ASSESSING THE SUITABILITY OF TEA GROWING ZONES OF KENYA UNDER CHANGING CLIMATE AND MODELING LESS REGRET AGROMETEOROLOGICAL OPTIONS.

BY

GETRUDE TAUSI LESHAMTA

REG. NO: I54/81910/2015

PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR MASTER OF SCIENCE DEGREE IN CLIMATE CHANGE.

DEPARTMENT OF METEOROLOGY,

UNIVERSITY OF NAIROBI

2017.

DECLARATION

As I acknowledge the unfailing contribution of my supervisor towards the success of the research undertaken, I do hereby declare that this is my original work**.**

AUTHOR

Getrude Tausi Leshamta

SIGN:

SUPERVISOR

Prof. Nzioka John Muthama

University of Nairobi Wangari Maathai Institute for Peace and Environmental Studies,

University of Nairobi**.**

SIGN:

DEDICATION

This study is dedicated to my family for their unfailing support as far as education is concerned.

ACKNWLEGMENT

My sincere gratitude goes to the Almighty God for His sustenance throughout the course, I give Him glory, honor and praise.

I deeply appreciate my supervisor, Prof. J.N. Muthama who availed himself whenever I needed his guidance and wisdom and imparted the skill and potential acquired thereof. May God bless him.

I also appreciate the chairman, all the lecturers and all the workers in the Department of Meteorology, University of Nairobi for their generous support in this work. May God bless them all.

My sincere gratitude goes to the Kenya Meteorological Department and my family for their kind support during the entire period of study. May God bless them all.

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Index of Acronyms

BIOCLIM-	Bioclimatic Analysis and Prediction System.
CNRM-	National Centre for Meteorological Research.
ETP-	Ethical Tea Partnership.
FAO-	Food and Agriculture Organization.
GCM-	Global Circulation Model.
IPCC-	Inter-governmental Panel on Climate Change.
KMD-	Kenya Meteorological Department.
KTDA	Kenya Tea Development Authority.
Masl-	Meters above Sea Level.
MaxEnt-	Maximum entropy.
TDK	Tea Directorate of Kenya.
WMO-	World Meteorological Organization.

ABSTRACT

The suitability of tea production within the tea producing counties in Kenya by the years 2050 and 2070 was determined by the use of various methodologies where both ground based and satellite data was used. Tea production data from Tea Directorate of Kenya (TDK) and monthly precipitation, minimum and maximum temperature data for the period 1976-2014 from Kenya Meteorological Department (KMD) was used and supplemented with gridded data from Atlas KNMI.Data was analyzed to establish the trends, magnitude and frequency of extremes and the relationship between tea, temperatures and precipitation using R software. Bioclimatic variables data from National Centre for Meteorological Research (CNRM) model with worldclim.com using $1km^2$ resolution was extracted into the area of study and converted into a format readable in MaxEnt model using QGIS model. The QGIS model outputs were fed into the MaxEnt model as environmental layers together with samples data with different bioclimatic species under investigation through which the suitability of tea growing areas for tea and coffee production by the years 2050 and 2070 was determined. Suitability of the tea growing zones for climatic constraints such as frost and thunderstorms, existing pests such as tea Kangaita weevil, tea mosquito bug and existing crop diseases such as tea disease, was also determined.

Analysis of climate variability indicated that both the magnitude and frequency of precipitation and temperature variability have increased. Multiple linear regression between precipitation, maximum and minimum temperature indicated that night temperatures had a greater effect on precipitation compared to daytime temperatures. It was deduced that rainfall and temperatures in the highlands east of rift valley and Kericho correlated positively.

On the other side, it was found out that rainfall and minimum temperatures in the highlands west of rift valley correlated positively while correlated negatively with maximum temperatures. Multiple linear regression between tea, maximum and minimum temperatures and precipitation showed that temperatures and especially night temperatures had more effect on tea production as compared to precipitation. Maximum and minimum temperatures and precipitation were found to positively correlate with tea yields in the highlands east of rift valley. Conversely, maximum and minimum temperatures negatively correlated with tea yields, while precipitation positively correlated with tea yields in the highlands west of the rift valley. Peak seasons for tea production were found out to be MAM and OND with December experiencing the largest amounts of yields. Tea yields have been increasing until 2014 after which yields dwindled and the above normal production episodes were found out to be more as compared to below normal episodes.

The suitability analysis indicated that, around a half of the tea growing area in Kenya is going to be unsuitable for tea production by the year 2050 while only 40% of the region will be unsuitable by the year 2070. White tea is expected to be the most resilient variety to the changing climate for the highlands east while black tea the most resilient variety for the highlands west by the year 2070.Counties which might not be able to produce any tea variety in most parts such as Nyandarua, Nyeri north, parts of Kiambu and Nakuru are expected to be able to produce coffee as an option since coffee can bear more severe temperatures. Tea suitability drop was found out to be as a result of the hot season JFM getting warmer and the tea peak seasons which are also the wet seasons MAM and OND getting cooler. The cost of production for tea is likely to increase as pests broaden their coverage and tea disease prevalence intensify, especially over Transzoia, Nandi and most parts of the highlands east. This will as well affect the quality of Kenyan tea which is usually less sprayed with chemicals.

Contents

CHAPTER ONE: *INTRODUCTION.*

1.0: BACKGROUND

In the Agricultural sector, Tea sub-sector is the second largest foreign exchange earner after horticulture where the land under tea production with small holder farmers constitute about 80% in which they produce about 60% of processed tea in Kenya; (Koskei et al,2012). Kenya is number four globally in tea production, number one in Africa and number one in tea quality globally; (Kariuki, 2012).

Tea production in Kenya is mainly by small holder farmers within less than 1Ha farms which contributes to 57% of tea production ;(M'Imwere et al, 1997). Approximately an average of 0.27 ha in Kenya is the area under tea production that each smallholder farmer owns and is already threatened by a high population growth rate in the tea growing zones leading to sub-division of tea farms to much smaller tea farm units; (Kavoi et al, 2002 and Siele et al, 2002).

Tea earns the country's highest foreign income of up to 26% of exports and 4% of GDP from the fact that It is the largest exporter of black tea Worldwide with smallholder farms accounting for about 66% of total tea production which amounted to 378 million kilograms in 2011; (Changwony et al, 2012).

Tea production is carried out in the highlands east and highlands west of the rift valley regions due to their suitable altitude, soils and climate and therefore deviation from the mean especially temperature may tend to reduce their suitability.

Temperature extremes may take two forms of: extreme hot or extreme cold conditions.

Extreme cold conditions detrimental to tea production is frost condition;(Onywere et al, 2014), which damages tea leaves, roots and reduces efficiency of laborers in charge of tea leaves picking. Extreme hot conditions, besides speeding up hailstorms, may add heat stress to tea leaves, increase pest infestation and disease prevalence thus reducing both quality and quantity of tea leaves.

KTDA has taken the opportunity to supply small holder farmers with the improved variety of seedlings and fertilizer to see the industry through increased productivity. The Ethical Tea Partnership (ETP) trains farmers on mitigation measures such as use of biogas instead of wood when drying tea leaves to reduce carbon emissions and on adaptation processes such as planting of trees to allow frost to fall on tree leaves and not on tea leaves or mulching to prevent frost on the root area.

Hailstorms being one of the extreme weather conditions destructive to tea production ;(Bore, 2015) are as a result of deep convection over a relatively shorter period and is quite common in Kericho tea growing region.

Tea requires temperature range of between 19-29℃;(Kenya Tea Research Foundation, 2012) whereby it indicated that a 1/3 loss on harvest in 2012 was recorded.

Kenyan tea is free from pests or diseases hence not sprayed with much chemical thus making it of high quality and safest to consume according to Kenya Tea Research Foundation but the conditions may be altered by climate change thus reducing both quality and quantity or even increase the cost of production on the crop which is well known to be capital intensive.

The tea mosquito bug already threatening tea production in Rwanda is feared to also be a threat in the neighboring countries in Eastern Africa like Kenya if the climate conditions will favor the pest in the future; (Managua,2011).

Tea production being labor intensive supports over three million persons as a livelihood; (Tea Board of Kenya, 2008) which is equivalent to 8.7% of Kenya's total population now. Tea also supports many people directly or indirectly employed by the Tea sector in TDK, KTDA, the Multinational companies, export companies to mention but a few.

Tea production occupies the entire year, with two peak seasons of high yields being March to July, and October to December, which coincide with the main rainy seasons in Kenya; (Kinyili, 2003).

Black tea is the tea variety produced in plenty in Kenya and is used as a blender for other varieties. However with growth in the tea industry in the recent years, other varieties such as green tea and white tea have been introduced in Kenya. Kenya is used to develop new varieties of tea clones such as the *purple tea* for research purpose for other regions; (Cherotich, Leonida. 2017). However, considering the results for suitability for tea production in Kenyan districts, Meru, Embu, Kirinyaga, Nyeri, Murangá, Kiambu, Kisii, Nyamira, Kericho, Bomet, Narok, Migori were found out to be the most suitable regions for tea production;*(Managua et al, 2011)*. The remaining districts were considered rather less suitable.

The counties that will remain suitable for tea production by the year 2050 are: Bomet, Kisii and Nyamira and that the Key tea producing regions in Kenya are: Kericho, Kisii and Nandi hills; (*Managua, 2011*)

1.1: PROBLEM STATEMENT.

Variability of some weather elements such as temperature may have a great impact on human, plants and animals in terms of health, agriculture and natural resources. Warmer than normal temperatures have been experienced in Kenya but also cooler than normal temperatures have been experienced. In the extra tropics, temperatures are increasing both in the warm and cool seasons; (Elizbarashvili et al, 2013).

Climate hazards such as temperature extremes resulting to frost or heat stress are well known to reduce crop yields not to mention interfering with labor efficiency and therefore since tea production is both labor and capital intensive the damages may have diverse effects socially and economically.

The land tenure system in Kenya is in the category of Private ownership, Community (Trust) land and Government land which may not allow expansion for Agricultural land. Improving on the usability of the existing land under crop production which depends on the optimum weather conditions for some specific crops calls for analysis of climate extremes and suitability of areas for production of some particular crops such as tea which is highly sensitive to temperature changes.

As air temperatures get warmer than normal, the land suitable for tea production will be reduced while pests and diseases that never used to bother tea production in Kenya as it does to China, India and Sri Lanka will begin to interfere with its production; (Cheramgoi et al, 2016).

1.2: RESEARCH QUESTIONS.

How have the temperatures varied from the mean?

How has precipitation varied from the mean?

Is there any relationship between temperature, rainfall and tea yields?

Will the current tea growing regions remain suitable for tea production by the years 2050 and 2070?

Will the current tea growing regions become suitable for tea pests, diseases, frost and thunderstorms by the years 2050 and 2070?

1.3: OBJECTIVES

The overall objective of the study was to determine the suitability of tea growing zones of Kenya under changing climate.

The specific objectives that lead to the achievement of the main objective were:

- Examine the magnitude and frequency of temperature and precipitation extremes.
- Establish the relationship between temperature, precipitation and tea production.
- Establish the future suitability of tea growing areas for tea production by the years 2050 and 2070.
- Provide agro meteorological options for the tea growing areas.

1.4: JUSTIFICATION OF THE STUDY.

Kenya being part of the developing countries with a low financial capacity to sustain planned Adaptation, has a low adaptive capacity to climate change impacts such as extreme temperatures and change in seasonal weather patterns hence more vulnerable to climate change hazards and the associated disasters. As weather extremes become more severe according to IPCC, the level of exposure differs from place to place hence rendering different communities vulnerable differently.

The agricultural land in Kenya is around 57.6m Ha, 17% of which falls under high or medium farming potential while the remaining 48.0m Ha falls under semi-arid or arid land and only half of this land is able to support agriculture or livestock grazing; UNEP, 2009.

Land is a fixed factor of production but its usage is variable in such a way that it is easy to shift from agricultural production to real estate investment but the reverse is impossible. The conservation of the existing farm lands through agricultural production ensures sustainable development whereby the future generations will have the same resources with the current generation.

Kenya ranking fourth globally in tea production and first in Africa puts tea yields in Kenya under much consideration. Tea production being the greatest foreign income earner in Kenya where tea exports account for 26% of the total exports and 4% of the GDP gives research on the effects of climate variability to tea yields more weight.

The tea sectors also offer employment all-year-round to the rural areas through the factories and farms and therefore contributing greatly to livelihoods of the entire nation.

This study will provide agrometeorological adaption options to the Tea sector in a location specific manner for the future hence reduce regrets associated with the changing climate and also ensure that farmers would not switch tea production to non-agricultural activities such as real estate ownership.

1.5: AREA OF STUDY.

Tea is grown over the highlands west and east of the rift valley regions in Kenya which are cooler and wetter. These regions are within the altitude range of 1000m-1700m m.a.s.l (meters above sea level) and with red volcanic soils conditions that are favorable for tea production; Kenya Tea Research Foundation (KTRF).

The tea growing region covers an extent of Latitude 1.3N to 1.3S and Longitude 38.4Eto 34.3E.

Tea being a highland crop grows well where the soils have proper drainage as in the sloppy areas. These areas are located mainly in the highlands of Kenya which are above 1,500m.a.s.l; Brown, 1966. Kericho, Nandi, Kakamega, and Cherangani hills in the Highlands west of the Rift valley and Nyambene hills, Nyeri, Murang'a, Thika and Maragua in the Highlands east of the Rift valley make the seven tea growing regions in Kenya according to KTDA.

The area under tea production covers around 500 kilometers by 400 kilometers which is being threatened by high rates of population growth leading to the subdivision of farms to off springs of farmers and family members to much smaller units; Kavoi et al, 2000 and Owuor et al., 2001.

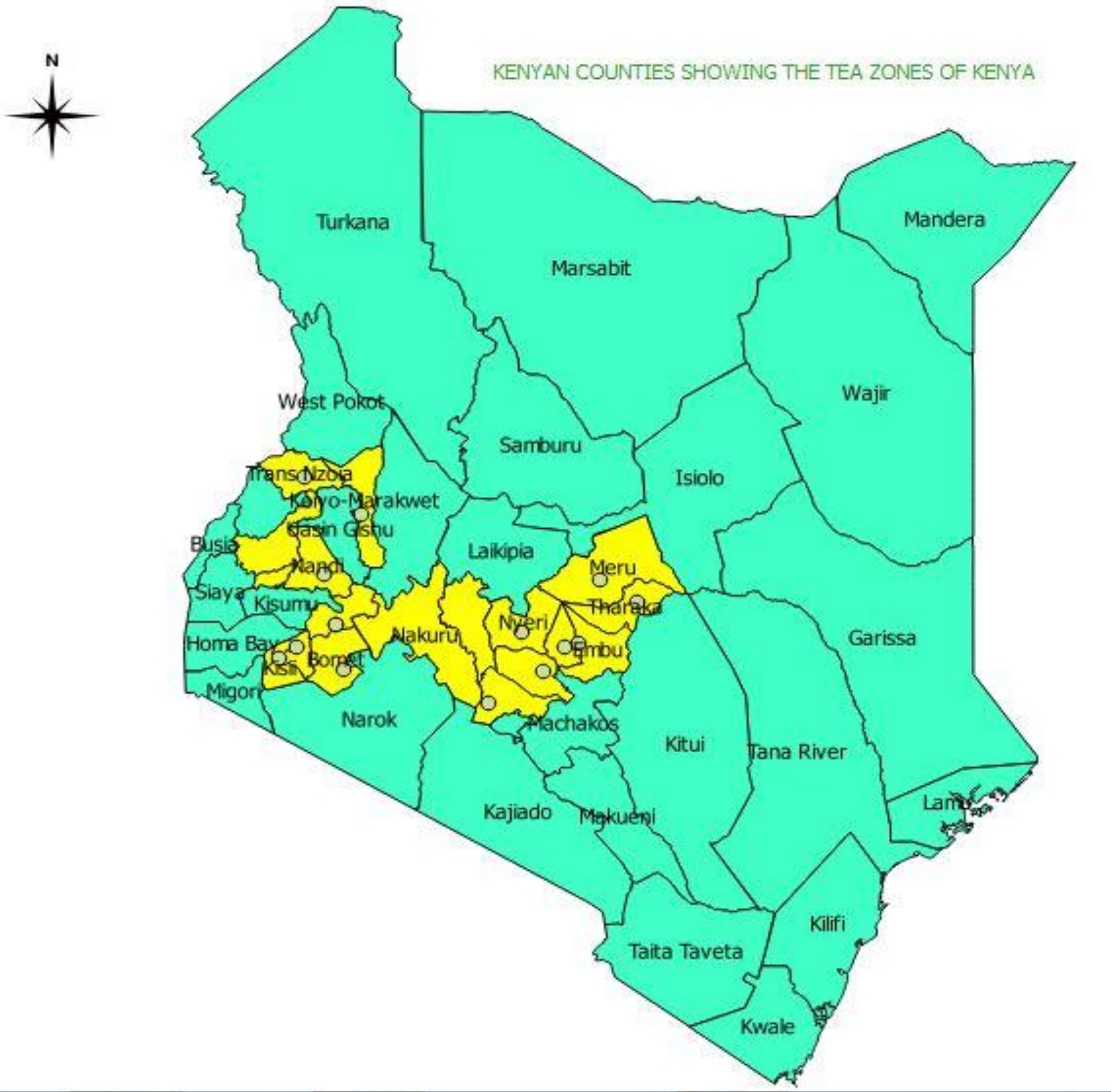


Fig1.5.1: Tea growing regions in Kenya (yellow).

From fig.1.5.1, in Kenya tea is found in plenty in the Aberdares and Mt Kenya in the highlands east of the Rift Valley within: Nyeri, Muranga, Kiambu, Kirinyaga, Embu, Meru, Nyambene, and TharakaNithi counties. Over the highlands west of rift valley region, tea is found in the Mau, Nandi, Kisii and Kakamega Hills within: Kericho, Bomet, Nyamira, Kisii, Nandi, Kakamega, Vihiga, Trans Nzoia and ElgeyoMarakwet counties; Owuor et al, 2011.

The following map is a clear representation of the spatial distribution of tea production in Kenya.

Fig 1.5.2: Tea growing counties in Kenya.

Fig.1.5.2 shows the key tea growing counties where tea is grown in several parts. The figure shows that the tea growing region covers an extent of Latitude 1.3N to 1.3S and Longitude 38.4Eto 34.3E as visualized with QGIS.

Table 1.5.1: The altitude, longitude and latitude of the tea growing counties.

COUNTY NAME	ALTITUDE (in m.a.s.l)	LONGITUDE	LATITUDE
1. **KERICHO**	**2014**	**35.28629**	**-0.3689**
2. **NANDI**	**2065**	**35.17637**	**0.10307**
3. **KIAMBU(LIMURU)**	**2255**	**36.64**	**-1.10693**
4. **KIRINYAGA**	**1285**	**37.32547**	**-0.57317**
5. **NYERI**	**1832**	**36.94336**	**-0.42778**
6. **MURANGA**	**1359**	**37.1322**	**-0.7957**
7. **MERU**	**1659**	**37.6456**	**0.05147**
8. **KISII**	**1694**	**34.7796**	**-0.67733**
9. **KAKAMEGA**	**2014**	**34.75229**	**0.28422**
10. **BOMET**	**1962**	**35.35**	**-0.7833**
11. **EMBU**	**1319**	**37.45964**	**-0.53884**
12. **THARAKA NITHI**	**586**	**37.97819**	**-0.15695**
13. **NYAMIRA**	**1992**	**34.93412**	**-0.56694**
14. **TRANS-NZOIA**	**1895**	**35.0023**	**1.01909**
15. **E. MARAKWET**	**2363**	**35.50804**	**0.67261**
16. **VIHIGA(KAIMOSI)**	**1673**	**34.95**	**0.2**
17. NAKURU (MOLO)	**2423**	**35.73**	**-0.2479**

From table 1.5.1, it is observed that tea growing zones of Kenya are high altitude regions with an exception of Tharaka and that most regions are above1200m.a.s.l.

1.6: CLIMATOLOGY OF THE AREA OF STUDY.

The climate of Kenya is mainly controlled by the northward and southward movement of the large scale (synoptic) system “ITCZ”(Inter-Tropical Convergence Zone) according to Asnani, 1993; Mukabana and Pielke, 1996 and Okoola, 1996 and it follows the overhead movement of the sun with a lag of one month when the north east and the south east winds converge.

After the northern hemisphere summer, the ITCZ trails behind the overhead sun in September as the sun moves towards south , giving way to the short rains season between October and December (OND) in the study region. Similarly, as the sun moves northwards after the southern hemisphere summer, the ITCZ trails behind the overhead sun in March to allow the long rains season to take over from March to May in the region of study. The ITCZ moves North-South and East-West to exhibit its Meridional and Zonal arms respectively where much precipitation is experienced.

Over the entire East African region including Kenya, positive and negative phases of ENSO are respectively accompanied by above-normal (flood) and below-normal (drought) conditions; Indeje*et al*., 2000.

An anomalous SST (Sea Surface Temperature) gradient between the western and southeastern equatorial Indian Ocean (50°E-70°E and 10°S-10°N) and (90°E-110E and 10°S-0°N) respectively determines the intensity of the IOD (Indian Ocean Dipole). The gradient is referred to as the Dipole Mode Index (DMI) according to Saji*et al*, 1999.

The rainfall regime experienced in East Africa where Kenya lies is mainly bimodal with the long rains experienced in March-May (MAM) and the short rains in October - December (OND) according to Nicholson, 2014; Hastenrath el al., 2010; Camberlin and Okoola, 2003; Owiti, 2012 and Ogwang et al., 2012.

The El-Nino Southern Oscillation (ENSO) exhibits the inter-annual variability of rainfall according to Ogallo, 1988; Indeje et al., 2000 and Mutemi, 2003.

Apart from the ENSO, IOD, ITCZ and their teleconnections, several other systems also control the temporal and spatial characteristics of the East African climate. These include the intensity, location and orientation of the subtropical anticyclones, monsoonal wind systems, tropical cyclones, jet streams and easterly-westerly wave perturbations; (Mahongo et al, 2013).

There exist other synoptic scale systems apart from the ITCZ that control the climate of Kenya namely the:

- Tropical cyclones which are low pressure systems influencing strong winds in a cyclonic motion, as a result of low pressure cells due to intensive heating that trigger the temperature differences in the Indian Ocean region adjacent to the East African Coast, result to deep convection and may either enhance or deny the area of study of rainfall if the system is experienced nearer or furthest from the coastline respectively depending on the wind flow pattern. The cyclones in the East African Coast are mostly experienced from October through May. Whenever the wind flow pattern and position of the cyclones favor the region of study, moisture incursions are experienced causing much precipitation in the highlands east and west of the rift valley during the Tropical cyclones season, a condition that gives advantage to the study region for tea production under rain fed conditions.

- Jet streams and particularly the East African Low Level Jet, is a narrow current band perpendicular to the west coast influenced by very strong winds traversing the East African Coast during the Southern hemisphere winter and during the period the Asiatic summer monsoons are experienced. The Jetstream is experienced in especially June, when the Mascarene High pressure cell in the South of Indian Ocean intensifies, causing strong winds greater than 64kts to move through the Mozambique channel as the East African Ridge develops and brings much precipitation in the Kenyan Coast and by extension the Highlands west/east of the rift valley regions lying parallel to the coastline.

- Subtropical High Pressure Cells, virtually based in the southern Atlantic (St. Helena), southern Indian Ocean (Mascarene), north Atlantic (Azores) and The Arabian Ridge from the Siberian High control the wind flow pattern hence pulling or pushing away wet weather activities into or far away the region of study as well as controlling the temperatures depending on their intensity and orientation . It is during the southern hemisphere winter that the region of study is at its coolest due to straight southerlies as a result of the strengthening of the two subtropical high pressure cells in the south Atlantic/Indian Ocean that extends into East Africa as the East African Ridge which when positioned in the country causes the extreme cold season in June, July and August which is characterized by frost conditions that damage tea leaves and obstruct tea picking. Depending on where the ridging is being geared from, the gearing of the East African Ridge from south Atlantic brings rainfall activities associated with stratified clouds while gearing from the relatively warmer south Indian Ocean brings rainfall activities associated with deep convective clouds in the region of study as well as controlling the temperatures.

ENSO (Elnino Southern Oscillation) activities which are influenced by the pressure differences in a sea saw manner as a result of temperature differences in the equatorial Pacific, is characterized by either Elnino or Lanina in the region of study whose magnitude depends on the sea surface temperature (SST) anomaly index and the system is greatly enhanced when it occurs in phase with the Indian Ocean Dipole (IOD).The SST anomalies correlate positively with the vertical extent of the convective clouds; (Mathew, A. J., &Kaimal, S. U. (2001))on a study of evening convective clouds over Kochi and neighborhood.

The study area has a tropical climate which is influenced by the varied topographic features in the western and central parts of Kenya such as the Great Rift Valley, Lake Victoria, Nandi hills, Aberdares and Mt. Kenya.

However the highlands west of the rift valley experiences off-season rainfall due to local effects of the influence of the Lake Victoria air mass, Nandi hills and the Congo air mass. The region's rainfall activities are greatly enhanced whenever the country experiences westerly anomalies in the medium level (700mb level) which fetch moisture from the wet Congo basin into the adjacent western part of the country thus allowing the formation of deep convective clouds which precipitate in the form of showers accompanied by thunderstorms and sometimes hailstorm which is a common weather menace in the Kericho tea growing region and is detrimental to tea production.

Similarly the wet Lake Victoria breeze occurring during the day is predominantly south westerly and on meeting the prevailing north/south easterlies at around the high altitude Nandi hills, form deep convective clouds after adequate insolation in the afternoon thus allowing the western parts of the country to shower and thunder with possible hailstorm in most afternoons from Kericho, Bomet, Kisii, Nyamira, Kakamega which are key in tea production.

The highlands east of the rift valley lies parallel to the Kenyan coastline and its high altitude influences orographic lifting in the “Anabatic” upslope daytime winds which enhances wet weather activities especially whenever the country experiences easterly anomalies at the medium level that fetch moisture from the Indian Ocean into the region.

However, amidst moisture incursions for rain formation in the region of study; confluence and difluence of air control convective activities. Confluence refers to low level convergence with high level divergence whereas Difluence refers to low level divergence and high level convergence/divergence of wind. Confluence ensures wet weather activities while difluence maintains dry weather activities. These local weather activities guarantee tea production in the Western and Central highlands throughout the year if temperatures are unvaried, therefore giving more concern to temperature extremes.

However, literature has revealed an average increase in temperature for both the hot and cold seasons in general, during the day and at night although not limited to hot and cold spells. Increased amounts of precipitation during the short rains in the area of study have also been revealed; (Omondi et al, 2006).

CHAPTER TWO: LITERATURE REVIEW.

2.0: LITERATURE REVIEW.

The area suitable for tea production in the existing tea growing regions have been changing drastically with some regions getting more suitable while others getting less suitable. The optimum tea-producing zone in Kenya was at an altitude of 1500 to 2100 m.a.s.l and is expected to rise to an altitude of 2000 to 2300 m.a.s.l by the year 2050 and Compared with that time then, by 2050, areas within altitudes of 1400 to 2000 m.a.s.l will suffer the highest decrease in suitability while areas around 2300 m.a.s.l suffer the highest increase in suitability; (Managua et al, 2011).The distribution of suitability within the current tea-growing areas in Kenya would decrease not because of rainfall amounts, but its distribution and rise in mean air temperatures beyond the threshold of 23.5 ºC.The same results suggested that the suitability of tea growing areas is expected to increase by 8% by 2025, but drop by 22.5% by the year 2075; (FAO, 2010).

Temperature variability in terms of extreme cool and extreme warm seasons getting warmer in the extra tropics is evident; (Elizbarashvili et al, 2013), the mean global surface air temperatures have been recorded to have warmed by 0.8°C in the past century and 0.6°C in the past three decades; (Hansen et al, 2006) and moderate warming in temperate regions at a local scale would improve crop yields but decrease them in the tropics including Africa; (IPCC AR4, 2007).Climate change and its variability have been observed to adversely affect the agricultural industry with the situation expected to get worse in the future; (Ochieng et al, 2016).Evidence of climate change impacts in East Africa has been shown in various ways, including the rising of air temperatures and fluctuations in precipitation patterns; (Kipkoech et al, 2015).The likelihood of extreme events areon the rise; (Easterling et al, 2000) andthe overall future occurrence of warm days and nights areprojected to be more frequent in the entire GHA, while the occurrence of cold nightevents is likely to decrease; (Omondi et al, 2014).There is need to weigh whether climate variability is more important than gradual changes; (Porter and Semenov, 2005). Still recommendations on studies looking at crop response under above optimum temperatures are necessary; (Challinor and Wheeler, 2007).

It was discovered that, all the tea estates in Kenya experienced increasing temperatures; (Cheserek et al, 2015) and thatthe tropics and subtropics were registered to encounter declines in yields due to excessive heating; (Deryng and Delphine, 2014).Stern, (2007) and Challinor et al, (2007) identified Africa as one of the region that is most vulnerable to changing climate and the reason could be factors such as poverty, culture, social equity and governance;(FAO, 2008) and on the other hand Henrik et al, (2016) revealed that Patterns of changing climatic conditions may result in variations in weevil distribution over years due to both climate change and clearing of forests for agricultural purposes.

Surface air temperatures for the globe have increased by around 0.2°C per decade in the past 30 years where warming have been observed to be larger in the Western Equatorial Pacific than in the Eastern Equatorial Pacific over the past century, and suggestions are that the increased West–East temperature gradient may have increased the likelihood of strong El Niño events, such as the 1983 and 1998 episodes; (Hansen et al, (2006).The mean global temperatures are expected to increase from 1.4 to 5.8°C by the end of the 21st century; (IPCC, 2001) where East Africa is expected to experience warmertemperatures, a 5-20% increase in rainfall from December-February and a 5-10% decrease in rainfall from June-August by 2050; (Hulme et al, 2001 and IPCC, 2001), which is good news and bad news at the same time for tea production which has two peak seasons; March –July and October-December since warmer moist seasons are more conducive for leaf development while drier cold seasons are less conducive. The evidence of warming trends in the maximum and minimum temperatures in Kericho within the Kenyan highlands have been observed; (Omumbo et al, 2011), where an upward trend of around 0.2◦C/decade was recorded.

Observations on the increase in East African rainfall have been made and that the increases in rainfall and temperature will cause an increase in agricultural productivity in specific locations. However it was seen that the increases in temperature may as well speed up evapotranspiration and counteract any potential possibility on the increase in productivity but will on the other hand increase the removal of crop growth constraints in the highlands, thus leading to higher yields; (Herrero and Mario et al, 2010).

It was found out that temperature had more effect on yields than precipitation; (Bilham, 2011), Plant growth, development and yields are affected by various environmental conditions including temperature, solar radiation, precipitation, transpiration, frequency of extreme precipitation and temperature events;(IPCC, 2007) and that the three most important climatic parameters for tea yields in Kiambu are the mean minimum, mean maximum temperature and the terrestrial radiation; (Rwigi et al, 2009).According to John K et al, 2013, mean air temperatures, radiation and rainfall correlate positively with tea yields but over a long term basis, While Porter and Semenov, (2005) in their conclusion found out that radiation, mean air temperatures, and rainfall positively correlated with tea yields. Harzianum and Trichoderma, 2013, on whether weather parameters affect tea yields discovered that increase in maximum air temperature, changes in annual rainfall pattern, soil water deficits are the main environmental factors that influence the variability of tea production .They also found out that Temperatures have been increasing annually by a margin of 0.020C while rainfall has slightly declined by 5mm a condition that has reduced tea productivity by 20 to 30%. It was clearly observed that dwindling rainfall reduces tea yields but it is limited to the distribution of rainfall and that during the long rains, tea production is not as high as compared to the short rains period. Also rising temperatures beyond 16.5 degrees Celsius were observed to significantly reduced tea yields

Uncertainties on simulated impacts were seen to have increased with CO_2 concentrations and the consequent warming and that the uncertainties can be minimized by working on temperature and CO_2 relationships in models; (Asseng et al, 2013). Tea requires temperature range of between 19-29℃ according to Kenya's Tea Research Foundation whereby it indicated that a 1/3 loss on harvest in 2012 was recorded in Kenya. Similarly, the disturbing trends of decline in tea yields is believed to be due to the fact that tea grows well under a certain range of temperature ;(Nyabundi et al, 2012). Above temperatures of 22℃, tea yields decreaseand that there is more correlation of yield with moisture than with temperature;(Ratnasiri et al, 2008) Analysis indicated that the tea growing regions with temperatures range of 15.5ºC-18.5℃ and 1000-2700mm rainfall are favourable for thriving of Kangaita weevil. And these tea growing regions are all in the highlands east of rift valley except the Meru North area, near Mt. Kenya in Kirinyaga and Embu and Meru south areas where conditions exceed these thresholds ;(Cheramgoi et al, 2016).

Tea production cannot stand both extreme high and extreme low rainfall in terms of both magnitude and frequency of variability therefore both floods and drought occurrences are a threat. Tea yields have been observed to be decreasing with drought;(Burgess and Carr, 1996) although it may not matter much for crops under irrigation but altitude due to temperature differences;(Squire et al, 1993) and is very important for a highland crop like tea; Bilham, (2011). According to Kenya Tea Research Foundation, tea only grows well at hill slopes which offer natural drainage that keeps the land under tea growing free from floods. It is therefore clear that tea cannot stand floods hence analysis of precipitation extremes is mandatory in tea production.

Snipes and Kate, 2013, referred to Kenya as the world's top exporter of black tea by weight and pinpointed that tea exports have been competing with the tourism and horticulture sectors for the country's top foreign exchange earner and that tea production and processing is currently carried out in 15 out of the Kenya's 47 counties and impacts a large proportion of Kenya's population. About 14% world tea production comes from Kenya which is the 3rd leading tea producer worldwide ;(Owuor et al, 2011).

Agriculture which is the main socio-economic activity in Africa takes care of around 80% of the Kenya's population and constitutes 53% of its GDPand since Climate change comes with and is caused by global warming, its effects in agricultural production will greatly affect most of the livelihoods in the region in such a way that farmers who are being forced to be flexible, will depend on scientific options to adjust to the change; (UNESCO, 2006 and WRI, 2007).

The major impacts of climate change are the occurrence of extreme weather conditions either in form of hailstorm, frost or drought. The western tea producing counties of Kenya, especially; Kericho, Bomet (Sotik) and Nandi, normally have a remarkable loss of tea leaves due to hail estimated at over 2 million kilograms per year; (Bore, 2015). They also observed that the occurrence of Frost on the other hand, is less but when it does strike, there are huge losses incurred and that generally, frost occurrence is on valley bottoms and low lying areas. They talked of the analysis of long-term data suggesting that the frost incidences are increasing. Year in and year out, frost is an agricultural menace that causes crop damage resulting to tremendous losses in the agricultural field within the Kenyan highlands; (Onywere et al, 2014), where their research mapped frost hotspots within the Aberdare and Mount Kenya regions and identified the extent of arable land prone to frost risk. The most common extreme weather conditions in the region of study are floods and drought according to Ogwang et al, (2015).

An improved prediction of the magnitude of temperature changes and the knowledge of the impacts of temperature changes on crop yields at a local or regional scale are considered important areas for future research; (Lobell et al, 2008), that makes it necessary to subdivide a local region into smaller tea growing zones so as to monitor the temperature impacts in each zone. Climate change is expected to greatly affect agricultural production into the future; (Brown and Funk, 2008, Lobell et al, 2008b). Onduru et al, 2012, showed that the smallholder tea systems are moving towards social sustainability and economic returns were positive while Indicator scores for sustainability, for FFS members, increased by 4% from the base period.

Mitigation of climate change through Organic farming due to its focus on closed nutrient cycles, increases resilience and productivity; (Niggli et al, 2008). KTDA has taken the opportunity to supply small holder farmers with the improved variety of seedlings and fertilizer to see the industry through increased productivity. Technologies including high yielding clones, proper selection of herbicides application, control of insects, pests and weeds, improved fertilizer recommendation and timely harvesting practices have been developed by the Ministry of Agriculture and the Tea Research Foundation of Kenya; (Koskei et al, 2012). Large tea estates manage eucalypts for fuelwood within the tea farms as a form of renewable energy; (Oballa et al, 2010).

Tea production in Kenya is carried out in small and large scale (estate) farms. The smallholder tea production, processing and marketing, was until 1997 subject to government controls. The controls were implemented by the Kenya Tea Development Authority (KTDA) which was established under the agricultural Act, Cap 318 as a parastatal and given the mandate to control and regulate the small holder tea sub-sector in Kenya; ((Drucker, 2006).Despite that KTDA continued to be in control of some of the services especially tea processing, marketing and the supervision of the smallholder tea farming even after the de-control and subsequent tea market liberalization by the government, farmers have been selling green tea leaves directly to private factories or to middlemen for immediate payments without any contractual arrangements; (Kavoi et al, 2008).Kiprono et al and Hellen et al, 2014 in their papers on social- economic effects of liberalization on small scale tea production in Kenya said that liberalization has exposed the smallholder tea farmers and factories to stiff competition due to entrance of new firms into the tea business. Factories have been forced to streamline their operations to cope with competition.

CHAPTER THREE: DATA AND METHODOLOGY.

This section discusses the data source, period and methods used to achieve the set objectives.

3.0: DATA TYPES AND SOURCES.

Three datasets were used in the study for the period 1976 to 2014 obtained from KMD.

One dataset was used in the study for the period 2006 to 2015 obtained fromTDK.

Nineteen bioclimatic variables were used in the study for the period 2030 to 2060 and 2060 to 2080 for the worldclim.com averaged GCM data for 2050 and 2070 respectively.

The monthly temperature and Precipitation ground based data within the neighborhood of the tea growing regions were obtained from Kenya Meteorological Department as shown in table 3.1 below.

The satellite data was obtained from ATLAS KNMI by dividing the tea zones into smaller grids at a spatial resolution of 0.5 degrees= 50km which was divided into two and added to the longitude and latitude of each point of interest where precipitation and temperature raw data was obtained from.

Monthly Tea production data for the KTDA factories and the multinational companies was obtained from Tea Directorate of Kenya (TDK).

Bioclimatic variables data in tiff format for RCP 4.5 and 8.5 for the years 2050 and 2070 was obtained from worldclim.com using resolution of 1km squared with CNRM model which is basically collected from the National Meteorological Research Centers globally and conformed to the observed KMD data. The data was used in the QGIS and thereafter in MaXent Models.

Table 3.1: KMD stations in the neighborhood of Tea growing counties.

TEA GROWING COUNTY NAME	KMD STATION NAME
1. KERICHO	KERICHO
2. NYERI	NYERI
3. MERU	MERU
4. KISII	KISII
5. KAKAMEGA	KAKAMEGA
6. EMBU	EMBU
7. TRANS-NZOIA	KITALE
8. NAKURU	NAKURU

3.1: DATA SAMPLING.

Data samples were collected from various sources and parts of the region of study and used in the analysis as follows:

Simple random sampling was applied when selecting stations within each tea growing zones based on availability of data whereby the stations within the neighborhood of the tea growing zones were picked.

Systematic random sampling was applied when picking the 24hrs lowest temperature of the night and the highest temperature of the day at 0600z and 1200z respectively whereby Maximum and Minimum temperature data was chosen so as to save time and reduce duplication of work while capturing both the night and day time temperature patterns.

Purposive sampling was applied whereby stations with datasets period exceeding thirty years were selected so as to capture the climatology of the region.

3.2: DATA QUALITY CONTROL

3.2.1: PEARSON'S CHI-SQUARE HYPOTHESIS AND SIGNIFICANCE TEST.

*The Chi-square statistical test was performed using R on each dataset and gave P values far much less than 0.05 as shown in the Kericho precipitation results which meant that at least one of the samples in the entire population was different hence the data was non homogeneous therefore the null hypothesis was rejected and the alternative hypothesis adopted due to inconsistency of data.*P values less than 0.05 also was an indication that there existed a significant change in the slope of the trends.

The following are the output equations for the Kericho precipitation data:

$\mathcal{X}^2$=16960, df = NA, p-value = 0.000999

3.2.2: MODEL JUSTIFICATION.

TABLE 3.2.1: ***CORRELATION BETWEEN DIFFERENT MODEL'S DATA AND KMD OBSERVED DATA.***

MODEL (CNRM) JUSTIFICATION USING CORRELATION ANALYSIS AND TIMESERIES ANALYSIS.

MODEL	CORRELATION COEFFICIENT
CNRM	0.765501132
MIROC	0.585597135
MPI	0.689443753
NOAA	0.286493263

It was noted from Table 3.2.1that the CNRM data had the highest correlation coefficient hence correlated best with the observed data and therefore justified to be the best model among the four to be used for data acquisition in the region of study.

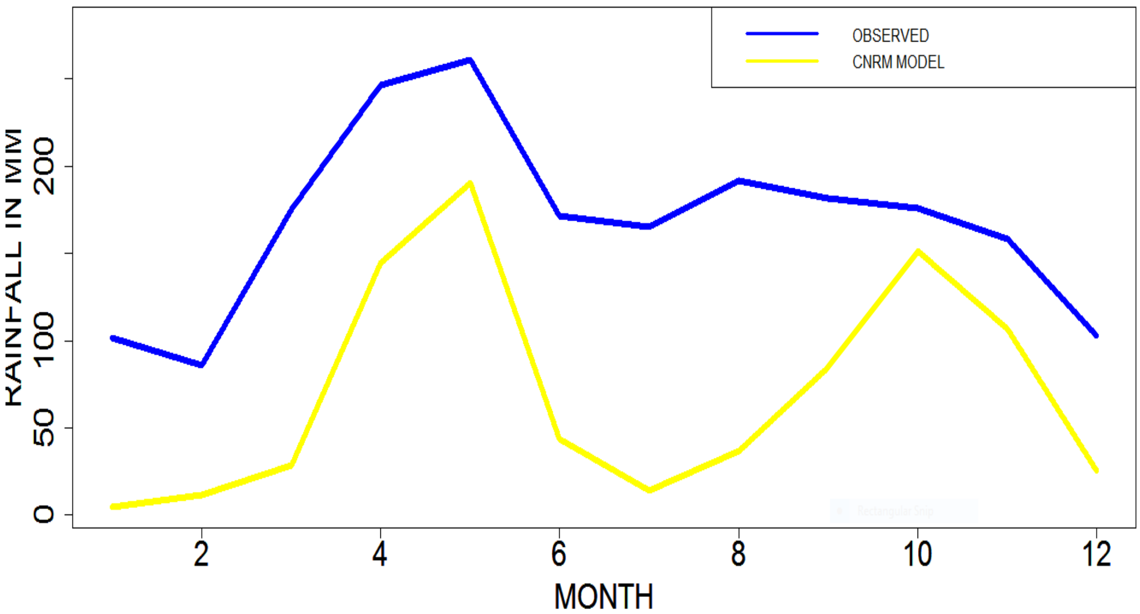
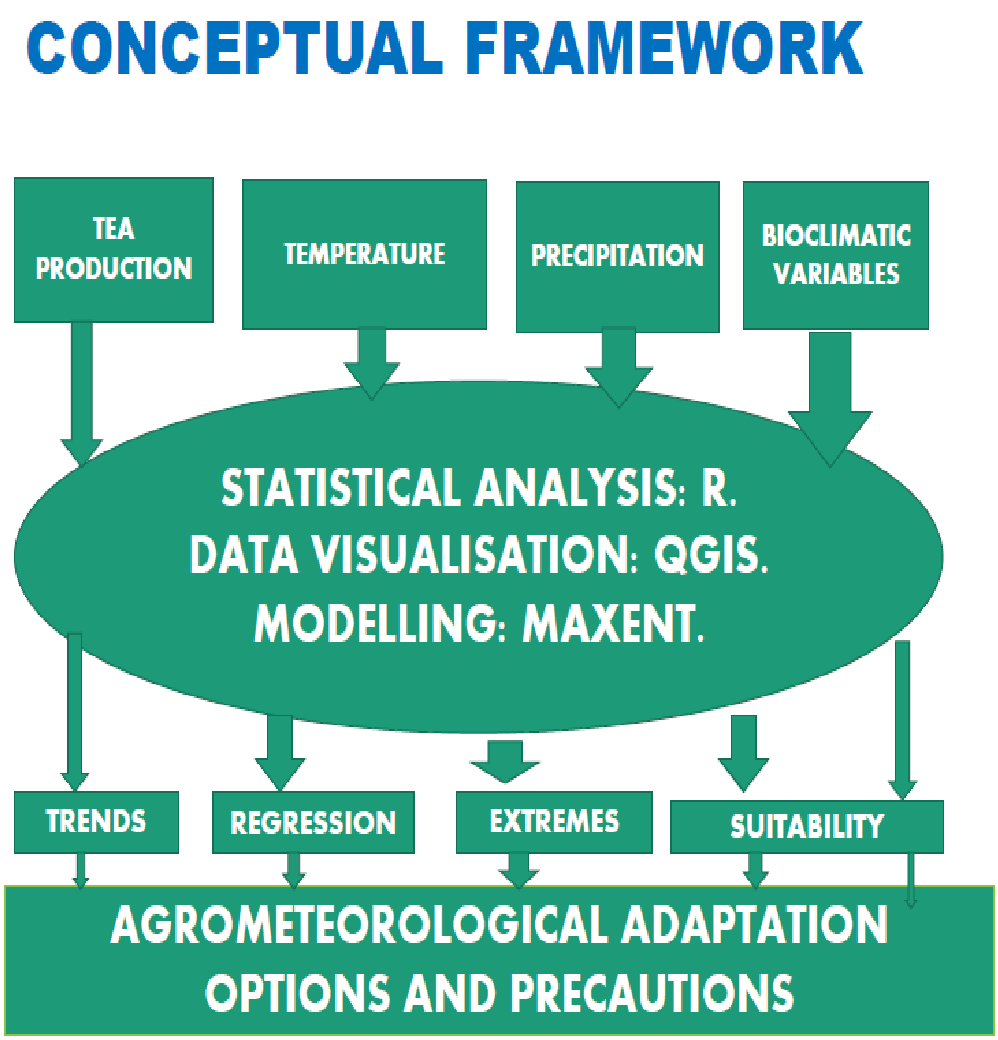


Fig.3.2.1: Time series analysis between CNRM precipitation data and Observed data.

It was observed from the time series curves in Fig.3.2.1that CNRM data assumed a similar pattern with the KMD observed data hence found to conform to the observed data's pattern.

The results justified the selection of CNRM GCM among the rest of the models for the study.

3.3: CONCEPTUAL FRAMEWORK



3.3.1: Direction and flow of relationships in the conceptual framework.

To arrive at the solution on mapping of the future suitable tea growing areas and providing agricultural options to sustain tea and agricultural production in Kenya, data was subjected to various processes using MaXent model, QGIS model and R software as illustrated in the framework above.

The KMD, and tea production TBK datasets were analyzed using R to identify trends, extremes, precipitation distribution as well as their effect on tea production through regression analysis.

The bioclimatic data was fed into the MaXent model which performed some simulations and came up with outputs of maps showing the probability of suitability within each existing tea growing county in the area of study projected up to the years 2050 and 2070.

Simulations performed by the MaXent model on the major crops that match the economic value of tea and the worst pest currently causing havoc on tea production in Rwanda gave outputs of their suitability in the region of study that were used in the formulation of agro meteorological options.

3.4: METHODOLOGY

Methods that were used to achieve the set objectives included both graphical and statistical with the aid of scientific software besides the use of models as follows:

3.4.1: Trend analysis.

Trend analysis of the temperature, precipitation and tea yields for the region of study was performed graphically using R software to depict the historical temporal variations.

3.4.2: Identification of extremes and frequency distribution.

Monthly Mean plus or minus 1 Standard deviation for the entire period of study was used to show the average, above average and below average values hence establish the magnitude and frequency of variability of the variables on both seasonal and inter-annual basis using R.

The equation for extremes is given by**: É=μ±σ………………………………….. (1)**

Where: **É** stands for Extremes which are departures from the Mean.

μ stands for the Population Mean which is the climatological Mean.

σ stands for one Standard deviation which represents 68% of the data.

Frequency distribution curves showing the spread of precipitation over years were plotted using R to identify the distribution pattern in the category of Gaussian/Normal, positive or negatively skewed.

The equation for skewness is given by: $Skewness = \frac{3(Mean - Median)}{Standard\ deviation}$…………….. (2)

3.4.3: Regression analysis.

Multiple Linear Regression analysis between temperature, precipitation and tea yields using R was carried out where tea yields were used as the dependent variable (Y) in order to show the effect of the variations of these climate variables to the yields with the equation showing the coefficients of each variable as follows:

$$\widehat{Y} = b_o + b_1X_1 + b_2X_2 + \ldots + b_pX_p + \mathcal{E} \qquad (3)$$

Where $\widehat{Y}$ *is the expected value of the dependent variable*, b_o is the theoretical y-intercept, $b_1/b_2/b_p$ are the theoretical slopes standing for the effects of $X_1/X_2/X_p$ on $\widehat{Y}$ and $\mathcal{E}$ is the residual error.

Multiple Linear Regression analysis between maximum/minimum temperature, and precipitation using R was carried out where precipitation was used as the dependent variable in order to show the effect of the variations of these climate variables to precipitation.

Multiple Linear Regression analysis between maximum/minimum temperature, precipitation and tea production using R was carried out where tea production was used as the dependent variable in order to show the effect of the variations of these climate variables to tea production.

3.4.4: Climate Projections.

Worldclim.com CNRM scenario data under RCP 4.5 and 8.5 provided the bioclimatic projections used in the MaXent model where simulations on 19bioclimatic variables were performed to establish the suitability of the region of study up to the year 2070. 1km squared resolution was used in the worldclim.com data acquisition.

MAXENT model

Maximum entropy (MaXent) is a general-purpose method for making predictions or inferences from incomplete information. The idea is to estimate a target probability distribution by finding the probability distribution of maximum entropy, subject to a set of constraints that represent incomplete information about the target distribution.

The information available about the target distribution often presents itself as a set of real-valued variables, called 'features', and the constraints are that the expected value of each feature should match its empirical average -"average value for a set of sample points taken from the target distribution"(Phillips *et al*., 2006). Similar to logistic regression, MaXent weights each environmental variable by a constant. The probability distribution is the sum of each weighed variable divided by a scaling constant to ensure that the probability value ranges from 0 to 1. The program starts with a uniform probability distribution and iteratively alters one weight at a time to maximize the likelihood of reaching the optimum probability distribution. Everything in MaXent is performed automatically by the model according to specified settings by the analyst.

MaXent is considered among other crop models to be the most accurate model for suitability mapping; (Elith*et al*, 2006).

3.4.5: Suitability mapping.

The QGIS model was used to extract the bioclimatic data from worldclim.com by clipping it into the area of study and then translating the data into ASCII format which is readable in MaxEnt model.

Resolution of 30 degree Sec equivalent to 1km squared in the Worldclim CNRM Global Circulation Model which had been used by most researchers in Africa was chosen.

The future suitability of the region of study for tea production was determined by feeding the QGIS model outputs in ASCII format as environmental layers into MaxEnt Model. Comma delimited files of tea, avocado, banana and tea mosquito bug were also fed as sample species in the MaxEnt model.

The suitability of the region of study for tea and coffee production and the existence of pests and tea diseases was hence established and the suitability of coffee was used to provide agro meteorological options.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.0: RESULTS AND DISCUSSIONS

This chapter deals with results and discussions of the various analyses that were made using statistical, graphical methods and Species Distribution Model ling.

4.1: RAINFALL TRENDS

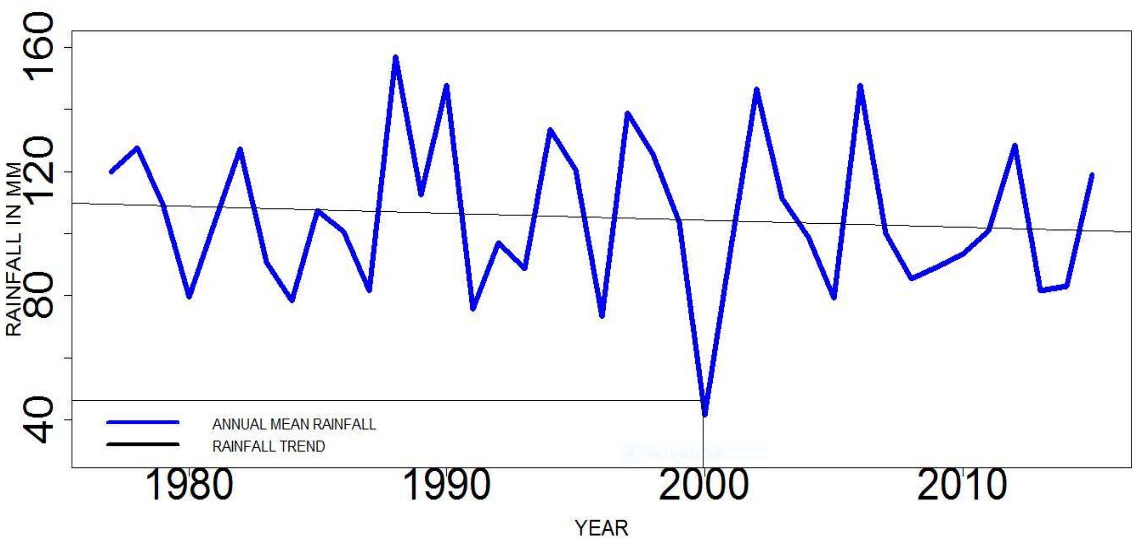


Fig.4.1a: Rainfall trend for Embu.

On observing the trend line in Fig.4.1a, decreasing precipitation trends have been experienced over years in Embu which lies in the Highlands east of rift valley region.

This implies that rainfall has been decreasing with time in Embu by up to 10mm.

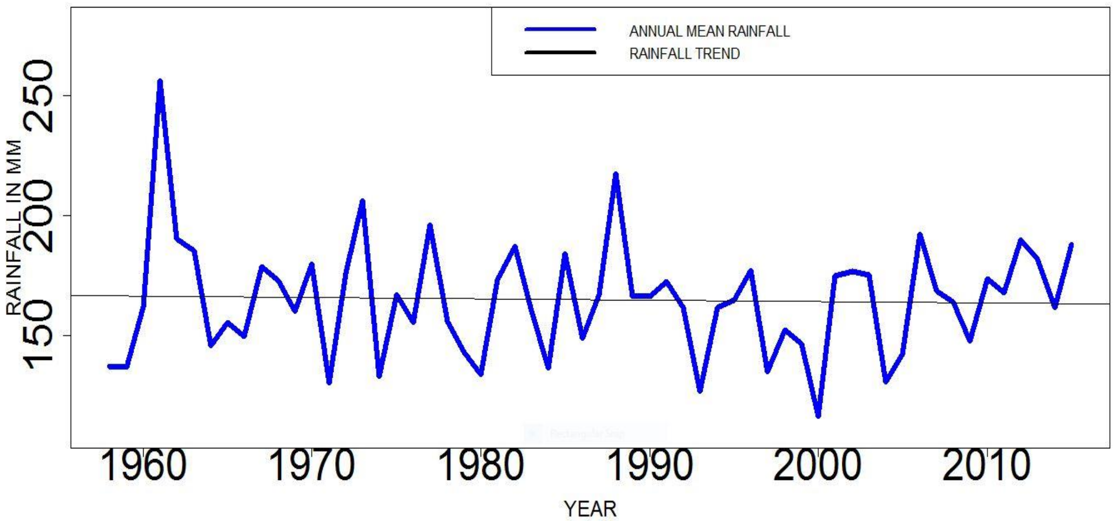


Fig.4.1b: Rainfall trend for Kakamega.

On observing the trend line in Fig.4.1b, decreasing precipitation trends have been experienced over years in Kakamega which lies in the Highlands west of rift valley region.

This implies that rainfall has been decreasing with time in Kakamega by up to 7.0mm.

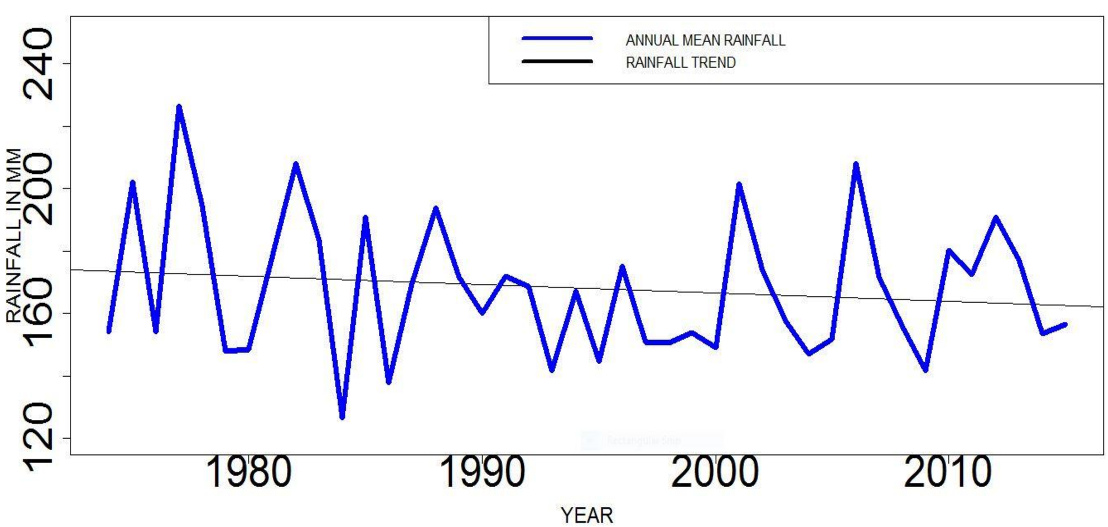


Fig4.1c showing the rainfall trend in Kericho.

On observing the trend line in Fig.4.1c, decreasing precipitation trends have been experienced over years in Kerichowhich lies in the Highlands west of rift valley region.

This implies that rainfall has been decreasing with time in Kericho by up to 15mm.

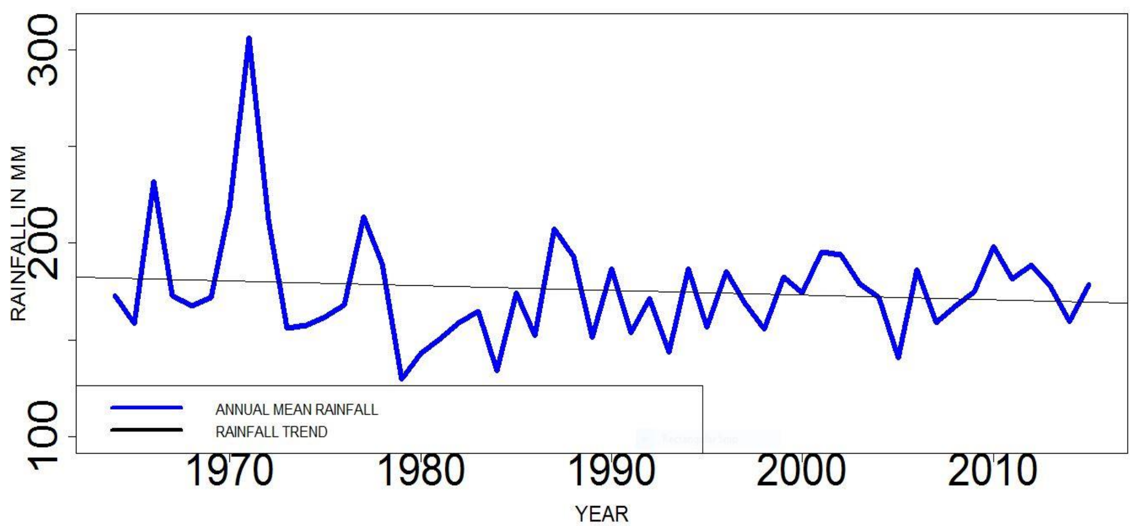


Fig4.1d showing the rainfall trend in Kisii.

On observing the trend line in Fig.4.1d, decreasing precipitation trends have been experienced over years in Kisii which lies in the Highlands west of rift valley region.

This implies that rainfall has been decreasing with time in Kisii by up to 10mm.

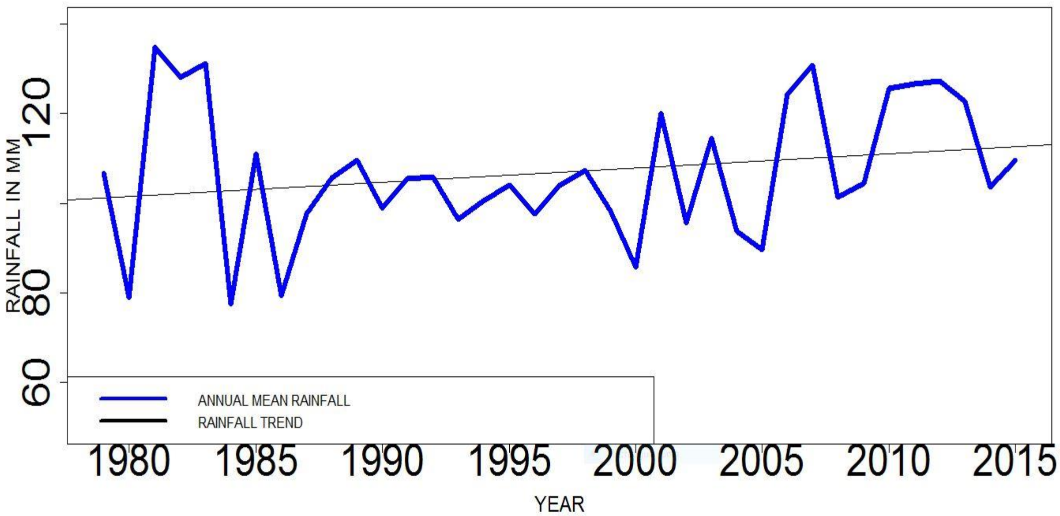


Fig4.1e: The rainfall trend in Kitale

On observing the trend line in Fig.4.1e, increasing precipitation trends have been experienced over years in Kitale which lies in the Highlands west of rift valley region.

This implies that rainfall has been increasing with time in Kitale by up to up to 10mm.

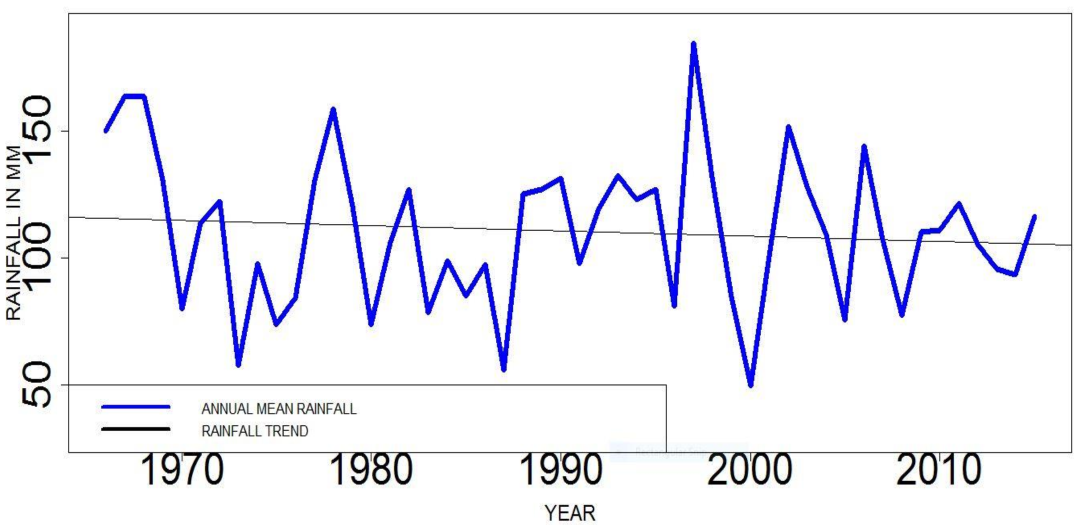


Fig4.1f: The rainfall trend in Meru

On observing the trend line in Fig.4.1f, decreasing precipitation trends have been experienced over years in Meru which lies in the Highlands east of rift valley region.

This implies that rainfall has been decreasing with time in Meru by up to 5mm.

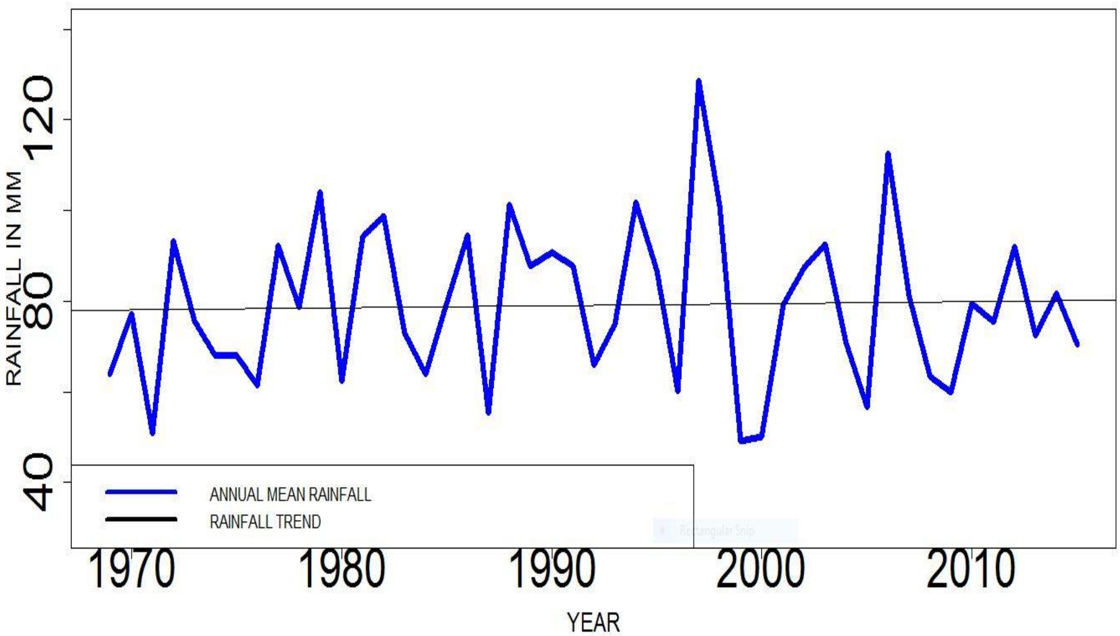


Fig4.1g: The rainfall trend in Nyeri

On observing the trend line in Fig.4.1g, no significant change in precipitation trends have been experienced over years in Nyeri which lies in the Highlands east of rift valley region.

This implies that rainfall amounts have remained unchanged in Nyeri.

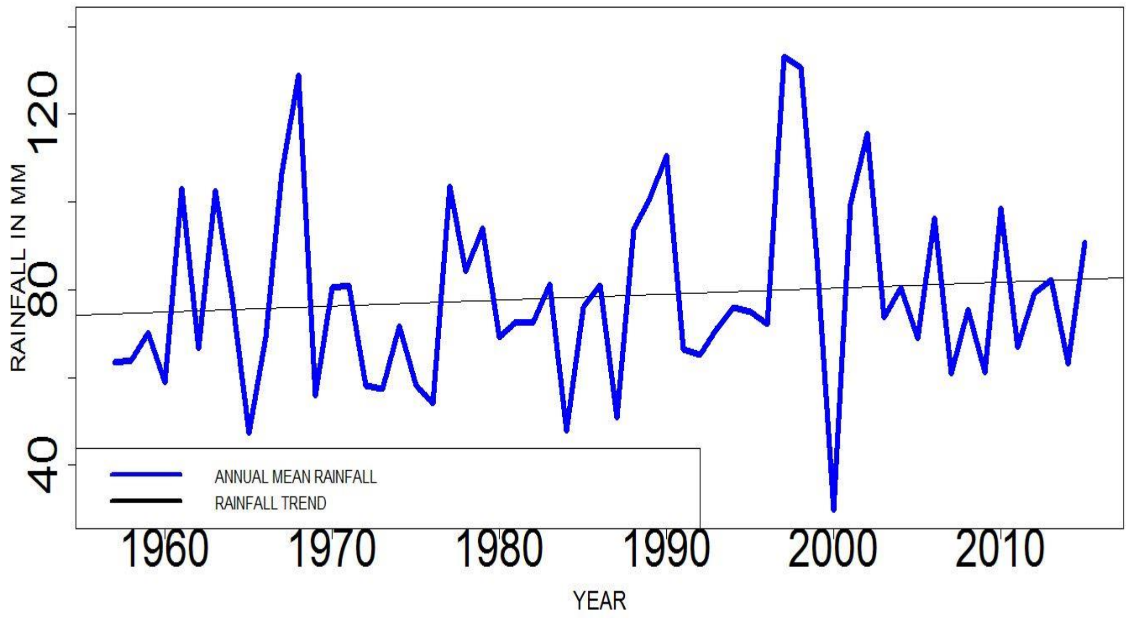


Fig4.1h: The rainfall trend in Thika

On observing the trend line in Fig.4.1h, increasing precipitation trends have been experienced over years in Thika which lies in the Highlands east of rift valley region.

This implies that rainfall has been increasing with time in Thika by up to 10mm.

4.2: RAINFALL EXTREMES IN TERMS OF MAGNITUDE

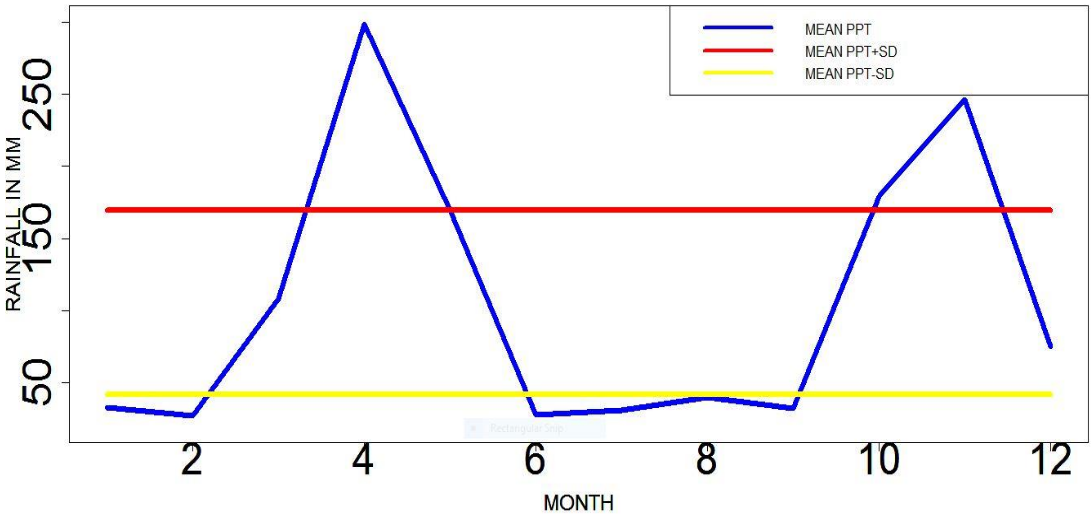


Fig.4.2a: The magnitude and frequency of rainfall extremes in Embu.

From Fig. 4.2a we observe that the wet months are wetter by up to 120mm in Embu and that dry months are slightly drier. MAM is wetter by around 120mm while OND is wetter by 80mm. JJA and JF are drier by around 10mm.

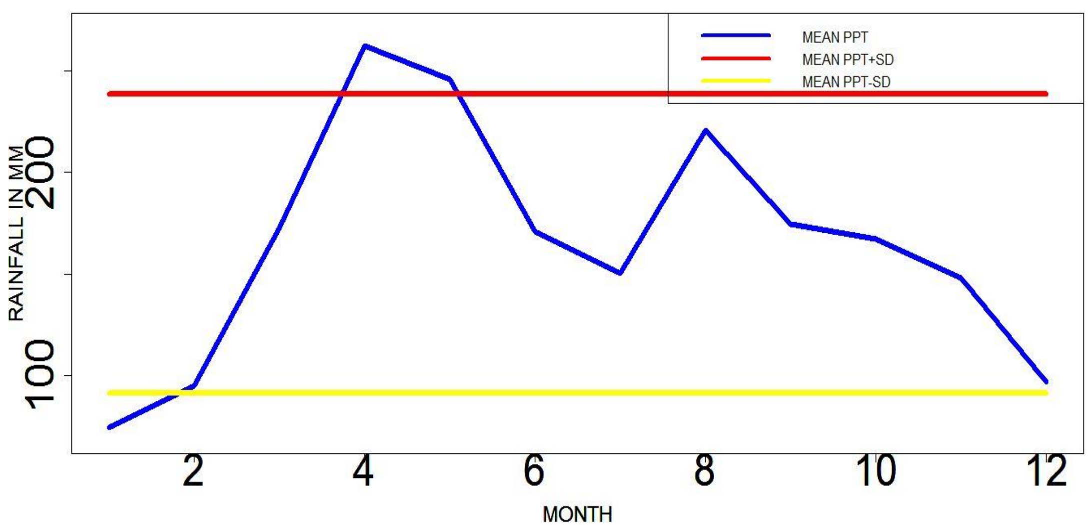


Fig.4.2b: The magnitude and frequency of rainfall extremes in Kakamega.

From Fig. 4.2b we observe that the wet months are slightly wetter by up to 20mm in Kakamega and that dry months are within average. MAM is wetter by around 20mm while OND and JJA are within average. The month of January is drier by around 20mm.

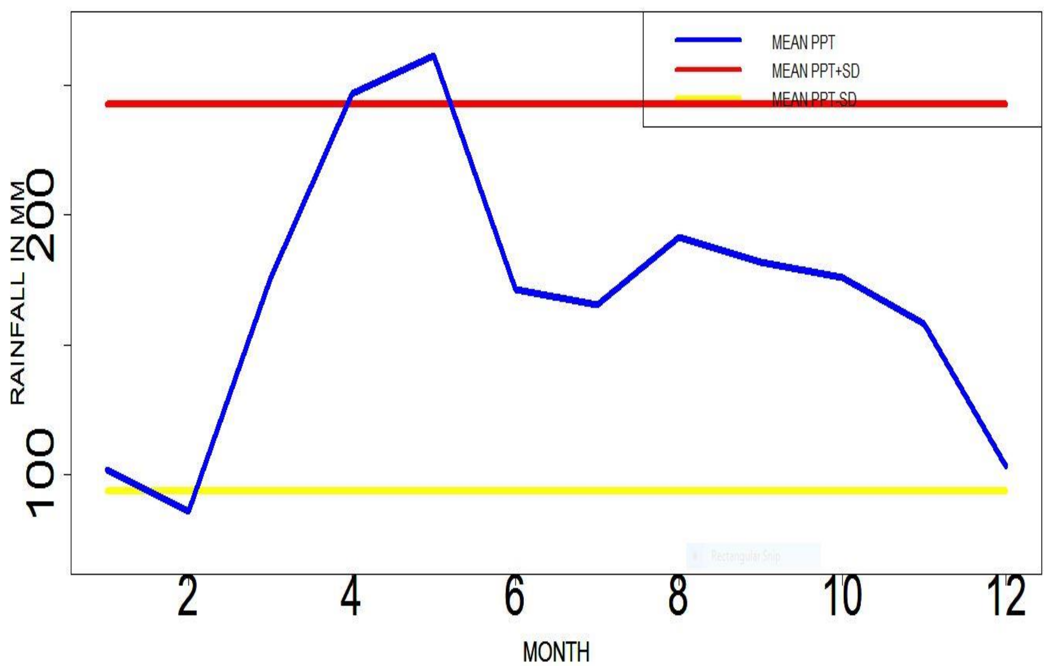


Fig.4.2c: The magnitude and frequency of rainfall extremes in Kericho.

From Fig. 4.2c we observe that the wet months are slightly wetter by up to 30mm in Kericho. MAM is wetter by 30mm, February is drier by around 10mm while OND and JJA are within average.

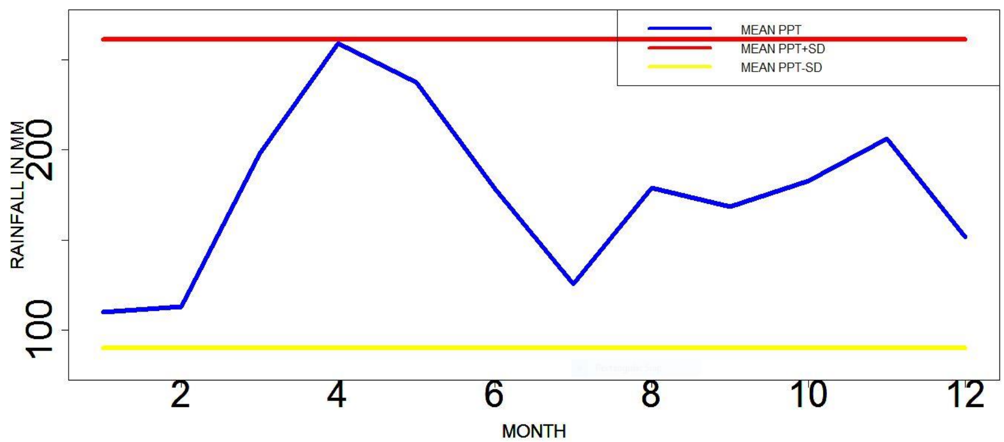


Fig.4.2d: The magnitude and frequency of rainfall extremes in Kisii.

From Fig. 4.2d we observe that the dry months and wet months are within average in Kisii. All the seasons are within average with MAM season approaching above normal.

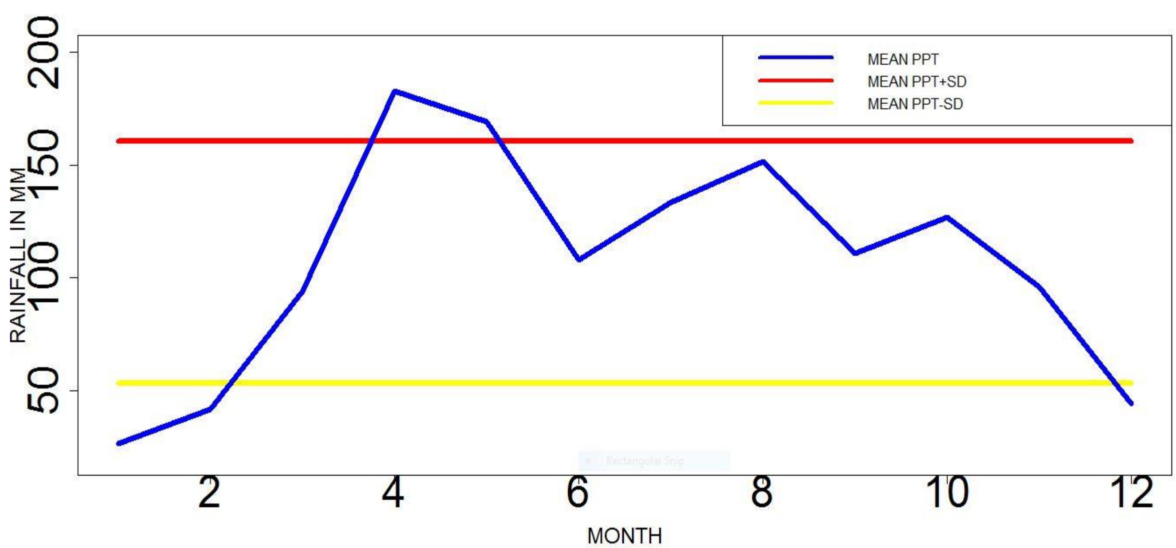


Fig.4.2e: The magnitude and frequency of rainfall extremes in Kitale.

From Fig. 4.2e we observe that the wet months are slightly wetter by up to 20mm in Kitale and that the dry months are drier. MAM is wetter by around 20mm, JJA and OND are within average and JF are drier by around 25mm.

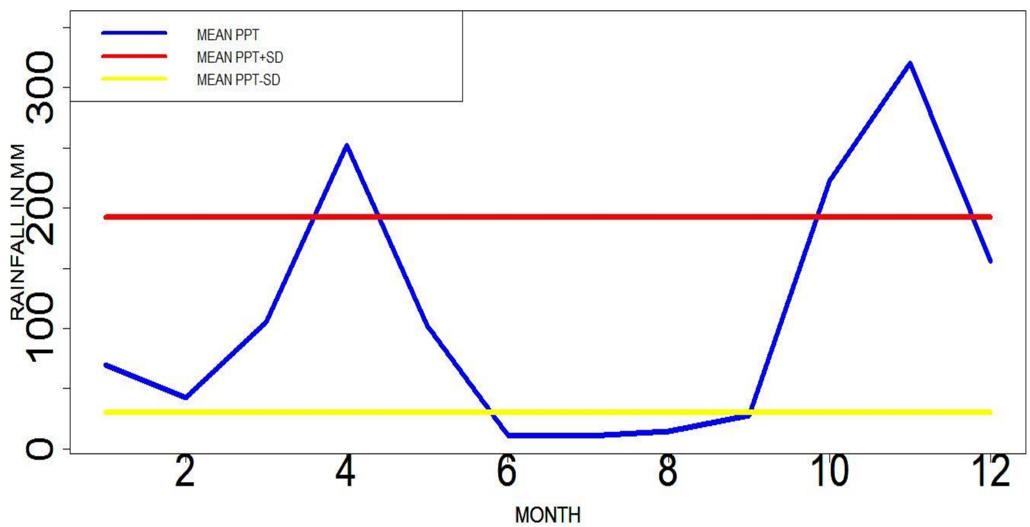


Fig.4.2f: The magnitude and frequency of rainfall extremes in Meru.

From Fig. 4.2f we observe that the wet months are wetter by up to 110mm in Meru and that the dry months are slightly drier. MAM is wetter by around 50mm, OND is wetter by around 110mm, JJA is drier by 20mm and JF is within average.

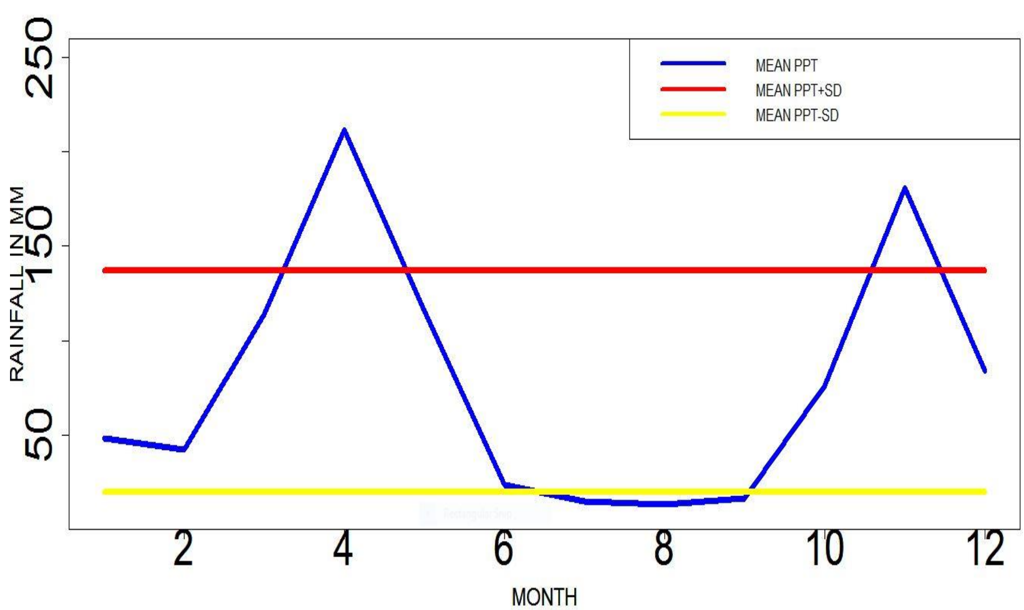


Fig.4.2g: The magnitude and frequency of rainfall extremes in Nyeri.

From Fig. 4.2g we observe that the wet months are wetter by up to 50mm in Nyeri and that the dry months are approaching below normal. MAM is wetter by 50mm, OND is wetter by 30mm, JF are within average and JJA is drier by around 10mm.

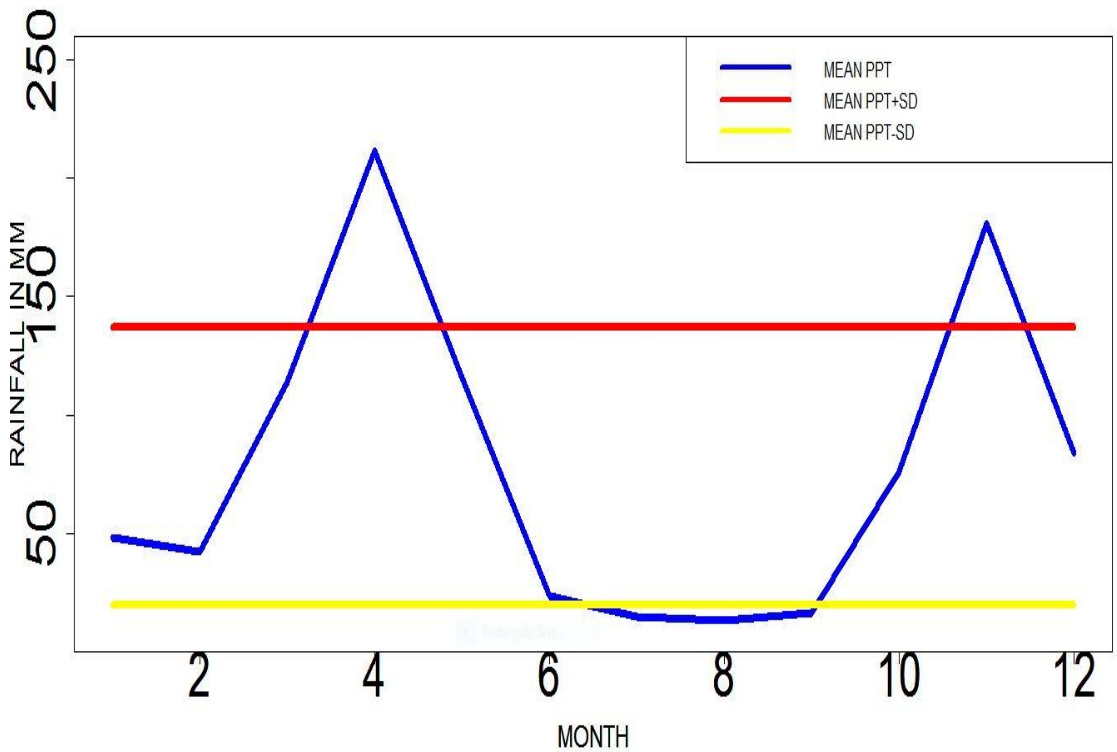


Fig.4.2h: The magnitude and frequency of rainfall extremes in Thika.

From Fig. 4.2h we observe that the wet months are wetter by up to 60mm in Thika and that the dry months are slightly drier. MAM is wetter by 60mm, OND is wetter by 30mm, JJA is drier by 5mm and JF is within average.

4.3: TEMPERATURE TRENDS

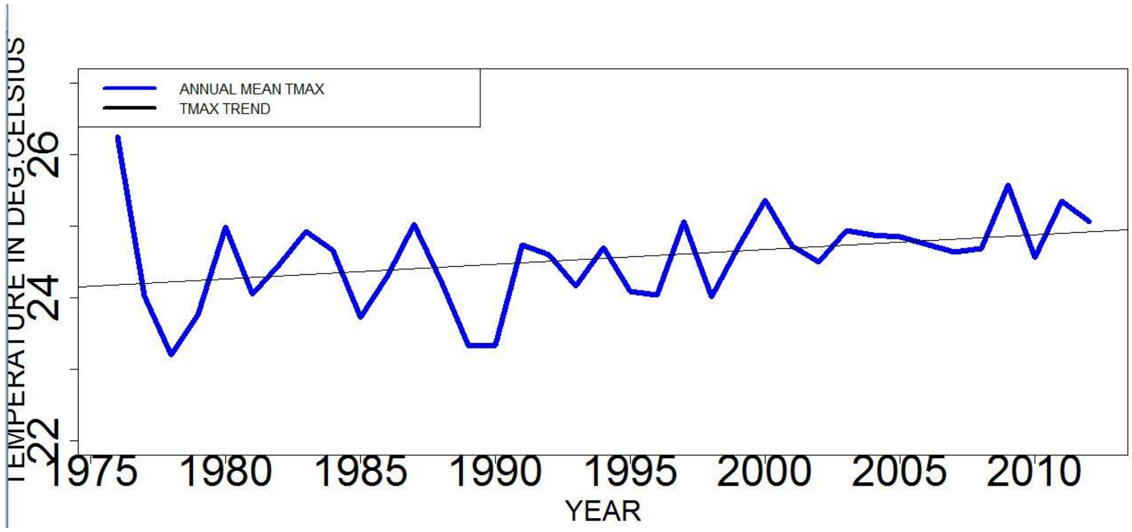


Fig 4.3a: The maximum temperature trends in Embu

From Fig. 4.3a we observe increasing trends of maximum temperature in Embu, implying that daytime temperatures have been increasing over years in this county by up to 0.5℃.

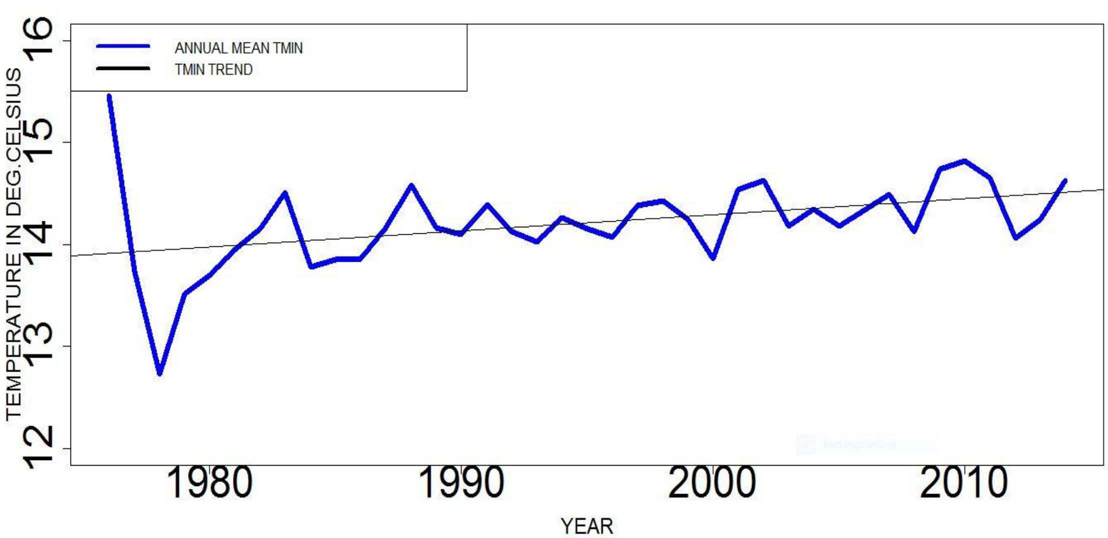


Fig 4.3b: The minimum temperature trends in Embu

From Fig. 4.3b we observe increasing trends of minimum temperature in Embu, implying that night temperatures have been increasing over years in this county by up to 0.4℃.

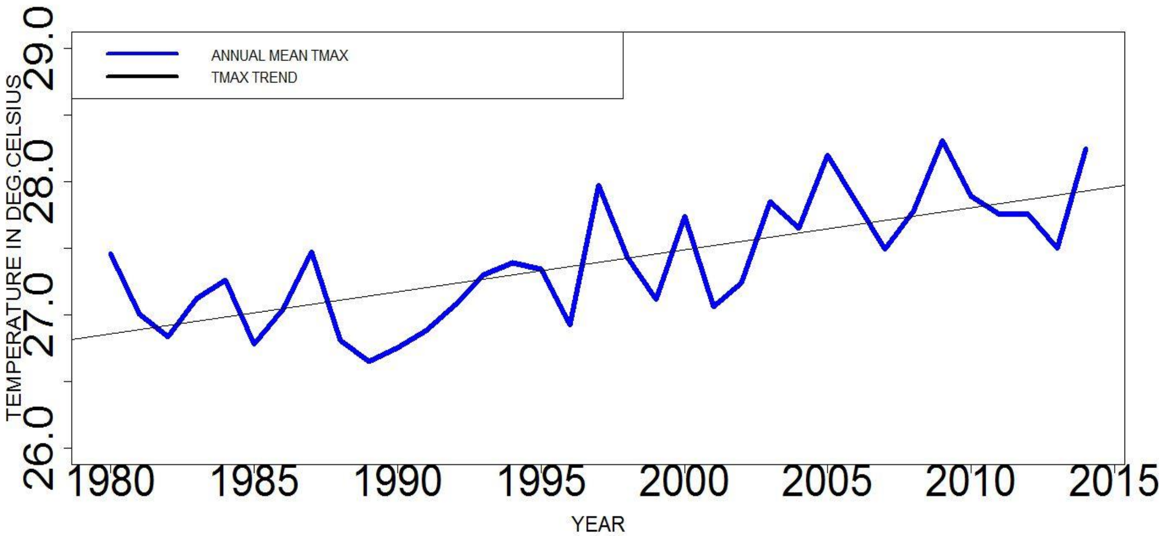


Fig 4.3c: The maximum temperature trends in Kakamega

From Fig. 4.3c we observe increasing trends of maximum temperature in Kakamega, implying that daytime temperatures have been increasing over years in this county by up to 0.7℃.

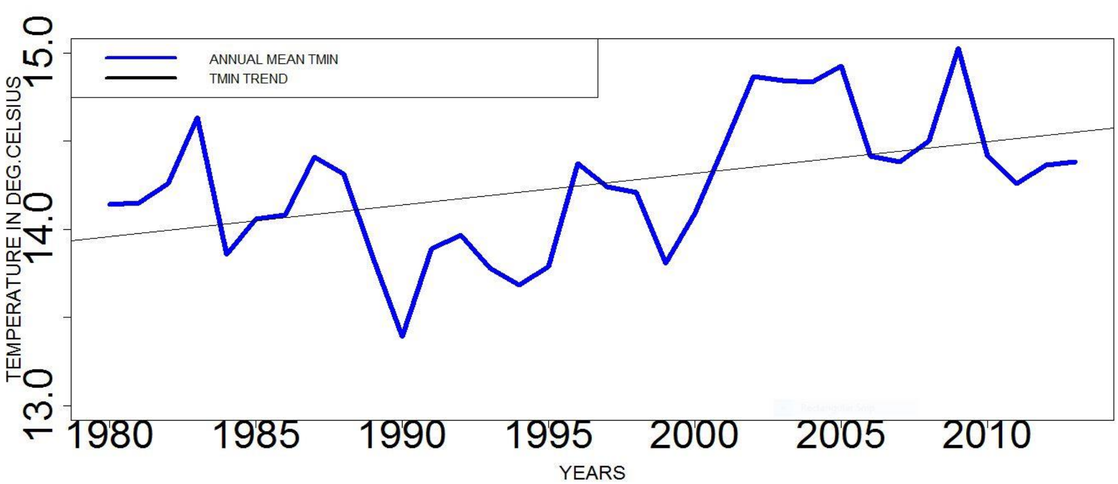


Fig 4.3d: The minimum temperature trends in Kakamega

From Fig. 4.3d we observe increasing trends of minimum temperature in Kakamega, implying that night temperatures have been increasing over years in this county by up to 0.4℃.

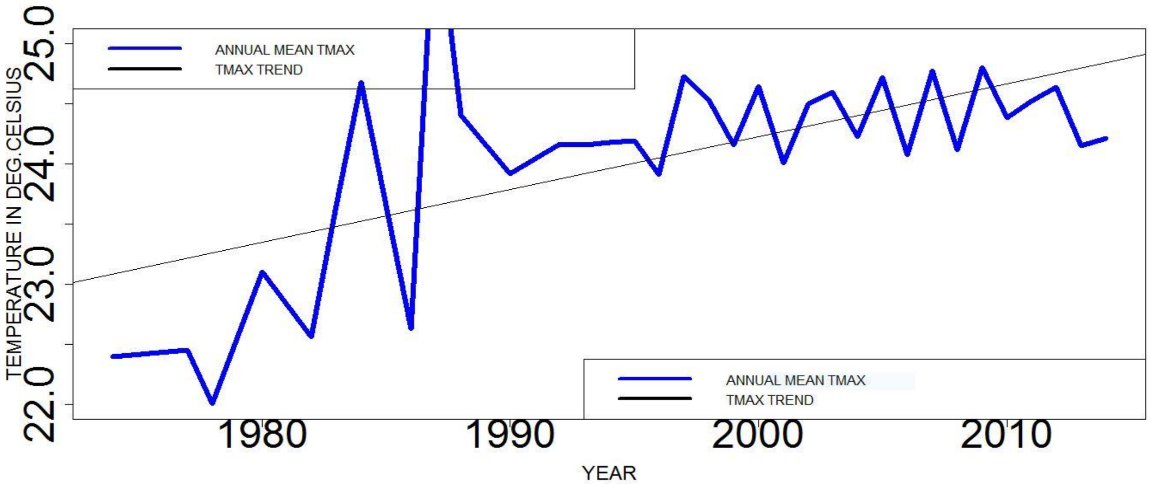


Fig 4.3e: The maximum temperature trends in Kericho

From Fig. 4.3e we observe increasing trends of maximum temperature in Kericho, implying that daytime temperatures have been increasing over years in this county by up to 1.0℃.

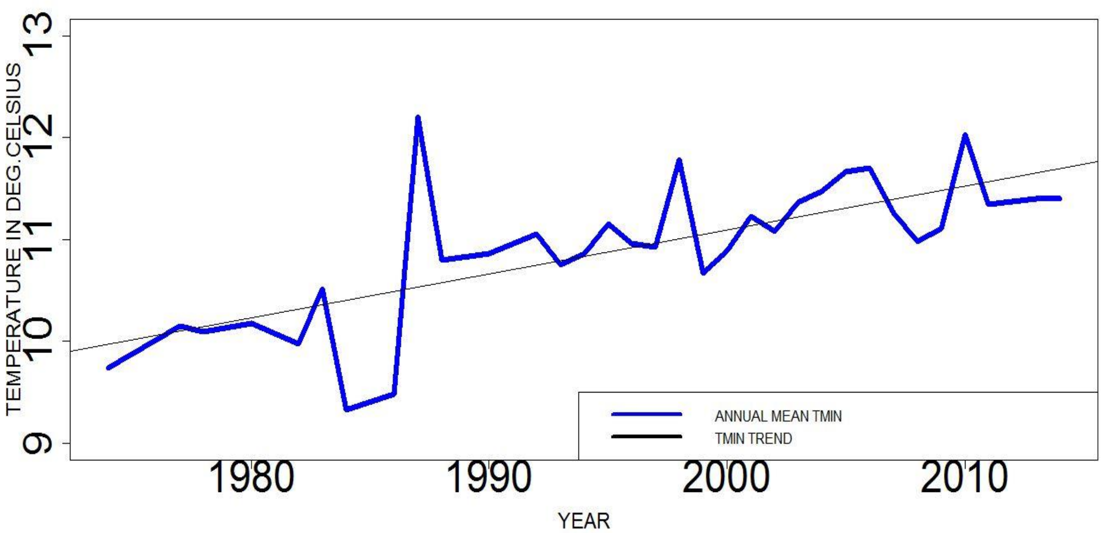


Fig 4.3f: The minimum temperature trends in Kericho

From Fig. 4.3f we observe increasing trends of minimum temperature in Kericho, implying that night temperatures have been increasing over years in this county by up to 1.6℃.

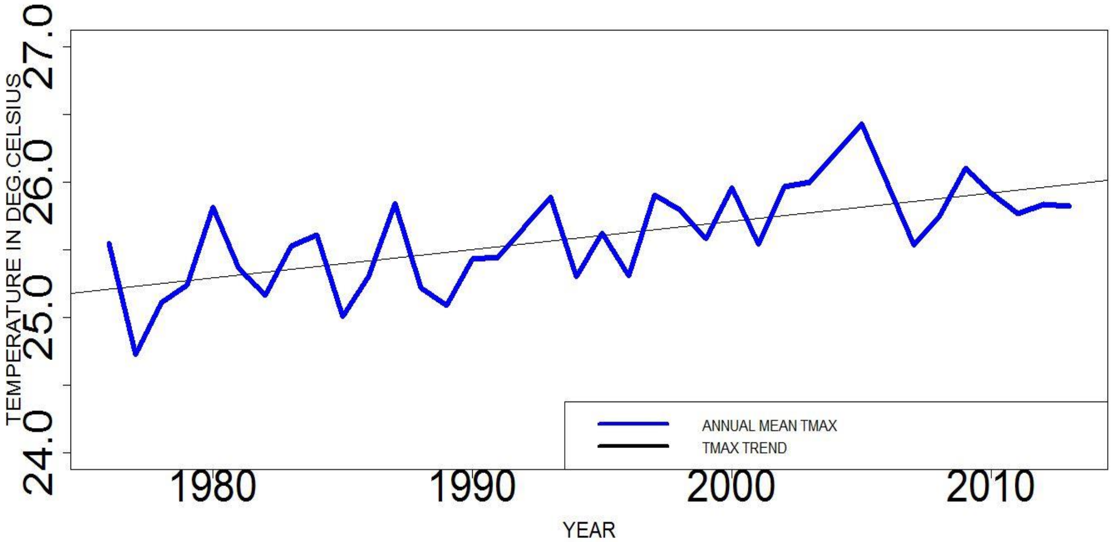


Fig 4.3g: The maximum temperature trends in Kisii

From Fig. 4.3g we observe increasing trends of maximum temperature in Kisii, implying that daytime temperatures have been increasing over years in this county by up to 0.5℃.

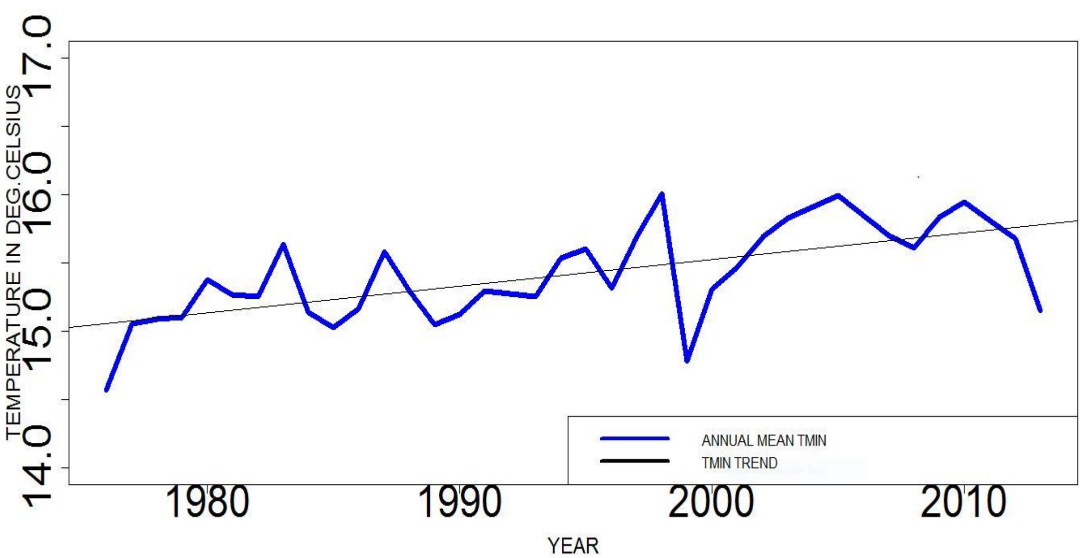


Fig 4.3h: The minimum temperature trends in Kisii

From Fig. 4.3h we observe increasing trends of minimum temperature in Kisii, implying that night temperatures have been increasing over years in this county by up to 0.6℃.

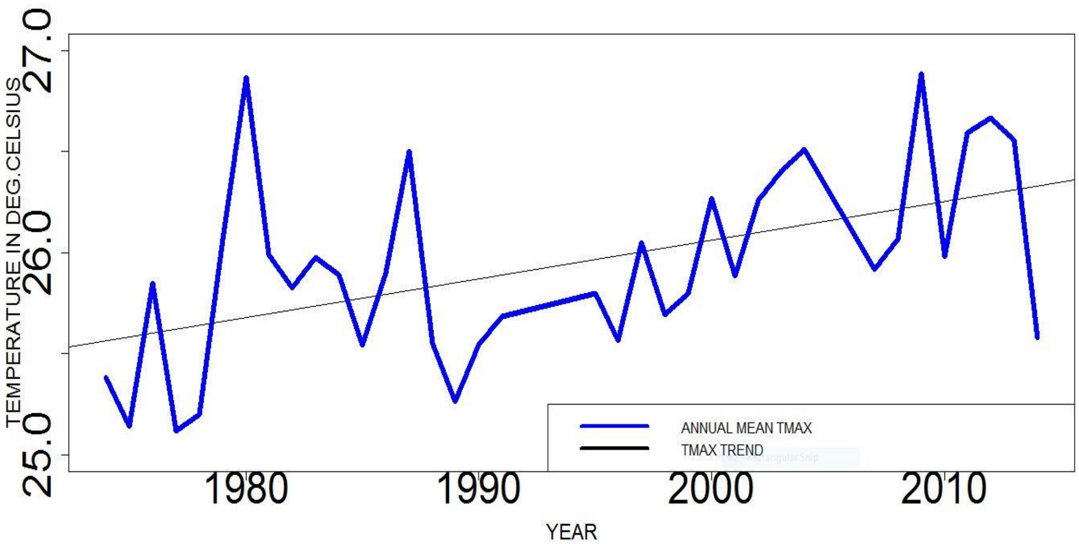


Fig 4.3i: The maximum temperature trends in Kitale

From Fig. 4.3i we observe increasing trends of minimum temperature in Kitale, implying that daytime temperatures have been increasing over years in this county by up to 0.5℃.

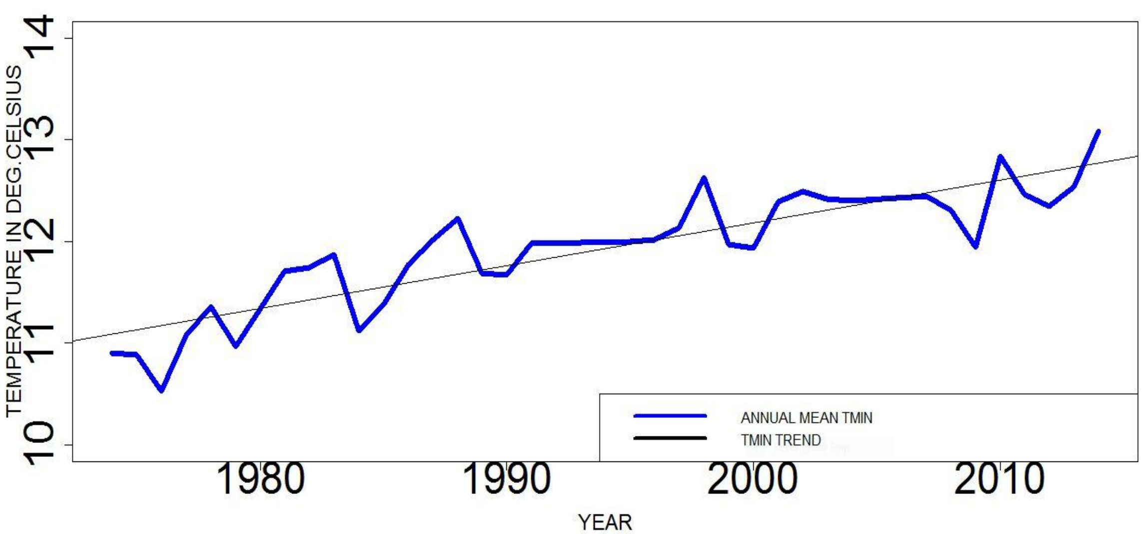


Fig 4.3j: The minimum temperature trends in Kitale

From Fig. 4.3j we observe increasing trends of minimum temperature in Kitale, implying that night temperatures have been increasing over years in this county by up to 1.2℃.

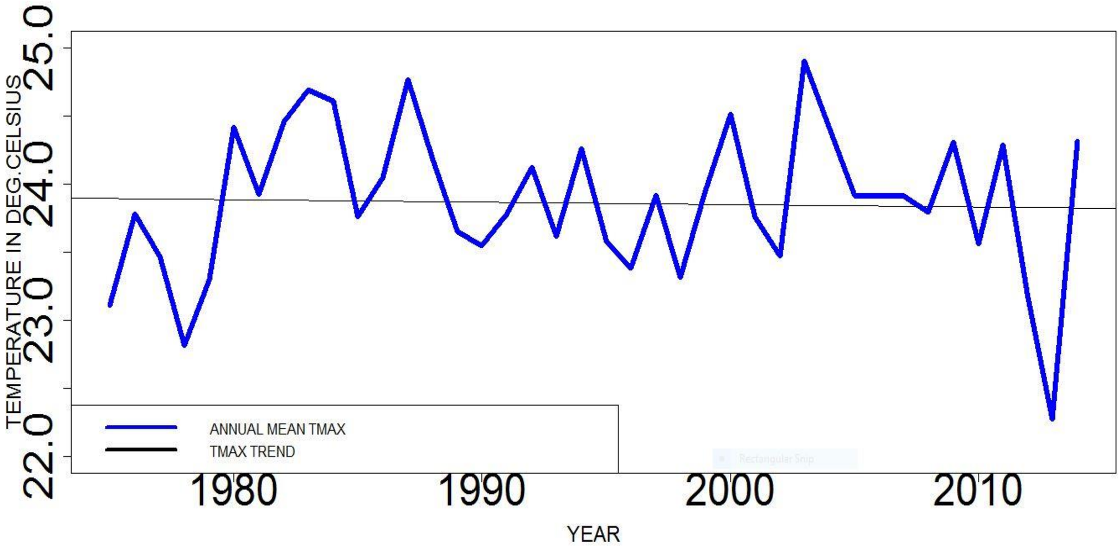


Fig 4.3k: The maximum temperature trends in Meru

From Fig. 4.3k, we observe no significant change in trends of maximum temperature in Meru, implying that day temperatures have remained constant over years in this county.

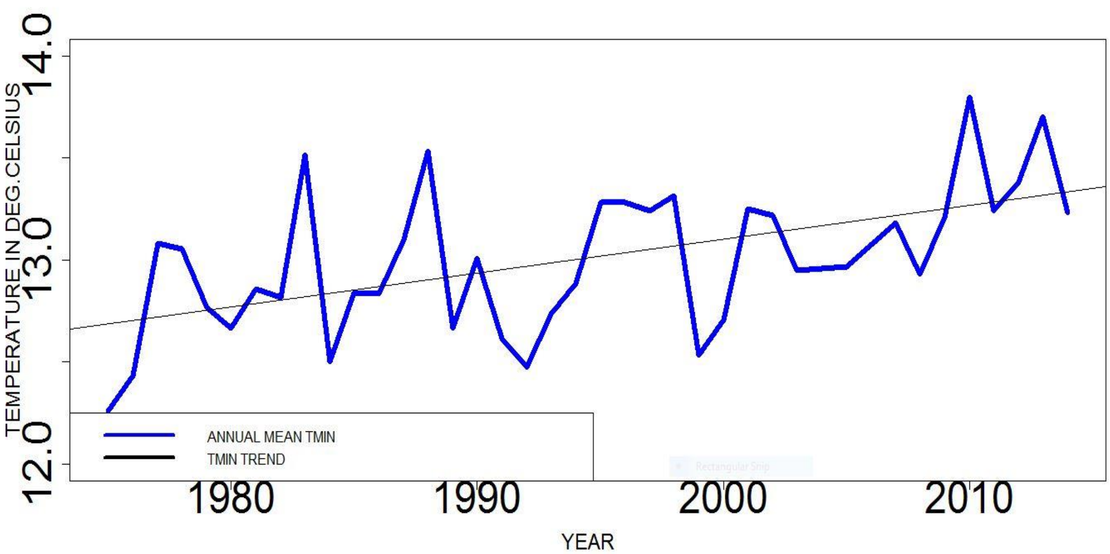


Fig 4.3l: The minimum temperature trends in Meru

From Fig. 4.3l we observe increasing trends of minimum temperature in Meru, implying that night temperatures have been increasing over years in this county by up to 0.4℃.

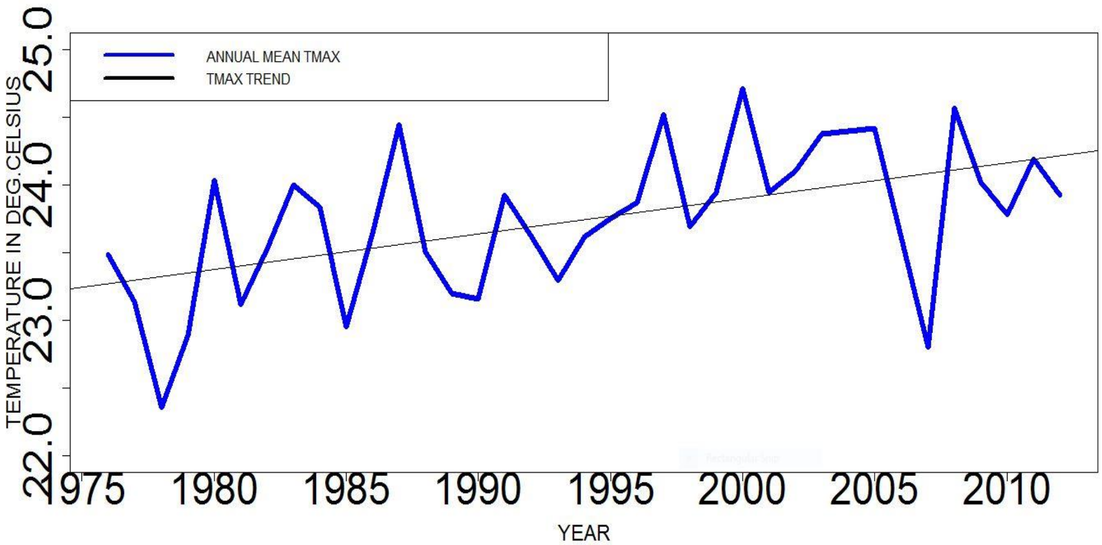


Fig 4.3m: The maximum temperature trends in Nyeri

From Fig. 4.3m we observe increasing trends of maximum temperature in Nyeri, implying that daytime temperatures have been increasing over years in this county by up to 0.8℃.

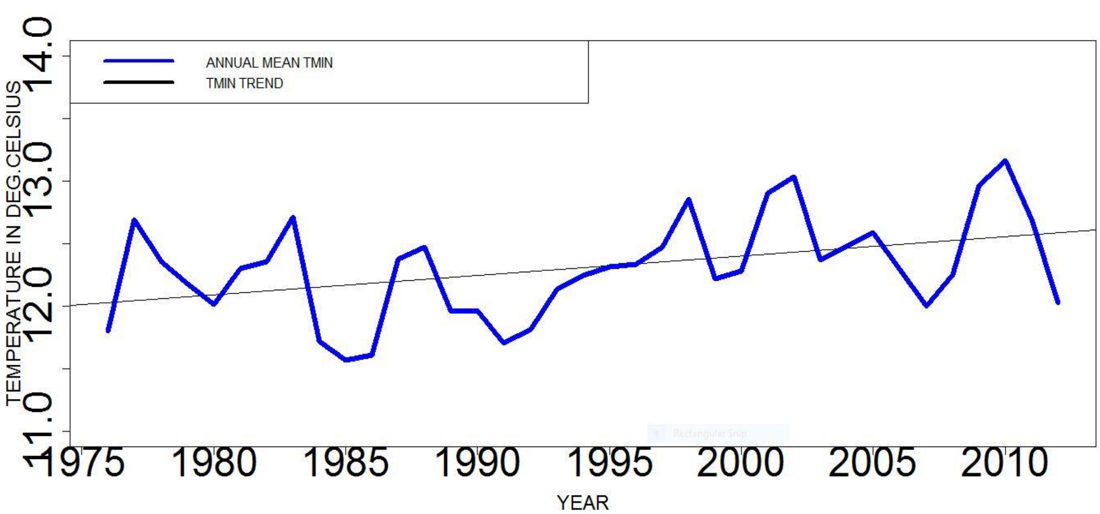


Fig 4.3n: The minimum temperature trends in Nyeri

From Fig. 4.3n we observe increasing trends of temperature during the night in Nyeri, implying that night temperatures have been increasing over years in this county by up to 0.4℃.

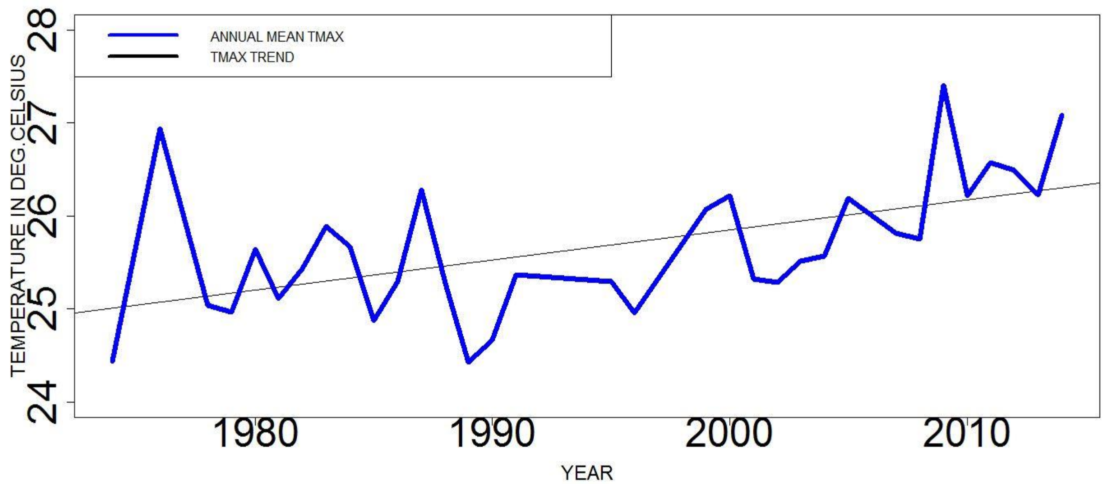


Fig 4.3o: The maximum temperature trends in Thika

From Fig. 4.3o we observe increasing trends of temperature during the day in Thika, implying that daytime temperatures have been increasing over years in this county by up to 1.0℃..

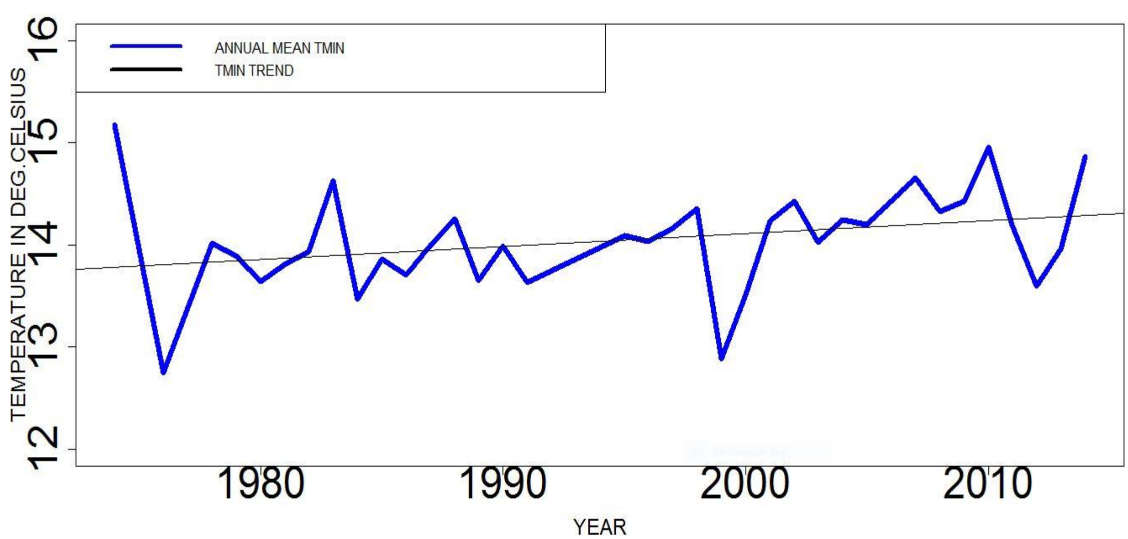


Fig 4.3p: The minimum temperature trends in Thika

From Fig. 4.3p we observe increasing trends of minimum temperature in Thika, implying that night temperatures have been increasing over years in this county by up to 0.4℃.

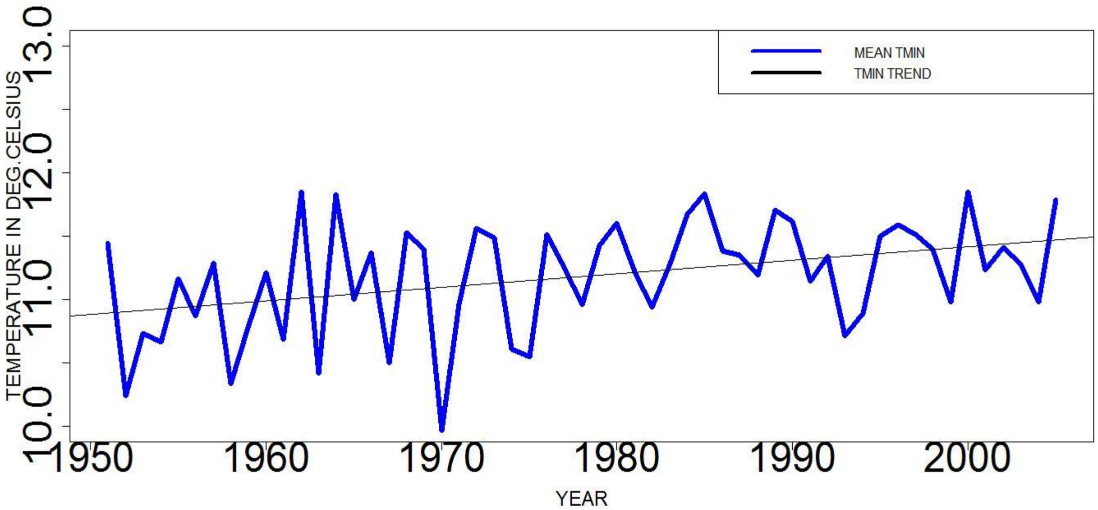


Fig 4.3q: The minimum temperature trends in Bomet

From Fig. 4.3q we observe increasing trends of minimum temperature in Bomet, implying that night temperatures have been increasing over years in this county by up to 0.5℃.

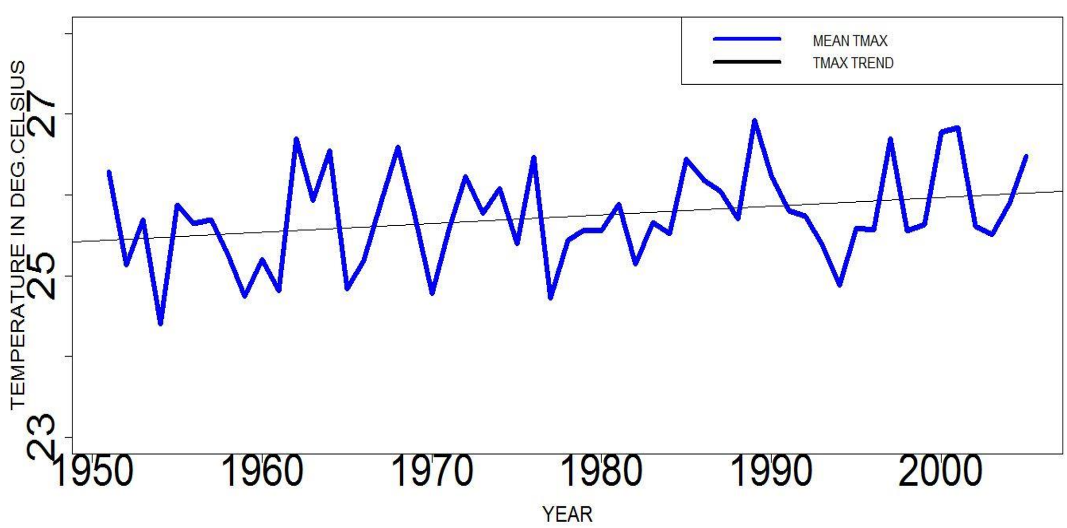


Fig 4.3r: The maximum temperature trends in Bomet

From Fig. 4.3r we observe increasing trends of maximum temperature in Bomet, implying that daytime temperatures have been increasing over years in this county by up to 0.4℃.

4.4: TEMPERATURE EXTREMES IN TERMS OF MAGNITUDE

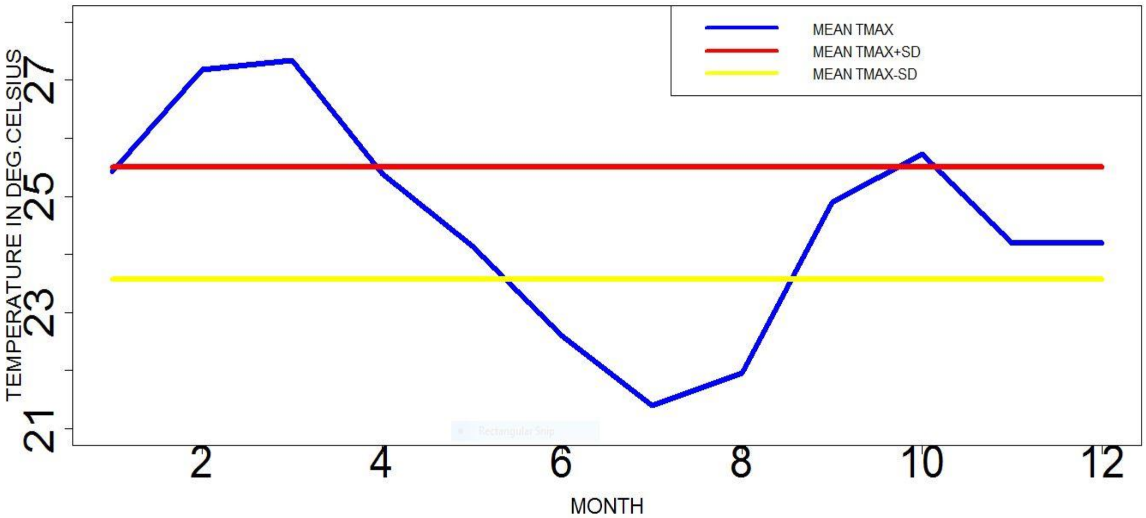


Fig.4.4a: The magnitude of Maximum temperature extremes in Embu.

From Fig.4.4a it was observed that in Embu, during daytime, the cold months are cooler by around 2.0℃ whereby JJA has cooled by up to 2.0℃ while the hot months are warmer by around 1.5℃ whereby February, March and April have warmed by up to 1.5℃, October has warmed by 0.2℃ and May, September, November, December, January are within average. In summary; the hotter than normal months are Feb-April and October while the cooler than normal months are June-August.

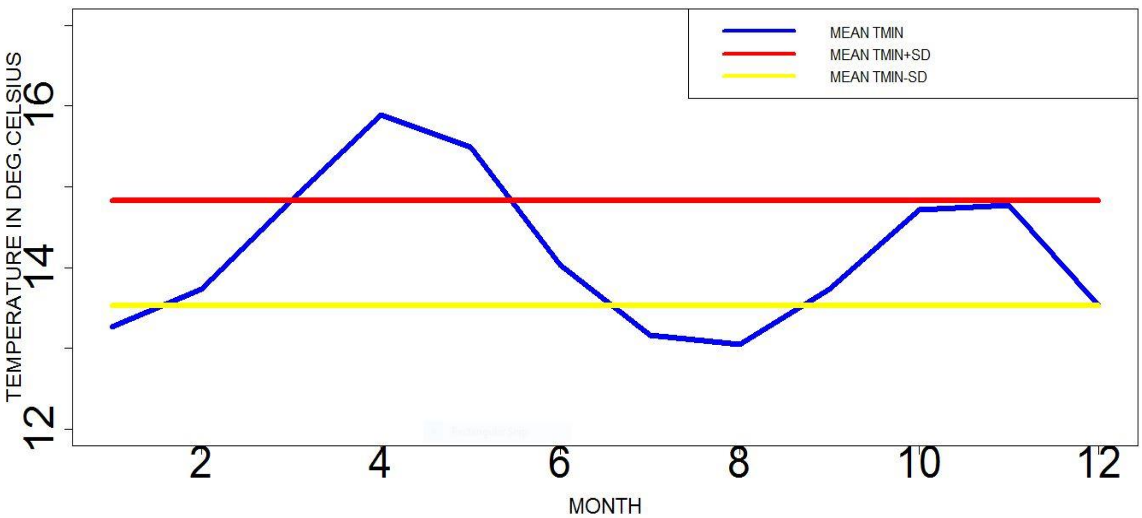


Fig.4.4b: The magnitude of Minimum temperature extremes in Embu.

From Fig.4.4b it was observed that in Embu, at night, the cold months are cooler by around 0.5℃ whereby JJA and January are cooler by around 0.5℃ while some hot months with an exception of January have warmed by around 1.0℃ whereby MAM is warmer by 1.0℃. February and OND are within average. In summary; the hotter than normal months are March-May while the cooler than normal months are June-August and January.

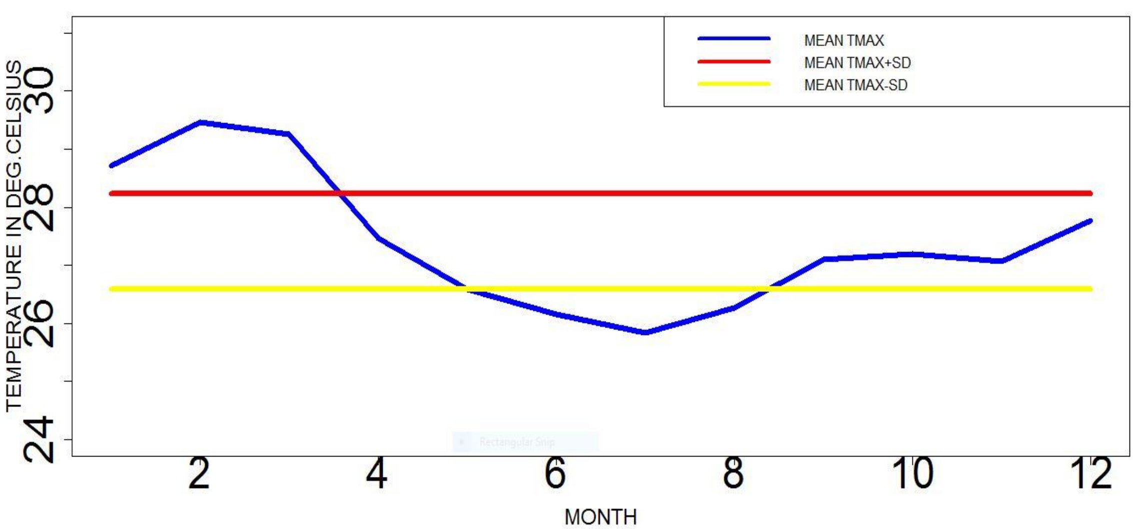


Fig.4.4c: The magnitude of Maximum temperature extremes in Kakamega.

From Fig.4.4c it was observed that in Kakamega, at daytime, the cold months are cooler by around 0.7℃ whereby JJA is cooler by 0.7℃ while the hot months have warmed by around 1.1℃ whereby January-April is warmer by 1.1℃. September-December is within average. In summary the hotter than normal months are Jan-April while the cooler than normal months are June-August.

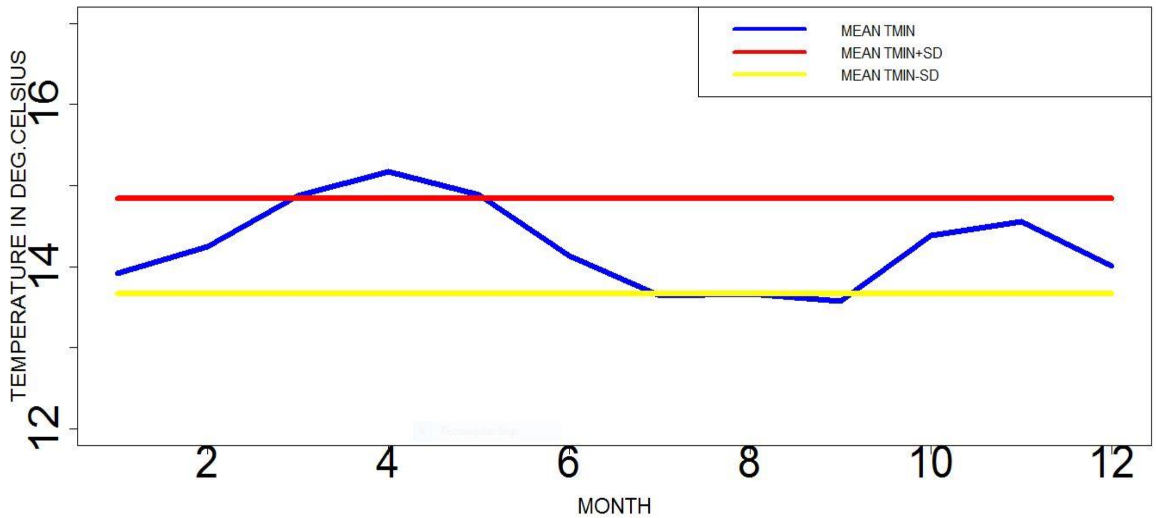


Fig.4.4d: The magnitude of minimum temperature extremes in Kakamega.

From Fig.4.4d it was observed that in Kakamega, at night, the cold months are cooler by around 0.1℃ whereby September emerges to be the coolest month and have cooled by up to 0.1℃ while the hot months have warmed by around 0.3℃ whereby March-May have warmed by up to 0.3℃. October-February are within average. In summary, the hotter than normal months are March-May while the cooler than normal months are June-September.

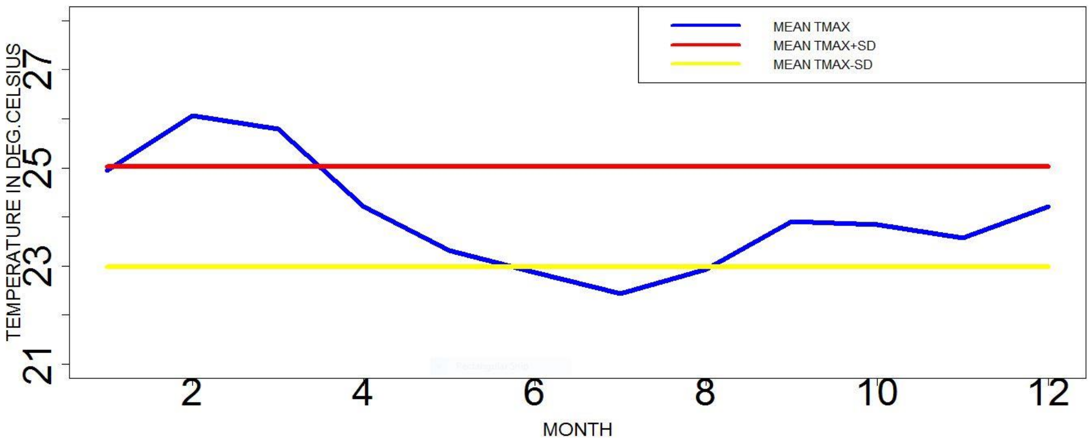


Fig.4.4e: The magnitude of Maximum temperature extremes in Kericho.

From Fig.4.4e it was observed that in Kericho, at daytime, the cold months are cooler by around 0.5℃whereby JJA has cooled by up to 0.5℃while the hot months have warmed by around 0.9℃ whereby ℃ January –April has warmed by up to 0.9℃.May and September-December have been within average. In summary, the hotter than normal months are Jan-April while the cooler than normal months are June-August.

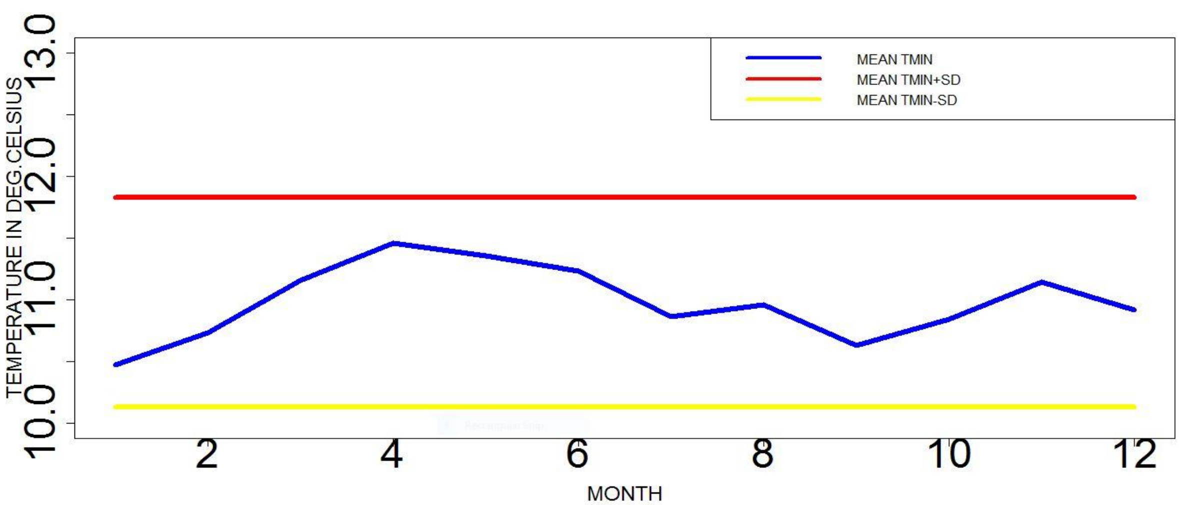


Fig.4.4f: The magnitude of minimum temperature extremes in Kericho.

From Fig.4.4f it was observed that in Kericho, at night, both the cold and hot months are within average.

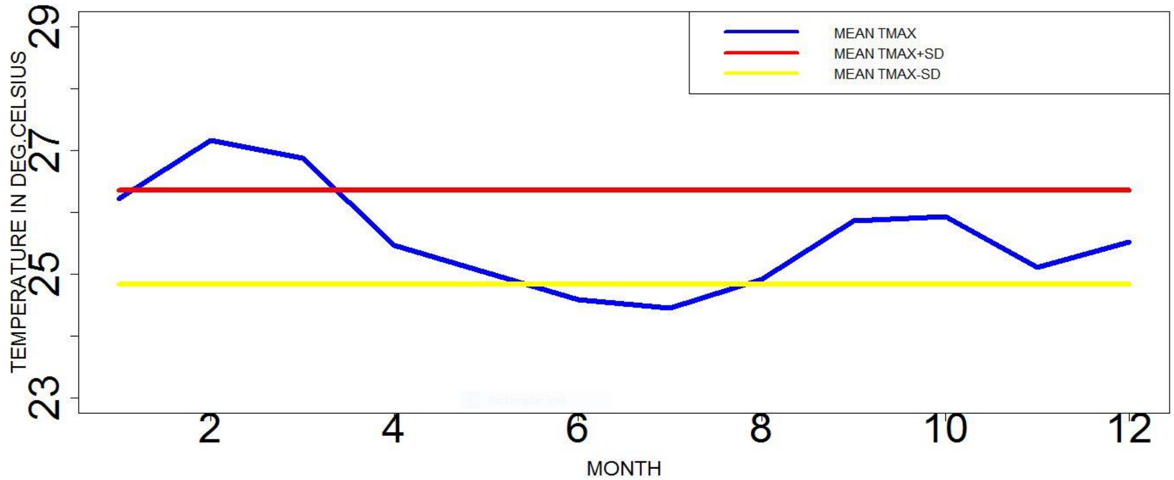


Fig.4.4g: The magnitude of Maximum temperature extremes in Kisii.

From Fig.4.4g it was observed that in Kisii, at daytime, the cold months are cooler by around 0.5℃whereby JJA has cooled by up to 0.5℃while the hot months have warmed by around 0.7℃.whereby January – April has warmed by up to 0.7℃. May and September-December are within average. In summary, the hotter than normal months are Jan-April while the cooler than normal months are June-August.

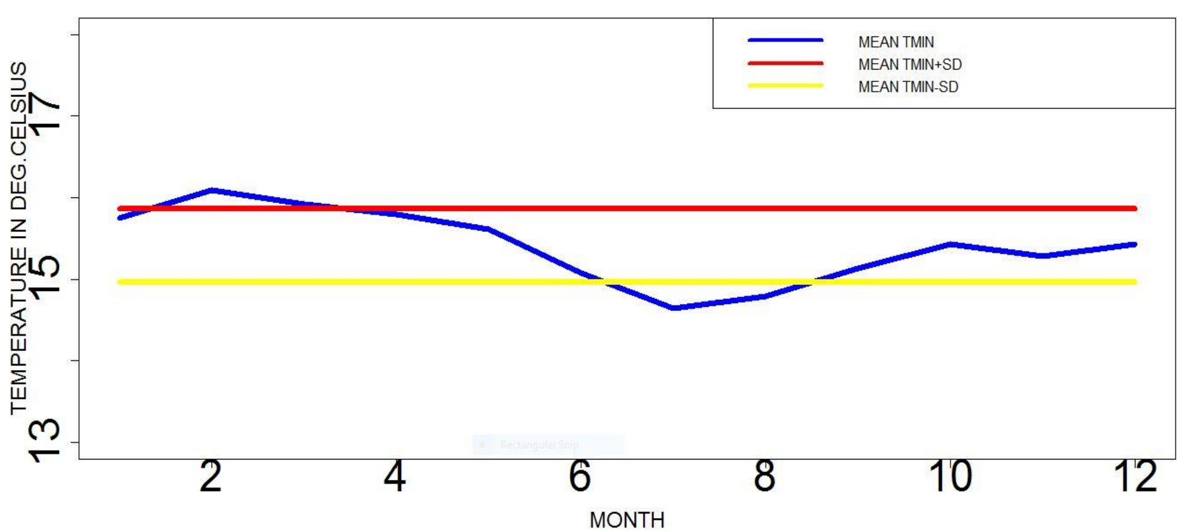


Fig.4.4h: The magnitude of minimum temperature extremes in Kisii.

From Fig.4.4h it was observed that in Kisii, at night, the cold months are cooler by around 0.4°C whereby June-August have cooled by up to 0.4°C while the hot months which are January-April have warmed by around 0.2°C. September-December and May are within average. In summary, the hotter than normal months are Jan-April while the cooler than normal months are June-August.

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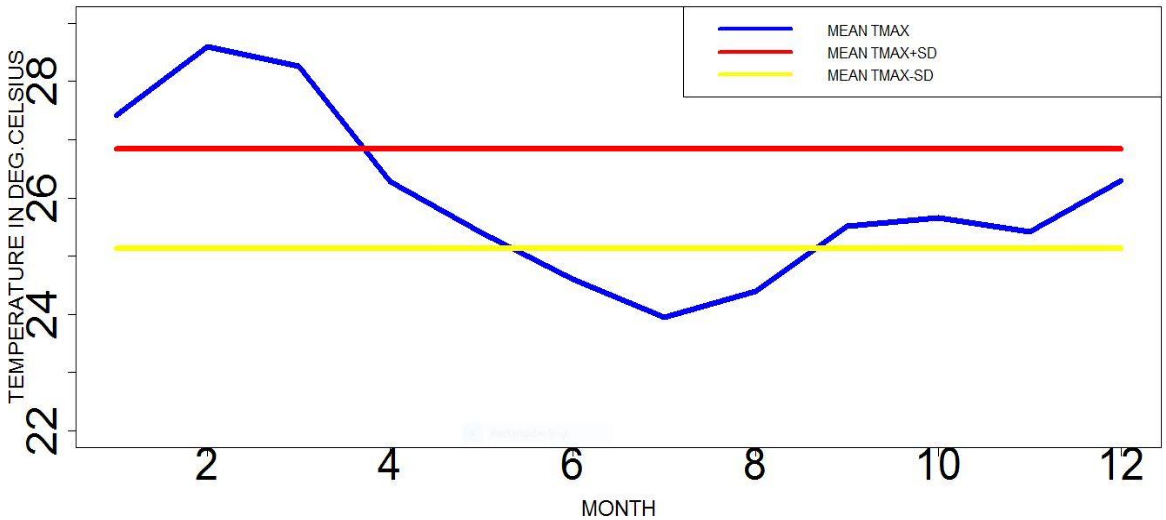

Fig.4.4i: The magnitude of Maximum temperature extremes in Kitale.

From Fig.4.4i it was observed that in Kitale, at daytime, the cold months are cooler by around 1.0°C whereby JJA have cooled by up to 1.0°C while the hot months have warmed by around 1.3°C whereby January –April have warmed by up to 1.3°C. May and September-December are within average. In summary, the hotter than normal months are Jan-April while the cooler than normal months are June-August.

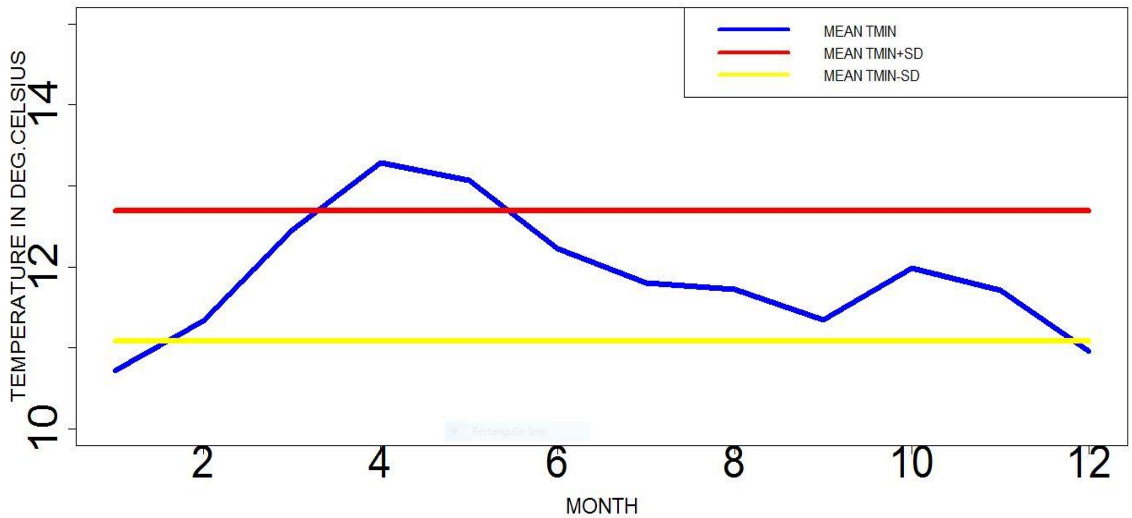

Fig.4.4j: The magnitude of Minimum temperature extremes in Kitale.

From Fig.4.4j it was observed that in Kitale, at night, the cold months JJA, February, and OND are within average while the hot months have warmed by around 0.5℃ whereby MAM have warmed by up to 0.5℃. In summary, the hotter than normal months are March-May.

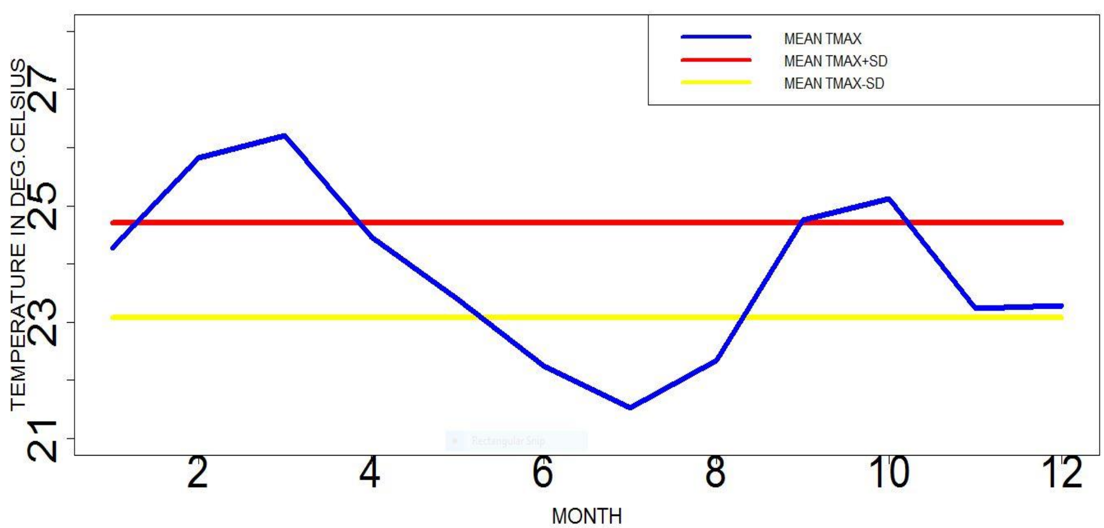

Fig.4.4k: The magnitude of Maximum temperature extremes in Meru.

From Fig.4.4k it was observed that in Meru, at daytime, the cold months are cooler by around 1.3℃ whereby JJA has cooled by up to 1.3℃ while the hot months have warmed by around 1.1℃ whereby February-April have warmed by up to 1.1℃ and September-October have warmed by up to 0.3℃. November, December, May and January are within average. In summary, the hotter than normal months are Feb-April and September- October while the cooler than normal months are June-August.

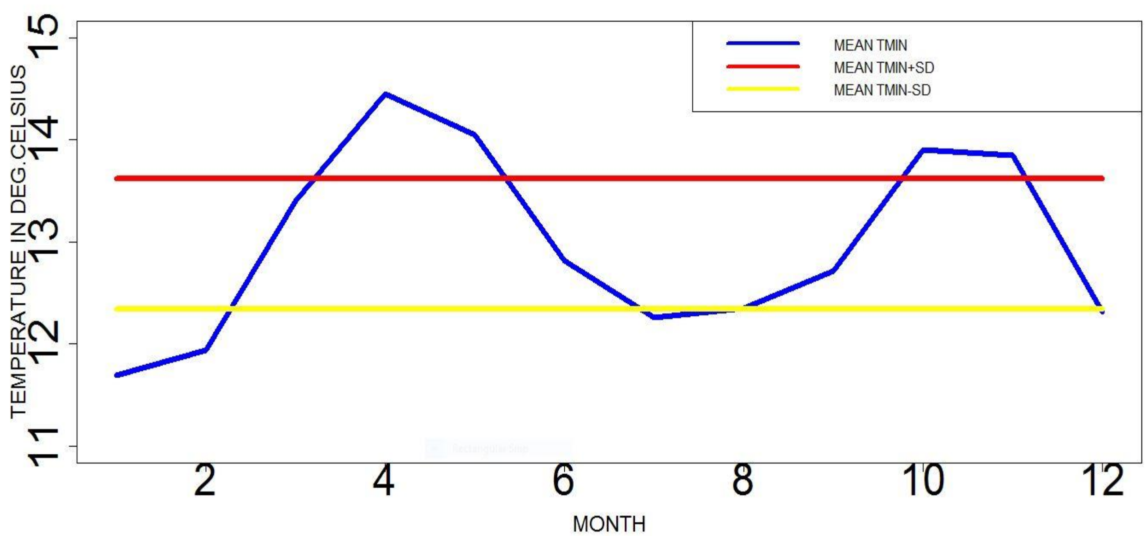

Fig.4.4l: The magnitude of Minimum temperature extremes in Meru.

From Fig.4.4l it was observed that in Meru, at night, the cold months with an exception of July are within average. July has cooled by up to 0.1℃, January and February have cooled by up to 0.4℃ while March, June, August,September and December are within average.The hot months have warmed by around 1.0℃ whereby April-May have warmed by up to 1.0℃ while October-November have warmed by up to 0.3℃. In summary, the hotter than normal months are April, May, October and November while the cooler than normal months are July, January and February.

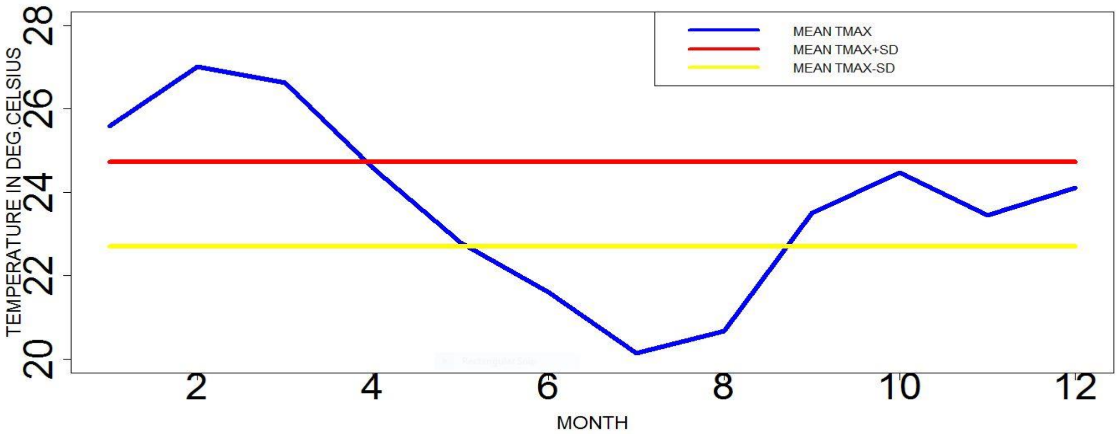

Fig.4.4m: The magnitude of Maximum temperature extremes in Nyeri.

From Fig.4.4m it was observed that in Nyeri, at daytime, the cold months are cooler by around 2.2℃ whereby JJA has cooled by up to 2.2℃ while the hot months have warmed by around 2.0℃ whereby January-April have warmed by up to 2.0℃. May and September-December are within average. In summary, the hotter than normal months are Jan-April while the cooler than normal months are June-August.

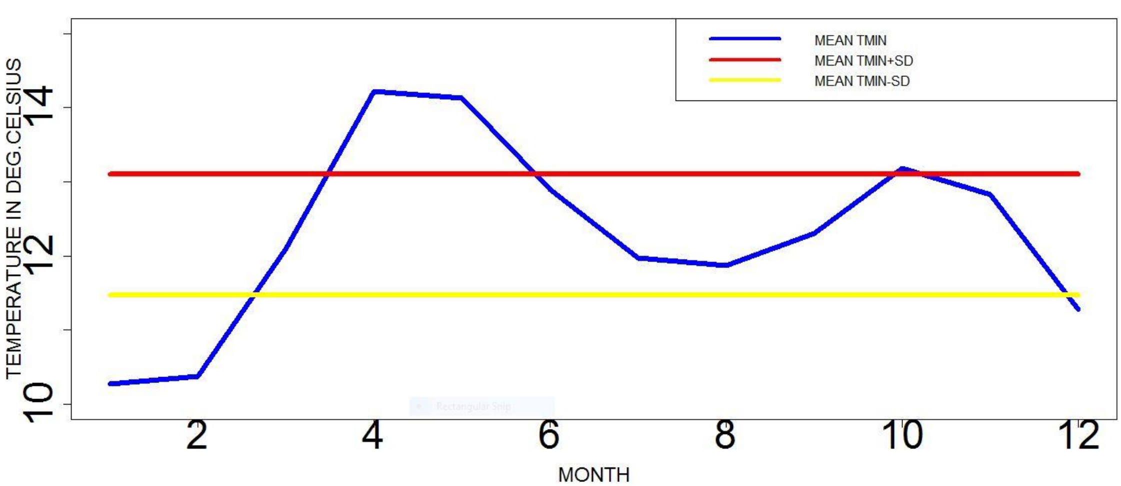

Fig.4.4n: The magnitude of Minimum temperature extremes in Nyeri.

From Fig.4.4n it was observed that in Nyeri, at night, the cold months JJA, September-December and March are within average while January and February are cooler by up to 1.1℃.The hot months MAM have warmed by around 1.1℃. In summary, the hotter than normal months are March-May and October while the cooler than normal months are January-February.

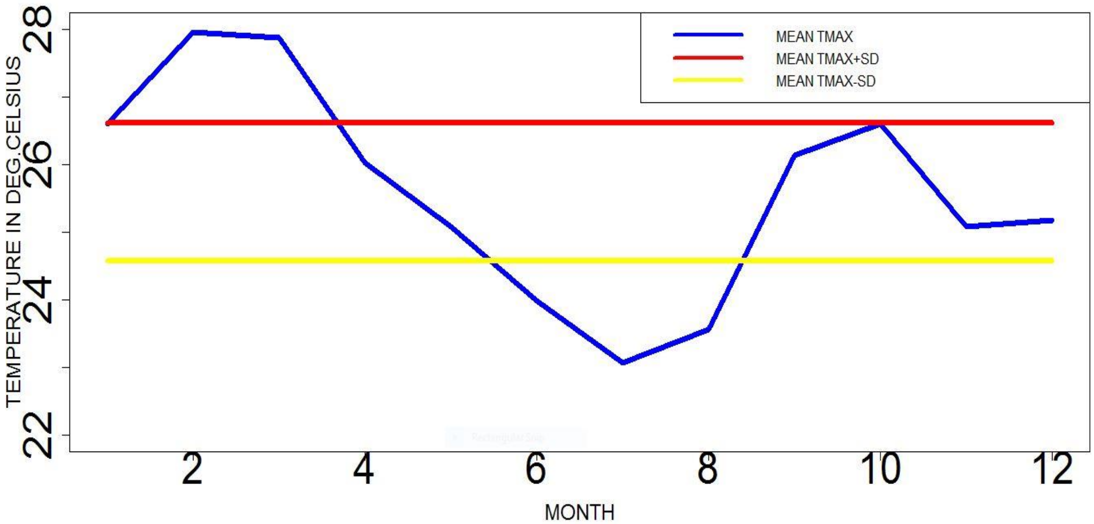

Fig.4.4o: The magnitude of Maximum temperature extremes in Thika.

From Fig.4.4o it was observed that in Thika, at daytime, the cold months JJA have greatly cooled by around 1.5°C. May and September-December are within average while the hot months January- April have warmed by around 1.0℃. In summary, the hotter than normal months are Jan-April while the cooler than normal months are June-August.

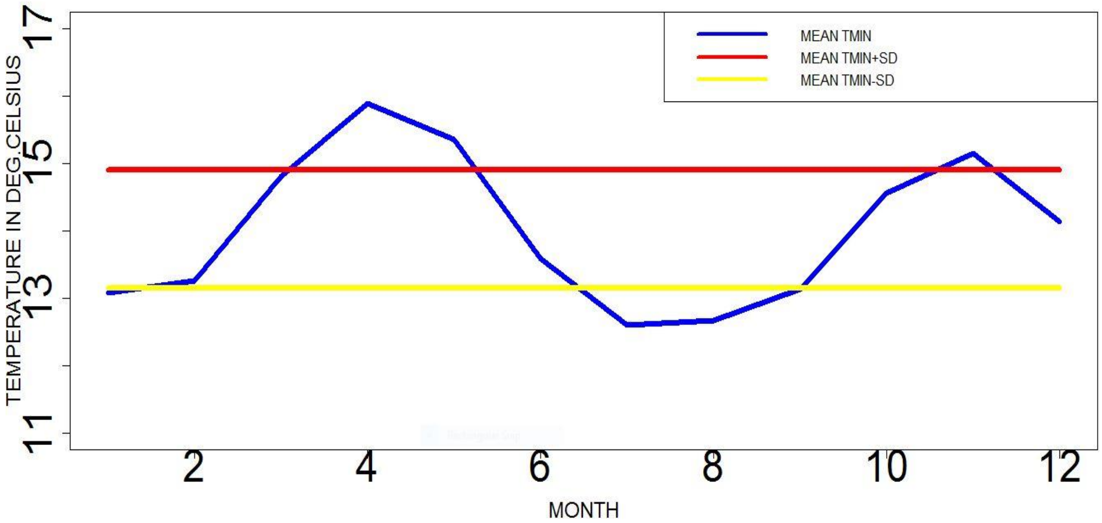

Fig.4.4p: The magnitude of Minimum temperature extremes in Thika.

From Fig.4.4p it was observed that in Thika, at night, the cold months JJA have slightly cooled by around 0.5℃ while the hot months MAM have warmed by around 0.8℃ and November has warmed by up to 0.2℃. February, October and December are within average. In summary the hotter than normal months are March-May and November while the cooler than normal months are June-September.

4.5: REGRESSION BETWEEN PRECIPITATION, MAXIMUM AND MINIMUM TEMPERATURE

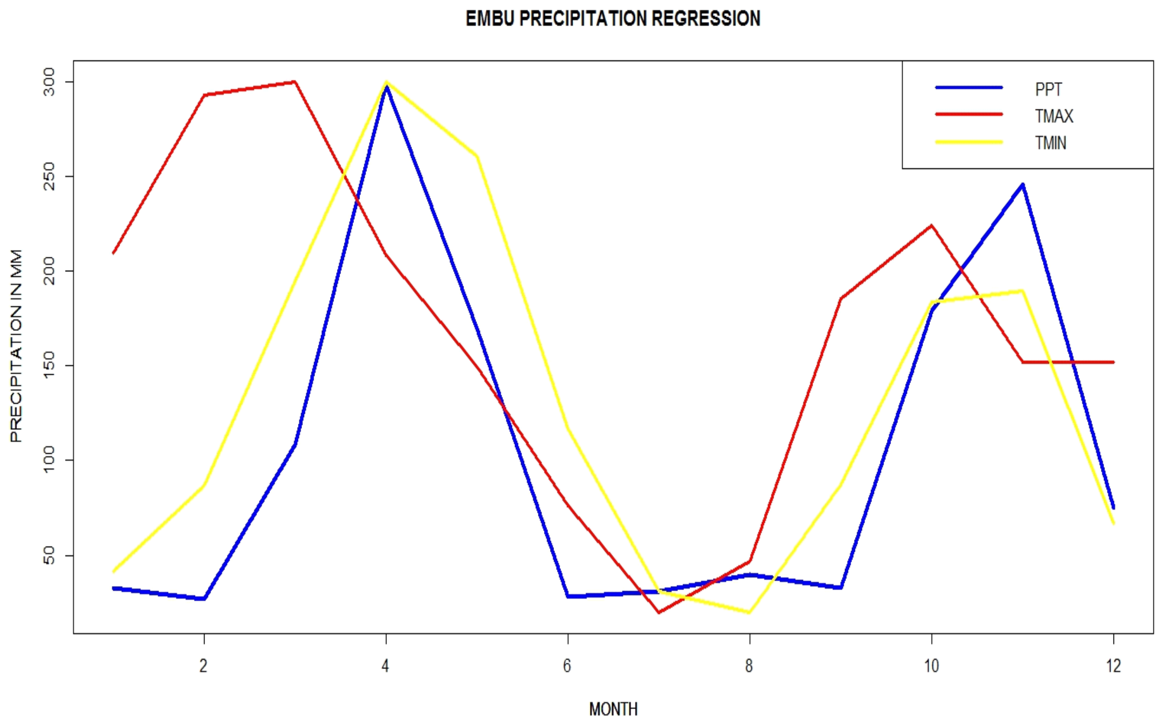

Fig.4.5a: The monthly patterns of Maximum temperature, minimum temperature and precipitation in Embu.

From fig 4.5a and the coefficients, it is observed that rainfall in Embu has been increasing with temperatures and that night temperatures have the biggest effect to precipitation compared to daytime temperatures.According to the graphs, OND rainfall in Embu has been increasing with increasing night temperatures and decreasing daytime temperatures while MAM has been decreasing with decreasing temperatures.Fig 4.5a also shows that Embu has been experiencing a bi-modal rainfall pattern.

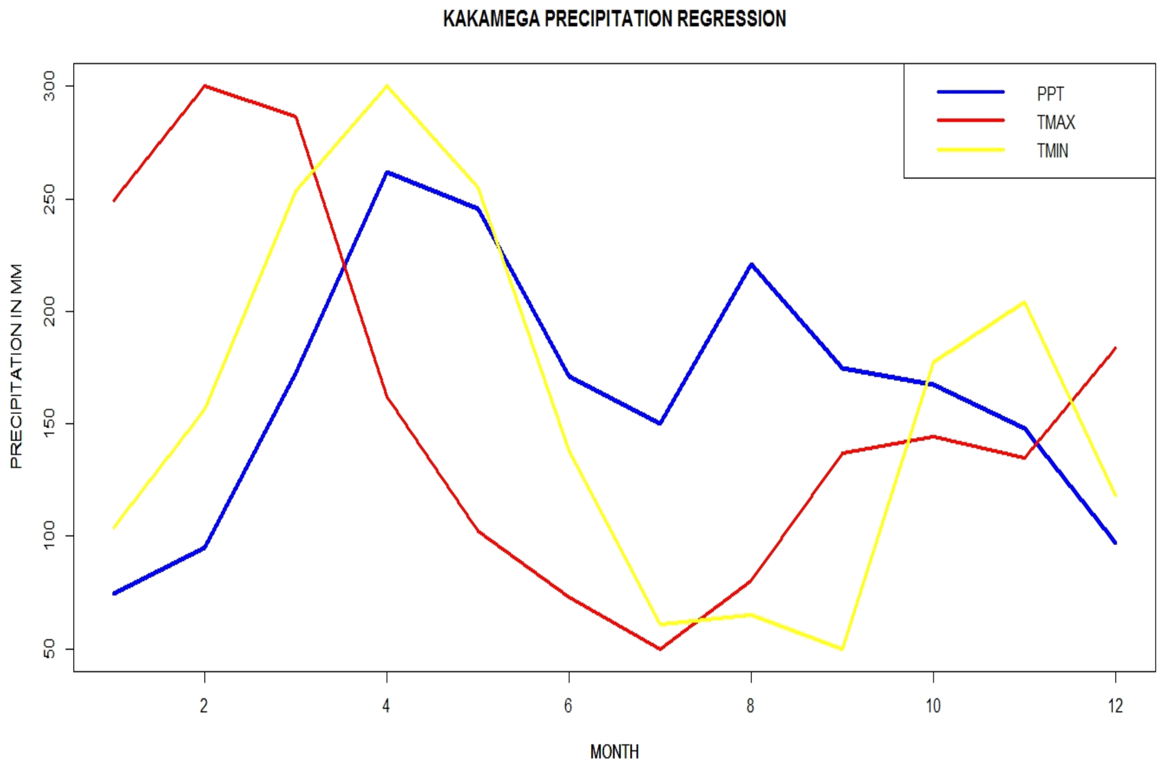

Fig.4.5b: The monthly patterns of Maximum temperature, minimum temperature and precipitation in Kakamega.

From fig 4.5b and the coefficients, it is observed that rainfall in Kakamega has been increasing with night temperatures and decreasing with increasing day temperatures and that the night temperatures have the biggest effect to precipitation compared to daytime temperatures. According to the graphs, MAM and OND rainfall is increasing with decreasing day temperatures and increasing with night temperatures while JJA rainfall increase with temperatures.Fig 4.5b also shows that Kakamega has been experiencing a tri-modal rainfall pattern.

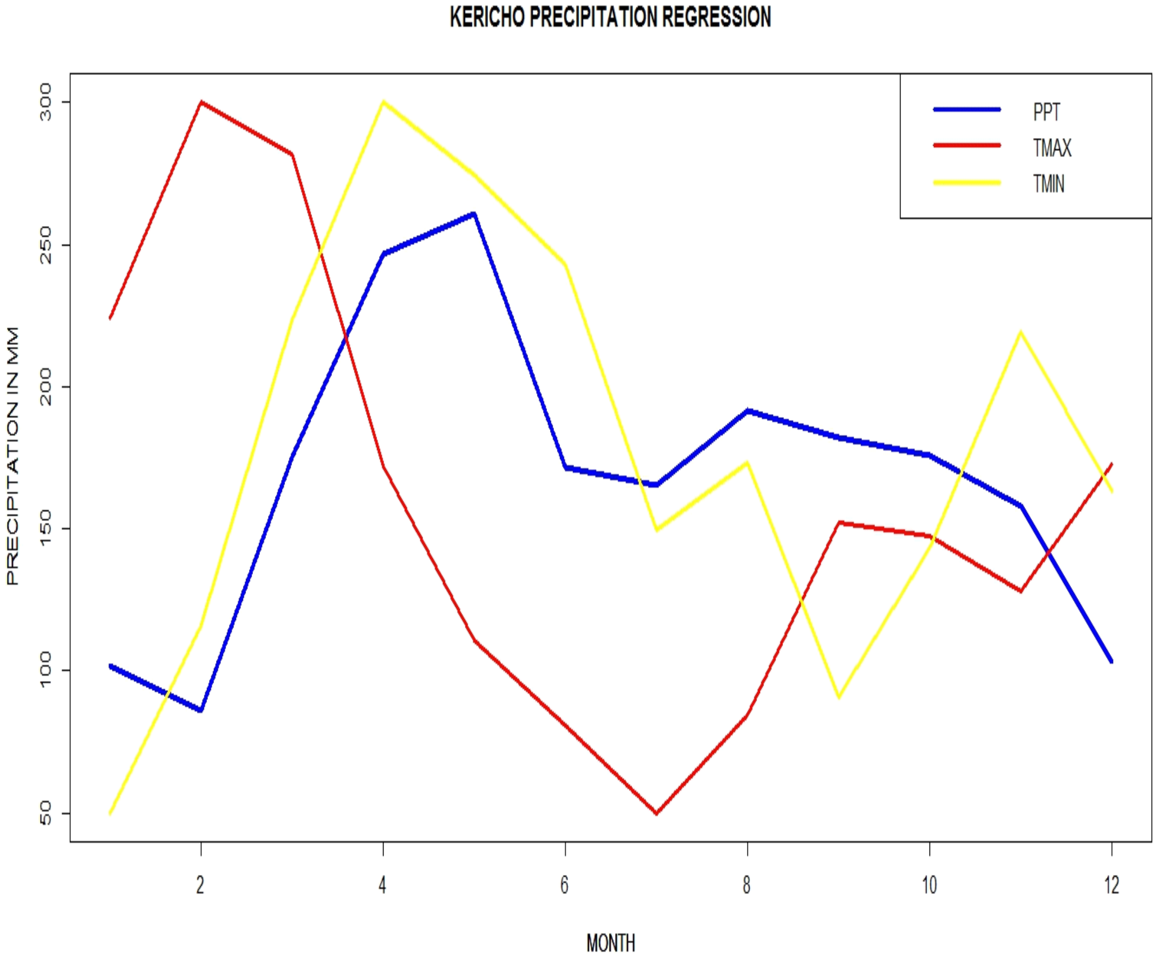

Fig.4.5c: The monthly patterns of Maximum temperature, minimum temperature and precipitation in Kericho.

From fig 4.5c and the coefficients, it is observed that rainfall in Kericho has been increasing with temperatures and that night temperatures have the biggest effect to precipitation compared to daytime temperatures. According to the graphs, MAM and OND rainfall is increasing with decreasing temperatures while JJA rainfall increase with temperatures.Fig 4.5c also shows thatKericho has been experiencing a tri-modal rainfall pattern.

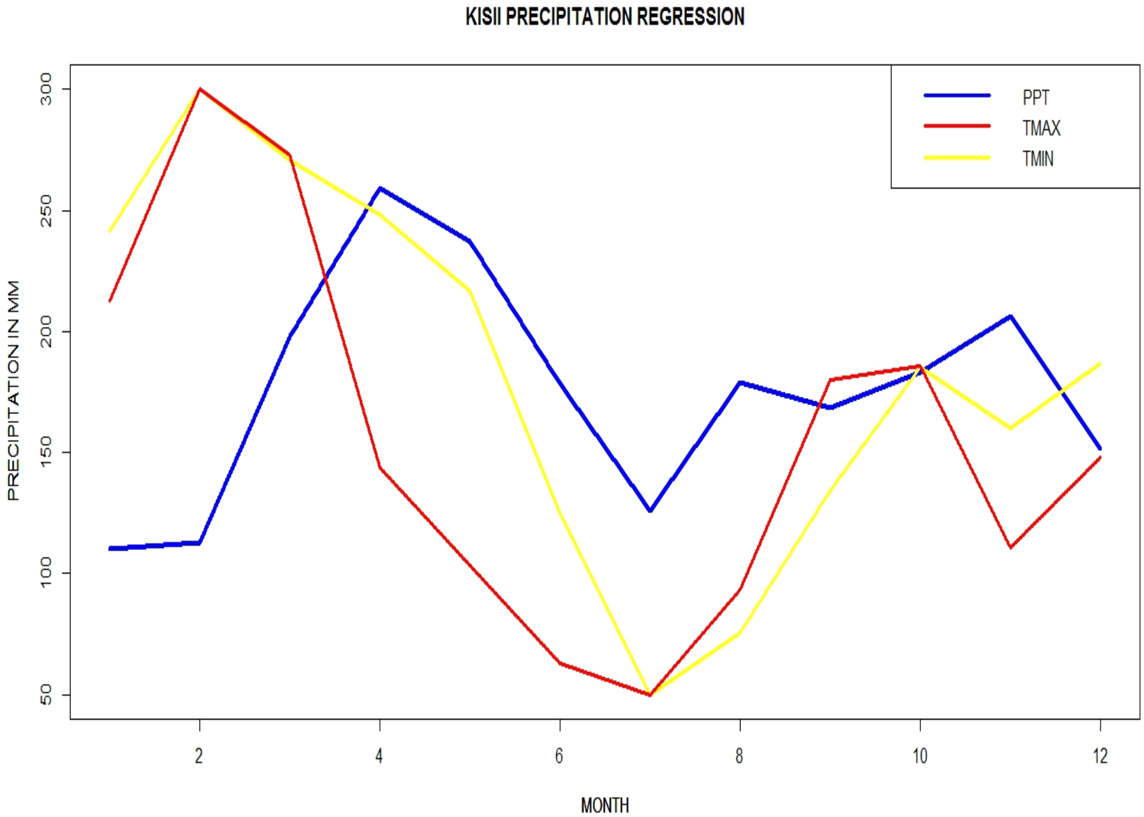

Fig.4.5d: The patterns of Maximum temperature, minimum temperature and precipitation in Kisii.

From fig 4.5d and the coefficients, it is observed that rainfall in Kisii has been increasing with night temperatures and decreasing with increasing day temperatures and that the day temperatures have the greatest effect to precipitation compared to daytime temperatures. According to the graphs, MAM and OND rainfall is increasing with decreasing temperatures while JJA rainfall increase with temperatures.Fig 4.5d also shows that Kisii has been experiencing a tri-modal rainfall pattern.

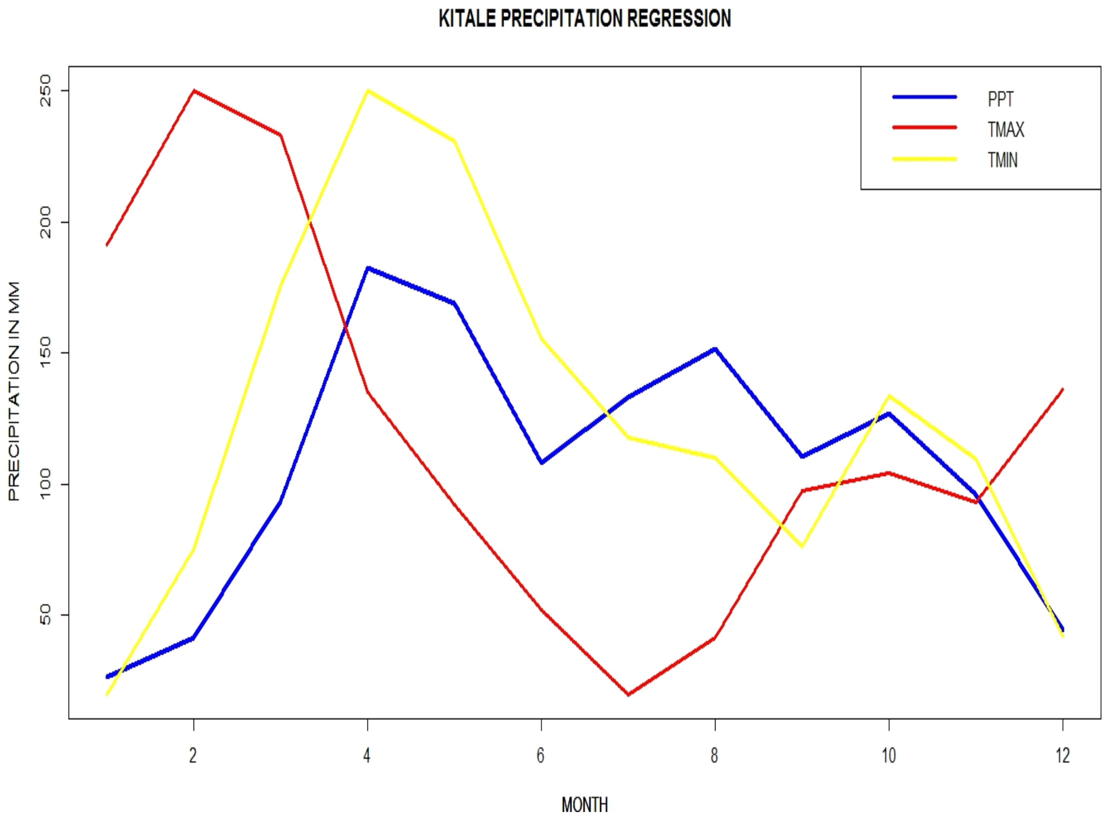

Fig.4.5e: The monthly patterns of Maximum temperature, minimum temperature and precipitation in Kitale.

From fig 4.5e and the coefficients, it is observed that rainfall in Kitale has been increasing with night temperatures and decreasing with increasing day temperatures and that the night temperatures have the biggest effect to precipitation compared to daytime temperatures. According to the graphs, MAM and JJA rainfall is increasing with increasing night temperatures and decreasing day temperatures while OND rainfall increase with both.Fig 4.5e also shows that Kitale has been experiencing a tri-modal rainfall pattern.

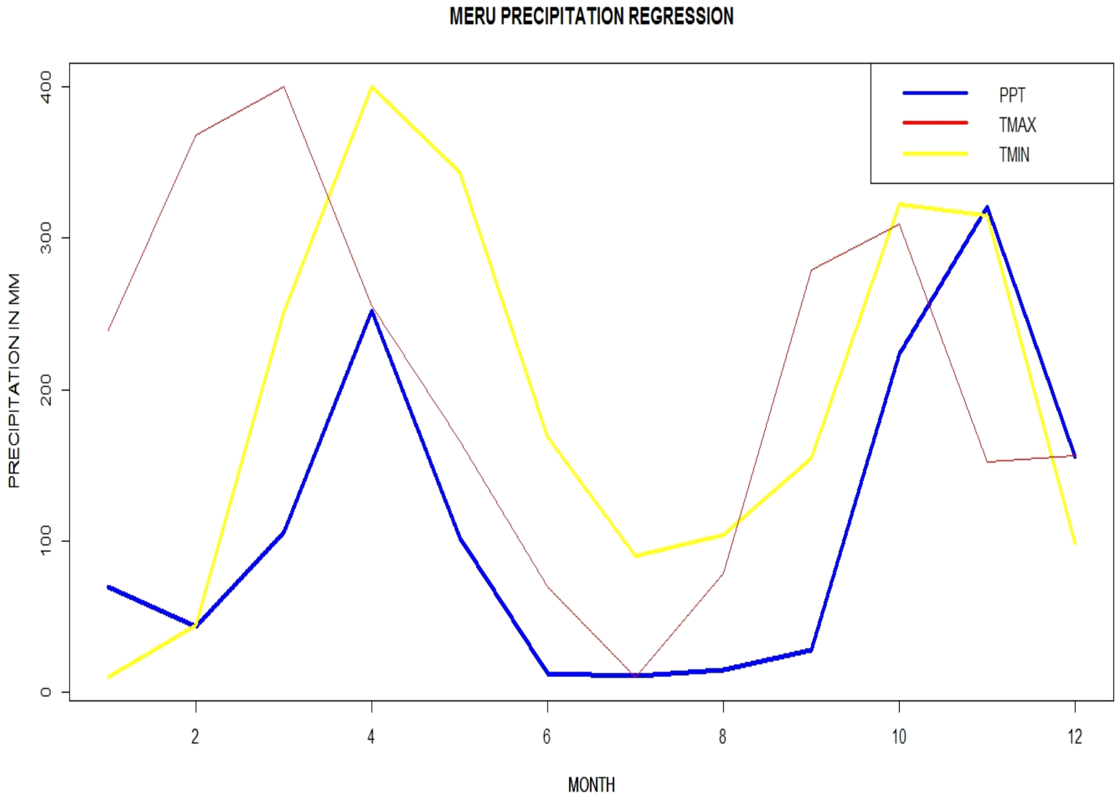

Fig.4.5f: The monthly patterns of Maximum temperature, minimum temperature and precipitation in Meru.

From fig 4.5f and the coefficients, it is observed that rainfall in Meru has been increasing with temperatures and that the night temperatures have the biggest effect to precipitation compared to daytime temperatures. According to the graphs, OND and rainfall is increasing with increasing night temperatures and decreasing day temperatures.Fig 4.5f also shows that Meru has been experiencing a bi-modal rainfall pattern.

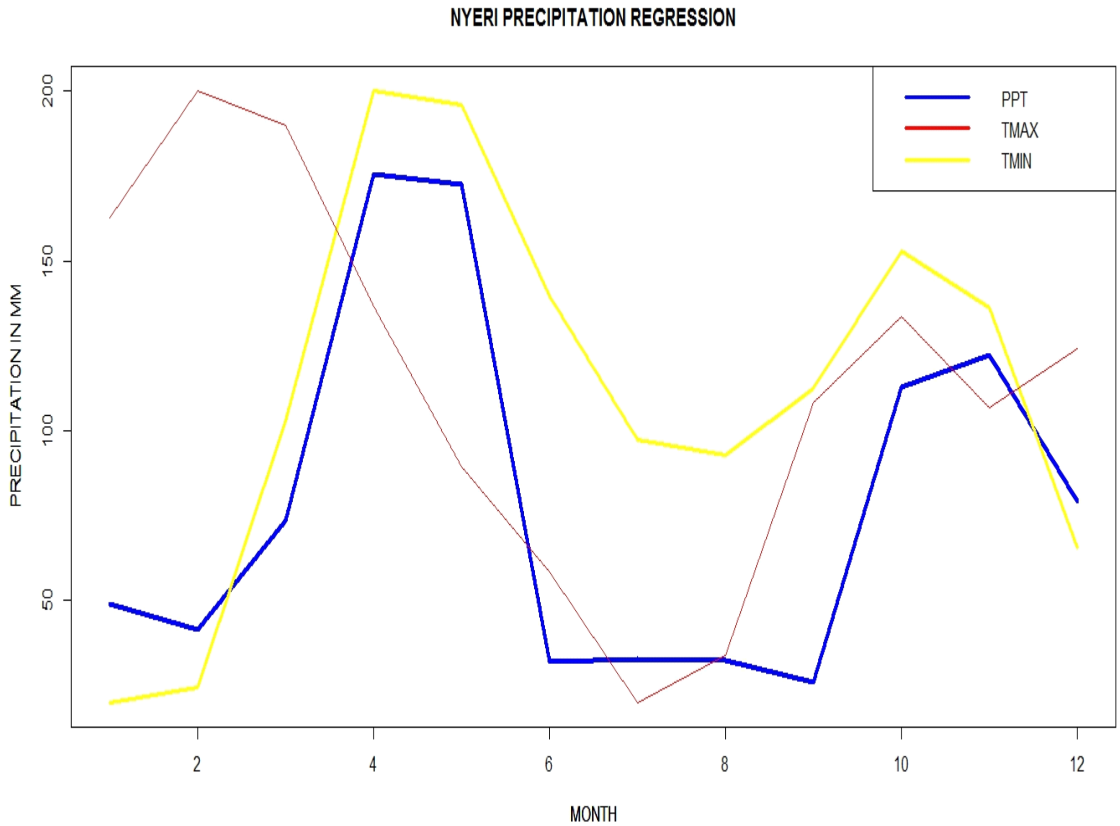

Fig.4.5g: The monthly patterns of Maximum temperature, minimum temperature and precipitation in Nyeri.

From fig 4.5g and the coefficients, it is observed that rainfall in Nyeri has been increasing with temperatures and that the night temperatures have the biggest effect to precipitation compared to daytime temperatures. According to the graphs, OND and MAM rainfall is increasing with increasing night temperatures and decreasing day temperatures.Fig 4.5g also shows that Nyeri has been experiencing a bi-modal rainfall pattern.

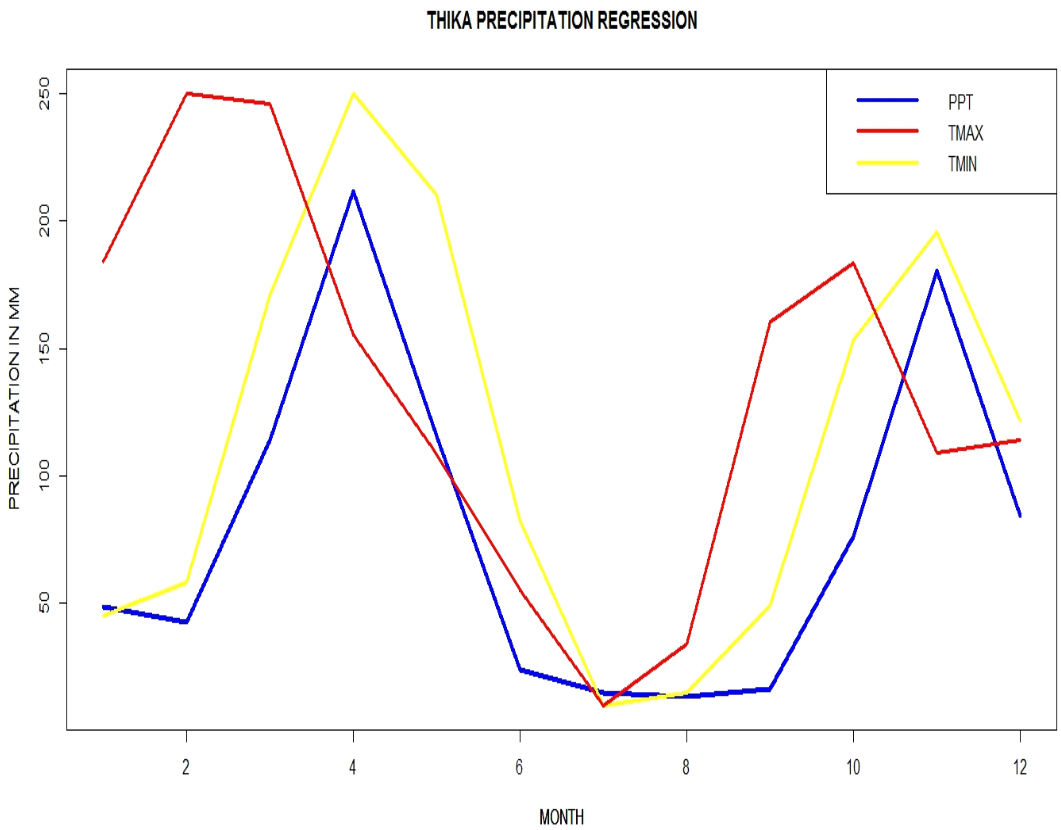

Fig.4.5h: The monthly patterns of Maximum temperature, minimum temperature and precipitation in Thika.

From fig 4.5h and the coefficients, it is observed that rainfall in Thika has been increasing with temperatures and that the night temperatures have the biggest effect to precipitation compared to daytime temperatures. According to the graphs, OND and MAM rainfall is increasing with increasing night temperatures and decreasing day temperatures.Fig 4.5h also shows that Thika has been experiencing a bi-modal rainfall pattern.

4.6: TEA TRENDS, PRODUCTION EXTREMES AND REGRESSION BETWEEN TEA PRODUCTION, PRECIPITATION, MAXIMUM AND MINIMUM TEMPERATURE.

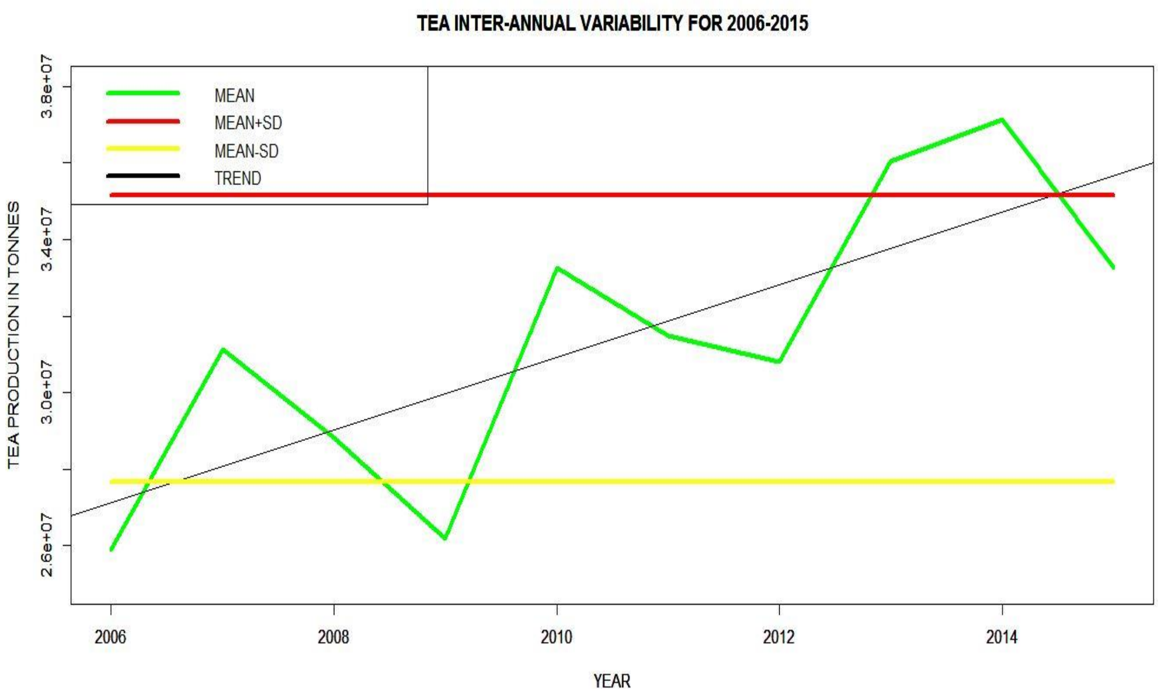

Fig.4.6a: Interannual variations of tea production in Kenya.

From fig 4.6a, it is observed that increasing trends of tea production were experienced between the years 2006 to 2015 in Kenya. The figure also shows that lower than normal production was experienced in 2006 and 2009 while higher than normal production was experienced in 2013 and 2014, after which production decreased.

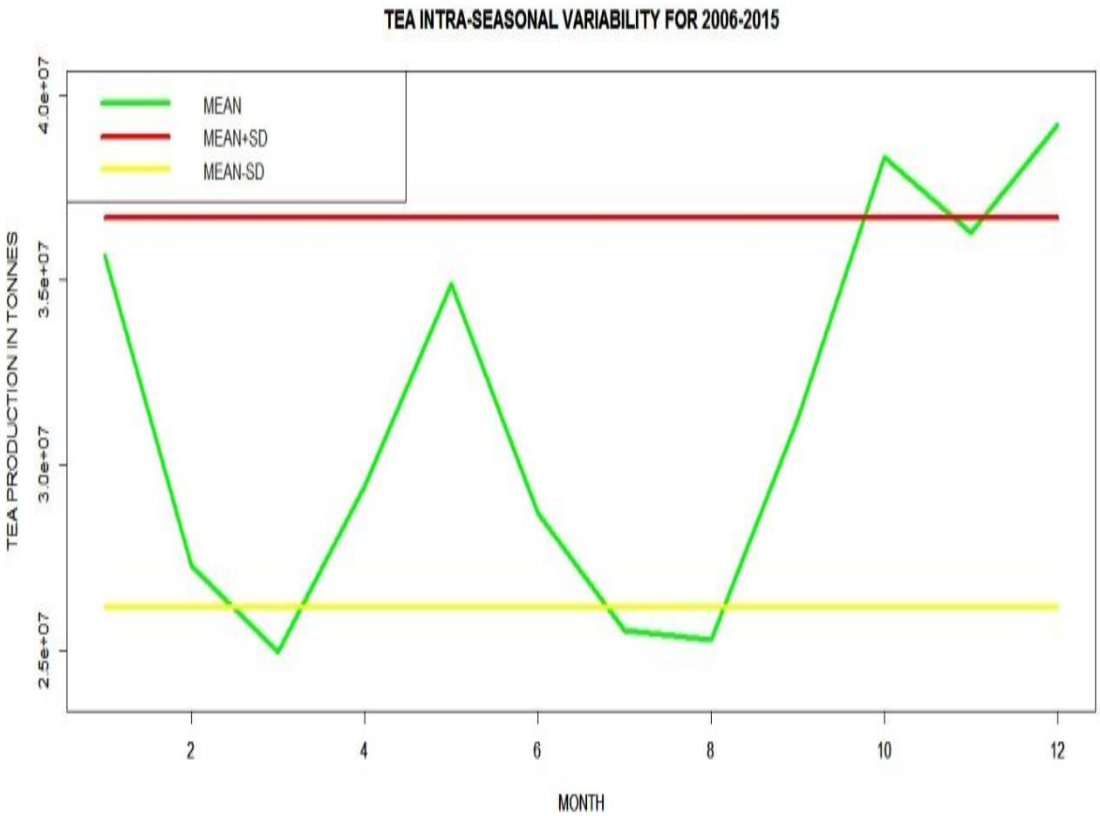

Fig.4.6b: Monthly variations of tea production in Kenya.

From fig.4.6b, it is observed that MAM and OND are the tea peak seasons while the hot and cold seasons have poorer than normal yields.

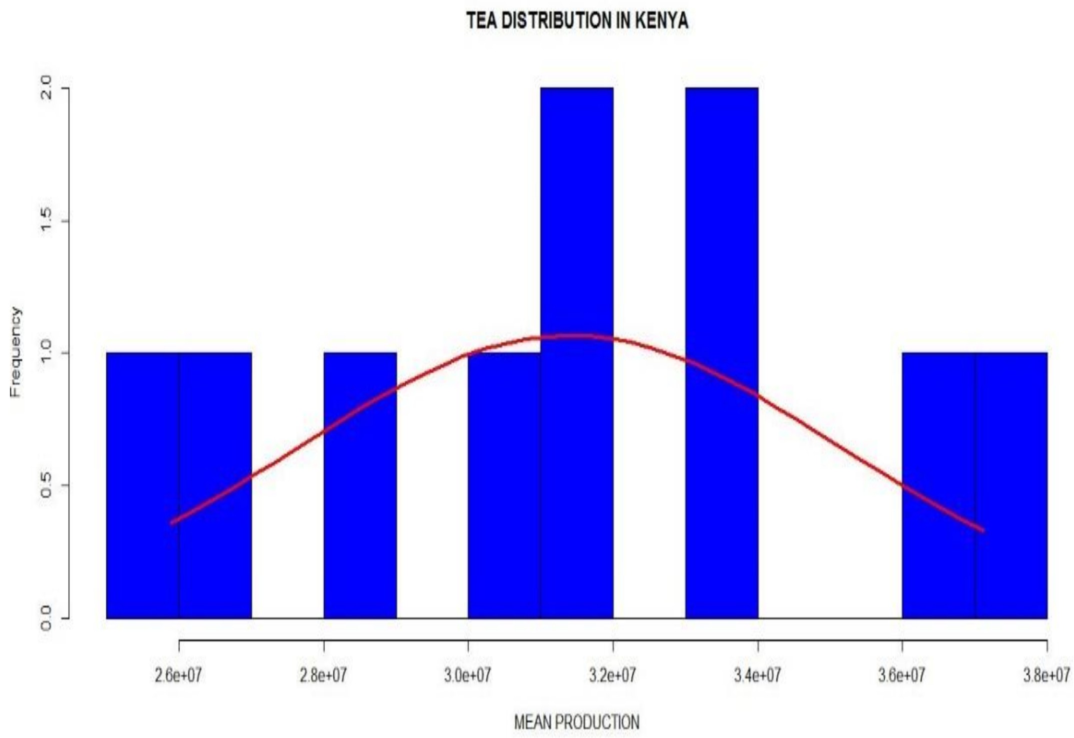

Fig.4.6c: Frequency distribution of tea production in Kenya.

From the frequency distribution curve in fig 4.6c, it is observed that tea production is slightly skewed to the right hence more episodes of higher than normal production were experienced in Kenya.

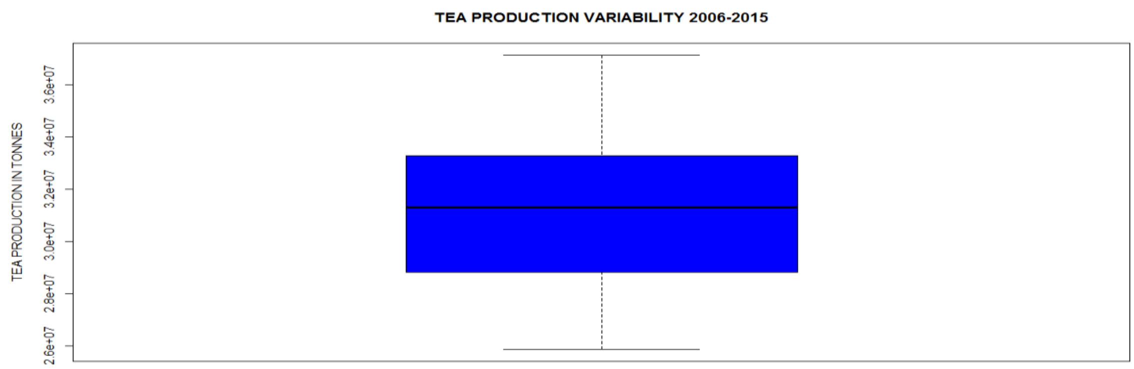

Fig.4.6d: The spread of tea production in Kenya.

From the whiskers length which is longer for the above normal side as compared to the below normal side in fig.4.6d, it is observed that tea production is slightly skewed positively hence a slightly higher frequency of higher than normal production was experienced in Kenya.

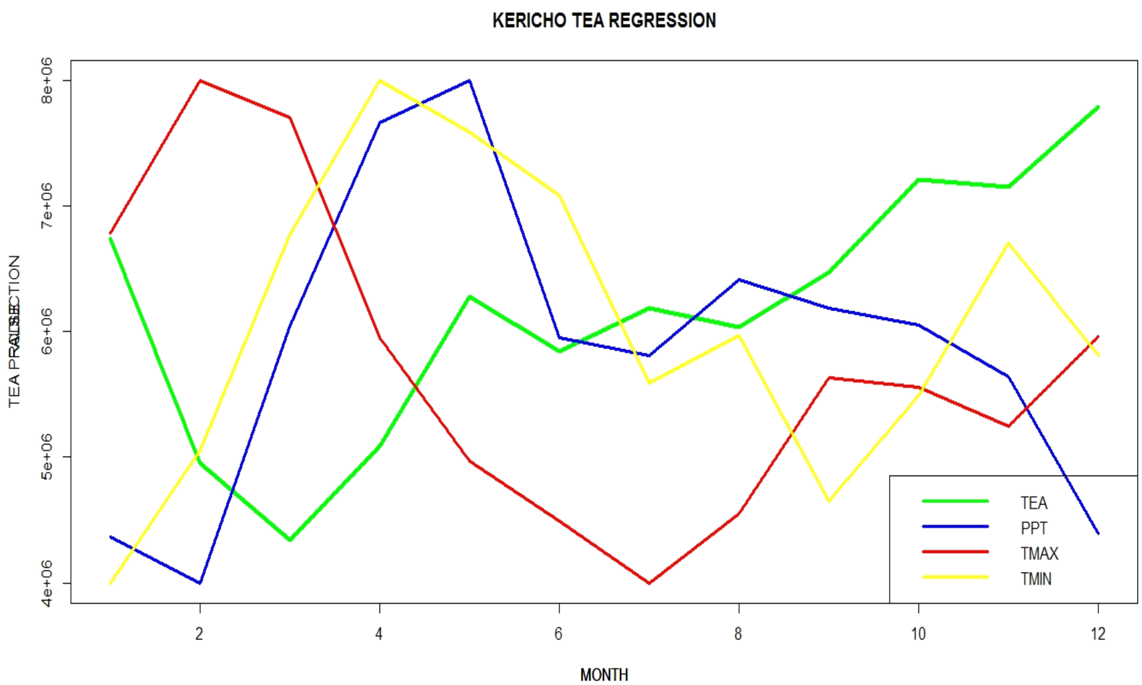

Fig.4.6e: Time series curve of tea production, maximum temperature, minimum temperature and precipitation in Kericho.

From fig.4.6e and the coefficients, it is observed that in Kericho, night and daytime temperatures had more effect upon tea yields than precipitation as derived from the magnitude of the coefficients. The figure also shows that increasing daytime/night temperatures and precipitation influence a decrease in tea yields from the negative sign of the coefficients.From the graphs, tea production has been at its lowest during Jan-March season while it has been at its highest over OND season with December experiencing the largest amounts of yields in Kericho.

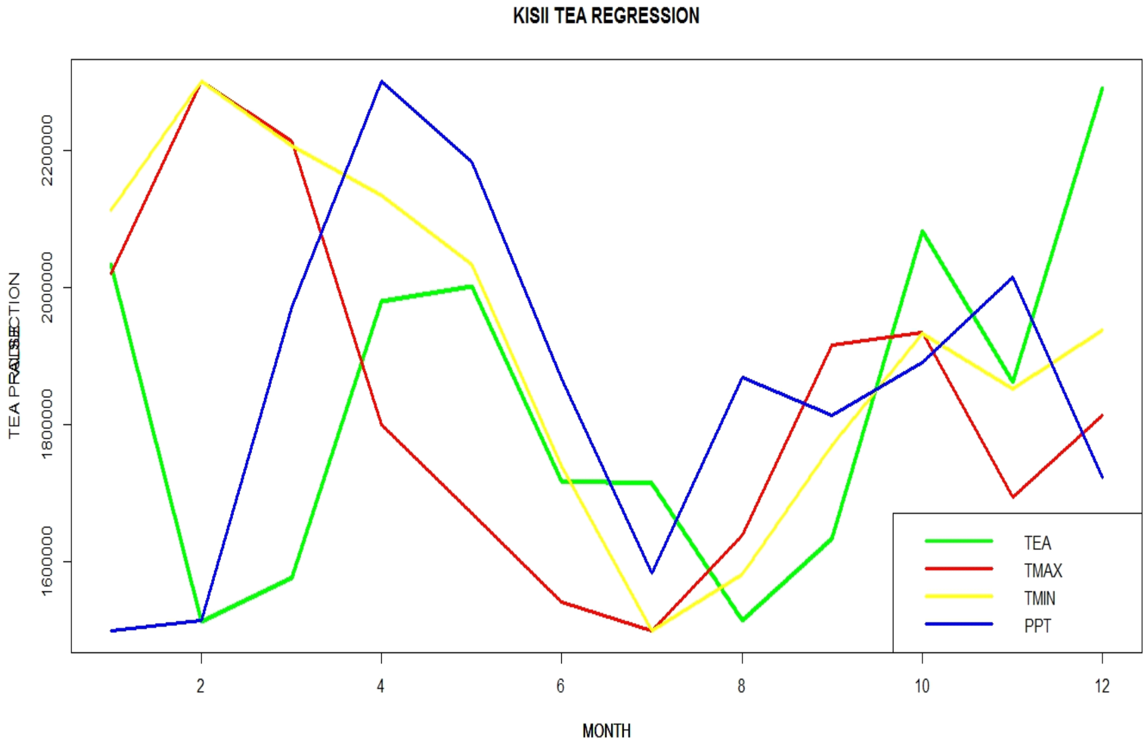

Fig.4.6f: Time series curve of tea production, maximum temperature, minimum temperature and precipitation in Kisii.

From fig.4.6f and the coefficients, it is observed that in Kisii, night and daytime temperatures had more effect upon tea yields than precipitation from the magnitude of the coefficients. The figure also shows that increasing daytime temperatures influence a decrease in tea yields from the negative sign of the coefficients while precipitation and night temperatures increase with tea yields.From fig.4.6f, tea production has been at its lowest during Jan-March season while it has been at its highest over OND season with December experiencing the largest amounts of yields in Kisii.

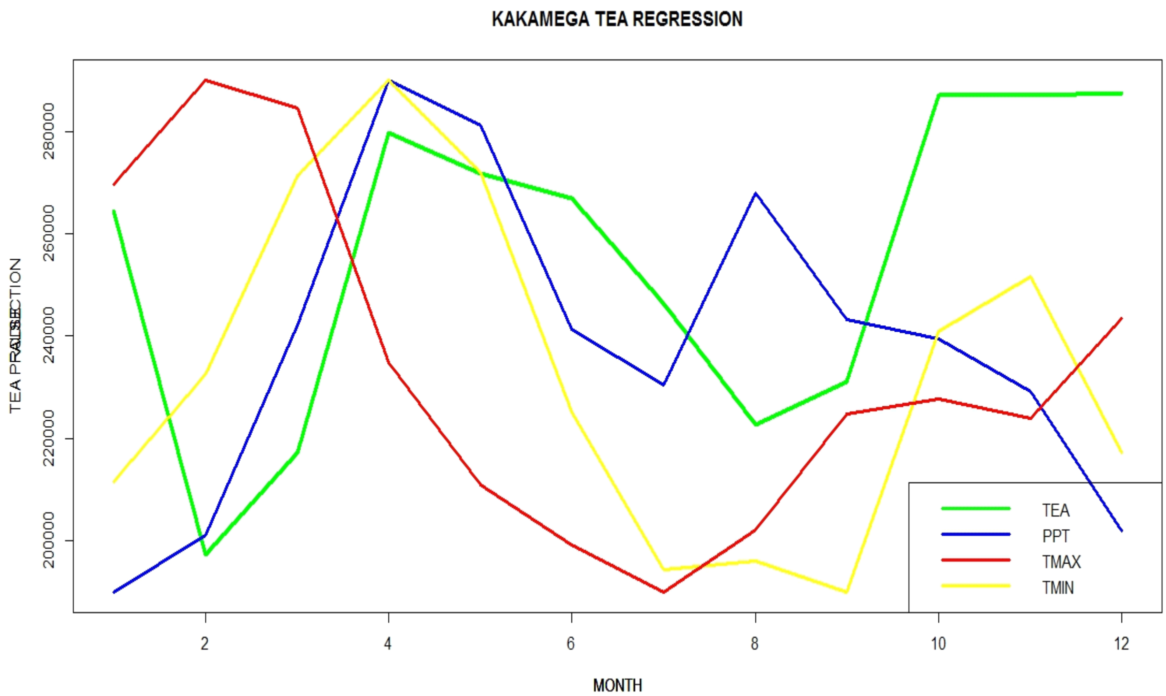

Fig.4.6g: Time series curve of tea production, maximum temperature, minimum temperature and precipitation in Kakamega.

From fig.4.6g and the coefficients, it is observed that in Kakamega, night and daytime temperatures had more effect upon tea yields than precipitation from the magnitude of the coefficients. The figure also shows that increasing daytime temperatures influence a decrease in tea yields from the negative sign of the coefficients while precipitation and night temperatures increase with tea yields.From fig.4.6g, tea production has been at its lowest during Jan-March season while it has been at its highest over OND season with October experiencing the largest amounts of yields in Kakamega.

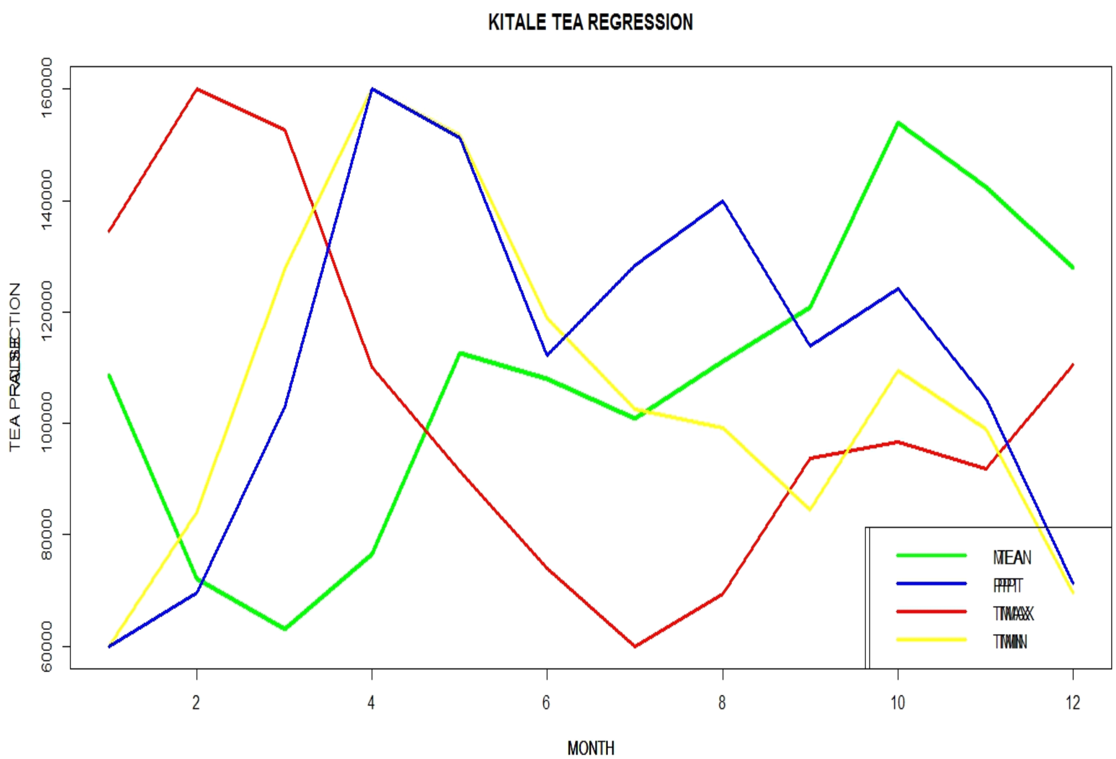

Fig.4.6h: Time series curve of tea production, maximum temperature, minimum temperature and precipitation in Kitale.

From fig.4.6h and the coefficients, it is observed that in Kitale, night and daytime temperatures had more effect upon tea yields than precipitation from the magnitude of the coefficients. The figure also shows that increasing daytime/night temperatures influence a decrease in tea yields from the negative sign of the coefficients while precipitation increase with tea yields.From fig.4.6h, tea production has been at its lowest during Jan-March season it has been at its highest over OND season with October experiencing the largest amounts of yields in Kitale.

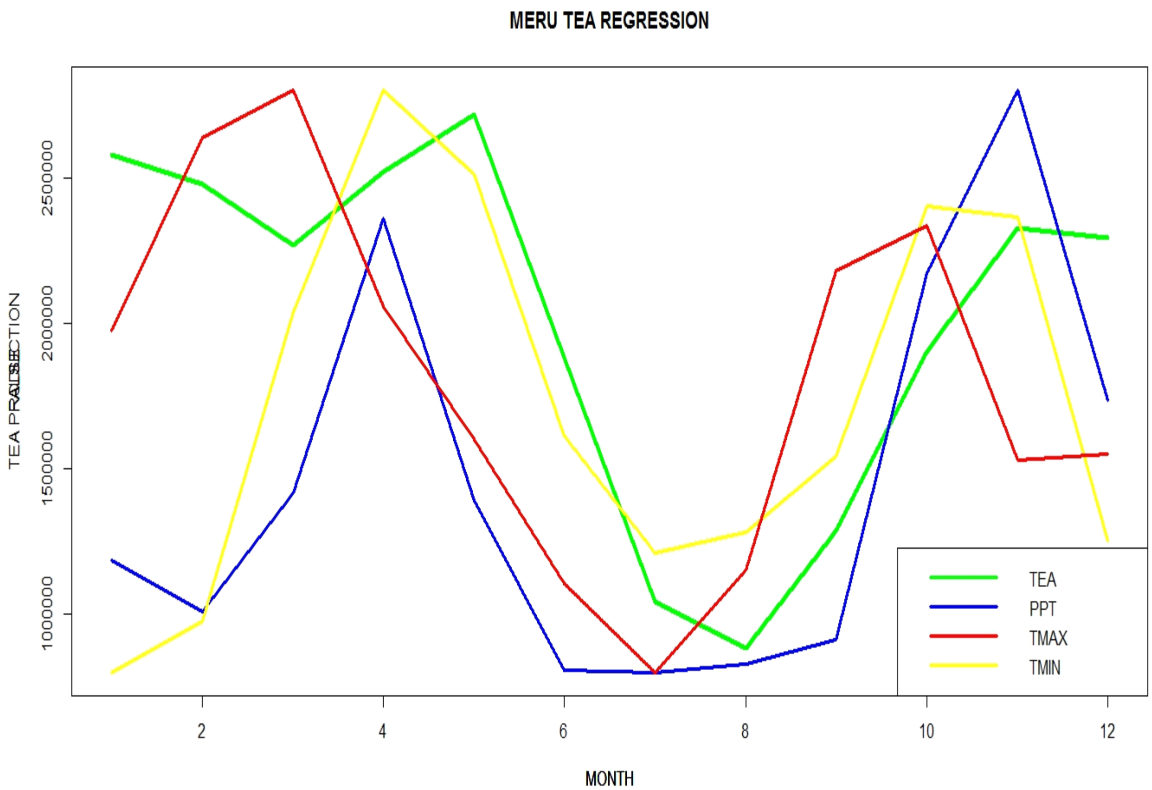

Fig.4.6i: Time series curve of tea production, maximum temperature, minimum temperature and precipitation in Meru.

From fig.4.6i and the coefficients, it is observed that in Meru, daytime temperatures had more effect upon tea yields than precipitation and night temperatures from the magnitude of the coefficients. The figure also shows that increasing daytime/night temperatures and precipitation influence an increase in tea yields from the positive sign of the coefficients.From fig.4.6i, tea production has been at its lowest during June-August while it has been at its highest over the rainy seasons with May experiencing the largest amounts of yields in Meru.

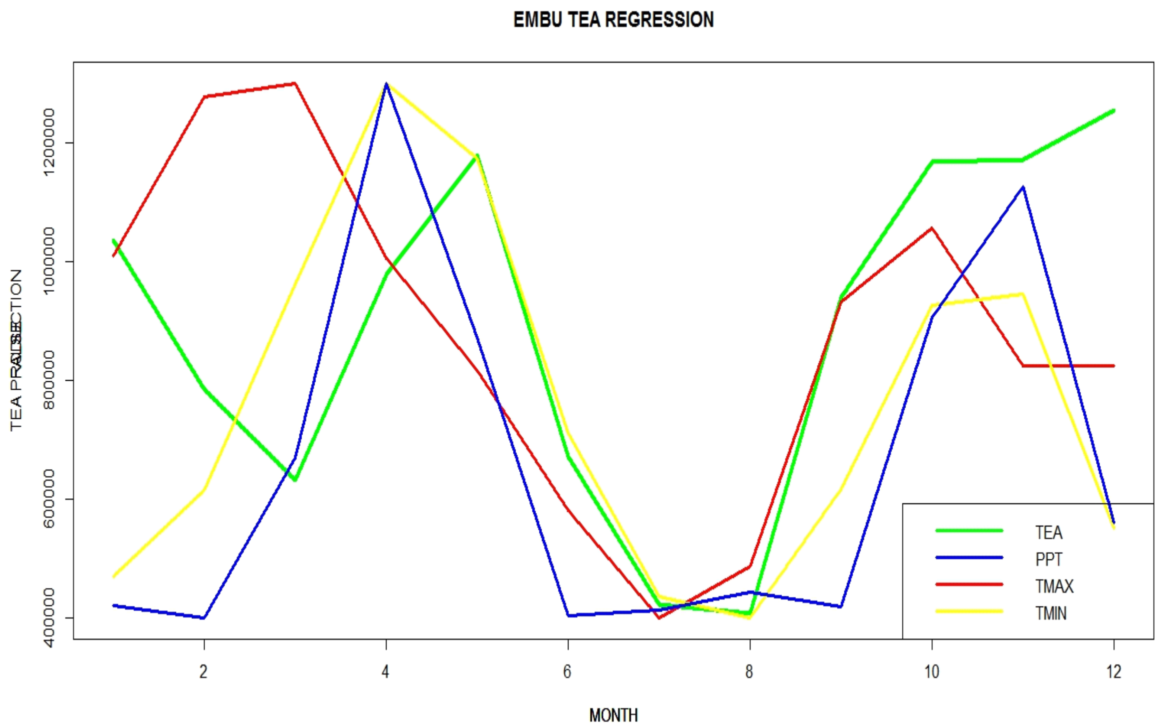

Fig.4.6j: Time series curve of tea production, maximum temperature, minimum temperature and precipitation in Embu.

From fig.4.6j and the coefficients, it is observed that in Embu, daytime temperatures had more effect upon tea yields than precipitation and night temperatures from the magnitude of the coefficients. The figure also shows that increasing daytime/night temperatures and precipitation influence an increase in tea yields from the positive sign of the coefficients.

From fig.4.6j, tea production has been at its lowest during June-August while it has been at its highest over OND season with December experiencing the largest amounts of yields in Embu.

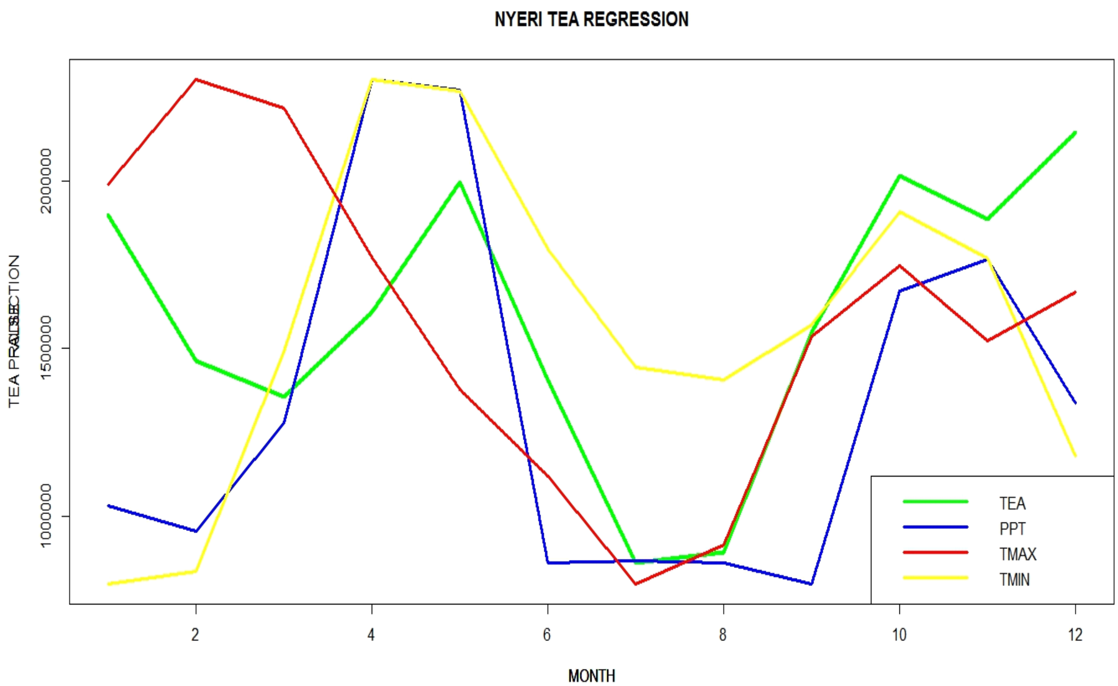

Fig.4.6k: Time series curve of tea production, maximum temperature, minimum temperature and precipitation in Nyeri.

From fig.4.6k and the coefficients, it is observed that in Nyeri, daytime temperatures had more effect upon tea yields than precipitation and night temperatures from the magnitude of the coefficients. The figure also shows that increasing daytime/night temperatures and precipitation influence an increase in tea yields from the positive sign of the coefficients.From fig.4.6k, tea production has been at its lowest during June-August while it has been at its highest over OND season with December experiencing the largest amounts of yields.

4.7: DISTRIBUTION OF ANNUAL MEAN PRECIPITATION

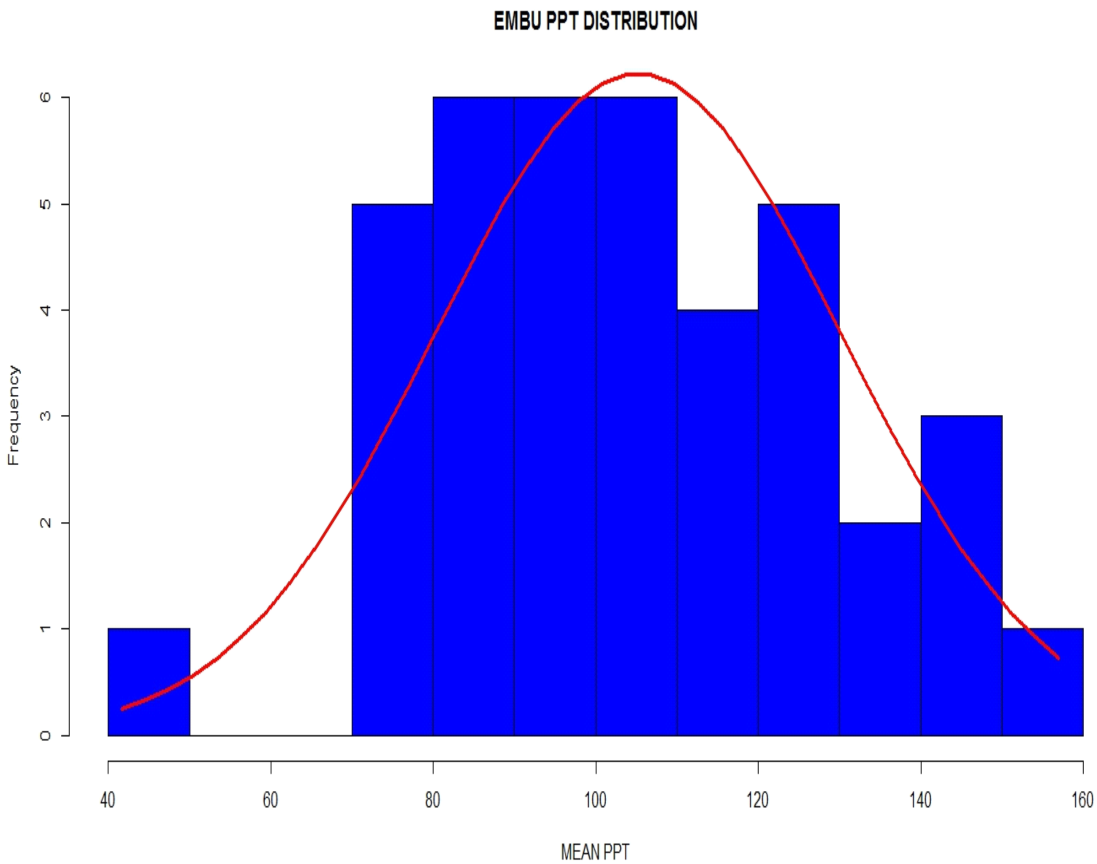

Fig 4.7a: The distribution of annual rainfall in Embu.

From fig.4.7a, Embu has been experiencing above normal rainfall most of the years as shown in the distribution curve skewed to the right, implying that more flood episodes have been experienced compared to drought episodes.

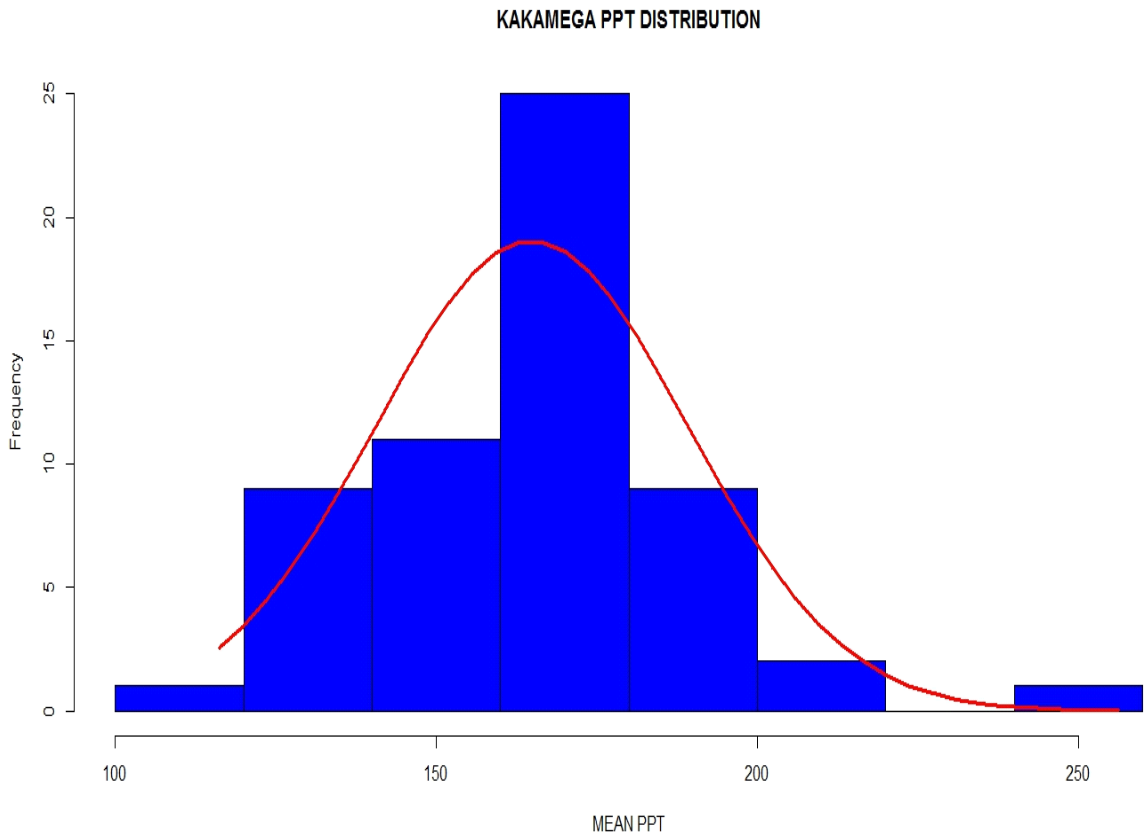

Fig 4.7b: The distribution of annual rainfall in Kakamega.

From fig.4.7b, Kakamega has been experiencing above normal rainfall most of the years as shown in the distribution curve skewed to the right, implying that more flood episodes have been experienced compared to drought episodes.

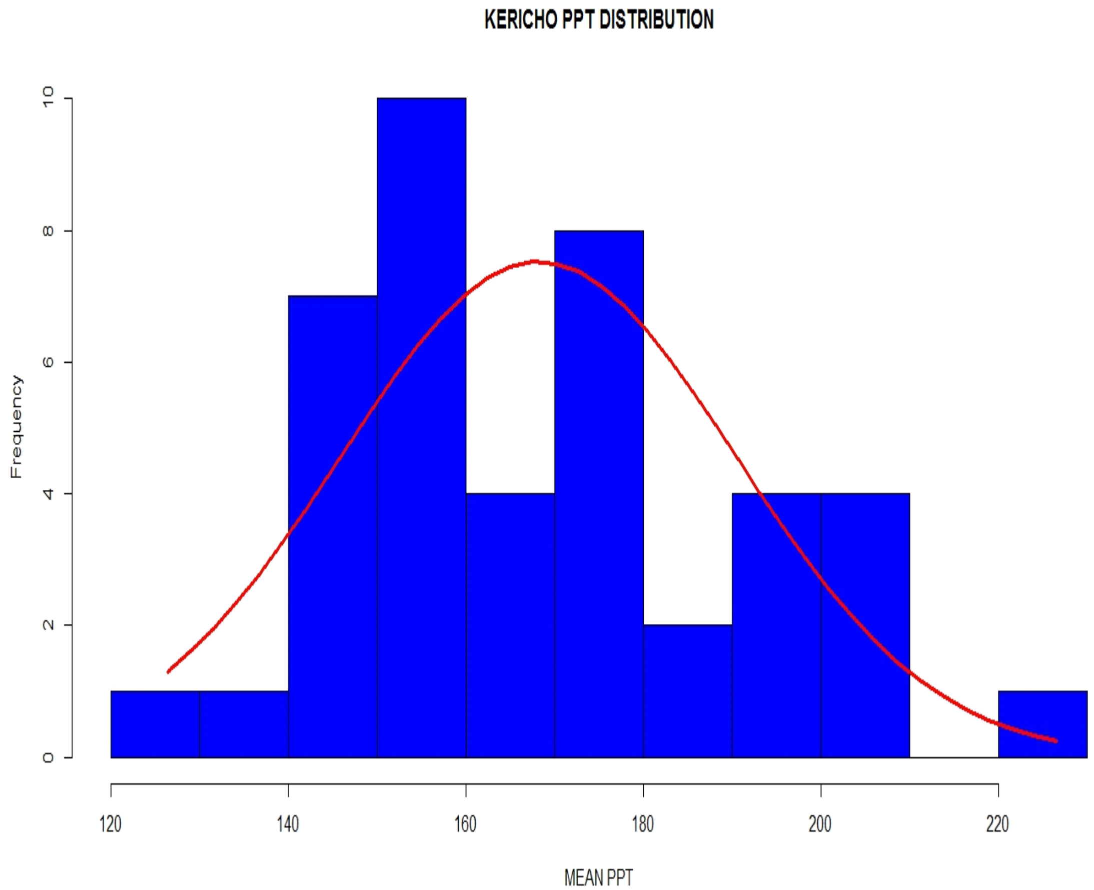

Fig 4.7c: The distribution of annual rainfall in Kericho.

From fig.4.7c, Kericho has been experiencing above normal rainfall most of the years as shown in the distribution curve skewed to the right, implying that more flood episodes have been experienced compared to drought episodes.

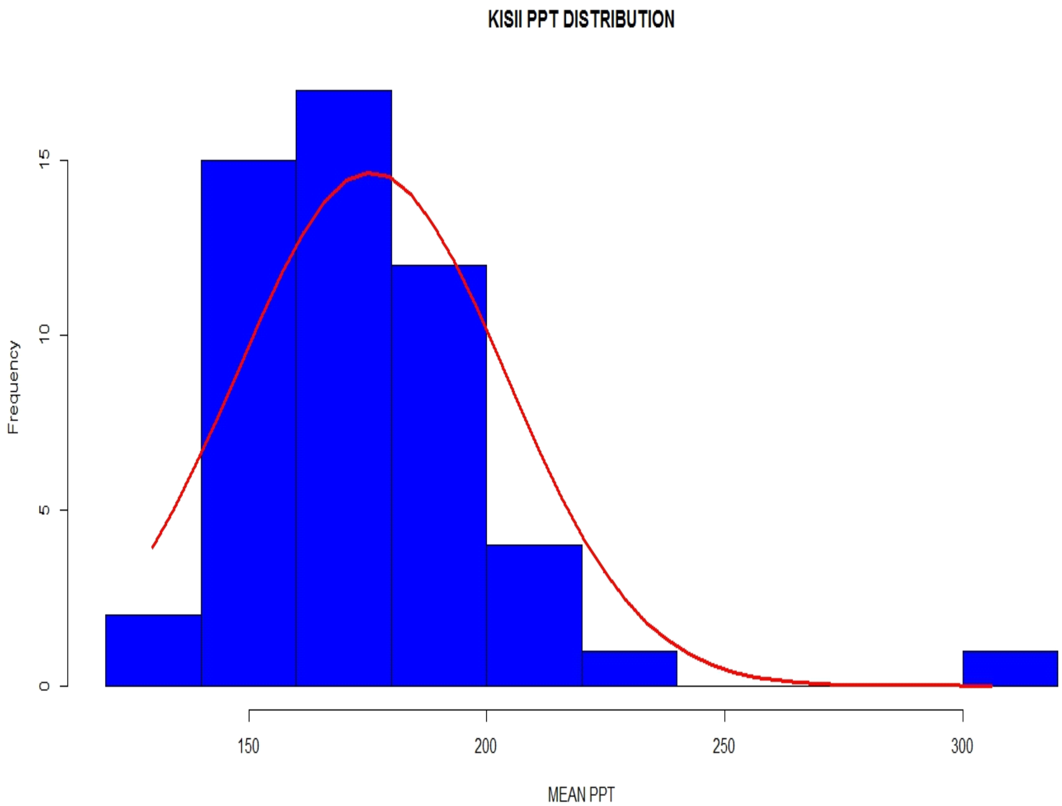

Fig 4.7d: The distribution of annual rainfall in Kisii.

From fig.4.7d, Kisii has been experiencing above normal rainfall most of the years as shown in the distribution curve skewed to the right, implying that more flood episodes have been experienced compared to drought episodes.

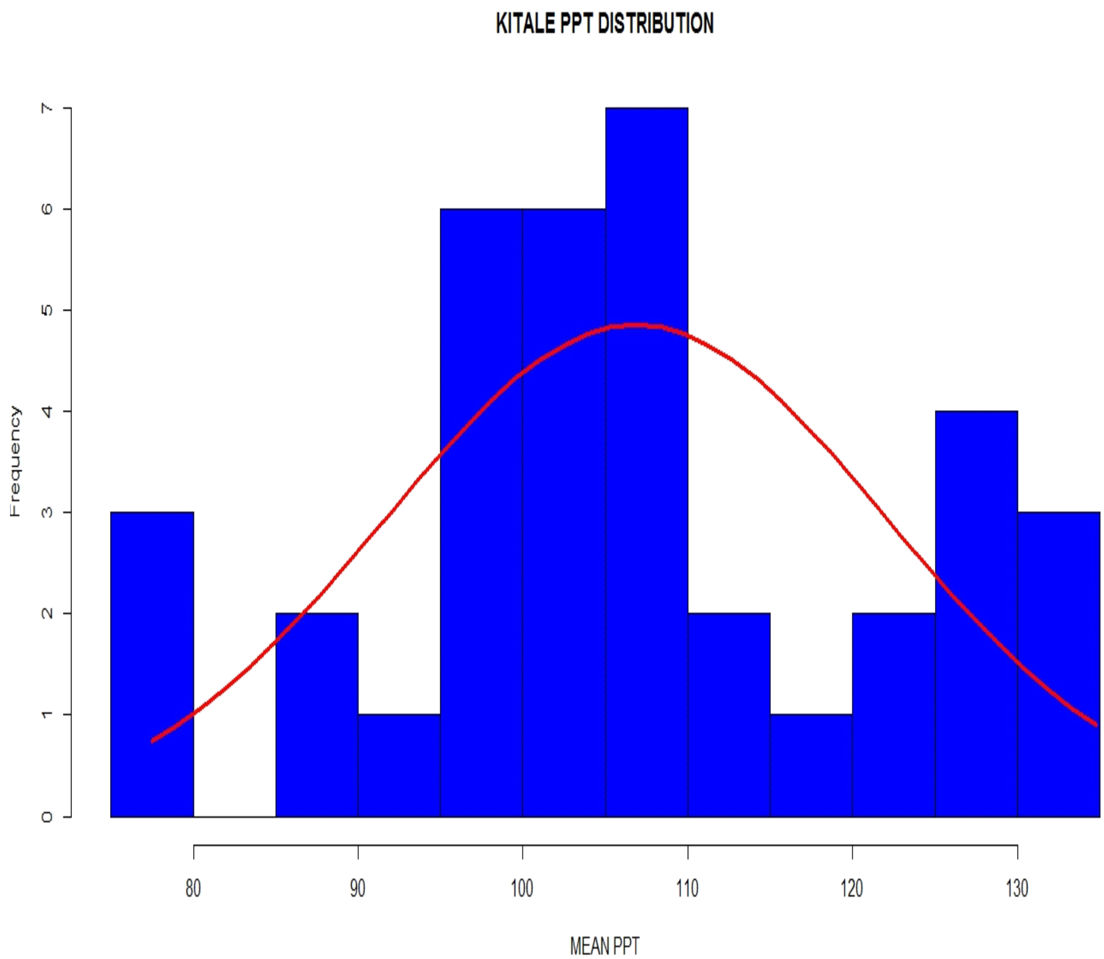

Fig 4.7e: The distribution of annual rainfall in Kitale.

From fig.4.7e, Kitale has been experiencing normal rainfall most of the years as shown in the curve's normal distribution.

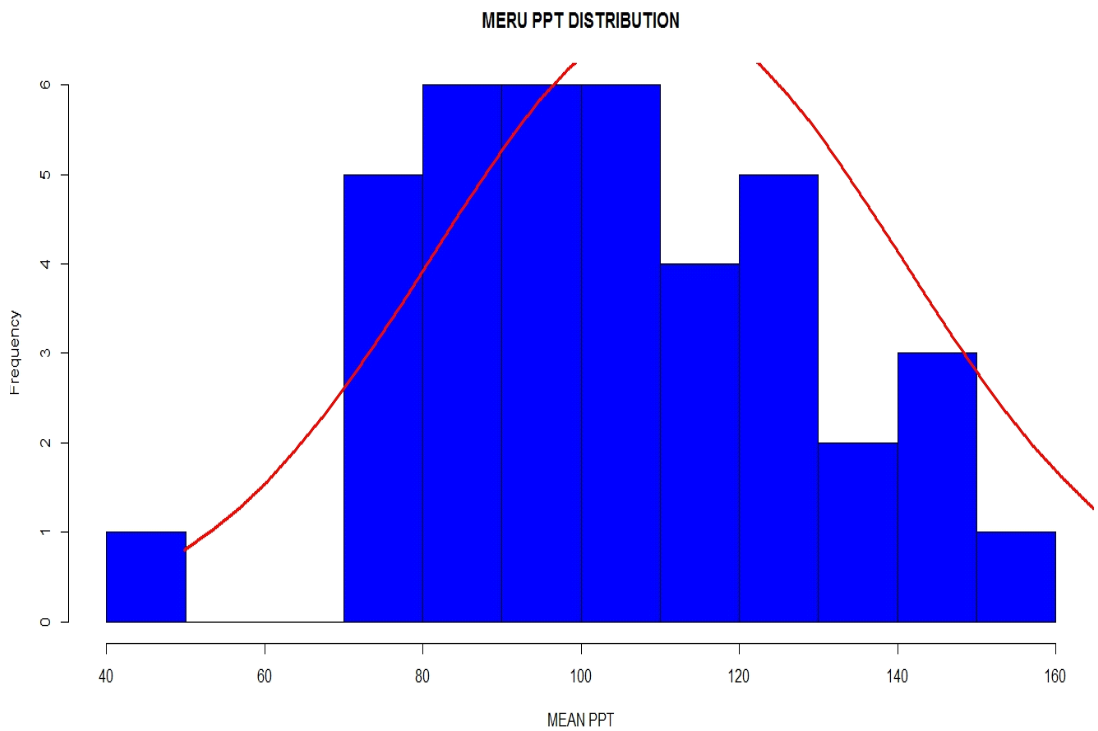

Fig 4.7f: The distribution of annual rainfall in Meru.

From fig.4.7f, Meru has been experiencing above normal rainfall most of the years as shown in the distribution curve skewed to the right, implying that more flood episodes have been experienced compared to drought episodes.

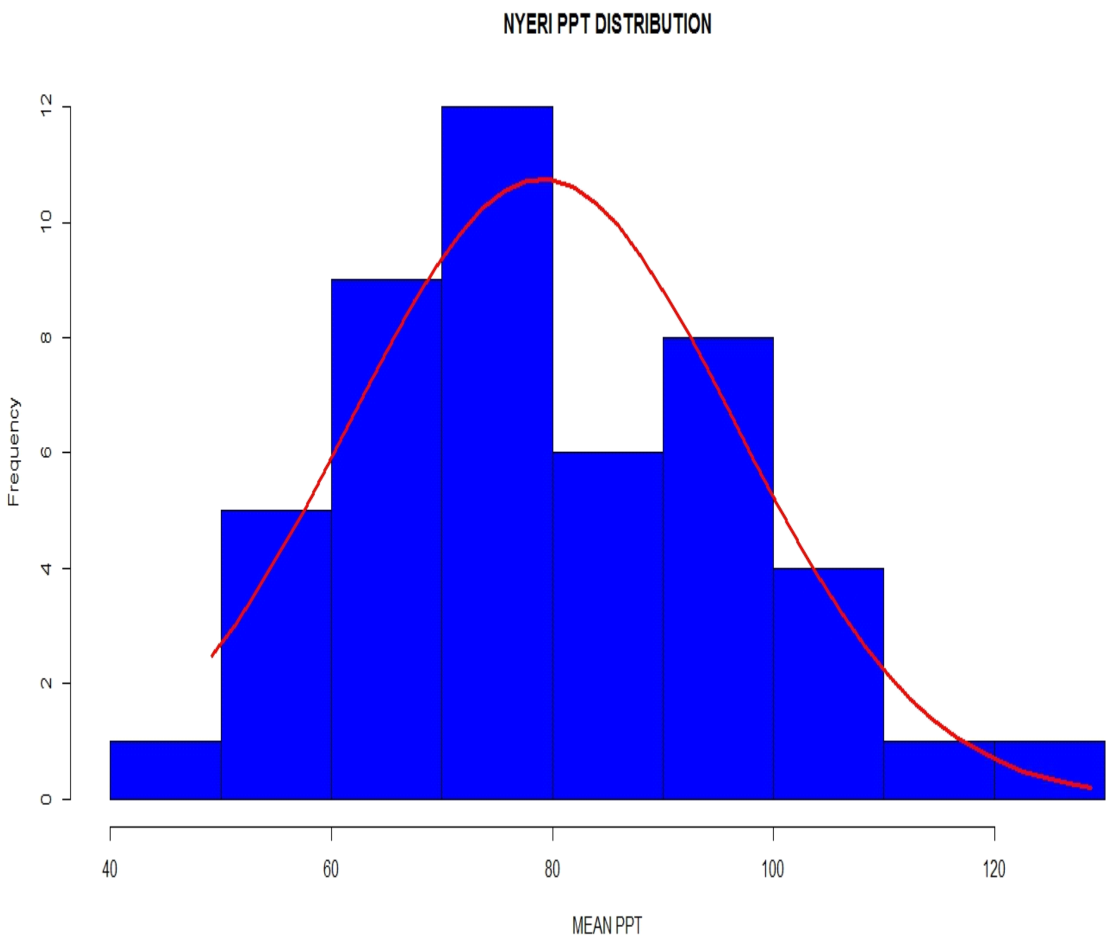

Fig 4.7g: The distribution of annual rainfall in Nyeri.

From Fig 4.7g, Nyeri has been experiencing above normal rainfall most of the years as shown in the distribution curve skewed to the right, implying that more flood episodes have been experienced compared to drought episodes.

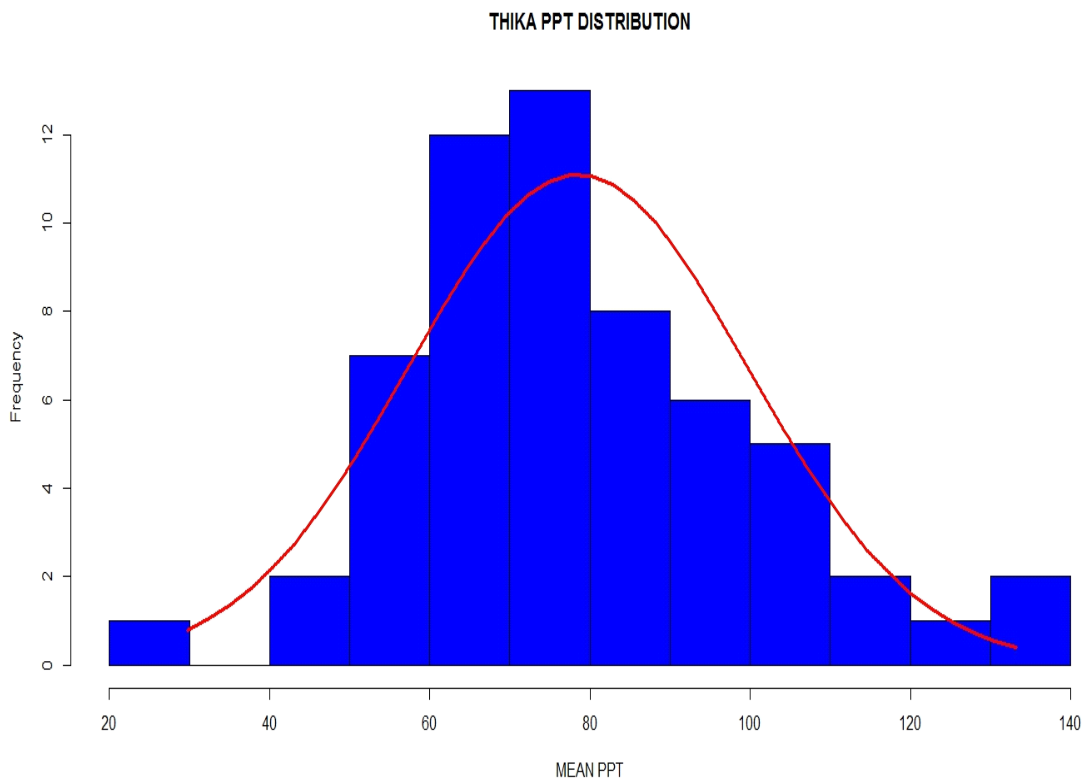

Fig 4.7h: The distribution of annual rainfall inThika.

From Fig 4.7h, Thika has been experiencing above normal rainfall most of the years as shown in the distribution curve skewed to the right, implying that more flood episodes have been experienced compared to drought episodes.

4.8: SUITABILITY OF TEA GROWING AREAS.

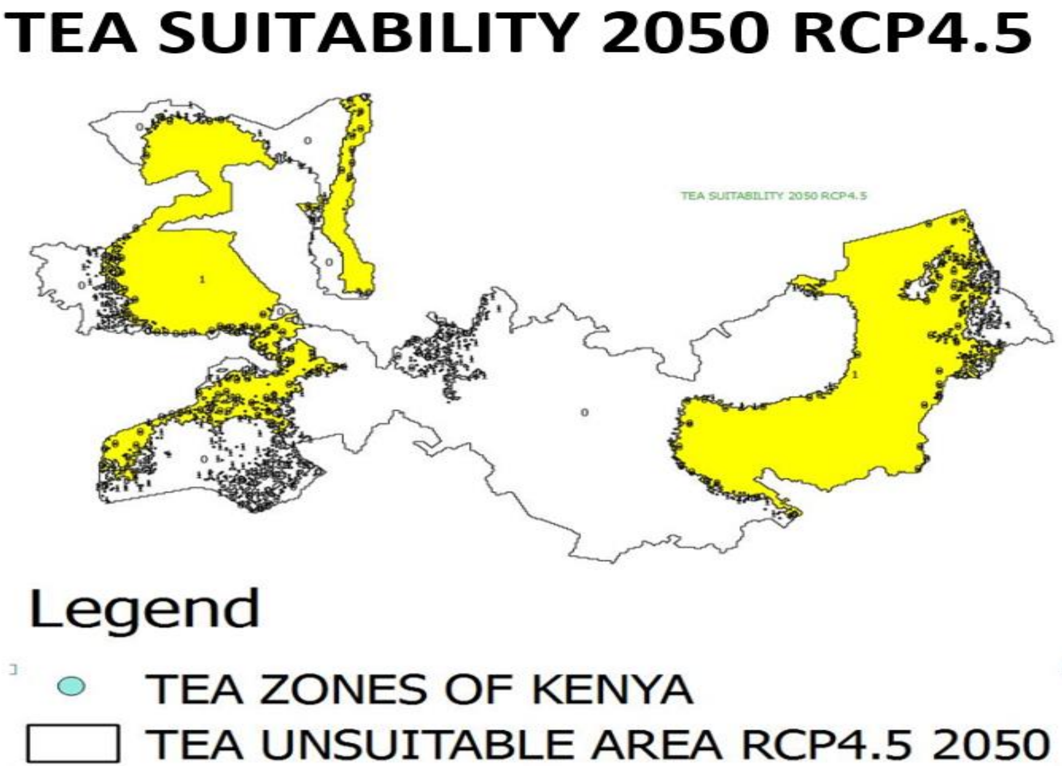

Fig 4.8.a: Suitability for all tea varieties.

From Fig 4.8.a, around a half of the tea growing region is expected to lose suitability for tea production by the year 2050 with Nyamira, Nakuru, Bomet, Vihiga, Kiambu, Meru west, Nyandarua and Nyeri north becoming unsuitable for tea production.

These findings are almost similar to Managua et al, 2011 where around 40% suitability drop was expected by the year 2050.

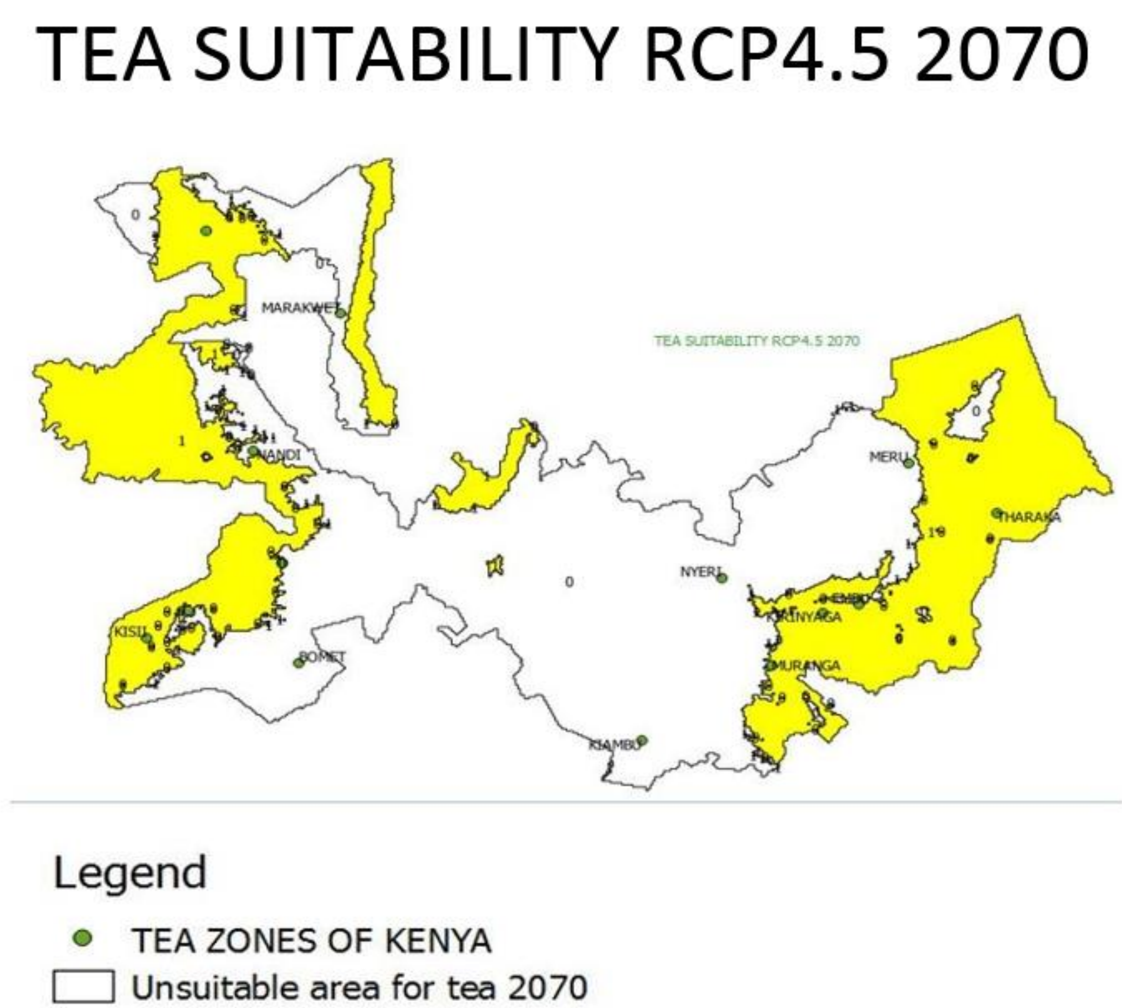

Fig 4.8.b: Suitability for all tea varieties by the year 2070.

From Fig 4.8b, it is observed that the Suitability for tea production increase by around 10% after the year 2050 where around forty percent of the tea growing region loses suitability for tea production by the year 2070.Bomet, Nandi, Kiambu, Nyeri, Nyandarua, Nyamira, Nakuru and Meru west would be greatly affected.

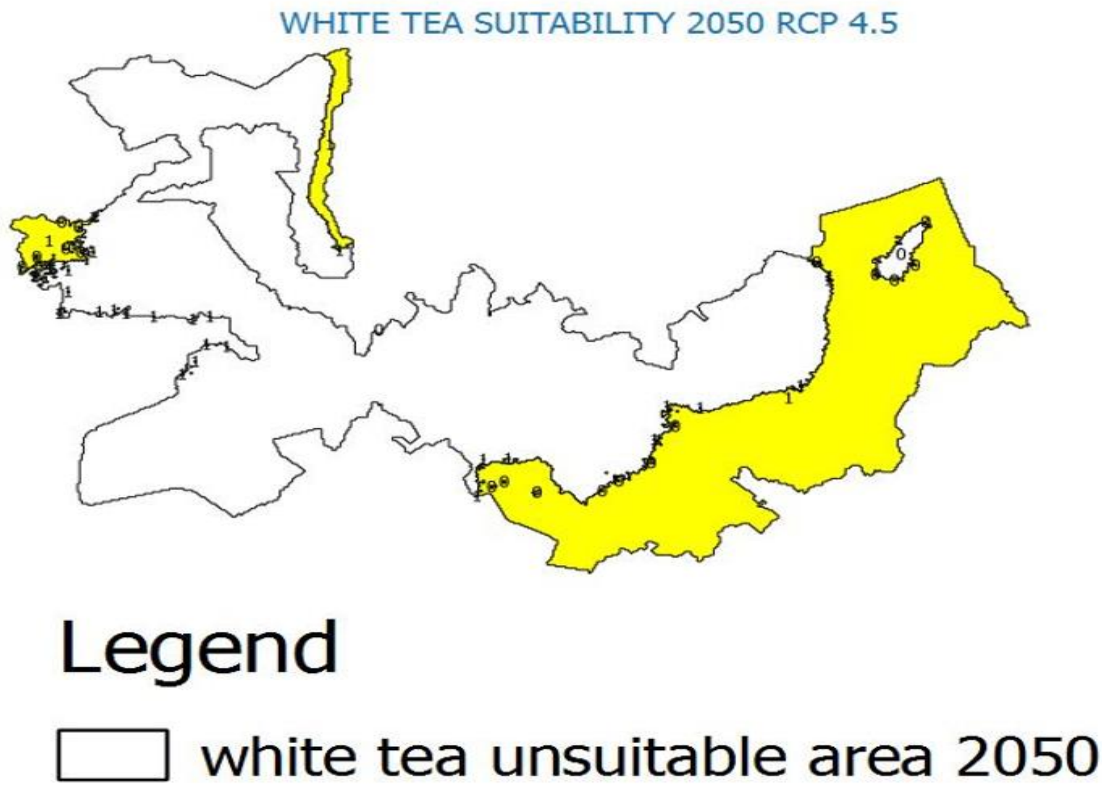

Fig 4.8.c: Suitability for White tea by 2050.

From Fig 4.8c, it is observed that most parts of the highlands west counties except Vihiga and parts of Marakwetmay lose suitability for white tea production by the year 2050.

However, most parts of the highlands eastexcept Nakuru, Nyandarua, Upper parts of Nyeri and Meru west are expected to be suitable for white tea variety by 2050.

It is therefore observed that White tea will be the most suitable tea variety by the year 2050 in the highlands east of riftvalley.

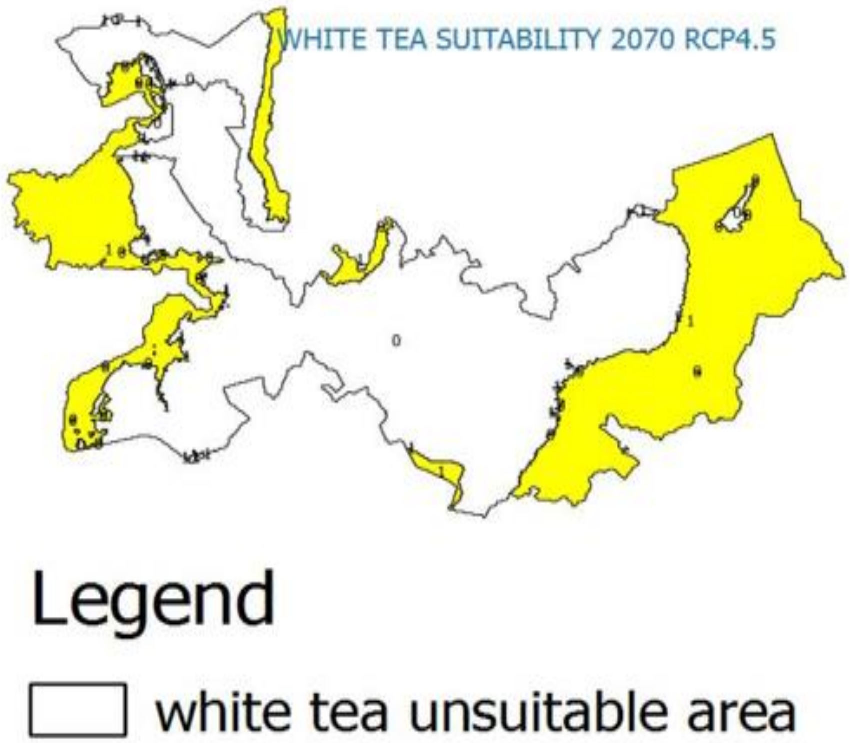

Fig 4.8.d: Suitability for White tea by 2070

From Fig 4.8d, it is observed that around a half of the tea growing region lose suitability for white tea production by 2070 with Kakamega, Kisii, Vihiga and parts of Kericho and Transnzoia regaining suitability. On the other hand, most parts of the highlands eastexcept Nakuru, Nyandarua, Upper parts of Nyeri and Meru west are expected to be suitable for white tea variety by 2070.

It is therefore observed that White tea will be the most suitable tea variety by the year 2070 in the highlands east of rift valley.

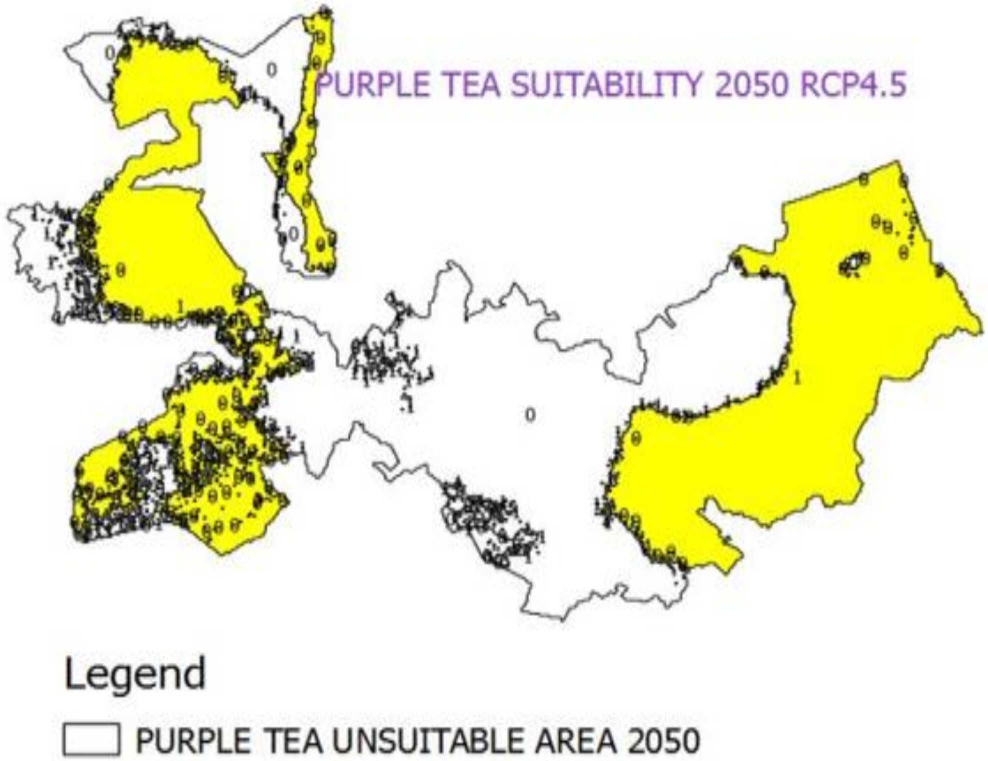

Fig 4.8.e: Suitability for purple tea by 2050

Fig 4.8.eshows that, apart from Nyeri, Vihiga, Nyandarua, Nakuru, Kiambu and Meru west, the rest of the tea growing counties will be suitable for purple tea production by the year 2050.

It is therefore observed that, Purple tea will be generally the 2nd most suitable tea variety by 2050 in the tea zones of Kenya.

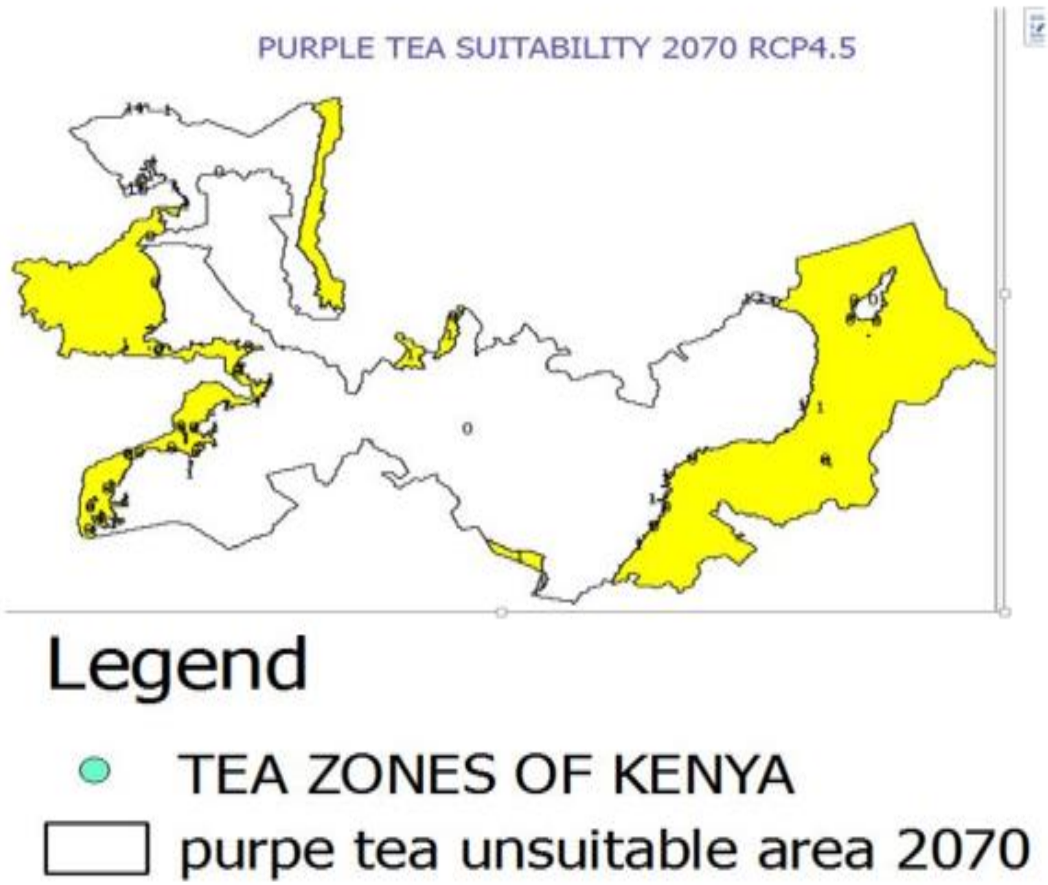

Fig 4.8.f: Suitability for purple tea by 2070

Fig 4.8.fshows that the highlands west counties except Vihiga, Kakamega, Kisii and parts of Marakwet and a few parts of highlands east lose suitability for purple tea production by 2070**.**

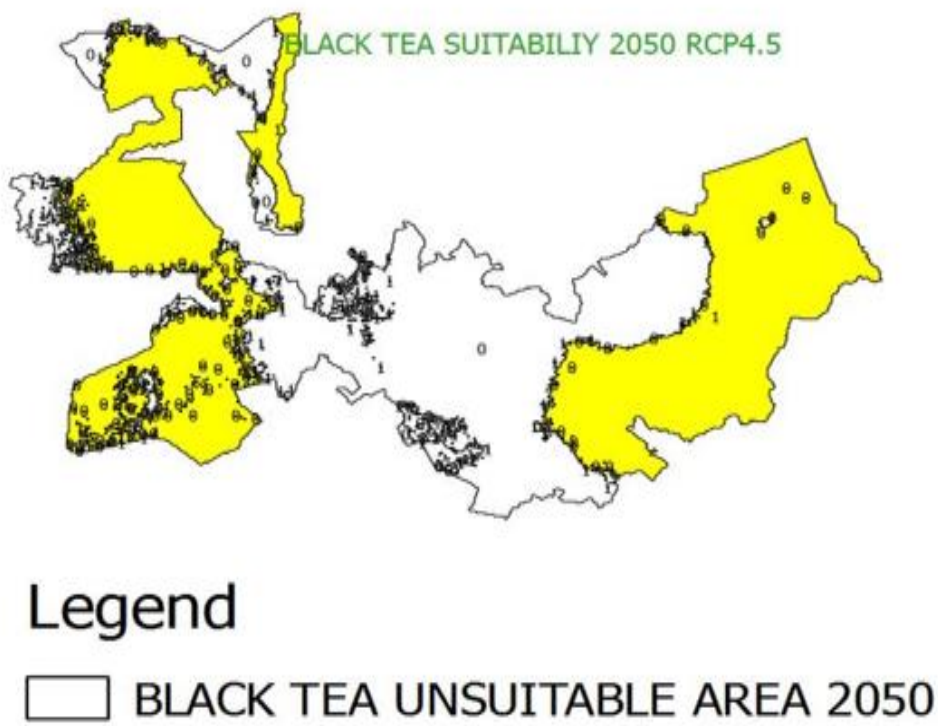

Fig 4.8.g: Suitability for black tea by 2050

Fig 4.8.g shows that, apart from Nyeri, Vihiga, Nyandarua, Nakuru, Kiambu and Meru west, the rest of the tea growing counties will be suitable for black tea production by the year 2050.

It is therefore observed that black tea will be the most suitable tea variety by 2050 in the highlands west of rift valley.

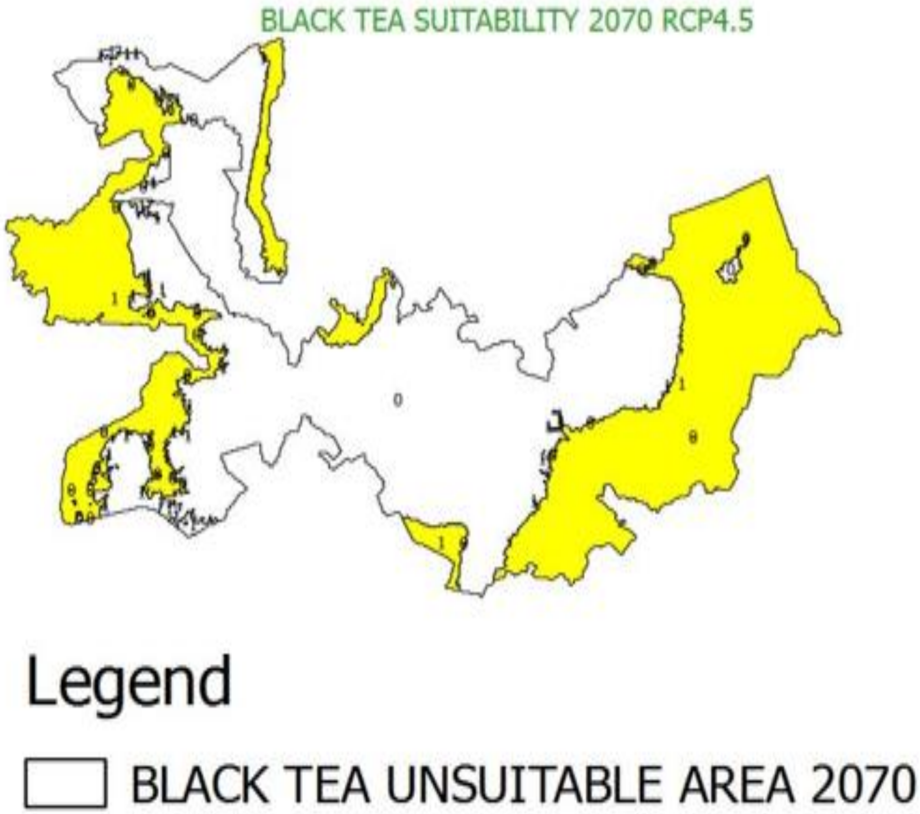

Fig 4.8.h: Suitability for black tea by 2070

Fig 4.8.h shows that, apart from Nyeri, Kericho, Nandi, Nyamira, Kiambu, Nyandarua, Nakuru, and Meru west, the rest of the tea growing counties will be suitable for black tea production by the year 2070.

4.8. b: SUITABILITY FOR PESTS AND DISEASES

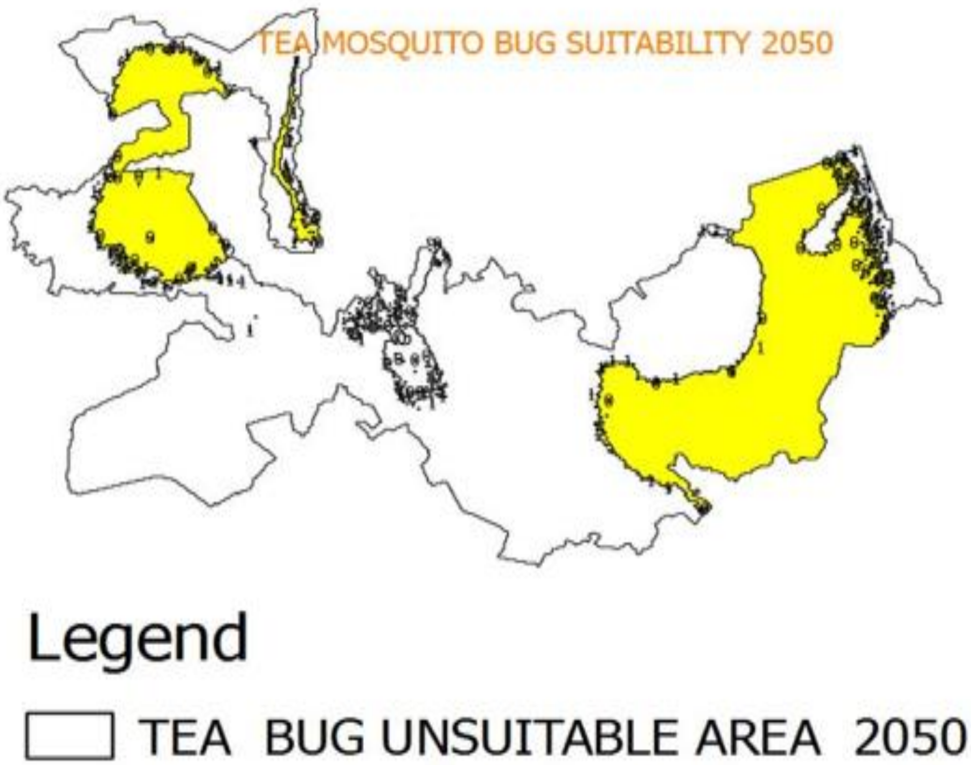

Fig 4.8.i: Suitability for tea mosquito bug by 2050

Fig 4.8.i shows that the tea mosquito bug is likely to infest Transnzoia and Nandi counties in the highlands west while several parts (33% -66%) of the highlands eastexceptNakuru, Nyandarua, Kiambu and Meru west will be suitable.

The tea mosquito bug has only been spotted in Rwanda; Managua et al, (2011).

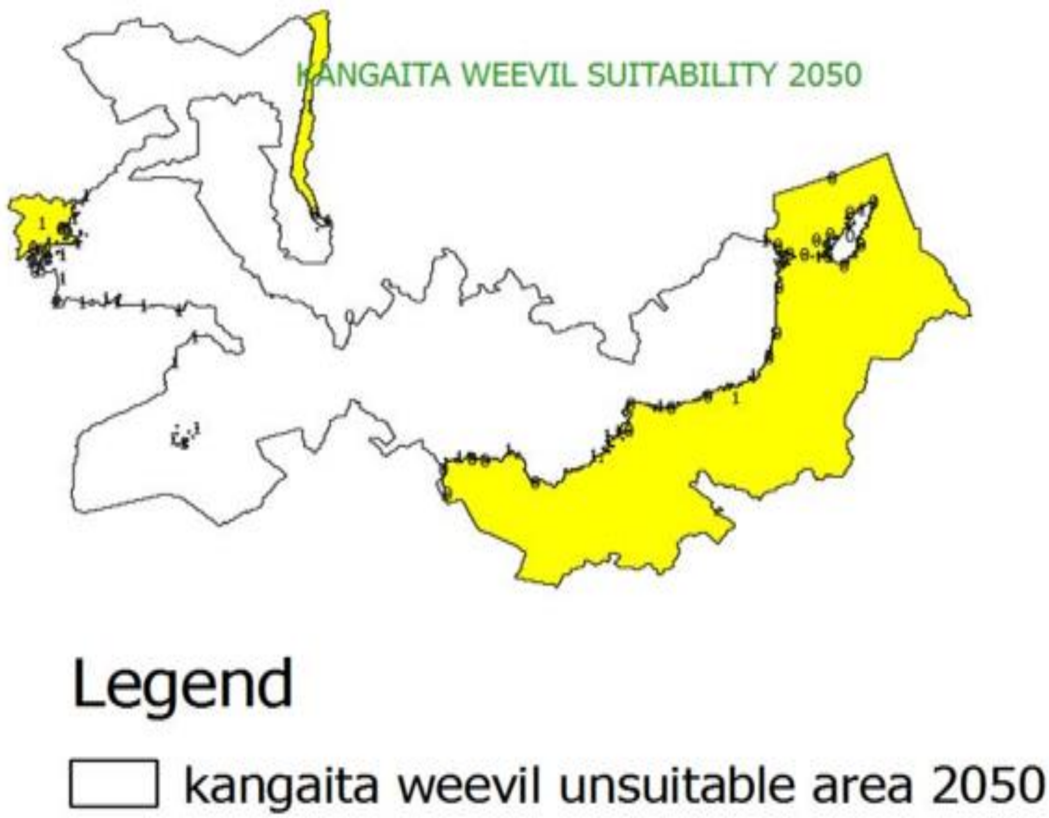

Fig 4.8.j: Suitability for Kangaita weevil by 2050

Fig 4.8.jshows that the Kangaita weevil is likely to infest Vihiga and mostparts (>66%) of the highlands east region by 2050.

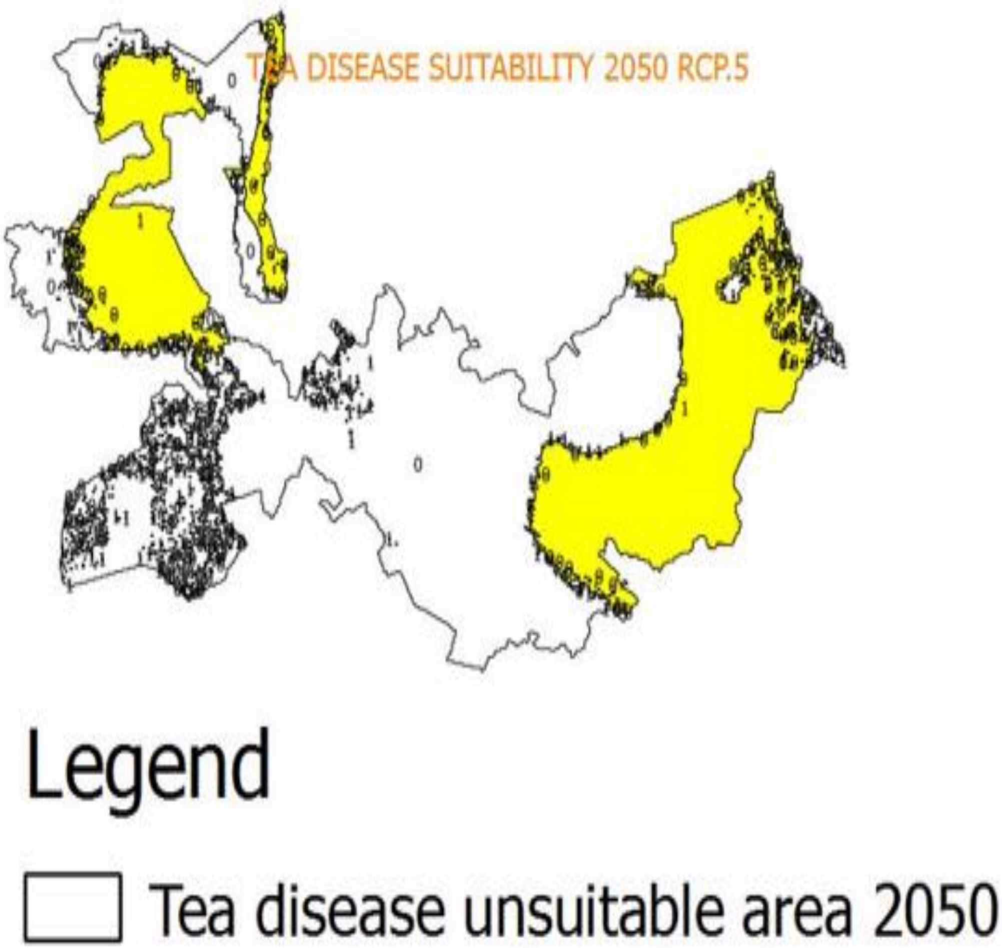

Fig 4.8.k: Suitability for tea disease by 2050

Fig 4.8.kshows that the Tea disease is likely to thrive in Transnzoia and Kakamega counties in the highlands west while several parts (33% -66%) of the highlands east will be suitable.

SUITABILITY FOR CLIMATIC CONSTRAINTS

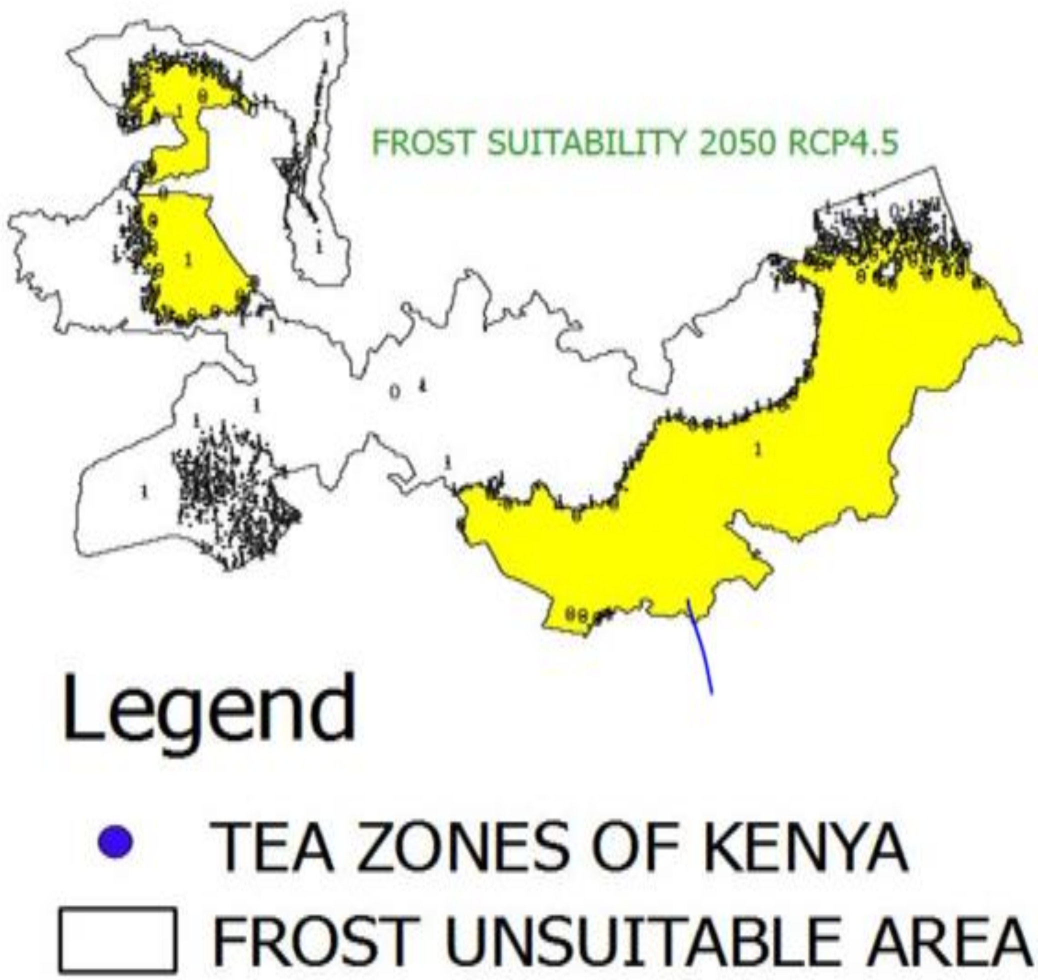

Fig 4.8.l: Suitability for frost by 2050

Fig 4.8.l shows that frost is likely to prevail over Transnzoia, Nandi and most parts (>66%) of the highlands east counties by 2050.

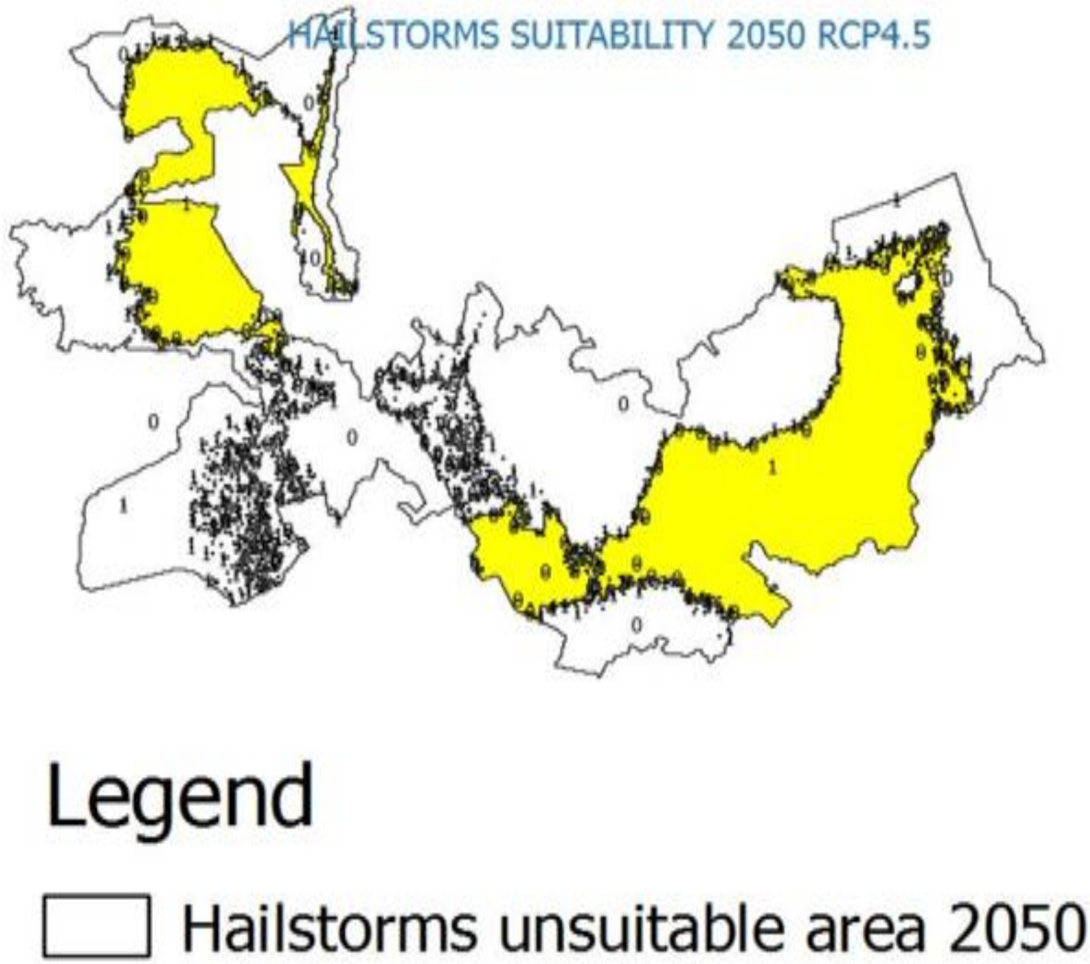

Fig 4.8.m: Suitability for hailstorms by 2050

Fig 4.8.m shows that Hailstorms are likely to prevail over Transnzoia, Nandi and several parts of the highlands east counties by 2050.

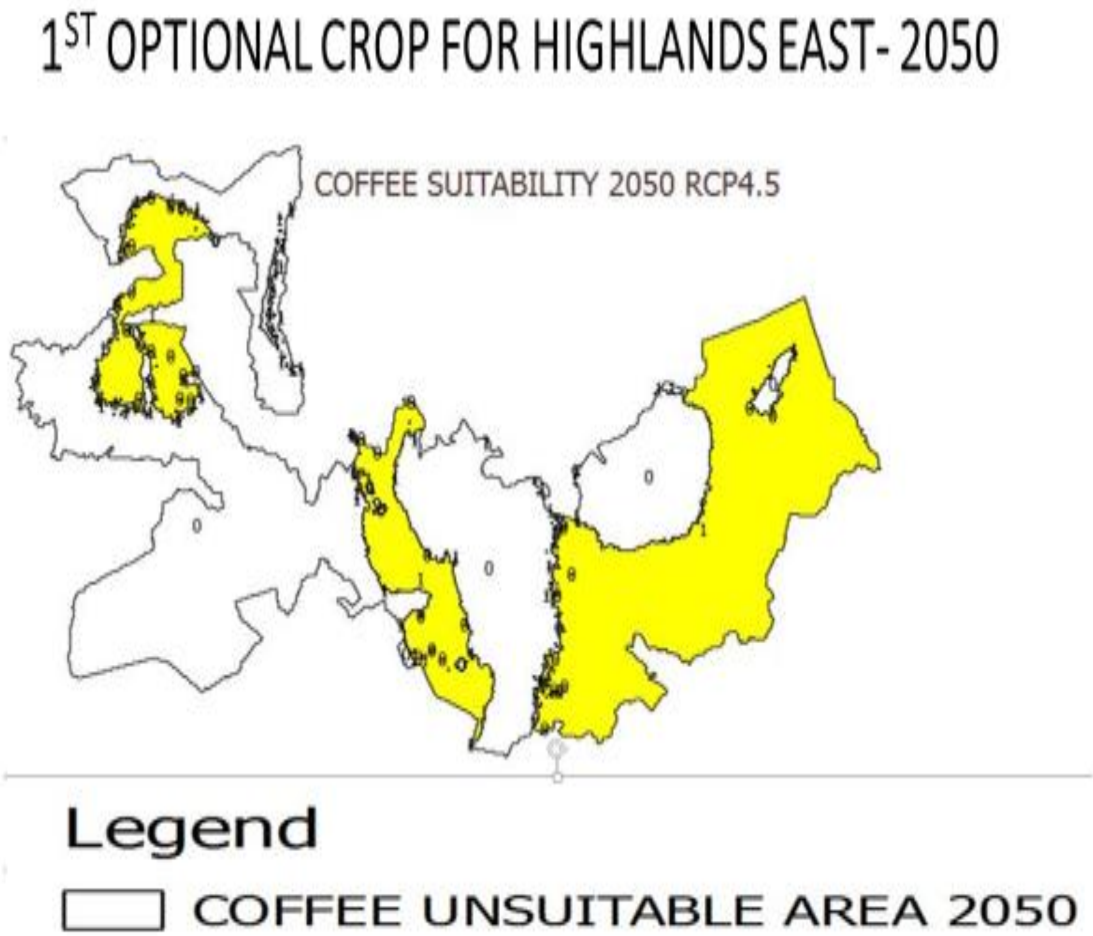

Fig 4.8.n: Suitability for coffee by 2050

Fig 4.8.n shows that, Coffee production will be the best alternative for tea in some parts of Kiambu, Nakuru, Nyandarua and parts of Nyeri by 2050 since they may not be able to produce any tea variety by 2050.

4.8. o: HOW MAXENT MODEL OPERATES

- MaxEnt uses the concept of probability distribution of real valued variables to map suitability of bio-climatological species. (Phillips *et al*., 2006 pg234).
- Similar to logistic regression, MaxEnt weights each environmental variable by a constant.
- The probability value ranges from 0 to 1 and is interpreted as false or true in QGIS model.
- Results are obtained by performing 5,000 iterations on the features.
- 25% of the data was assigned to test while the rest was used for training (develop the models).
- Suitable means at least 50% presence of the species in question in that particular area.

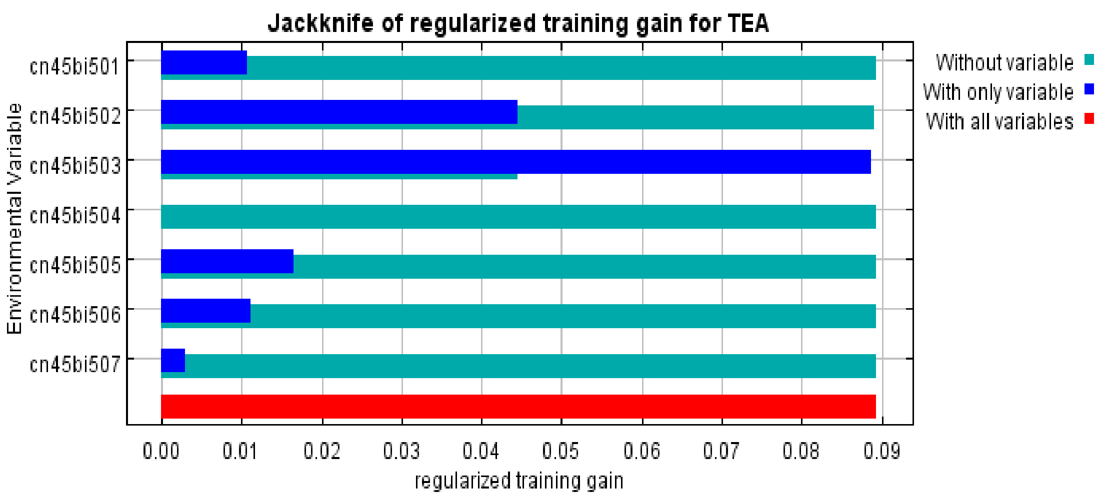

Fig.4.8. p: Contribution of bioclimatic variables in the prediction of suitability of tea production.

Fig.4.8. p shows that, Bi03 (isothermality) has the most impact in tea production prediction.

Where:

Bio_1 = Annual Mean Temperature

Bio_2 = Mean Diurnal Range (Mean of monthly (max temp – min temp))

Bio_3 = Isothermality (P2/P7)*(100)

Bio_4 =Temperature Seasonality (standard deviation*100)

Bio_5 = Max Temperature of Warmest Month

Bio_6 =Min Temperature of Coldest Month

Bio_7 =temperature Annual Range (P5-P6)

MODEL PREDICTIVE STRENGTH-2050

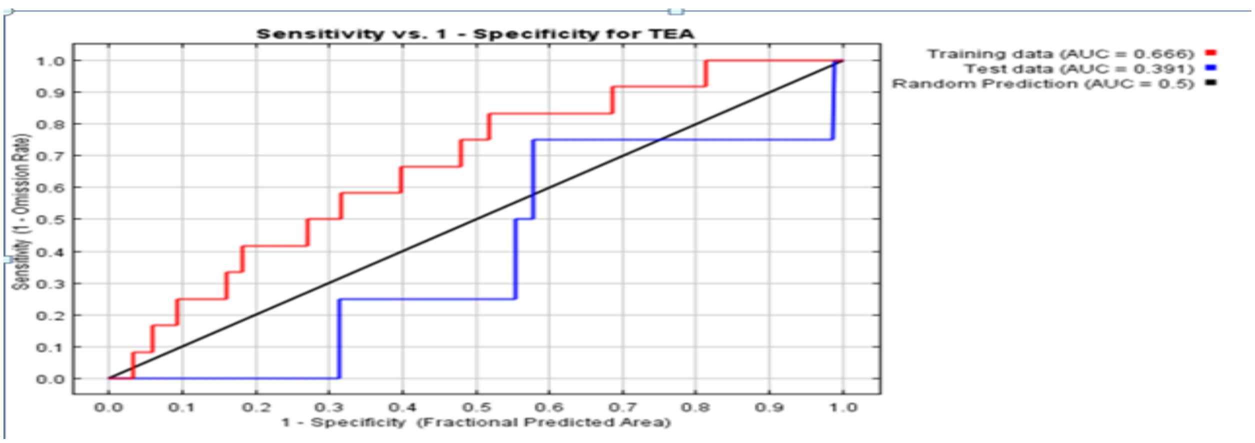

Fig 4.8q: Model predictive strength

Fig 4.8q shows that the model fit is good since the random prediction value is 0.5

4.9 TEMPERATURE ANOMALIES FOR YEARS 2050 AND 2070.

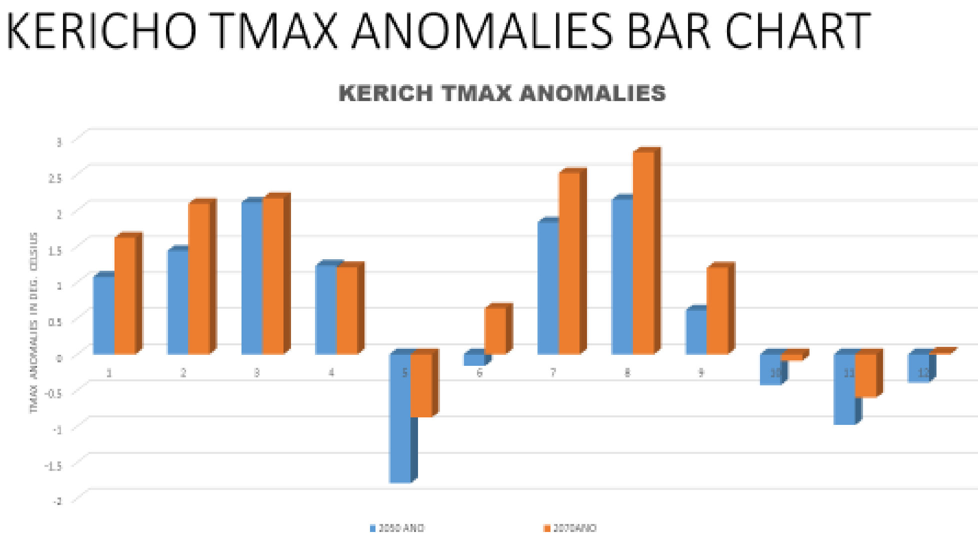

Fig 4.9.1: Temperature anomalies for Kericho for years 2050 and 2070.

Fig 4.9.1 shows that, there exists a larger deviation of cooler temperatures during tea peak seasons over MAM and OND for the period 2020 to 2050 as compared to 2050 to 2070.

Fig 4.9.1 also shows that, there exists a larger deviation of warmer temperatures during the cold season JJA for the period 2050 to 2070 as compared to 2020 to 2050.

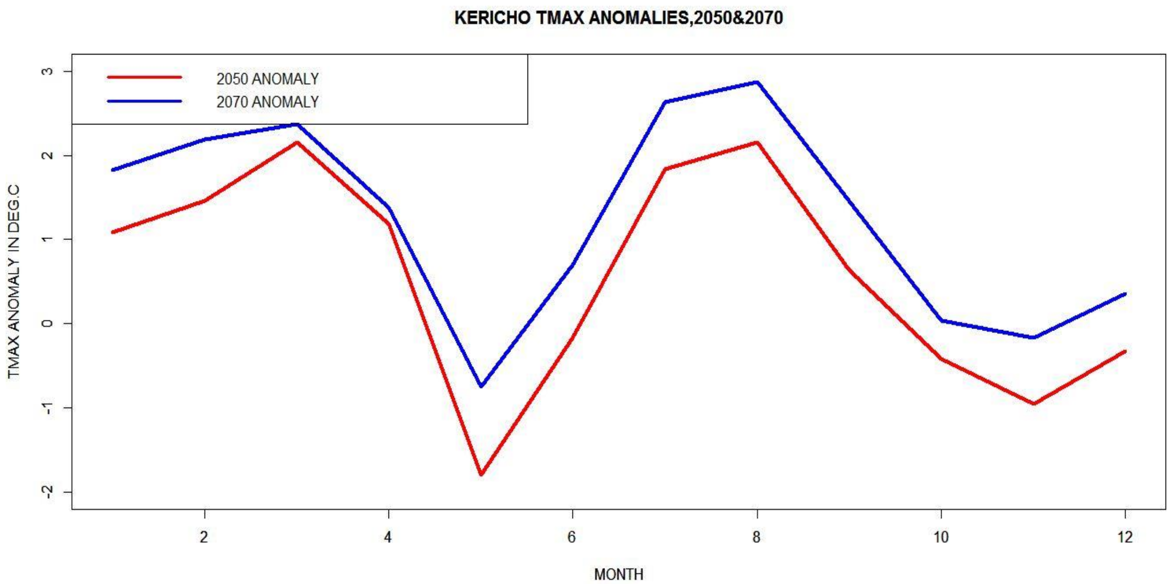

Fig 4.9.2: Seasonal pattern for temperature anomalies for Kericho for years 2050 and 2070.

Fig 4.9.2 shows that, warmer temperatures are expected during the warm season JFM and the cold season JJA while the rainy seasons MAM and OND are expected to be cooler by the years 2050 and 2070.

5.0: SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1: SUMMARY

The suitability of tea production within the tea producing counties in Kenya by the years 2050 and 2070 was determined by the use of various methodologies where both ground based and satellite data was used.Tea production data from Tea Directorate of Kenya (TDK) and monthly precipitation, minimum and maximum temperature data for the period 1976-2014 from Kenya Meteorological Department (KMD) was used and supplemented with gridded data from Atlas KNMI.

Tea production data, precipitation, maximum and minimum temperature data was analyzed to establish the trends, magnitude and frequency of extremes and the relationship between tea, temperatures and precipitation.

Bioclimatic variables data from worldclim.com was extracted into the area of study and converted into a format readable in MaxEnt model using QGIS model. The QGIS model outputs were fed into the MaxEnt model as environmental layers together with samples data (bioclimatic species under investigation) through which the suitability of tea growing areas for different varieties of tea, coffee, climatic constraints such as frost and thunderstorms, existing pests such as Tea Kangaita Weevil and Tea Mosquito Bug and existing crop diseases such as Tea disease by the years 2050 and 2070 was determined.

5.2: CONCLUSIONS

Suitability for tea production is expected to decrease up to the year 2050 thenthereafter increase by around 10% by the year 2070. The increase in suitability for tea production over 2070 was observed to be associated with relatively smaller magnitudes of cooler temperatures during the tea peak seasons MAM and OND and relatively larger magnitudes of warmer temperatures during the cold season JJA over the years 2060 to 2080 as compared to the years 2030 to 2060, which implied that temperatures will be more conducive for crop and especially leaf development for 2070 than 2050.

Generally, the future tea production suitability is expected to drop as a result of the warm season JFM getting warmer and the tea peak seasons MAM and OND which are also the wet seasons getting cooler, thus opening up more room for climatic constraints inhibiting crop and more especially leaf development since cooler than normal temperatures during the wet MAM and OND seasons may aggravate chilling effect while the warmer than normal temperatures during the warm JFM season may speed up sunburn and wilting on tea plantations.

On account of season specific temperature variations, it is observed that around a half of the tea growing region is expected to lose suitability by the year 2050 while around forty percent of the tea growing region loses suitability by the year 2070.

The resilience of different tea varieties to the changing climate is observed to be location specific whereby White tea variety is expected to be the most suitable variety in the highlands east of rift valley while the Black tea variety is expected to be the most suitable variety in the highlands west of rift valley.

The viability of different Tea pests and diseases and suitability for climatic constraints such as frost and hailstorms is also observed to be location specific, whereby a higher chance for their prevalence is expected to be in Transnzoia, Nandi and most parts of the highlands east.

Coffee, which has the same economic value with tea, is found to be more resilient to the changing climate in the highlands east of rift valley region as its suitability covered nearly the entire region thus making it the best adaptation option for Nyandarua,Nyeri and Kiambu counties which may not be able to produce any tea variety in several parts between the years 2040 to 2080.

More episodes of higher than normal production of tea have been experienced in the region of study as compared to lower than normal production events. However, dwindling tea yields have been recorded in the recent past (beyond the year 2014).

Both magnitude and frequency of climate extremes were observed to have increased, whereby the hot seasons were observed to be warmer, cold seasons cooler, wet seasons wetter and dry seasons drier with the frequency of wetter than normal episodes surpassing that of drier than normal hence making it possible for the region of study to use the flood episodes to cope with drought.

The rainfall pattern for the highlands east of rift valley region was observed to assume a bi-modal pattern while that of the highlands west of the rift valley region tri-modal.

Decreasing trends of rainfall have been experienced over years while increasing trends of temperature have been experienced in the region of study.

Temperatures were observed to have more effect on tea production than precipitation and the effect is location specific whereby a positive correlation was observed between temperatures, precipitation and tea production in the highlands east of rift valley while a negative correlation existed between maximum temperature and tea production and a positive correlation existed between minimum temperature, precipitation and tea production in the highlands west of rift valley region.

5.3: RECOMMENDATIONS

1. I would like to recommend for tea suitability research beyond the year 2070.
2. I recommend the production of white tea variety for the highlands east counties since it was found to be more resilient to the changing climate in the future up to the year 2070.
3. I recommend the production of coffee for Kiambu, Nyandarua and Nyeri counties since it was found to be the most resilient crop for the counties to the changing climate in the future up to the year 2050.
4. I recommend the production of black tea variety for the highlands west counties since it was found to be more resilient to the changing climate in the future up to the year 2070.
5. Transnzoia, Nandi and most parts of the highlands east of rift valley to prepare for control measures against tea pests and diseases.

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APPENDICES

I. REGRESSION ANALYSIS FOR PRECIPITATION, MAXIMUM AND MINIMUM TEMPERATURE USING R.

```
>leshamta<-read.csv("C:/Users/Mulatya/Desktop/TAUSI TEMP & PPT ANALYSIS/MERU REG.csv",header=T,sep=",")

>leshamta

>attach(leshamta)

>names(leshamta)

> fit<-lm(MONTH~PPT)

>plot(MONTH,PPT,type="l",col="blue",main="MERU PRECIPITATION REGRESSION",ylab="PRECIPITATION IN MM",ylim=c(20,300))

>plot(MONTH,PPT,type="l",col="blue",main="MERU PRECIPITATION REGRESSION",ylab="PRECIPITATION IN MM",ylim=c(10,400))

>lines(MONTH,PPT,col="blue",lwd=4)

>par(new=T)

>plot(MONTH,TMIN,col="yellow",type="l",ylab="PRECIPITATION IN MM",xaxt="n",yaxt="n",axis=F)

>lines(MONTH,TMIN,col="yellow",lwd=3)

>par(new=T)

>plot(MONTH,TMAX,col="red",type="l",ylab="PRECIPITATION IN MM",xaxt="n",yaxt="n",axis=F)

>legend("topright",col=c("blue","red","yellow"),lty=1.5,lwd=3,legend=c("PPT","TMAX","TMIN"))

>summary(leshamta)

>model<-lm(PPT~TMAX)
```

```
>model
>model<-lm(TMAX~PPT)
>model
>model<-lm(PPT~TMIN)
>model
>model<-lm(TMIN~PPT)
```

II. ANALYSIS OF EXTREMES USING R.

```
>leshamta<-read.csv("C:/Users/Mulatya/Desktop/TAUSI TEMP & PPT ANALYSIS/embupptvar.csv",header=T,sep=",")
>leshamta
>attach(leshamta)
>names(leshamta)
[1] "MONTH"     "MEAN"      "MEAN.SD"   "MEAN.SD.1"
> fit<-lm(MONTH~MEAN)
>plot(MONTH,MEAN,type="l",col="blue",main="EMBU PRECIPITATION VARIABILITY",ylab="PRECIPITATION IN MM",ylim=c(20,300))
>lines(MONTH,MEAN,col="blue",lwd=4)
>par(new=T)
>plot(MONTH,MEAN.SD,type="l",col="red",main="EMBU PRECIPITATION VARIABILITY",ylab="PRECIPITATION IN MM",ylim=c(20,300))
>lines(MONTH,MEAN.SD,col="red",lwd=3)
>par(new=T)
```

```
>plot(MONTH,MEAN.SD.1,type="l",col="yellow",main="EMBU PRECIPITATION VARIABILITY",ylab="PRECIPITATION IN MM",ylim=c(20,300))

>lines(MONTH,MEAN.SD.1,col="yellow",lwd=3)

>legend("topright",col=c("blue","red","yellow"),lty=1.5,lwd=3,legend=c("PPT","TMAX","TMIN"))
```

III:TREND ANALYSIS USING R.

```
>leshamta<-read.csv("C:/Users/Mulatya/Desktop/TAUSI TEMP & PPT ANALYSIS/embu.csv",header=T,sep=",")

>leshamta

>attach(leshamta)

>names(leshamta)

> fit<-lm(YEAR~MEAN)

>plot(YEAR,MEAN,type="l",col="blue",main="EMBU PRECIPITATION TREND",ylab="PRECIPITATION IN MM",ylim=c(20,300))

>plot(YEAR,MEAN,type="l",col="blue",main="EMBU PRECIPITATION TREND",ylab="PRECIPITATION IN MM",ylim=c(20,200))

>lines(YEAR,MEAN,col="blue",lwd=4)

>abline(lm(MEAN~YEAR))

>legend("topleft",col=c("blue","black"),lty=1.5,lwd=4,legend=c("ANNUAL MEAN PPT","TREND"))
```

III. FREQUENCY DISTRIBUTION CURVE USING R.

```
>attach(leshamta)

>names(leshamta)

>hist(MEAN)

>summary(leshamta$MEAN)

> x<-leshamta$MEAN

> h<-hist(x,breaks=10,col="blue",xlab="MEAN PPT",main="THIKA PPT DISTRIBUTION CURVE")

>min(MEAN)

>max(MEAN)

>xfit<-seq(min(MEAN),max(MEAN),length=40)

>yfit<-dnorm(xfit,mean=mean(MEAN),sd=sd(MEAN))

>yfit<-yfit*diff(h$mids[1:2])*length(MEAN)

>lines(xfit,yfit,col="red",lwd=3)
```

IV. TEA REGRESSION ANALYSIS USING R.

```
>attach(leshamta)

>names(leshamta)

>model=lm(TEA~PPT)

>model

>model=lm(TEA~TMAX)
```

```
>model

>model=lm(TEA~TMIN)

>model
```

V. HOMOGENEITY TEST FOR QUALITY CONTROL USING R CHISQUARE.

```
>leshamta<-read.csv("C:/Users/Mulatya/Desktop/TAUSI TEMP & PPT ANALYSIS/KERICHO TEST.csv",header=T,sep=",")

>leshamta

>attach(leshamta)

>names(leshamta)

>chisq.test(leshamta)

>chisq.test(leshamta,simulate.p.value=T,B=1000)

X-squared = 16960, df = NA, p-value = 0.000999
```

VI. TEA PRODUCTION BOX PLOT

```
>boxplot(TPMEAN,col="blue",main="TEA PRODUCTION VARIABILITY 2006-2015",ylab="TEA PRODUCTION IN TONNES").
```