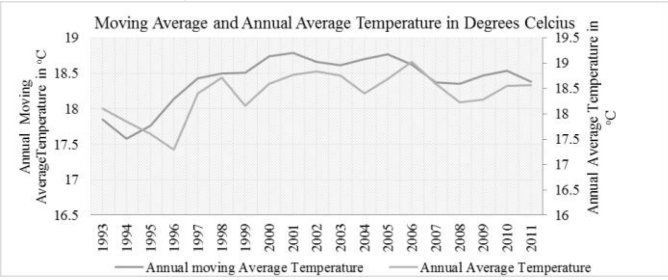
Figure 4.2: Temperature from 1993–2013 for Bomet Central sub-County.

Temperature was also analyzed with a moving average of 5 years. This indicated that there was an increase trend in temperature from 1995 to 2004 and gradual decrease from 2004 to 2013 (Figure 4.3).



Source: computed from field data, 2015

Figure 4.3: Time series analysis for average temperature over 21 years for Bomet Central sub-County

c. TEA PRODUCTION FROM 1993–2013 IN BOMET CENTRAL SUB-COUNTY

The tea yields analyzed from January to December from 1993–2013 shows a big variation. The maximum standard deviation was 1.38 million Kgs in January and minimum standard deviation was 0.89 million Kgs in February and August. The maximum tea yield was attained in May with 2.47 million Kgs at peak of first rain season and October with 2.47 million Kgs which marks the peak of second rain season (Table 4.7). This indicates that rainfall is a very important factor for tea production.

Tea Yields (millions Kg)	N	Sum in millions kg	Mean in Millions	Std. Deviation in millions
January	21	50.39	2.40	1.38
February	21	39.43	1.88	0.89
March	21	37.42	1.78	0.90
April	21	45.34	2.16	0.99
May	21	51.81	2.47	1.28
June	21	47.21	2.25	0.97
July	21	45.60	2.17	0.91
August	21	46.16	2.20	0.89
September	21	47.43	2.26	0.92
October	21	51.79	2.47	1.21
November	21	49.07	2.34	1.05
December	21	49.21	2.34	0.96
Valid N (listwise)	21			

Source: computed from field data, 2015

Table 4.7: Tea Yields from January to December over 1993 – 2013

The regression analysis indicated that there was a growth in tea yields forming a relationship with the number of years from 1993-2013. Indeed, most farmers in Bomet Central Sub-County preferred growing tea to other crops. The regression model connecting the tea yields and time is given by:

$V = -3418611000.511 + 1720076.548Y$ Equation 2

Where V refers to tea yields and Y refers to time in years (Table 4.8).

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	-3418611000.511	279452279.895		-12.233	.000
	Years from 1993–2013	1720076.548	139516.227	.943	12.329	.000

a. Dependent Variable: Annual tea yields (Kg)

Source: computed from field data, 2015

Table 4.8: Regression Model for Tea Yields Time Series

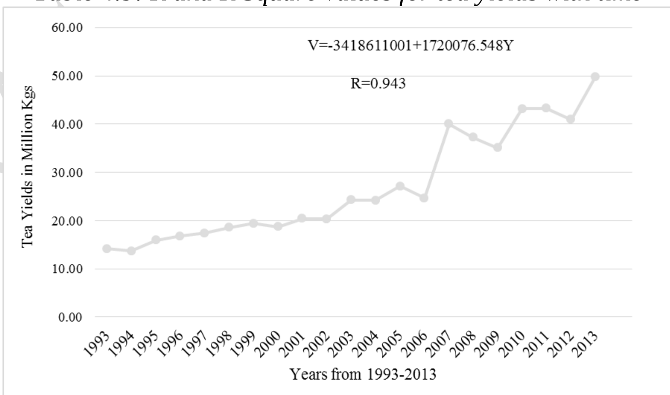
The correlation co-efficient R = 0.943 indicated a very strong correlation between the tea yields and years (Figure 4.4). This showed that as the time in years increased from 1993–2013, the production of tea also increased. The coefficient of determinant was $R^2 = .889$ which means that 88.9% of the data was used while 11.1% can be based on other factors that affect the production of tea (Table 4.9).

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.943[a]	.889	.883	3871418.186

a. Predictors: (Constant), Years from 1993-2013

Source: computed from field data, 2015

Table 4.9: R and R Square values for tea yields with time



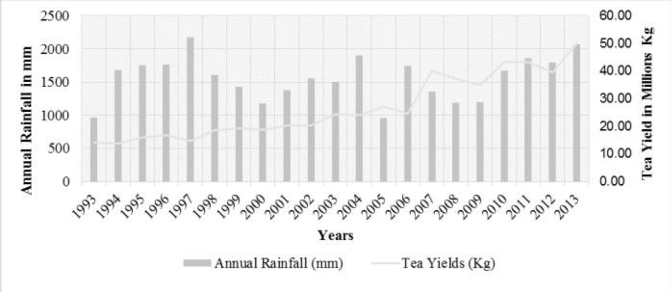
Source: computed from field data, 2015

Figure 4.4: Time series analysis for tea yields from 1993–2013

d. RELATIONSHIP BETWEEN RAINFALL VARIABILITY AND TEA PRODUCTION FROM 1993–2013

The Figure 4.5 shows the variability of the tea production per year in Bomet Central sub-County. There has been an increase of tea production from 1993–2013 with a marked increase in productivity from 2007 to 2013. The technological improvements such as fertilizer inputs and introduction of high yielding cultivars have led to the overall increase in tea production. However, a significant drop was observed in 1997, 2006, 2009 and 2012. The loss of tea in the year 1997 was about 12% compared to the 1996 while the loss in the year 2006 was 9% compared to the 2005. There was a remarkable increase of tea yields in year 2013 due to high and well distributed rainfall throughout the year (TBK, 2014). Over the past 21 years, 2013 recorded the highest production level at 432.2 million kilograms countrywide (TBK, 2014).

Comparing the annual rainfall and tea yield in the study area revealed that some years with low annual rainfall still recorded high production of tea (as was the case in 2007 and 2009) (Figure 4.5). This could be attributed to rainfall distribution patterns. Tea yield per hectare is largely influenced by the rainfall distribution rather than total rainfall in the year (Wijeratne *et al*, 2007).



Source: computed from field data, 2015

Figure 4.5: Tea yields (Kg) and Rainfall (mm) over 21 years for in Bomet Central sub-County

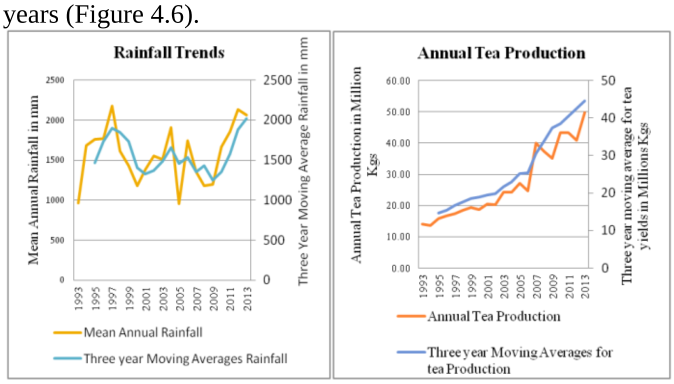
The Pearson correlation between the tea yields in Kgs and average annual rainfall in mm indicated weak positive relationship R=0.122 (Table 4.10). This indicated that with an increase in rainfall, there was a slight increase in amount of tea produced. Consequently, the study rejected the first research hypothesis that there is no significant relationship between rainfall variability and the amount of tea produced by smallholder tea farmers in the study area.

		Annual tea yield (Kg)	Average rain in mm
Annual tea yield (Kg)	Pearson Correlation	1	0.122
	Sig. (2-tailed)		0.599
	N	21	21
Average rain in mm	Pearson Correlation	0.122	1
	Sig. (2-tailed)	0.599	
	N	21	21

Source: computed from field data, 2015

Table 4.10: Covariance for the year 1993–2013 on rainfall in mm and tea yields in kg

Further analysis was done on total rainfall and tea production from 1993 to 2013. The 3 year moving average indicated that between 1993 and 2003 the rainfall declined and from 2003 to 2013 the rainfall trend increased by about 40 mm per year but the tea production has steadily increased over the years (Figure 4.6).



Source: computed from field data, 2015

Figure 4.6: Variability of rainfall and annual tea production from 1993–2013 in Bomet Central sub-County

A model was attained from analysis where the dependent variable was tea yield and the independent variable was the annual rainfall and number of years under investigation. The model is given by:

Annual Tea Yields = -3414918214 + 323.859 [Annual rain in mm] + 1717980.889 [Year] Equation 3

This model indicated that 323.859 Kgs of tea was produced per one mm of rainfall. On the other hand, the year factor produced 1,717,980.889 Kgs of tea and this can be used as a predictor for the further years beyond 2013 (Table 4.11). The regression model indicates that at any time, one can estimate the amount of tea yield produced based on the year of production and the rainfall amount in that given year. This shows that despite the year of production, rainfall plays a major role in production of tea. Hence, smallholder tea farmers need to use adaptation strategies to reduce the effects of rainfall variability on tea production.

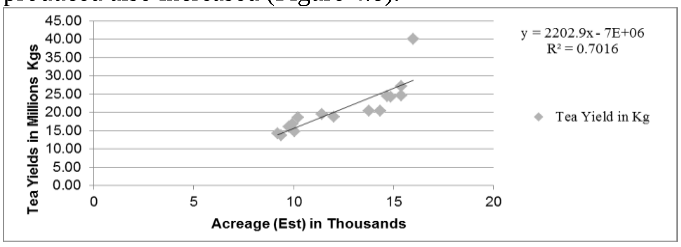
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-3414918213.516	288588886.212		-11.833	.000
	Average rain in mm	323.859	2659.087	.010	.122	.904
	Years from 1993–2013	1717980.889	144309.761	.942	11.905	.000

a. Dependent Variable: Annual tea yields (Kg)

Source: computed from field data, 2015

Table 4.11: Regression analysis between annual tea yields, rainfall and years from 1993–2013

Analysis was done on relationship between tea yields and acreage under tea from 1993 to 2013. The results showed that R = .838 which is a strong positive relationship between tea yields and acreage under tea in Bomet Central sub-County (Figure 4.7). This shows that the number of smallholder tea farmers has been increasing over the years from1993–2013 in Bomet Central sub-County. This is mainly brought about by constant payments made on tea and tea bonuses which make farmers to start growing tea in their farms (CPDA, 2008). Hence as the acreage under tea increased, the amount of tea produced also increased (Figure 4.8).



Source: computed from field data, 2015

Figure 4.7: Relationship between Tea yields and Acreage (Estimate)

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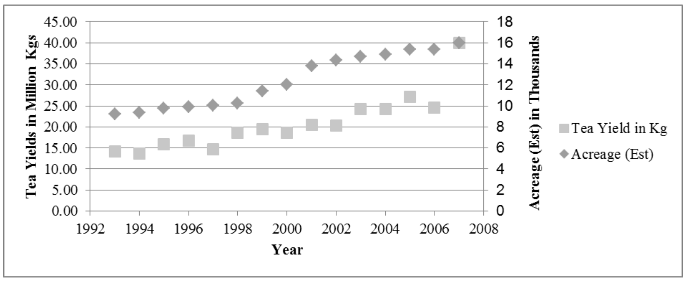
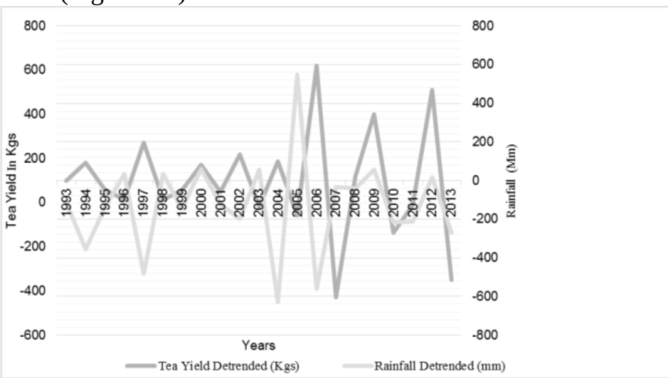


Source: computed from field data, 2015

Figure 4.8: Relationship between Tea yields and Acreage (Estimate)

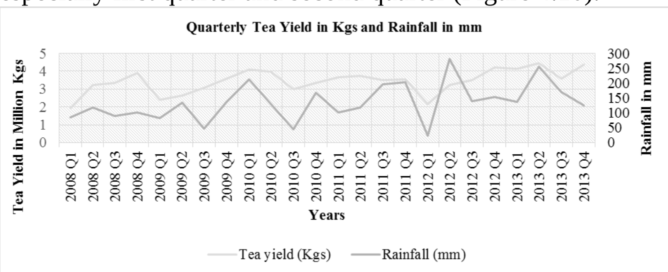
The detrended data for tea yields and rainfall were analyzed using moving average of 3 years. The results showed a negative correlation between the detrended tea yields and rainfall from 1993–2004 and a positive correlation from 2005–2013 (Figure 4.9).



Source: computed from field data, 2015

Figure 4.9: Detrended rainfall (mm) and Tea yield (kg) using 3 year moving average

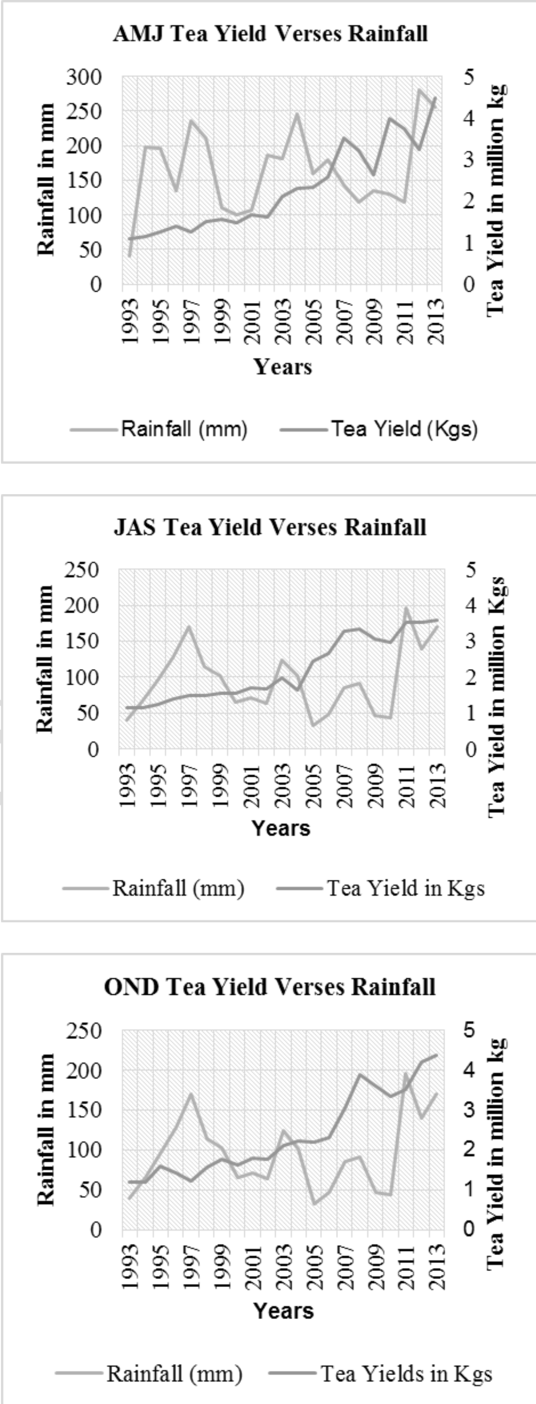
Similarly, the Pearson correlation between the average quarterly tea yields and rainfall from 2008–2013 indicated weak positive relationship (R=0.306). There was significant relationship between the quarters of tea yields and the rainfall especially first quarter and second quarter (Figure 4.10).



Source: computed from field data, 2015

Figure 4.10: Tea yields in Kg and Rainfall in mm from 1993–2013 in Bomet Central sub-County

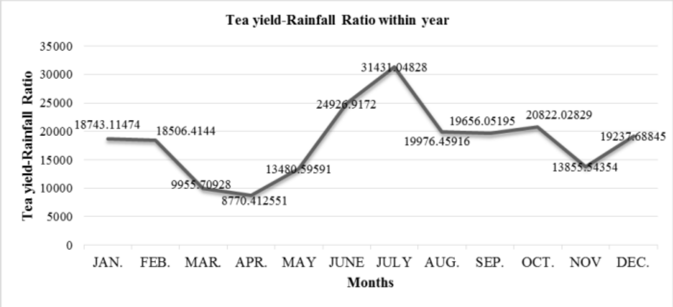
Tea and rainfall data were also extrapolated to obtain quarterly report per year of tea yield and seasonal rainfall. Figure 4.11 clearly shows that JFM and AMJ rainfall seasons are the most variable, while the JAS and OND have least variability. There appears to be a slight increase in AMJ, JAS and OND seasonal rains beginning in the year 2010. The study showed that for the period 1993–2013, high rainfall (wet seasons) were experienced in the month of April, May, June (AMJ season). Tea yields also increased significantly beginning in the year 2007 in all the seasons. From the figure, there was a significant relationship between the seasonal rainfall and tea yields in JFM and JAS seasons which are the dry seasons having less than 200 mm of rainfall per quarter.



Source: computed from field data, 2015

Figure 4.11: Quarterly tea yields and rainfall from 1993–2013 in Bomet Central sub-County

Analysis on tea yield–rainfall ratio was also done to determine the amount of tea yield per 1mm of rainfall. It was noted that July which marks the end of first rain season recorded the highest tea yield per 1mm of rainfall. April and November which marks the peak of rain seasons, recorded lowest tea yield–rainfall ratio. It means that too much rainfall does not necessarily represent high production return per 1 mm of rainfall increase. This relationship was identified by plotting the tea yield– rainfall ratio against months (Figure 4.12).



Source: computed from field data, 2015

Figure 4.12: Tea yield–Rainfall Ratio within Year in Bomet Central sub-County from 1993–2013

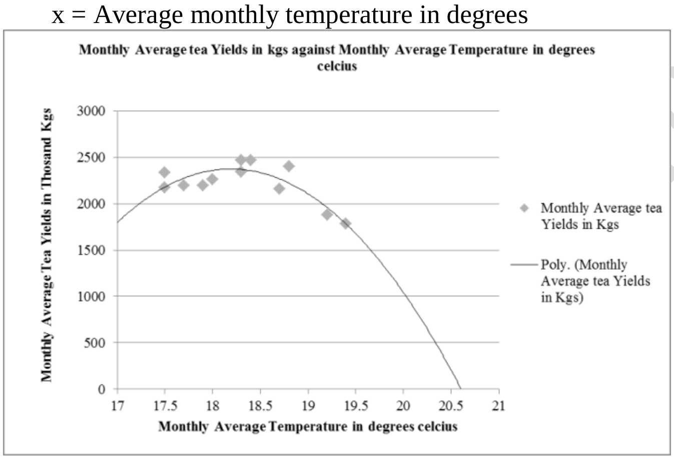
e. RELATIONSHIP BETWEEN TEMPERATURE VARIABILITY AND TEA PRODUCTION FROM 1993–2013

After using a plot graph, curvilinear regression was attained with aid of SPSS Non- linear regression analysis. The data indicated that there was a strong positive relationship between tea yields and changes in temperature (Figure 4.13). This is given by the following quadratic equation.

$$y = -158360226.873 + 17607283.072x - 482192.631x^2 \quad \text{Equation 4}$$

Where, y = Average monthly tea yield in Kgs

x = Average monthly temperature in degrees



Source: computed from field data, 2015

Figure 4.13: Average monthly tea yield (Kgs) and temperature (^{o}C) from 1993–2013

The Figure 4.13 shows the quadratic relation which indicates that highest tea yields were obtained at an average temperature of 18.3^{o}C. High average temperature of 19.5^{o}C produced lowest tea yields while low temperature of 17.5^{o}C produced moderately high tea yields. There was strong coefficient of determination based on quadratic equation above of R^2= 0.825. This showed that 82.5% of variation was caused by temperature and remaining percentage was due to other factors (Table 4.14). This indicated that there exists a strong positive relationship between temperature and yield of tea. Hence, the second hypothesis was rejected that there is no significant relationship between temperature and tea production in Bomet Central sub-County.

Dependent Variable: Average Tea Yields

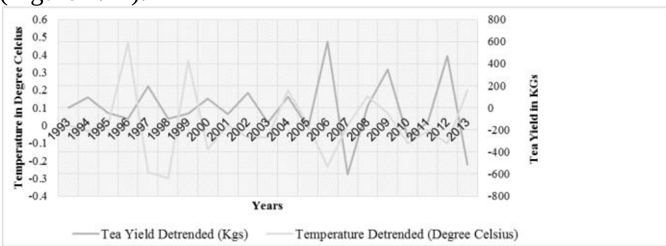
Equation	Model Summary					Parameter Estimates		
	R Square	F	df1	df2	Sig.	Constant	b1	b2
Quadratic	.825	21.164	2	9	.000	-158360226.873	17607283.072	-482192.631

The independent variable is Average Temperature.

Source: computed from field data, 2015

Table 4.12: Regression of temperature in relation to tea yield from 1993–2013

The detrended data for tea yields and temperature using moving average of 3 years was done to remove the effects of trend and to show only the differences in values from the trend. The results showed a significant relationship between temperature and tea yields. Tea yields are lowest when temperatures are either lowest or highest especially during dry season. On the other hand, tea yields are highest when temperatures are moderate particularly during the rainy season (Figure 4.14).



Source: computed from field data, 2015

Figure 4.14: Detrended Temperature (^{o}C) and Tea yield (kg) using 3 year moving average

f. RELATIONSHIP BETWEEN RAINFALL, TEMPERATURE, YEARS AND TEA YIELD.

The relationship between tea yields, rainfall and temperature over the number of years of production were analyzed to form a regression model. This indicated a correlation R = .962 which is a very strong positive relationship (96.2%) between total annual tea yield (kg), temperature (^{o}C) and the annual rainfall (mm) over the number of years of study. The regression model further indicated a co-efficient of determination R^2 = .925 which indicates that 92.5% of the data was used and that 7.5% of the data can be attributed to other factors within tea production (Table 4.13). Hence, the third hypothesis was rejected that there is no significant relationship between both rainfall and temperature and amount of tea produced by smallholder tea farmers in Bomet Central sub-County.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.962[a]	.925	.911	3373030.267

a. Predictors: (Constant), Average Temperature, Annual rain in mm, Years from 1993-2013

Source: Computed from field data, 2015

ANOVA analysis (F $_{(5\%, 2, 15)}$ = 69.422, p = .000) indicate significant relationship between dependent variable and the independent variables (Table 4.14). This means that the years of growth of tea from 1993–2013, temperature (^{o}C) and annual rain (mm) has significant relationship.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2369525798301012.000	3	78984193276700 4.000	69.422	.000[b]
	Residual	193414664089922.800	17	11377333181760.166		
	Total	2562940462390935.000	20			

a. Dependent Variable: Annual tea yield (Kg)
b. Predictors: (Constant), Average Temperature, Annual rain in mm, Years from 1993–2013
Source: Computed from field data, 2015.

Table 4.13: ANOVA (Analysis of Variance) for Regression analysis

The model was attained from analysis where the dependent variable was tea yield and the independent variables were the years of tea production and annual rainfall from 1993–2013. The model is given by;

$$V = -3661221173.159 - 1135.543R - 5833039.740T + 1895597.898Y \quad \text{Equation 5}$$

Where V –Tea Yields in Kgs,
R – Rainfall in mm
T – Temperature in ^{o}C
Y – The year

The model indicated a decrease of 1135.543 Kgs per one mm increase of rainfall, a decrease of

5833039.740 Kgs tea yields per one ^{o}C and increase of 1895597.898 Kgs of tea yields with increase of one year. This can be used as a tool of tea production estimates in future (Table 4.15).

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
(Constant)	-3661221173.159	259841000.083		-14.090	.000
Years from 1993-2013	1895597.898	137578.770	1.039	13.778	.000
Annual rain in mm	-1135.543	2314.097	-.034	-.491	.630
Average Temperature	-5833039.740	2061137.692	-.214	-2.830	.012

a. Dependent Variable: Annual tea yields (Kg)
Source: Computed from field data, 2015

Table 4.14: Regression analysis on tea yields, rainfall, temperature and time from 1993–2013

The regression model indicated that at any time one can estimate the amount of tea yield produced based on the year of production, temperature and the rainfall in that given year. This showed that despite the year of production, rainfall and temperature variability plays a big role in production of tea. Hence, rainfall and temperature variability need to be moderated by using adaptation strategies.

V. SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

A. INTRODUCTION

This chapter deals with summary of the findings, conclusion and recommendations of this study and areas of further research. The main objective of this study was to evaluate the effects of climate variability on tea production in Bomet Central sub-County, Bomet County from 1993–2013.

B. SUMMARY OF THE FINDINGS

The objective of the study was to evaluate the effects of rainfall and temperature variability on smallholder tea production in the study area. The study established that in the period 1993–2013, Bomet County experienced a slight increase in rainfall and temperature trend of 6.471mm and about 0.029^{o}C respectively per year. Pearson correlation showed that there was a weak positive relationship between rainfall variability and tea production R=0.122 (R^2=0.015). Consequently, the study rejected the first research hypothesis that there is no significant relationship between rainfall variability and the amount of tea produced by smallholder tea farmers in the study area.

The study also established that there exists a strong relationship between temperature and tea yields R=0.908 (R^2=0.825). Hence, the second hypothesis was rejected that there is no significant relationship between temperature and tea production in in the study area. The quadratic relation indicated that highest tea yields were obtained at average temperature of 18.25^{o}C while average temperature of 19.5^{o}C and 17.5^{o}C produced lowest and moderately high tea yields respectively. In addition, the results showed that there was a very strong positive relationship (96.2%) between total annual tea yield, temperature (^{o}C) and the annual rainfall in (mm) over the number of years of study. Hence, the third hypothesis was rejected that there is no significant relationship between both rainfall and temperature and amount of tea produced by smallholder tea farmers in Bomet Central sub-County.

C. CONCLUSION

Based on the findings of this study, rainfall variability has negatively affected tea production in Bomet Central sub-County. The covariance on rainfall for the years under study was found to be 102.96 mm. This shows that there was substantial change in rainfall patterns and if not taken into consideration will affect the tea farming in Bomet. The maximum tea yields were attained in May with 2.47 million Kgs at peak of first rain season and October with 2.47 million Kgs which marks the peak of second rain season. A significant drop of tea yields was observed in 1997, 2006, 2009 and 2012 due to dry weather conditions. The loss of tea in the year 1997 was about 12% compared to the previous year while the loss in the year 2006 was 9% compared to the previous year. This indicates that rainfall is a very important factor for sustainable tea production.

The study also concluded that in Bomet Central sub-County, there is an evidence of temperature variability and it had an impact on tea yields. It was noted that there was a positive correlation between temperature and tea yields. However, extreme temperature either hot or cold reduces tea production and is seen as a major threat to tea production in Bomet Central sub-County.

D. RECOMMENDATIONS

- ✓ The study recommends that farmers be advised to establish and manage shade trees in their tea farms so as to reduce ambient temperature around the tea bushes, add organic matter to soil and reduce drought effects.

E. RECOMMENDATION ON FURTHER RESEARCH

The following areas should be further researched on;

- ✓ Further research should be done on effects of other climatic and non-climatic factors on tea production in Bomet central sub-County.
- ✓ Research on the best tea clones suitable for Bomet County with respect to climate variability.

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