

CLIMATE VARIABILITY AND ITS IMPACTS ON SMALLHOLDER TEA FARMING IN MULANJE DISTRICT

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DECLARATION

I *Patrick Chiwalo* declare that this research project represents my work and that it has never been submitted to this institution or any other institution for any academic purpose. All sources of information have been appropriately acknowledged.

Signature: 

Date: 20 July 2021

DISSERTATION APPROVED BY:

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This document describes work undertaken as part of a program of study at Ndata School of Climate and Earth Sciences of the Malawi University of Science and Technology. All views thoughts and opinions expressed in this report remain the sole responsibility of the authors, and not necessarily to the university.

DEDICATION

I dedicate this work to my family. Mr Trust D. Chiwalo and Mrs Grace Chiwalo, daddy and mommy, your love for one another and your sons have made reach this far. I will be forever grateful to God for giving me the best parents in the world. To my brothers, Precious, Promise, Praise, Ernest and Elliot, my sister-in-law Wongani and Aunt Cathy, thank you all for your encouragement.

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ABSTRACT

The study evaluated the variability and trends of rainfall and temperature from 1988 to 2020 and assessed the impacts of climate variations on smallholder tea farming in the Mulanje district. The study found that the annual rainfall was decreasing, although the trend was not significant. The study also found that annual mean temperature had a significant increasing trend. The study also found that yields reduced when annual rainfall was above or below the range of 1200-1750 mm. The study also found that the annual mean temperature did not have a significant effect on tea yields. The study also found that the climate adaptation measures that have been taken in the smallholder tea sector in Mulanje have made tea be resilient to droughts and temperature fluctuations but not to high amounts of rainfall. The rainfall and temperature data was retrieved from the DCCMS for 33 from 1988 to 2020 while the smallholder farmers' tea yield data was retrieved from Sukambizi Association trust for 20 years 2001 to 2020. The Mann-Kendall test was used to analyse the trends in weather parameters and the correlation test was used to analyse the relationship between smallholder farmers' tea yields and weather parameters. The study concluded that the variations in weather parameters affect smallholder tea yields.

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ACRONYMS AND ABBREVIATIONS

CI4TEA	Climate Information for Resilient Tea Production
CIAT	International Centre for Tropical Agriculture
DCCMS	Department of Climate Change and Meteorological Services
IPCC	Intergovernmental Panel on Climate Change
MATECO	Malawi Tea Company
SAT	Sukambizi Association Trust
STA	Smallholder Tea Authority
STECO	Smallholder Tea Company
STGT	Smallholder Tea Growers Trust
Tmax	Maximum Temperature
Tmin	Minimum Temperature
Tmean	Mean Temperature
WMO	World Meteorological Organisation

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CHAPTER 1: INTRODUCTION

1.1 Background

Climate and weather variables play a major role in crop production. Climate is the average or mean state of the atmosphere over a long time preferably 30 years or more. When observing average weather conditions in long time frames like 30 years or fewer variations can be seen but if we lower the range of our observation more variation is seen. According to the WMO (2021), Climate variability is the variations in the mean state and other statistics of the climate on all temporal and spatial scales, beyond individual weather events and it is measured by deviations, which are usually termed as anomalies. According to IPCC (2007) "Climate change is the change in the state of climate which can be statistically identified by changes in mean and/or variability of its properties".

Climate is an important factor that determines whether a crop will thrive or fail in an area. The climatic requirements vary from crop to crop. Some crops may thrive at a wide range of climatic conditions while some only at a narrow range. Tea for example has a narrow range of conditions that need to exist for it to thrive in an area, as evidenced by the beginning of tea farming in Malawi where the crop was tried in some areas like Zomba and Mwanza but only found success in two neighbouring districts which are located in the Shire Highlands, Thyolo and Mulanje (Hadlow, 1960). Malawi is only second to Kenya when it comes to tea production in Africa. 94% of the tea is produced in large estates, most of which are owned by foreign entrepreneurs and firms, while the rest is produced by approximately 75000 small-scale farmers who share 14% of tea farmland (TopicTea Team, n.d.).

Climate change poses a threat to tea production in Thyolo and Mulanje. The changes in temperatures and rainfall may make the districts no longer conducive to tea production. This in turn poses a threat to the economy as tea is one of Malawi's major exports. Smallholder tea farmers are one the most vulnerable groups to climate change and variability in the tea industry due to other factors like low literacy and lack of access to loans (Malawi CARER, 2007).

1.2 Problem Statement

Smallholder tea farmers in Malawi have income levels below the optimum due to challenges in production (Malawi Tea 2020, 2016). According to the General Manager of Sukambizi Association Trust Mr A. Changazi (Personal Communication, May 15, 2021), tea farmers in Malawi produce below the optimum level of 13000 kgs/ha. Previous studies of climate change in Mulanje have called for further study on the impacts of climate change on tea farming (Kachaje et.al., 2016). While previous studies relating climate change to tea farming focused on large tea estates, this study focused on smallholder tea farmers, who have less adaptive capabilities compared to the estates.

1.3 Main Objective and Specific Objectives

1.3.1 Main Objective

To evaluate the annual variability of temperature and rainfall from 1988 to 2020 and assess how the changes have affected smallholder tea farming in the Mulanje district.

1.3.2 Specific Objectives

I. To examine the variability trend in, monthly seasonal and annual rainfall amount from 1988 to 2020 In Mulanje.
II. To evaluate the variability and trends of monthly, seasonal and annual Temperature from 1988 to 2020 in Mulanje.
III. To establish the effect of annual rainfall amounts on smallholder tea farming in Mulanje.
IV. To assess the effect of annual temperature on smallholder tea farming in Mulanje.

1.4 Research Hypotheses

I. There has been an increasing or decreasing trend in seasonal and annual rainfall in Mulanje from 1990 to 2020
II. There has been an increasing or decreasing trend in seasonal and annual temperature in Mulanje from 1988 to 2020.

III. Rainfall amounts variations have significantly affected tea smallholder tea production in Mulanje.

IV. Temperature variations have significantly affected tea smallholder tea production in Mulanje.

1.5 Significance of Study

The study gave us an understanding of how smallholder tea farming is affected by variations in rainfall and temperature. With this understanding better climate adaptive measures can be taken to boost the tea yields and income of smallholder farmers in Mulanje.

1.6 Scope of Study

This study focused on the variability of rainfall and temperature. Other factors such as soil fertility, pest and diseases, evapotranspiration rate also affect the tea yield but they were not considered in this study.

CHAPTER 2: LITERATURE REVIEW

2.1 The climate of Malawi and Mulanje

Mulanje is located in the southern region of Malawi in an area called Shire Highlands. The climate of Malawi consists of mainly three seasons, the warm, wet season from November to April, the cool, dry winter season from May to August and the hot, dry season from September to October. The hot-dry season is characterized by a mean temperature range between 25°C to 37°C and little amount of precipitation whereas the warm-wet season is when approximately 95% of annual precipitation takes place and the cool-dry winter season is characterized by a mean temperature range between 17°C to 27°C and temperatures might fall up to 4°C to 10°C (Department of Climate change and Meteorological Services (DCCMS), 2020).

The warm wet season is the main rainfall season in Malawi. The rain-bearing systems during this period are the Inter-Tropical Convergence Zone (ITCZ), Congo Air mass, Easterly waves and Tropical cyclones and these are influenced by mean sea level pressure, upper-level wind and Sea Surface Temperature over the Pacific, Indian and Atlantic tropical oceans (DCCMS, 2020). The wet season is also characterized by a short break in rainfall or a reduction in rainfall amounts in February and the southern parts of Malawi (Nicholson et.al., 2014)

During the cool, dry winter season, the Shire Highlands experience south-east trade winds which originate from the Indian Ocean and these winds are known as Chiperoni winds. These winds are regional winds that blow over Zimbabwe, Zambia and Malawi. The Chiperoni winds are named after the Chiperoni mountain in Mozambique which is located approximately 100 kilometres southeast of Mulanje. The Chiperoni winds bring about mist and light rains in form of drizzles.

The climate of Mulanje is characterized by an average annual rainfall of 1600 mm and an average temperature of 21-23 °C. Figures 1 and 2 show the average monthly rainfall and temperature distribution in the Mulanje district.

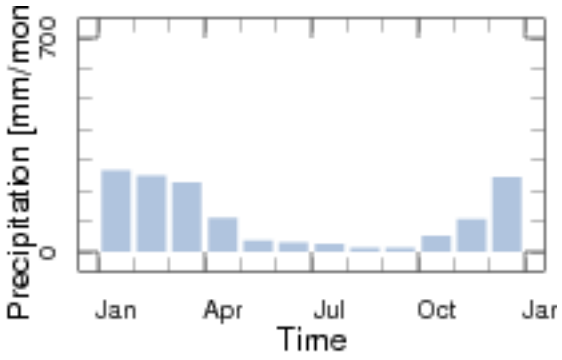


Figure 1: Mulanje Average Monthly Rainfall

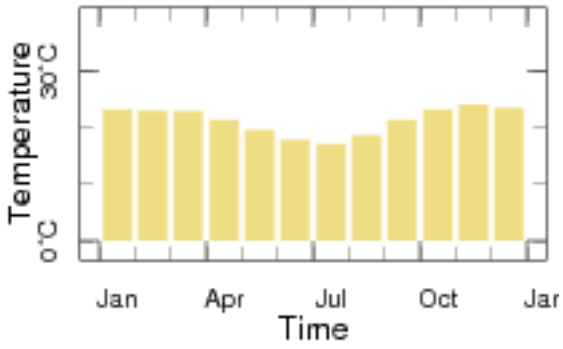


Figure 2: Mulanje Average Monthly Temperature

2.2 Malawi Climate Change Scenario

It is a fact that the climate of Malawi is changing. Observations show that between 1960 and 2006 temperatures increased by an average of 0.9 °C and annual seasonal rainfall for the months of March to December decreased but an increase has been noticed in January and February (Trocaire, 2014).

Malawi is an agriculture-based economy that relies mainly on rain-fed agriculture. Climate change has taken a huge toll on the country's economy. Malawi is vulnerable to climate change impacts, for example, due to climate change 60% of the population is food insecure year after year (Trocaire, 2014).

Future climate model projections for Malawi show that the mean annual temperature will increase by about 2.3-6.3°C by the 2090s and weather extremes such as droughts and floods will increase, also days with temperatures more than 30°C will increase (Climate Information for Resilient Tea Production (CI4TEA), 2019). These projected conditions will be detrimental to the agriculture in Malawi, even Tea farming, and to the country's economy at large.

2.3 Tea farming in Malawi

Malawi is the second largest tea producer in Africa after Kenya. In Malawi tea is grown in three districts, Nkhata-Bay, in the northern region, Mulanje and Thyolo in the southern region. However, a large proportion of tea is grown in Mulanje and Thyolo. 94% of the tea is produced in large estates, most of which are owned by foreign entrepreneurs and firms, while the rest is produced by approximately 75000

small-scale farmers who share 14% of tea farmland (TopicTea Team, n.d.). Tea farming contributes much to the economy of the country, for example, 8% of Malawi's annual export earnings are from tea (Future Climate Africa, 2019). Tea production also registered a profit of $11 million in 2016 (TopicTea Team, n.d.).

Tea requires more than 1200 mm annual rainfall to survive in a place, Thyolo and Mulanje meet this requirement, that is why tea farming has thrived in these districts (Future Climate Africa, 2019). Morris (2015) claimed that another factor that makes Thyolo and Mulanje conducive for Tea farming is the light rains and mist brought by the Chiperoni winds during the cool, dry winter season. At this time Thyolo and Mulanje receive a significantly higher amount of precipitation than other districts in the Shire Highlands. Tea is harvested all year round but the main harvesting season runs from the month of December to April, a time falling in the warm-wet season.

2.4 Smallholder Tea Farming in Mulanje

The smallholder tea farming sector started in the early 1960s, towards the end of colonial rule in Malawi. The sector is considered to have formally started with the establishment of the Smallholder Tea Authority (STA), a state-owned enterprise responsible for the development of the smallholder tea sector, in 1967 (Chirwa & Kydd, 2005). The genesis of the smallholder tea sector in Malawi was due to a government initiative to increase the participation of local farmers in tea farming (Chirwa & Kydd, 2005). The sector grew rapidly from 1970 to 1979 where about 130 hectares were planted each year (Chirwa & Kydd, 2005). This growth is attributed to the good services which were provided by STA during this time. During this time, the STA provided farmers with extension services, transportation, free seedlings, inputs on credit, maize on credit for new farmers to sustain them as they wait for their tea to mature and start giving out its economic value (Chirwa & Kydd, 2005; Malawi CARER, 2007). The STA also made timely payments to farmers, all these factors led more local farmers to venture into smallholder tea farming. During this expansion in the late 1970s, the government of Malawi through STA in conjunction with the Agriculture Development and Marketing Corporation (ADMARC) established the Malawi Tea Company (MATECO) which was responsible for buying green leaf from smallholder farmers, processing and selling it.

The smallholder tea sector encountered a lot of challenges in the early 1990s. During the change of regime at this time, most government-owned businesses, including STA and MATECO suffered gross mismanagement. This resulted in STA stopping providing some of their services such as extension services and inputs on credit, the transportation services were not timely leading to drying up of plucked green leaf value (Chirwa & Kydd, 2005; Malawi CARER, 2007). STA also started to delay farmers' payments, all these problems caused some farmers to opt-out of the sector. Other farmers started selling their green leaf to estate factories. In the early 2000s, smallholder tea farmer's associations began to emerge. These associations helped farmers to market their green leaf better and united them. Examples of these associations include; Sakumbizi Association Trust, formerly known as Sakumbizi Smallholder Tea Growers Association in Mulanje, Thyolo North Tea Growers Association and Chizunga Smallholder Tea Growers Association in Thyolo. Due to the challenges faced by STA and MATECO, a restructuring activity was undertaken and they were replaced by two other entities, Smallholder Tea Growers Trust (STGT) and Smallholder Tea Company (STECO). STGT was an association to which all smallholder tea farmers were supposed to belong to whereas STECO was a government-owned company that purchased and processed smallholder green leaf. Even though the restructuring occurred some farmers did not return to sell their tea to STECO. STECO also incurred debts and was later sold to private individuals in 2006.The challenges faced by STA and MATECO leading to the emergence of the smallholder tea farmer's association really revolutionised the smallholder tea sector in Malawi.

The smallholder tea sector in Mulanje though changed, still faces one long-term challenge, namely, climate change. In the past 20 years a series of droughts that occurred negatively affected the smallholder tea sector, by reducing yields. Some factors that exacerbate the problem of climate change are that fertilizers are expensive such that smallholder farmers cannot afford and seedlings are not easily accessible. Low literacy of the smallholder farmers hinders them from making proper management decisions, therefore, exacerbating the impacts of climate change.

2.5 Climate Adaptation in Malawian Smallholder Tea Sector

In recent years many organisations have been working to improve the tea sector in Malawi. In 2015 a programme aimed at reviving the tea sector in Malawi, called Malawi Tea 2020 was launched (Malawi Tea 2020, 2016). Organisations such as Tea Association of Malawi Limited, Ethical Tea Partnership, Oxfam, Unilever and UTZ are some of the partners in this programme. The fourth pillar of this programme is called Profitable Smallholder Sector. One of the focuses of this pillar is farmer field schools which teach smallholder farmers better farming methods that are climate-sensitive (Malawi Tea 2020, 2019).The Tea Research Foundation of Central Africa (TRFCA) also provided improved drought resilient varieties. These activities have worked to improve the smallholder sector and its evidenced by a tremendous increase in yields.

2.6 Tea Farming and Climate Change

Tea cultivation is a perennial rain-fed mono-cropping system of agriculture therefore its optimal growth depends on weather conditions (Han et al, 2018). Weather parameters such a Solar Radiation, Temperature, Precipitation and Humidity are very crucial for the optimal growth of tea. Studies have established that tea is one of the crops that will be adversely affected by climate change (Ochieng et.al, 2010, cited in Han et.al, 2018). The International Center for Tropical Agriculture (CIAT) (2017) pointed out that climate change poses a substantial risk to tea farming in Malawi. To understand how climate change will impact tea production, we need to know how each weather parameter affects the crop. This section as well as this study focused on temperature and precipitation.

2.6.1 Tea Yields and Temperature Variability

Temperature is one of the agrometeorological factors that affect tea yields. According to Hajiboland, 2017, "Tea yield is sensitive to increased average monthly temperatures, and sustained periods of higher temperatures reduce tea yield". Increasing trends in temperature in Mulanje district would therefore be a threat to smallholder tea production in the district. An increase in temperature also has the potential of making tea cultivating areas no longer suitable for the crop, therefore, leading to a significant decline in tea yields. For example, the reduction of suitable land due to temperature increases is expected to cause a tea yield loss of

approximately 40% in Eastern Africa (Adhikari et al., 2015, cited in Han et.al.). A study that was done by the International Center for Tropical Agriculture (CIAT) also projected a reduction in suitable land for tea farming in Malawi due to increasing temperature in the 2030ies and 2050ies (CIAT, 2017). The study further pointed out that the high suitability zones may migrate toward higher altitudes (CIAT, 2017). These projected changes will affect smallholder tea farming in Thyolo and Mulanje as many smallholder farmers may not have the capacity to migrate to the suitable land and they will be forced out of the tea sector. An increase in temperature in low-temperature regions or during low-temperature seasons will cause an increase in tea yield (Han et al, 2018).

Temperature also affects tea yield indirectly, as it affects insect pests. Temperature influences the life span, reproduction and dispersal of pests (Mavi & Tupper, 2004). The pests have ranges of temperature where they can survive, outside these ranges their survivability is low. Most pests are active in warm conditions and less active in cold conditions, temperature variation, therefore, acts as a control of the population of pests. Increasing temperatures during the cold seasons will aid the survival of pests in this critical time wherein they decline in number, therefore resulting in more yield losses due to pests (Han et al, 2018). The challenge posed by pests will require smallholder farmers to purchases more pesticides to prevent these losses, if they fail to do so they will fail to reach their yield potential.

2.6.2 Tea Yields and Rainfall Variability

Rainfall is also a significant meteorological variable when considering tea farming. According to Han et.al. (2018), the optimum rainfall amount required for tea is from 1500 mm to 1800 mm per annum. Erratic rainfall patterns are a very big challenge to tea farming around the world. In tropical countries, the effects of rainfall are relatively more important than temperature (Han et.al., 2018). Low amounts of rainfall lead to devastating losses in tea plantations (Juma, 2014; Ndamani & Watanabe, 2015, all cited in Bett, 2018).14 -20% reduction of tea yield and 6 – 19% of tea plant mortality is caused by drought (Cheruiyot et.al., 2008). Tea farming in Malawi has witnessed the impacts of droughts in the past for example the 2012 drought which lead to great losses (Ethical Tea Partnership, 2013). The increase in rainfall extremes as predicted by

CI4TEA is, therefore, a threat to tea farming in Mulanje. The increase in temperature will increase the evaporation rate, and this in conjunction with low amounts of rainfall will cause low amounts of soil water. Low amounts of soil water lead to lower tea yields (Bore et.al. 2013)

CHAPTER 3: METHODOLOGY

3.1 Study Area

The study area of this research is the Mulanje district, found in the southern region of Malawi. Mulanje is in a region known as the Shire Highlands, which also encompasses Thyolo, Zomba, Blantyre and Chiradzulo districts. The climatological data for this research is from the Mimosa weather station located at latitude - 16082, longitude +035583 and elevation 6530 m.

3.2 Research Design

This study was a quantitative descriptive research with two aspects. The first aspect focused on the annual and seasonal variability of minimum, maximum and mean temperature and rainfall amounts. The second aspect focused on smallholder farmers' tea production. The study finally linked the climate variables to the tea yields. Climate variables; annual rainfall amounts maximum, minimum and mean temperature were considered to be independent variables while annual tea yields were considered to be the dependent variable. All the data used in this study was secondary.

3.2.1 Climatological Data

This Climatological data were retrieved from the Department of Climate Change and Meteorological Services. The data comprised of monthly averaged maximum and minimum temperature and monthly rainfall amounts observed at Mimosa meteorological station. The period of the data was from 1988 to 2020 because the climate is defined in thirty years.

3.2.2 Tea Production Data

Annual smallholder tea farmers' yield data from 2001 to 2020 was retrieved from Sukambizi Association Trust (SAT). The tea yield data was in the form of yield per hectometre so that the results should not be affected by the increase or decrease in land used for tea cultivation.

3.3 Materials and Methods

The data collected in this research were analysed using R software and excel. Two methods of statistics were employed, namely the Mann-Kendall trend test and

correlation. The climatological data were analysed using the Mann-Kendall trend test and the relationship between the climatological data was analysed using the correlation test.

3.3.1 Mann-Kendall Trend Test

To achieve objectives 1 and 2 the Mann-Kendall trend test was used. This method gave the types researcher the trends in seasonal and annual rain amounts, average maximum, minimum and mean temperature. This test is a non-parametric test which suitable for data that is not uniformly distributed like most meteorological data is. The null hypothesis, H_0, for this test is that there is no monotonic trend in the variable and the alternative hypothesis H_1, is that a monotonic trend exists (whether increasing or decreasing) (Goswami, 2017). The following equations are used to calculate the Mann-Kendall statistic (S) and the standardized Mann-Kendall statistic (z_{mk}):

$$sgn(x_i - x_j) = \begin{cases} 1, & x_i - x_j > 0 \\ 0, & x_i - x_j = 0 \\ -1, & x_i - x_j < 0 \end{cases}$$

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_i - x_j)$$

If the value of S is positive, it shows an increasing trend, if negative it shows a decreasing trend if zero it shows neither an increasing nor decreasing trend. To get to the standardized Mann-Kendall variance must be computed first.

$$\sigma^2 = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j-1)(2t_j+5)\right]$$

where p is the number of tied groups in the data set, that is a set of sample data with the same values (Polert, 2020; Birara et al, 2018). t_j is the number of data points in the j^{th} tied group. Upon computing the variance then the standardized Mann-Kendall statistic, z_{mk} is computed as follows:

$$z_{mk} = \begin{cases} \frac{S-1}{\sigma} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sigma} & if \quad S < 0 \end{cases}$$

A positive z_{mk} value indicates an increasing trend while a negative value indicates a decreasing trend. When the $|z_{mk}| > z_{\alpha/2}$ then the null hypothesis is rejected. This test was conducted at a p-value of 0.05 where the $z_{\alpha/2}$ is 1.96.

3.3.2 Correlation Test

The third specific objective was accomplished using correlation. The crop yield was the dependent variable and it was correlated to the seasonal and annual rainfall amounts and mean temperature as the independent variables. The results of this analysis were coefficient of correlation, r. The values of the coefficient of correlation range from -1 to +1. When r is approaching -1, it shows that the variables have a strong negative correlation while when r is +1, it shows that the variables are in positive correlation. When r is approaching 0, it shows that the variables have a weak correlation. Positive correlation occurs when an increase in the independent variable corresponds to an increase in the dependent variable and negative correlation occurs when an increase in the independent variable corresponds to a decrease in the dependent variable (Woodbury, 2002).

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n(\sum x^2) - (\sum x)^2][n(\sum y^2) - (\sum y)^2]}}$$

To check the significance of r the t-Test for correlation coefficient was used at a significance level of 95%. The formula for this test is:

$$t = r\sqrt{\frac{n-2}{1-r^2}}$$

where n-2 is the degrees of freedom.

The null hypothesis of this analysis is that there is no correlation between x and y while the alternative hypothesis is that a significant correlation exists between the two

variables (Bluman, 2012). The null hypothesis is therefore rejected when the p-value is less than alpha, which in this case is 0.05.

CHAPTER 4: RESULTS AND DISCUSSIONS

3.1 Introduction

This chapter covers the data analysis and discussions and this chapter corresponds to the objectives of the study. The main objective of the study was to assess the seasonal and annual variability of temperature and rainfall from 1988 to 2020 and how the changes have affected smallholder tea farming in the Mulanje district.

3.2 Mulanje Rainfall Variability

This section gives the analyses of the variability of monthly, seasonal and annual Rainfall of Mimosa weather station in Mulanje from 1988 to 2020. The table below shows the results of the Mann-Kendall analysis for the monthly seasonal and annual rainfall in Mulanje.

Table 1: Mann-Trend test results for Rainfall

Month	S	Var (S)	zmk	p-value	Interpretation	Trend
JAN	-6	3802.67	-0.081	0.935	Accept	NST
FEB	6	3802.67	0.081	0.935	Accept	NST
MAR	-8	3802.67	-0.114	0.910	Accept	NST
APR	24	3802.67	0.373	0.709	Accept	NST
MAY	-32	3802.67	-0.503	0.615	Accept	NST
JUN	-15	3801.67	-0.227	0.820	Accept	NST
JUL	-28	3794.00	-0.438	0.661	Accept	NST
AUG	-156	3794.00	-2.516	0.012	Reject	Decreasing
SEP	-41	3677.67	-0.660	0.510	Accept	NST
OCT	-29	3801.67	-0.454	0.650	Accept	NST
NOV	-48	3802.67	-0.762	0.446	Accept	NST
DEC	5	3801.67	0.065	0.948	Accept	NST
COOL DRY	-78	3802.67	-1.249	0.212	Accept	NST
HOT DRY	-87	3801.67	-1.395	0.163	Accept	NST
WARM WET	-16	3802.67	-0.243	0.808	Accept	NST
ANNUAL	-56	3802.67	-0.892	0.372	Accept	NST

Table 4 shows that all the months have a decreasing trend in rainfall except February and December. The only month that has a statistically significant trend was August, which is also decreasing. All the seasons also showed a decreasing trend although none of them was statistically significant. The annual rainfall also showed a decreasing trend which was not statistically significant.

Figure 4, below shows that the annual rainfall varied in the range of 673 mm to 2266 mm. The year with the highest rainfall was 2015 with 2266 mm, then 1989 with 2198 mm, then 2000 with 1891. The year with the lowest rainfall was 1992 with 673 mm, then 2005 with 947 mm, then 2014 with 1241 mm. Indeed, annual rainfall amounts have fluctuated but the trend in annual rainfall is fairly constant. The average mean rainfall for the period was 1581 mm and the standard deviation was 320.6 mm.

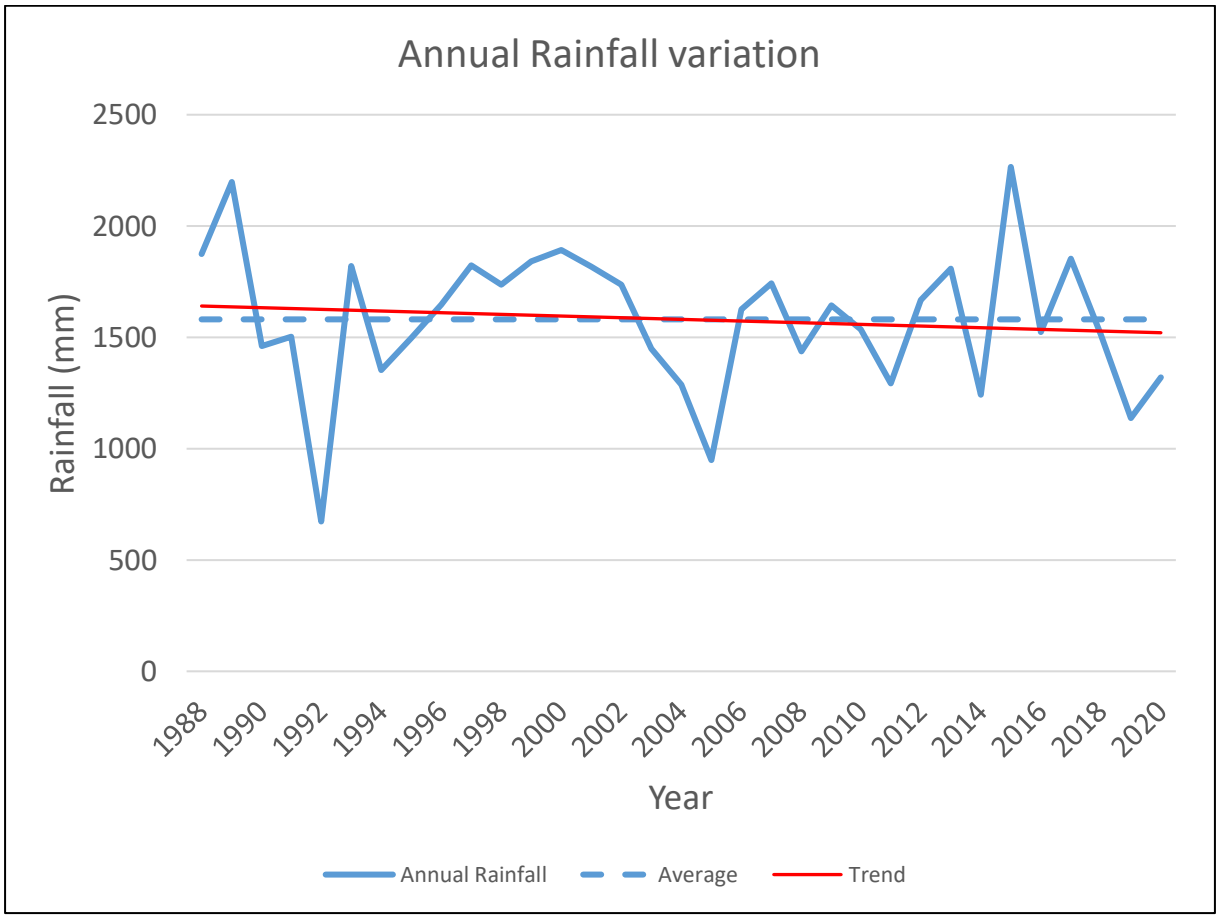


Figure 3: Graph showing annual variability of Rainfall

3.3 Temperature Variability

This section gives the analyses of the variability of monthly, seasonal and annual maximum, minimum and mean Temperature of Mimosa weather station in Mulanje from 1988 to 2020.

3.3.1 Maximum Temperature Variability

Table 2: Mann-Trend test results for Maximum Temperature

Month	S	Var (S)	Z_{mk}	p-value	Interpretation	Trend
JAN	-1	3788.33	0	1	Accept	NST
FEB	39	3788.33	0.61739	0.537	Accept	NST
MAR	-22	3791.33	-0.34105	0.7331	Accept	NST
APR	-37	3787.67	-0.58495	0.5586	Accept	NST
MAY	27	3790.33	0.42231	0.6728	Accept	NST
JUN	-42	3792.00	-0.66581	0.5055	Accept	NST
JUL	-33	3793.00	-0.51959	0.6034	Accept	NST
AUG	129	3787.00	2.08	0.03753	Reject	Increasing
SEP	109	3790.33	1.7542	0.07939	Accept	NST
OCT	87	3797.00	1.3957	0.1628	Accept	NST
NOV	41	3789.00	0.64983	0.5158	Accept	NST
DEC	65	3792.33	1.0393	0.2987	Accept	NST
COOL DRY	41	3779.67	0.65063	0.5153	Accept	NST
HOT DRY	110	3769.33	1.7754	0.07583	Accept	NST
WARM WET	25	3785.67	0.39007	0.6965	Accept	NST
ANNUAL	101	3783.00	1.6259	0.104	Accept	NST

According to the results displayed by the table, there was not much of an increasing or decreasing trend in the month of January. March, April, June and July, on the other hand, showed a negative trend and the rest of the months show a positive trend. From trends observed only the trend of the month of August was statistically significant. All the seasons showed increasing trends although none of them was

statistically significant. The Annual maximum temperature also showed an increasing trend, although not statistically significant.

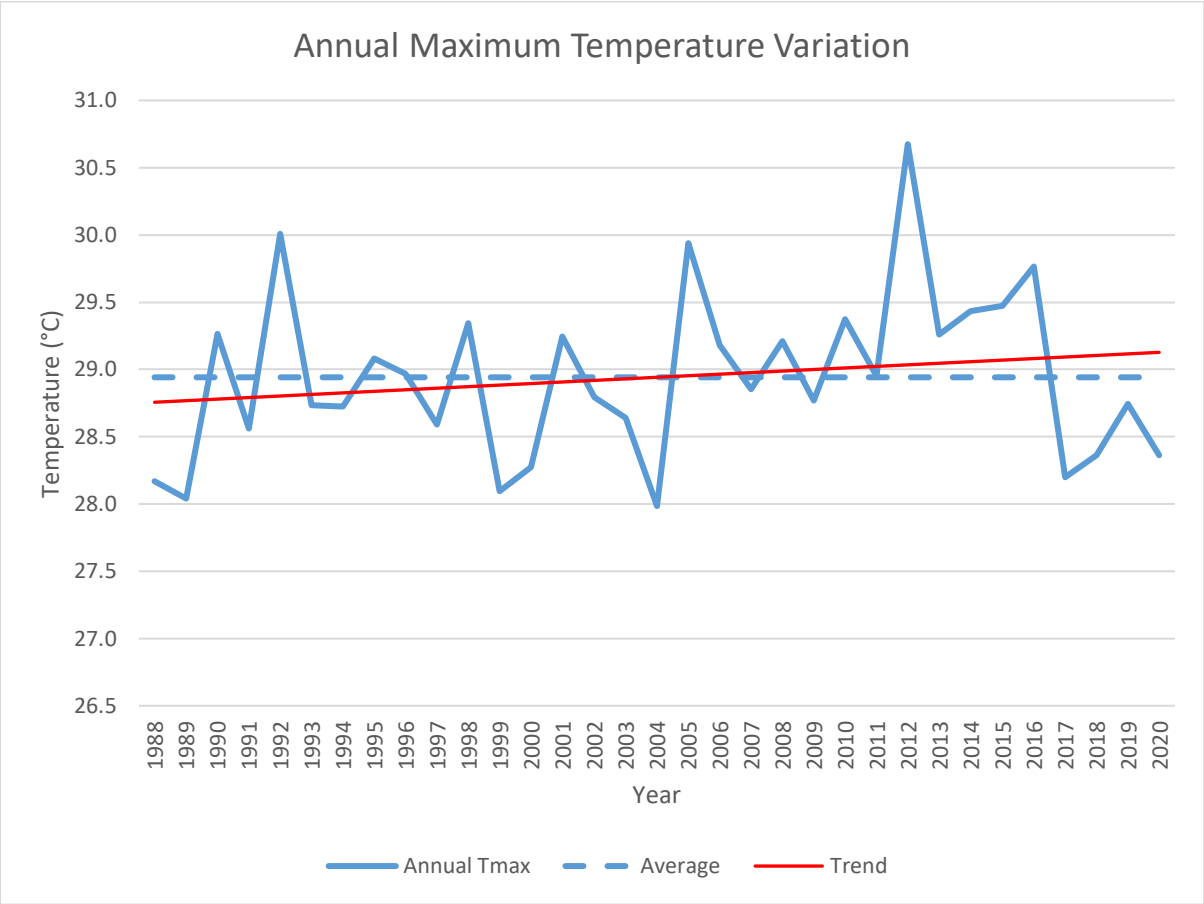


Figure 4: Graph showing annual variability of Maximum Temperature

Figure one shows that in the past 33 years the maximum temperature of Mulanje varied from 28 °C to 30.7 °C. The year with the highest maximum temperature was 2012 with 30.7 °C then 1992 with 30 °C then 2005 with 29.9 °C. The years with the lowest maximum temperatures were 1989 and 2004 with 28 °C then 1999 with 28.1 °C. The maximum temperature fluctuated a lot throughout the and no clear trend can be seen. The average maximum temperature for the period was 29 °C and the standard deviation was 0.613 °C.

3.3.2 Minimum Temperature Variability

Table 2 shows that the minimum temperature has an increasing trend in all the months of the year. The increasing trends of February, June, September, October and December were statistically significant while the increasing trends for the other months were not. All the seasons have also shown a statistically significant increasing trend in

minimum temperature. The average annual minimum temperature showed a statistically significant increasing trend. The average minimum temperature for the period was 17 °C and the standard deviation was 0.462 °C.

Table 3: Mann-Trend test results for Minimum Temperature

Month	S	Var (S)	Zmk	p-value	Interpretation	Trend
JAN	110	3766.00	1.776	0.0757	Accept	NST
FEB	163	3781.67	2.634	0.00843	Reject	Increasing
MAR	61	3785.67	0.975	0.3295	Accept	NST
APR	63	3787.67	1.007	0.3137	Accept	NST
MAY	113	3793.00	1.819	0.06898	Accept	NST
JUN	125	3778.33	2.017	0.04366	Reject	Increasing
JUL	74	3787.33	1.186	0.2355	Accept	NST
AUG	112	3792.00	1.803	0.07146	Accept	NST
SEP	215	3775.67	3.483	0.0005	Reject	Increasing
OCT	143	3787.67	2.307	0.02104	Reject	Increasing
NOV	81	3785.67	1.300	0.1935	Accept	NST
DEC	177	3791.00	2.859	0.00426	Reject	Increasing
COOL DRY	142	3762.00	2.299	0.02151	Reject	Increasing
HOT DRY	181	3785.67	2.926	0.00344	Reject	Increasing
WARM WET	176	3767.33	2.851	0.00436	Reject	Increasing
ANNUAL	227	3768.33	3.682	0.00023	Reject	Increasing

Figure 2 shows that the average annual minimum temperature varied from 15.8 °C to 18.1 °C. The lowest average annual minimum temperature was recorded in 1989 and 1991 which was 15.8 °C. The highest average annual minimum temperature was recorded in 2016 to be 18.1 °C. A generally increasing trend in the highest average annual minimum temperature was experienced from 1991 to 2004. A generally oscillating trend dominated the period from 2004 to 2011. An increasing trend was also experienced from 2011 to 2016 and a generally decreasing trend from 2016 to

2020. On average the minimum temperature has had an increasing trend from 1988 to 2020.

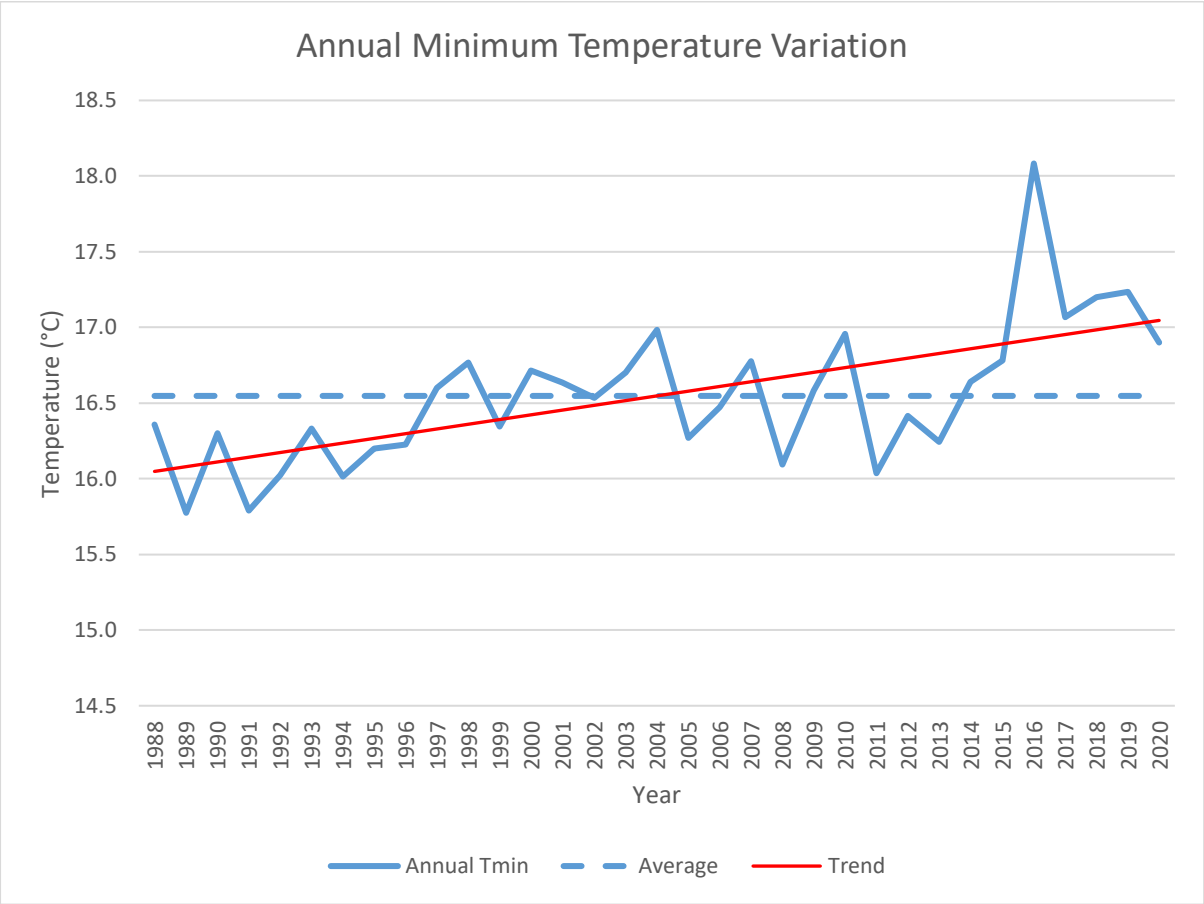


Figure 5: Graph showing annual variability of Minimum Temperature

3.3.3 Mean Temperature Variability

Table 3 below shows the results of the Mann-Kendall analysis for the monthly seasonal and annual mean temperature. Table 3 shows that the mean temperature had an increasing trend in all the months of the year. The increasing trends for May, August, September, October and December were statistically significant while the increasing trends for the other months were not. All the seasons also showed an increasing trend in mean temperature, although the increasing trend of the cool-dry and hot-dry seasons were statistically significant while the trend in the warm wet season was not statistically significant. The average annual mean temperature also showed a statistically significant increasing trend.

Table 4: Mann-Trend test results for Mean Temperature

Month	S	Var (S)	Zmk	p-value	Interpretation	Trend
JAN	21	3767.67	0.326	0.745	Accept	NST
FEB	83	3779.67	1.334	0.182	Accept	NST
MAR	19	3779.67	0.293	0.770	Accept	NST
APR	13	3781.67	0.195	0.845	Accept	NST
MAY	148	3777.33	2.392	0.017	Reject	Increasing
JUN	20	3778.00	0.309	0.757	Accept	NST
JUL	53	3767.67	0.847	0.397	Accept	NST
AUG	153	3791.00	2.469	0.014	Reject	Increasing
SEP	165	3785.67	2.666	0.008	Reject	Increasing
OCT	132	3791.33	2.128	0.033	Reject	Increasing
NOV	50	3786.67	0.796	0.426	Accept	NST
DEC	166	3791.33	2.680	0.007	Reject	Increasing
COOL DRY	149	3757.00	2.415	0.016	Reject	Increasing
HOT DRY	174	3783.33	2.813	0.005	Reject	Increasing
WARM WET	113	3762.33	1.826	0.068	Accept	NST
ANNUAL	203	3751.67	3.298	0.001	Reject	Increasing

Figure 3 shows that the average annual mean temperature varied from 21.9 °C to 23.9 °C. The lowest average annual mean temperature was recorded in 1989 to be 21.9 °C, then 1991 and 1999 with 22.2 °C. The highest average annual mean temperature was recorded in 2016 to be 23.9 °C, then in 2012 with 23.5 °C. The average annual mean temperature was fluctuating but it has shown a generally increasing trend in the whole period. The average mean temperature for the period was 23 °C and the standard deviation was 0.384 °C.

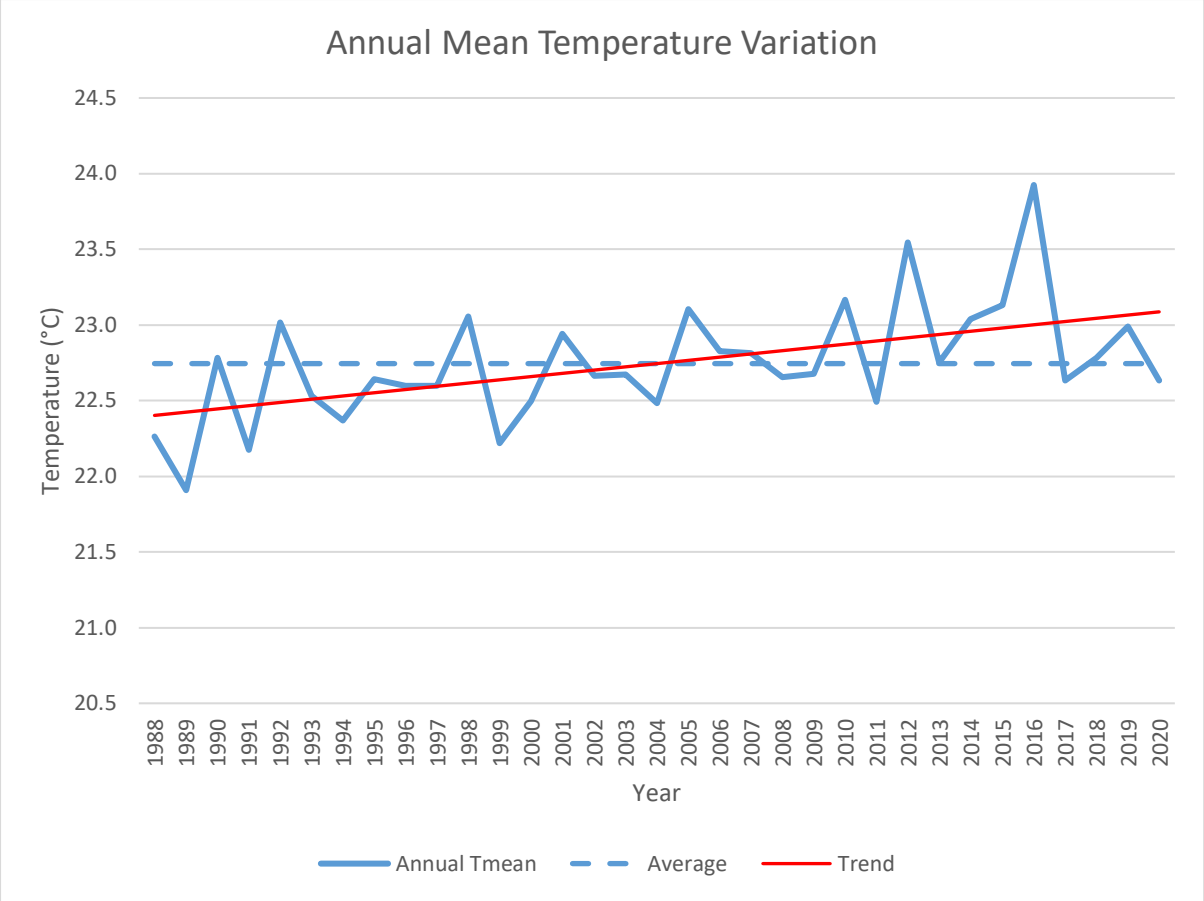


Figure 6: Graph showing annual variability of Mean Temperature

3.4 Tea Yields

The tea yield data that was obtained was from the year 2001 to 2020. Table 5 below shows the number of growers, the total sum of land used covered by mature tea (in hectares, the yield of green leaf and the yield per area.

The number of farmers under SAT has been increasing since its first full operation year 2001 to 2020. The number of farmers has grown from 1808 to 12761. The amount of land covered by mature tea increased from 2001 to 2006, thereafter that varying around an average of 1550 ha. It is also clear that the yield of the green leaf has been increasing.

Table 5: Tea Yield Data

Year	Growers	Hectares of Mature Tea	Green Leaf Yield (Kgs)	Yield of Green Leaf per hectare (Kgs/ha)
2001	1808	549	2,921,957	5322
2002	2887	823.8	5,471,926	6642
2003	2869	823.8	5,283,943	6414
2004	3314	823.8	6,423,711	7798
2005	4456	1091.5	5,453,718	4997
2006	5643	1569.5	7,988,756	5090
2007	5938	1641.7	8,382,239	5106
2008	5774	1688.8	6,529,429	3866
2009	5545	1650	7,654,003	4639
2010	6553	1357.7	7,734,820	5697
2011	6300	1252.1	7,556,363	6035
2012	7130	1488	7,375,293	4957
2013	8149	1701	9,601,484	5645
2014	8605	1502	9,945,928	6622
2015	9106	1481	10,235,139	6911
2016	9369	1442	11,401,307	7907
2017	9941	1575	12,190,251	7740
2018	10230	1613	13,690,018	8487
2019	11246	1640	14,311,538	8727
2020	12761	1650	15,642,471	9480

Figure 5 below shows the variations in the annual tea yield per hectare. We can see that from 2001 to 2012 the tea yield was fluctuating a lot. From 2012 to 2020 the tea yields have been increasing continuously. This is because of the measures that have been set in place since 2013 to improve the tea sector and the smallholder sector of tea farming. These measures include replacing old tea bushes with improved tea varieties that are also drought resistant.

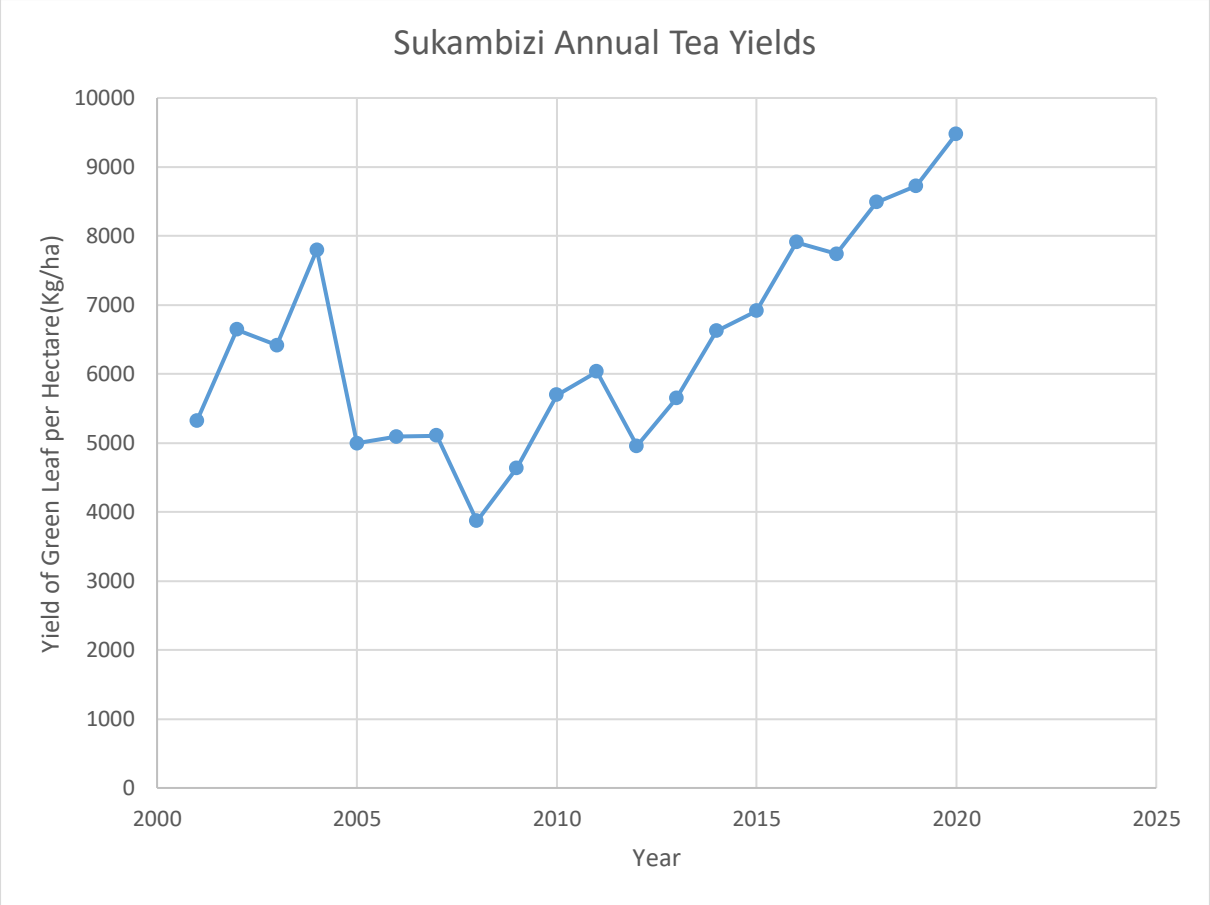


Figure 7: Graph showing annual tea yields

3.5 Effects of Weather and Climatic parameters on Tea Yields

This section assesses the effects of weather parameters on the tea yields of the Sukambizi smallholder farmers. The first sub-section assesses this using the correlation test analysis and the second one using graphs. This section does not imply that the researcher thinks that weather parameters affect tea yields independent of each other.

3.5.1 Correlation of Tea Yield and Weather Parameters

Since there has been a change in the practices and varieties of tea grown since 2013, the correlation analyses are in three parts. The first part for the whole period from 2001 to 2020, the second part from 2001 to 2012 and the third part from 2013 to 2020

Table 6: Correlation of yields and weather parameters from 2001 to 2020

Weather Parameter	dF	critical point	α	r	t	p-value	Interpretation
Annual Rainfall	18	2.101	0.05	-0.154	-0.659	0.518	Accept
Annual Tmax	18	2.101	0.05	-0.510	-2.516	0.022	Reject
Annual Tmin	18	2.101	0.05	0.663	3.756	0.001	Reject
Annual Tmean	18	2.101	0.05	-0.030	-0.125	0.902	Accept

Table 7: Correlation of yields and weather parameters from 2001 to 2012

Weather Parameter	dF	critical point	α	r	t	p-value	Interpretation
Annual Rainfall	10	2.228	0.05	-0.147	-0.470	0.648	Accept
Annual Tmax	10	2.228	0.05	-0.581	-2.257	0.048	Reject
Annual Tmin	10	2.228	0.05	0.477	1.715	0.117	Accept
Annual Tmean	10	2.228	0.05	-0.385	-1.317	0.217	Accept

Table 8: Correlation of yields and weather parameters from 2013 to 2020

Weather Parameter	dF	critical point	α	R	t	p-value	Interpretation
Annual Rainfall	6	2.447	0.05	-0.493	-1.389	0.214	Accept
Annual Tmax	6	2.447	0.05	-0.596	-1.819	0.119	Accept
Annual Tmin	6	2.447	0.05	0.548	1.604	0.160	Accept
Annual Tmean	6	2.447	0.05	-0.101	-0.250	0.811	Accept

All the tables show that the yields and annual rainfall had negative correlations and none of the correlations was statistically significant correlations. The correlations were weak in Tables 6 and 7, with correlation coefficients of -0.154 and -0.147. The correlation in table 8 the correlation was moderate with a correlation coefficient of -0.493. These results are not enough for one to conclude that rainfall was not affecting tea yields. In section 2.6.2 it was stated that tea has an optimum range of rainfall amounts which fosters good production, if the rainfall is above or below this range the yields are affected. This argument is going to be further clarified in section 4.5.2.

All tables also show negative correlations between tea yields and annual ma6imum temperature, the correlations in tables 6 and y are statistically significant while the correlation table z is not statistically significant. All tables show moderate correlations with correlation coefficients of -0.510, -0.581 and -0.596 in tables 6, 7 and 8 respectively. This shows that an increase in temperature caused a reduction in tea yields, proving what was stated in section 2.6.1. The fact that the correlation in table 8 is not statistically significant may prove that the climate adaptation measures taken are working.

All tables show positive correlations between tea yields and annual minimum temperature, the only correlation which statistically significant is in table 6. Table 6 shows a strong correlation with a correlation coefficient of 0.663 while tables 7 and 8 show moderate correlation with coefficients of 0.477 and 0.548 respectively.

All tables show a negative correlation between tea yields and annual mean temperature and all correlations are not statistically significant. All the correlations between yields and annual mean temperature are weak, with correlation coefficients of -0.030, -0.385 and -0.101 in tables 6, 7 and 8 respectively. This show that the mean temperature did not affect tea yield significantly.

3.5.2 Tea Yield and Weather Parameter Graphs

This sub-sections further clarifies the previous section using graphs that show the relationships between tea yields and the weather parameters.

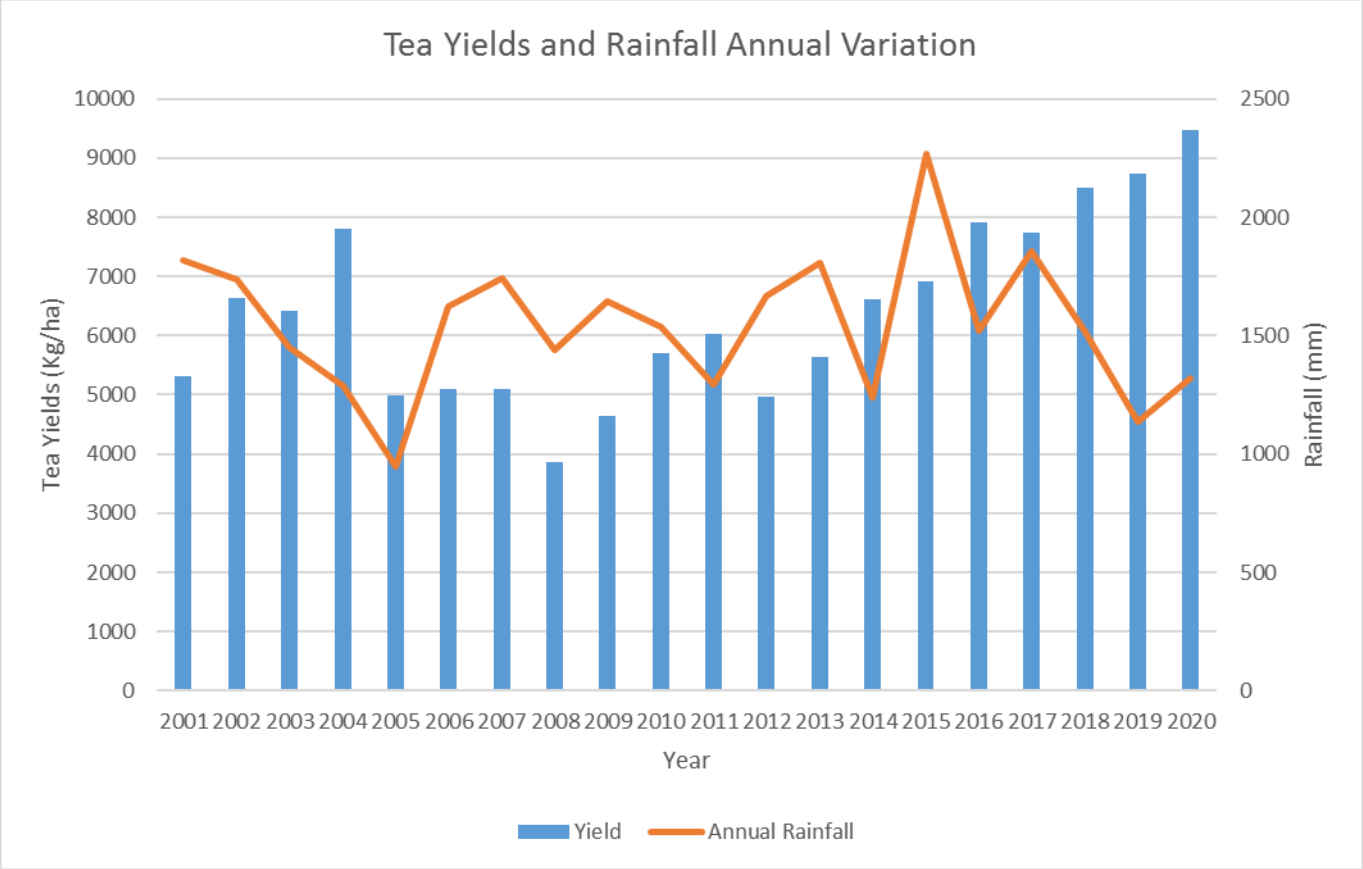


Figure 8: Graph showing relationship between tea yields and Annual rainfall

From the graph in figure 6, we can see the two important relationships between annual rainfall and tea yields. The years 2015, 2017,2013, 2001 and 2007 show the impacts of high amounts of rainfall on tea yields. We can see that when the rainfall is above or equal to 1750 mm it frequently resulted in low yields. 2005 and 2019 are the years with a noticeable decrease in annual rainfall. 2005 shows a reduction in tea yields while 2019 shows an increase, this is because of the climate adaptation measures that have been taken since 2012. This shows that when rainfall is below 1200 mm a reduction in tea yields may be expected. The years whose annual rainfall was between 1200 mm and 1750 mm showed good yields in tea, for example, 2002, 2003, 2004,2011, 2014, 2016, 2018 and 2020. The graph also shows that annual rainfall variations have not affected tea yield a lot from 2013 to 2020 as compared to the previous years.

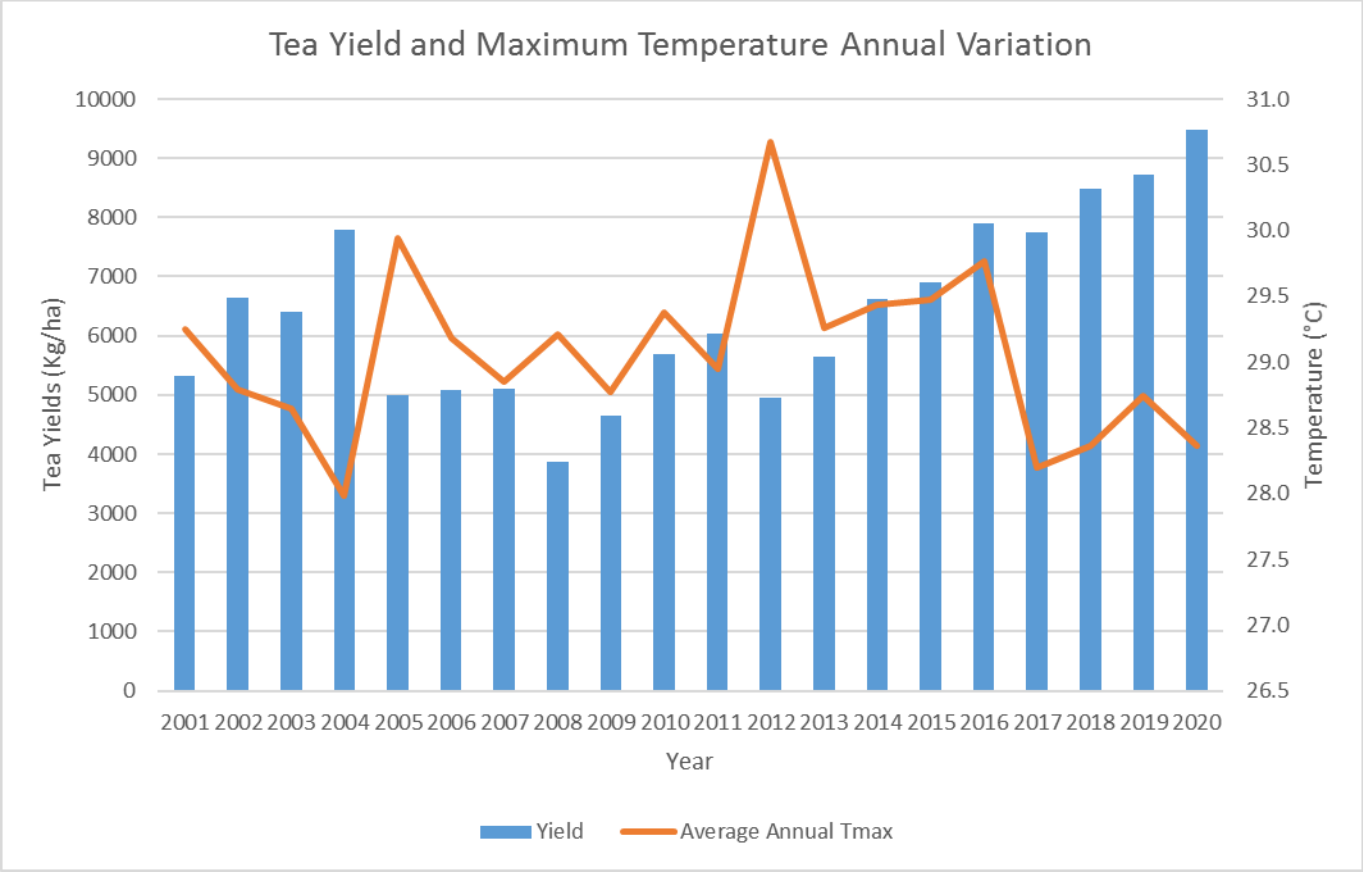


Figure 9: Graph showing relationship between tea yields and annual maximum temperature

The graph above shows the relationship between the annual maximum temperature and the tea yield. The graph shows that an increase in annual maximum temperature causes a decrease in yields. Most years with the temperature above 29 °C show a decrease in tea yields, for example, 2012, 2005, 2006 and 2008. Most years with annual maximum temperature less than 29 °C show good tea yields, for example, 2002, 2003, 2004. The graph also shows that after 2013 the maximum temperature variations are not affecting the tea yields much, as evidenced by the increase in yields from 2013 to 2016, a period when the annual maximum temperature was greater than 29 °C and was increasing annually.

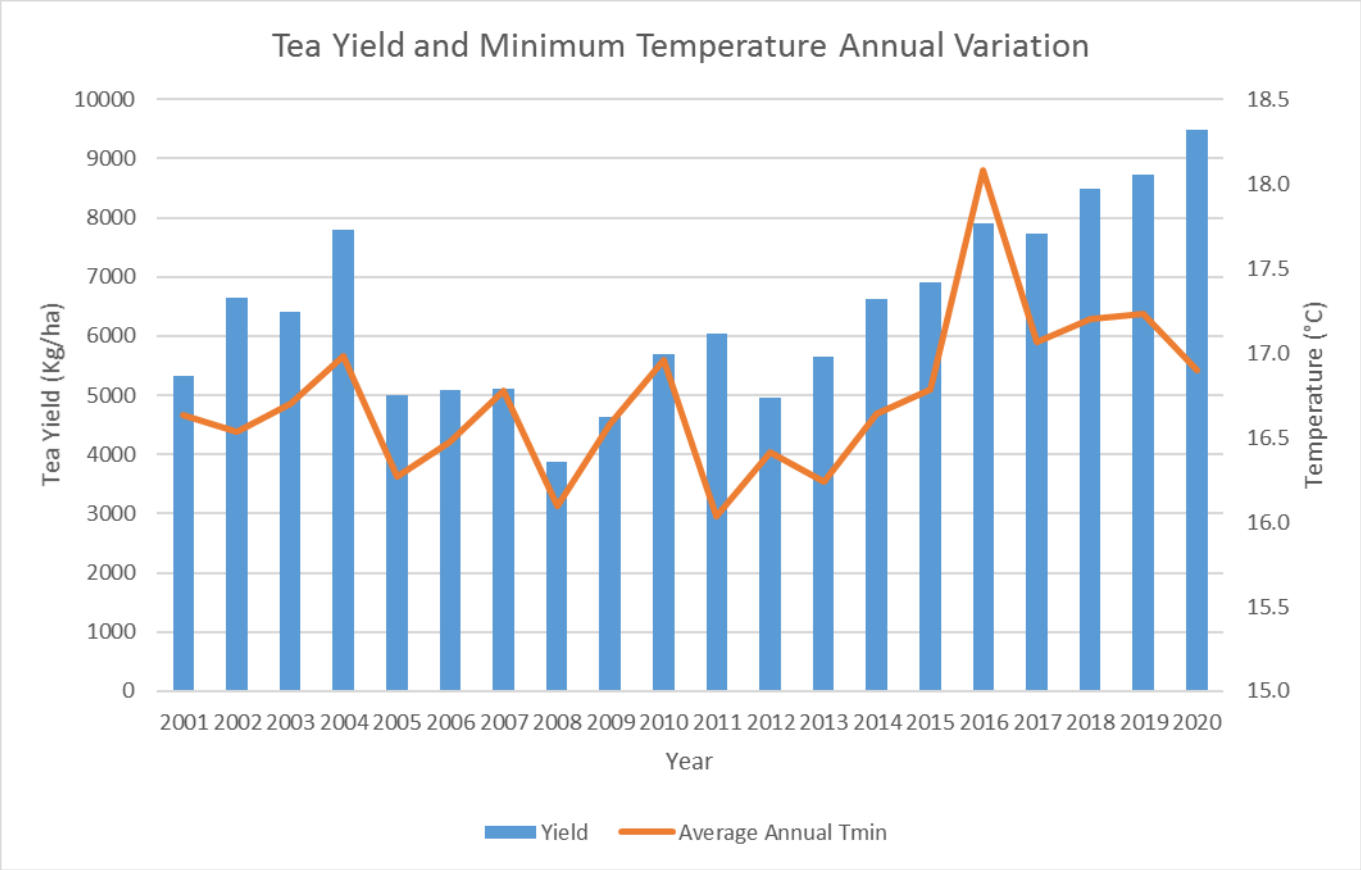


Figure 10: Graph showing relationship between tea yields and annual minimum temperature

The graph below shows the relationship between the annual minimum temperature and the tea yields. The graph shows that an increase in the minimum temperature results in an increase in tea yields. Years with a minimum temperature above or equal to 17 °C show increased yields, for example, 2004, 2010, 2016, 2018 and 2019. Most years with low minimum temperatures show reduced tea yields for example 2001, 2005, 2008 and 2009. After 2013 the minimum temperature does not affect tea yields a lot.

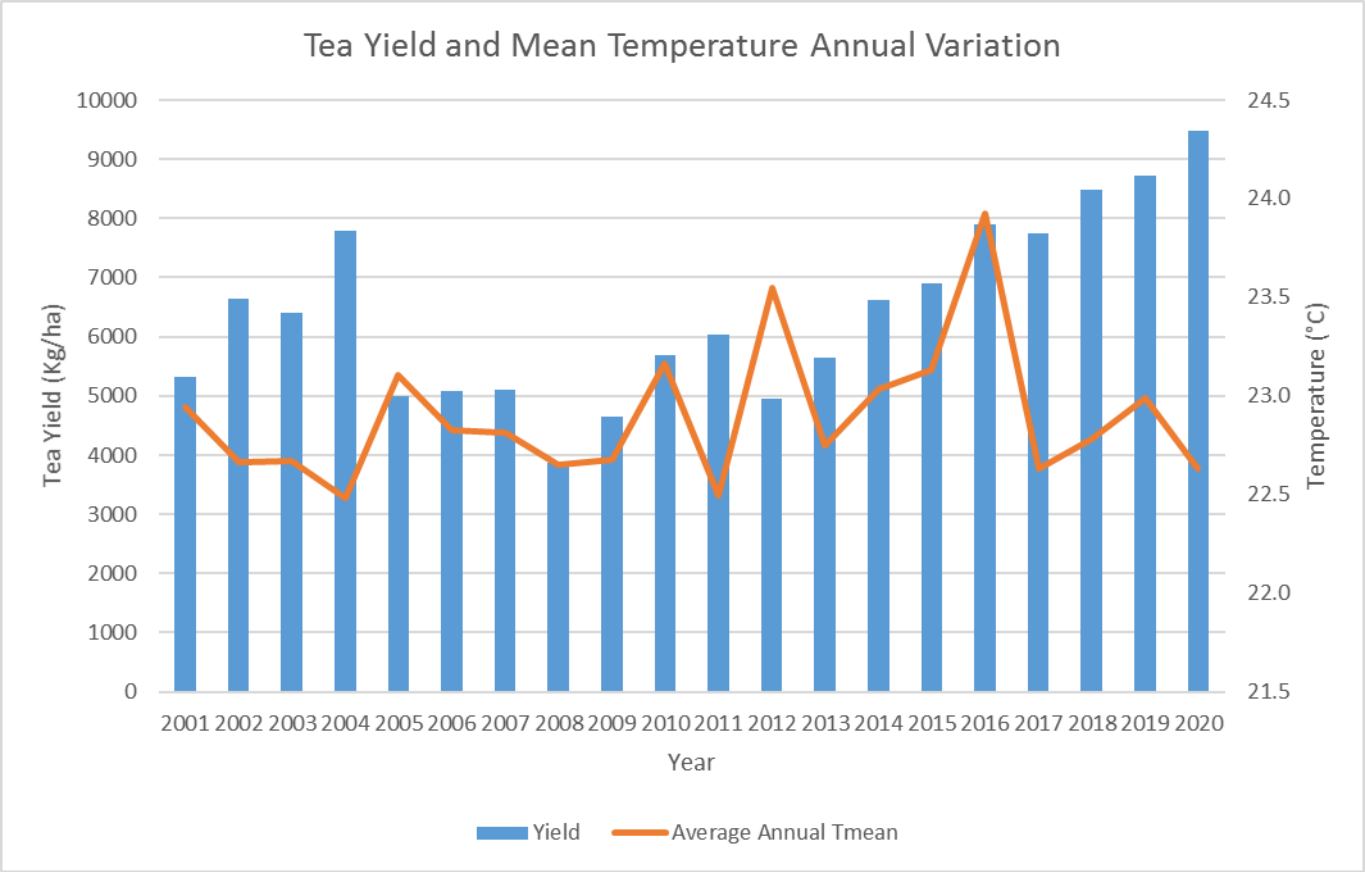


Figure 11: Graph showing relationship between tea yields and annual mean temperature

The graph above shows the relationship between the annual mean temperature and tea yields. As established in the previous section there is not a clear relationship between tea yields and annual mean temperature.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The study concludes that there is no significant increasing trend in annual maximum temperature in Mulanje. The study further concludes that there are significant increasing trends in minimum and mean temperature in Mulanje. The study also concludes there is no significant decreasing trend in rainfall in Mulanje.

The study concludes that annual rainfall variations affect tea yields. Annual rainfall amounts that are above or below the range of 1200 mm to 1750 mm cause a reduction in tea yields. And scenarios going above this range are more frequent than going below. The study further concludes that annual maximum temperature variations affect tea yields. Annual maximum temperatures of over 29 °C lower the smallholder farmer's yields. The study concludes that annual minimum temperature variations. High minimum temperatures are associated with an increase in tea yield. The study that the mean temperature variations do not affect tea yields much.

The study further concludes that the climate adaptation and tea sector improvement activities bring the desired outcome, although smallholder farmers have not yet reached their highest potential of productivity which is 13,000 kg/ha of green tea per annum.

Finally, the study concludes that the current climate variability trends, that is the trends in annual rainfall, maximum, minimum, and mean temperature does not pose a serious threat to smallholder tea farming.

The study found that both low and high amounts of annual rainfall negatively affect the smallholder farmer's yield and that sufficient measures have been put in place to address the issue of low rainfall amounts (droughts). Measures to address the high rainfall amounts (floods) have not been placed yet although they occur more frequently. The study, therefore, recommends that further studies should be done on flood adaption measures for smallholder tea farmers. These adaptation measures must be affordable and accessible to smallholder tea farmers.

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