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DEPARTMENT OF METEOROLOGY

THE ASSESSMENT OF THE TEMPORAL CHARACTERISTICS OF SURFACE AIR TEMPERATURES OVER KENYA

BY

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DECLARATION

This research project is my original work and has never been presented for a degree in any other University.

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DEDICATION

I dedicate this work to my Late parents who raised me and my wife Jemima for offering me unlimited support during the study and a source of encouragement to me.

ABSTRACT

The research assessed the temporal characteristic of surface air temperature over Kenya using graphical and statistical technique. The temporal characteristics investigated in the study included inter-annual trends in the extreme temperature, and determine the trend of temperature range

Daily records for all meteorological stations in Kenya for the period of 1975 to 2014 were used.

In the graphical approach, visual examination of inter-annual trend were used whilst analysis of variance (ANOVA) and non-parametric methods were used in statistical approach.

The data used was from all synoptic stations in Kenya from 1975 to 2014. All data was quality-controlled before using for analysis.

The inter-annual minimum and maximum temperature patterns showed distinct decadal variability observed in minimum and maximum temperature records. Similarly the temperature range showed a distinct decadal variability. Trends patterns in observed minimum and maximum temperature showed a lot of geographical and seasonal variations.

The findings of this study will be of utmost importance since temperature is an important parameter in the space-time distribution of natural resources, and life in general. These findings will therefore be useful to planners and managers of food, agriculture, water, social-economic, and many other natural resources that are climate-dependent.

ACRONYM/ ABBREVIATION

ITCZ ------Inter-Tropical Convergence Zone

AEJ -----Easterly Jet

TEJ------- the Tropical Easterly Jet

STJ ------The sub-tropical Jet streams

EALLJ----- East African Low Level Jet

SH -------Southern Hemisphere

SWIO ---South West Indian Ocean

ENSO ------El-Niño/ Southern Oscillation

QBO--- the Quasi-Biennial Oscillation

SO--Sother Oscillation

SWIO ---South West Indian Ocean

QBO ----Quasi-Biennial Oscillation)

KMD---- Kenya Meteorological Department

WMO----World Meteorological organization

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CHAPTER ONE

1.0 Introduction

This chapter gives the general information on the basic concepts addressed in the research. A brief review of problem statement, justification of the study and objective of the study, was addressed. Temperature is a parameter that determines species distribution because living organisms must maintain a specific internal temperature or inhabit an environment that keeps the body with a temperature range that support their metabolism. Global mean surface temperatures have risen by $0.74^{o}C \pm 0.18^{o}C$ through linear estimation trend over the last one hundred years (1905-2005). The rate of warming over the previous 50 years is almost twice that of the previous 100 years. (0.13 ± 0.03) vs $0.07 \pm 0.02\ ^{o}C$ each decade).Land areas have warmed at a higher rate than the oceans (IPCC 2007).

Changes in maximum and minimum temperature are also in line with warming of the climate. A widespread decline in the number of frost days and nights in mid-latitude regions and prevalence in the number of warm extremes and reduction in the number of daily cold extremes observed in 70 to 75% of the land regions where data are available. Warm nights have become more frequent. The increase in heat wave over Central and Western Europe in summer of 2003 is an example of exceptionally current extreme .It was the hottest since similar instrumental records started about 1780 and is very likely to have been the hottest since at least 1500 AD.

Significant cooling together with dominance of no significant trends are common in certain positions. Across East Africa, the spatial patterns of the observed warming and cooling trends however show significant geographical and seasonal variations (Kinguyu, 1994). Climate change is expected to increase temperature variability leading to a substantial increase in temperature extremes such as the daily maximum temperature (Tmax) (Easterling *et al*., 1997; IPCC, 2013). At the same time average temperatures in temperate regions are not expected to exceed normal average temperatures.

The dominating systems controlling the spatial and temporal characteristics of the climate of the region comprises of the inter-tropical convergence zone, subtropical anticyclones, monsoon wind systems, the African jet streams, easterly/westerly waves, tropical cyclones, and tele-connections with regional and large-scale quasi-periodic climate systems like the quasi-biennial oscillation (QBO), intra-seasonal waves, and El Nino–Southern Oscillation (ENSO), and many others. Thermally influenced meso-scale systems associated with orography and massive water bodies, which include inland lakes, introducing significant modifications to the large-scale flow over the region.

1.1 Problem Statement

Kenya is warming up yearly, and all projections indicate that things are about to get worse. The intergovernmental panel on climate change (IPCC) declares that close to 82% of Mt. Kilimanjaro ice cap has diminished in the previous 100 years, and the glaciers on top of Mt. Kenya is melting faster. High temperatures lead to occasional headaches and dryness of skin. Warmer average temperatures nearly influence everything. Warming trends are evident in increasing air and water temperature, affecting land and aquatic habitat and species. Increase in average temperature can cause shifting in seasons affecting species distribution.

Rising air temperature has triggered many climate impacts, for example; warmer water temperatures, greater flood rain, rise in sea level, changes in precipitation and strengthened storms. Global temperatures are expected to rise. These changes in temperature changes will vary from place to place i.e. some parts will experience warmer temperatures, some cooler while others will remain unchanged. In Kenya crop yields have decreased since the maximum temperature sometimes exceeds the temperature tolerance (optimum temperature)

Warming in Kenya during warm months has impacted negatively to livestock reproduction and production for example, slowed animal weight gain, reduced dairy yields and low feed conversion efficiency. Excessive heat has caused heat stress leading to illness or death for example early July this year a young man from Kitui was confirmed to have died as a result of heat waves. Increase in temperature has also lead to increase in areas infested by vectors transmitting diseases for example highlands of Kenya prevalence of malaria due to infestation of mosquitoes.

1.2 Justification and Relevance of the Study

Most of the studies done on climate change and variability have been rather global in nature. Very little of such work had been carried out within Kenya. Temperature is an important parameter that determines space- time distribution of natural and climate-dependent resources. The study is therefore devoted to temperature variation over Kenya. Human health can also be affected by temperature. For instance, vectors with short life span including mosquitoes', sandflies, blackflies are temperature-sensitive during extrinsic maturation period of the parasite. Therefore the frequency of outbreaks of vector borne diseases could be affected by the frequency of extreme temperatures. It is therefore imperative to find out if there is likelihood of increase or decrease of temperature (Min and Max) in different parts of Kenya.

1.3 Objectives of the Study

1.3.1Overall objective

To assess temporal characteristics of surface air temperature over Kenya.

1.3.2 Specific Objectives

i. Examine temporal trends in the maximum, and minimum temperatures over Kenya in order to determine any surface warming / cooling.
ii. Examine the temperature range trends over Kenya.

CHAPTER TWO

2.0 Literature Review

This chapter involves locating and evaluating reports of pasts studies, observations and ideas interrelated to my planned research work.

2.1 Introduction

The global mean climate of the earth is determined by incoming radiation from the sun and by the properties of the earth and its atmosphere, which include reflection absorption and emission of energy within the atmosphere and the surface. Changes have taken place in several aspects of the atmosphere and surface altering the global energy of the earth and therefore resulting to climate change. Increasing greenhouse gases primarily leads to increasing atmospheric absorption of outgoing radiation due to high heat absorption

Coefficients, and increase in aerosols acting in to reflection and absorbtion of incoming solar radiation and changing cloud radioactive properties (IPCC, 2007). Such changes lead to radioactive forcing of the climate system. Positive and negative radioactive forcing contributes to increasing and decreasing, global averages temperature respectively. In 1961 Calendar using data from 400 global meteorological stations found a rising trend in temperature from the Arctic to 45^{o}S. The trend was however quit small in most regions equator-ward of 35^{o}N, and not quite apparent in some.

Three different studies (Jones 1986, Hansen and Lebedeff, 1987, 1988, Vinnikov *et al*, 1987, 1990) have shown globally averaged land temperatures for the last decade to have been highest in the past 100-140 years. Inter-decadal and geographical variations are however common, with some showing cooling or no significant temperature change during some decades. Inter-hemispheric variations in the temperature have also been observed. Temperature changes in the northern hemisphere have for example been found to be abrupt and irregular over land. The early 1920’s are shown to have warmed by about 0.3^{o}C. Generally, however, the land surface temperatures are found to have oscillated about a stationary mean trend throughout most of the 19th and 20th centuries. A steady increase in temperature is seen to have occurred just before 1970.

Various studies have used climate models to examine the possibles impacts of any climate change on the physical environment. Climate models results have shown that the mean global temperatures are likely to rise by 1.5-4.5^{o}C by the year 2030, if man continues with business as usual in the degradation of environment. Around this time, the atmospheric concentrations of the greenhouse gases are expected to have an equal effect to that of the current carbon dioxide atmospheric levels (UNEP, 1987, IPCC, 1992). Some locations may even cool down or experience no change at all (IPCC, 1992).

Spatial coverage of polar ice and mountain glacier may be reduced through melting. IPCC (1990a,1990b, 1992a, 1992b) has observed that this melting coupled with thermal expansion of water in sea may lead to rise in sea-level of about 10-20cm by the year 2030.Changes in the traditional patterns of the natural climate variability could also accentuate those of large scale natural events lie droughts, floods, cyclones, and other weather related calamities. Semi-arid and arid regions and areas of high humidity where water demand and pollution have resulted to scarcity of will experience the greatest impacts on hydrological and water resources (IPCC,1990a, 1990b,1992a,1990b).

A study of the spatial and temporal characteristics of temperature and the zonal wind over the eastern have been the subject of various subject of various studies (Okoola, 1979; Kinuthia et al, 1991;Ogallo,1979; Kinuthia et al, 1991;Ogallo,1993a, 1993b). Okoola (1979) examined the temporal behavior of the Nairobi urban heat island using time series of extreme temperature data for the period 1969-1977. He found a strong seasonal component for both minimum and maximum temperature series and slight increasing in the city heat island. On the other hand, Kinuthia *et al*(1991) found that surface air temperature over Kenya to have increased by an average of 0.45^{o}C between 1965 and 1973 compared to a decrease of 0.35^{o}C between 1959 and 1964. No urbanization effects were removed from the records used in their study. Ogallo (1993a, 1993b) found that most of the extreme temperature anomalies over Eastern Africa can be explained in terms of ENSO and other climate system anomalies.

2.2 Description of the Area of Study.

Figure2. 1: Map of the study area by Nations online project

Kenya is enclosed by latitudes 0.5N –4.5S and longitudes 34E–42E

2.2.1 Factors affecting Kenya's Climate

Kenya is a country with different landscapes, extending from coastlines washed by the warm waters of the Indian Ocean to arid savannahs and snow-capped mountains. Every region has its own unique climate, making it difficult to generalize the weather of Kenya. On the coast, the climate is tropical, coupled by the warm temperatures and high humidity. In the lowlands, the dry and hot weather is more pronounced; while the highlands are temperate. Unlike the rest of the country, mountainous regions have four distinct seasons. In other locations, the weather is split into rainy and dry seasons instead of summer, fall, winter, and spring.

Although Kenya's climate is diversified, several rules can be applied universally. Monsoon winds dictates is Kenya's weather, by making the high temperatures of the coast more bearable. Rainy seasons are also affected by monsoon winds, the longest of which lasts from April to June while the second, shorter rainy season in November and December. The December to March period is the hottest; while the July to October period is the coolest. In general, rainstorms in Kenya are intense but short, with sunny weather between them. Since Kenya is a tropical zone, seasonal temperature changes are small due to insignificant seasonal changes in solar radiation. It is for this reason that tropical climatology is described in terms of seasonal rainfall variation than the temperature.

The climate of Kenya is controlled by various synoptic features which include the Inter-tropical Convergence Zone (ITCZ), monsoon winds and ocean currents, tele-connections, easterly waves ,jet streams, tropical cyclones, and the sub-tropical anticyclones

2.2.1.1 Inter-Tropical Convergence Zone (ITCZ)

It is a narrow band of low pressure in which air masses move equator-wards from the southern and northern hemispheres converging. This zone is characterized by high humidity, heavy precipitation, deep cloudiness, slow winds, and low pressure. The ITCZ over Kenya is complex, as it comprises of both zonal and meridional arms. The converging westerly and easterly winds from the Indian Ocean and the Atlantic Ocean respectively form the meridional arm. The zonal (East-West) arm of the ITCZ moves North-South and brings rainfall in the areas it passes.

The general passage of the ITCZ over Kenya has been known as the main factor causing rains during the MAM and OND seasons (especially in western Kenya and the Rift valley). A north-south pattern of rainfall is experienced due to the movement of the ITCZ, with most rainfall occurring during the MAM season (Nicholson, 1996). ITCZ is, therefore, the main synoptic system known to control the East African seasonal rainfall (Asnani and Kinuthia, 1979; Asnani, 2005).

In general, the zonal arm fluctuates north and south with the over-head sun. The seasonal fluctuations generally delineate the regional seasonal characteristics. Near the equator, the ITCZ passes twice each year, we have a bi-modal rainfall distribution accompanied by two rainfall peaks associated with seasonal passage of ITCZ over the location. Further away from the equator, we have only one rainfall season, i.e uni-modal distribution, with peak during the hemispheric summer seasonal when the ITCZ is located over the respective hemisphere.

2.2.1.2 Monsoon Winds and Ocean Currents

Monsoon winds and ocean currents provide the mode of moisture transfer. The speed of the monsoon winds determines how far they will penetrate the land, whilst their direction determines whether they will be moisture laden or dry. The north easterly monsoon current attains maximum intensity in January. Over northern Kenya, the current breaks into two, one branch flowing west-wards into the interior of Africa, and the other flowing south-wards parallel to the coast line (Anyamba,1983). These current are often hot and dry (Findlater, 1968).

Monsoons are low-latitude winds, which seasonally change direction. Depending on where the monsoon flows from (land (winter), water (summer), they cause drastic changes in temperature and precipitation patterns on the area they affect. Monsoons are mainly caused by differential heating causing land-ocean pressure differences. Due to high temperature difference between land and water in the tropical region, monsoon winds are majorly confined to this region. Kenya experiences two monsoonal circulations; the Southeast (SE) and Northeast (NE) monsoons. Okoola (1999) found out that these monsoons are experienced when the ITCZ is away from Kenya hence bringing little rainfall. The NE monsoon occurs during the DJF season originating from Arabian Peninsula and curves south of Equator to become a north westerly wind.

During this season, this monsoon drives dry continental air to Kenya hence; it is associated with little or no rainfall. The SE monsoon on the other hand occurs during the JJA season and emanates from the south Indian Ocean with cool and moist properties due to the Mascarene highs. Reaching the north of equator, this monsoon re-curves to become south westerly flow. These two monsoons flow parallel to the coast and are diffluent in the low levels

The major regional ocean currents include the Mozambique, Benguela, Somali, and Canary. The Mozambique current is warm, and flows from NE and SW, with maximum strength during the southern hemispheric summer season, due to the influence .of the North-easterly monsoon winds. This current helps reduce the diurnal and annual temperature ranges around the eastern coast of southern Africa and keeps the diurnal temperature maxima high (Griffiths, 1972) .

The Benguela cold current flows from the Antlantic ocean along the western coast of South Africa. Its effect and that of the Mozambique current are thought to be the cause of very high surface temperature anomalies (+8^{o}C) over broad areas of the southern Africa interior (Griffins, 1972). The Canary cold current blows along the western coast of North Africa. It is believed to be cause of decreased summer temperature over some north Africa countries and increased cloud cover over some parts f the Sudan in January (Griffins, 1972)

The Somali current flows over the Eastern coast of East Africa and the Horn of Africa during the southern winter season. The East African Low Level Jet, EALLJ is also peak during this time (Bunker, 1965; Findlater, 1969; Krishnamurti et al, 1976; Ngara, 1997).

2.2.1.3 Jet Streams

T The African Easterly Jet (AEJ), the Tropical Easterly Jet (TEJ), The sub-tropical Jet streams (STJ's), and the East African Low Level Jet (EALLJ) are the major jet streams over tropical Africa. There are also other small scale jets due to mountain channeling, like the Marsabit/Turkana (Kinuthia, 1991)s.During August and September a small number of meso-scale storm systems embedded in these waves develop into tropical cyclones after they move from west Africa into the tropical Atlantic. Tropical cyclone formation is suppressed when the jet is south of normal during the peak months of the Atlantic hurricane season.

The Tropical EasterlyJet over Africa is an extension of the Indian TEJ during the southern winter season.With maximum intensity being attained in July and August, and the jet core being found between 100mb and 200mb levels. Maximum intensities are sandwitched between 9-15N, and the jet core is found to be very steady in its direction, which is purely easterly (Ogallo, 1983).

The EALLJ is embedded in the SE/SW monsoon currents, with the jet being found around 1.5km above mean sea level. Core speeds of 13m/s in July and August are common (Ngara, 1977).The EALLJ is found to be steady in direction, maintaining a SE/SW flow south and north of equator respectively. It is found to be most intense at night and early morning, getting rather diluted in the afternoon due to the action of thermal eddies redistributing energy within the jet. The highlands of Eastern Africa and Malagasy are crucial in the evolution of the jet, confining it to a narrow zone. This jet is unique as it is known cross-equatorial jet. All others are zonal and confined to one hemisphere. It therefore its role is very crucial in transfer of mass and momentum from southern to northern hemisphere. It is found to transport almost half of the total mass transported across the equator from the southern to the northern hemisphere (Cadet and Reverdin, 1981).

The Turkana jet in the Turkana channel of Kenya is formed due to the channeling of winds between the highlandsof Ethiopia and mountains of East Africa.

2.2.1.4 Easterly Waves

Easterly waves are not well documented over the Indian ocean and eastern Africa , mainly due to their feeble nature. This makes them not easily discernible on synoptic charts, a problem also aggravated by scarcity of data over the region. Zangvil (1975) found westward moving waves over the Indian ocean between latitudes 5-15^{o}C both north and south of equator. These had a period of 5 days.

These easterly waves are westward propagating perturbations moving within an easterly current. They are related to the formation of tropical cyclones and display different characteristics depending on the stage of development 22 (formation, enhancement or decay). Passage of an easterly wave over an area is recognized by the change in the weather condition and surface pressure. Another study by Kabanda (1999) showed that convection is increased when upper level westerlies within the equatorial band increase. This impact is felt in Uganda and western Kenya during July and August.

Cadet and Olory-Togbe (1997) observed weak Easterly disturbances south of the equator and westerly equator ward northerly and over the Indian ocean. Other reports of westward propagating waves over the eastern Africa region include Thomson (1970), Gichuiya (1970), Fremmings (1970) , and Njau (1982). Njau (1992) presented evidence that Easterly waves penetrateas far inland as Nairobi and Entebbe.

2.2.1.5 Tropical Storms and Tropical Cyclones

A tropical cyclone is an intensified low pressure zone with minimum wind speed of 119 km/h while tropical storm is an area of low pressure with maximum wind speed of 117 km/h. A tropical cyclone is identified by a anti-clockwise rotation in the Northern Hemisphere (NH) and a clockwise rotation in the Southern Hemisphere (SH). Its formation is favored by sea surface temperatures of at least 26.5° C. A fully developed cyclone shows a centre characterized by sinking winds, which forms an ‘eye’. This centre has calm weather free of clouds. Outside this eye is the ‘eyewall’, which has the highest wind speeds, rising air, cloudiness, and heavy precipitation (Zehnder, 2013).

Cyclones' season over South West Indian Ocean (SWIO) spans from October to May with peaks in January and February. A cyclone would in most cases decay when it strikes land due to lack of moisture that is a source of latent heat of condensation providing the energy for its propagation. Tropical cyclones and storms have both male and female names; the naming is done by regional bodies in charge of the respective basins. A number of names to be used for six years are proposed by the different countries' members of the body in charge of the cyclone basin, and must meet specific criteria such as being short, easily understood when broadcast, culturally sensitive, and should not pass across unintended meaning (Landsea and Dorst, 2010). The name of a very destructive cyclone is retired once used.

\The cyclones and storms forming over the South West 13 Indian Ocean has greater influence on the rainfall over countries in the East Africa region compared to those over the East Indian Ocean (Elsberry, 2006). Tropical cyclones may cause rainfall during a dry season and suppresses during a rainfall season (Omondi, 2010).

2.2.1.6 The Sub-Tropical Anticyclones

The anticyclones that affect weather over Kenya are the Azores to the north-west of Africa, the Arabian over the Arabian subcontinent, the St. Hellena over the southern Atlantic, and the Mascarene over the southern Indian ocean. Depending on the relative locations, strength and spatial orientation, anticyclones will either pumping moist air or dry air, or even cause mass influence if they are directly over a region.

The Azores anticyclone is more prominent during northern hemispheric winter and is the cause of subsidence and heated desiccated air over the sahara and neighboring regions. Prominent during the same season is the Arabian anticyclone which leads to dry continental north-easterly flow in most of Eastern Africa (Griffiths, 1972). The Macarena anticyclone generally influences the characteristics of the humid south-easterly monsoon flow over the Indian ocean which influences rainfall over most of the East Africa. The relative strength and position of all these anticyclones will further determine the position and the intensity of the ITCZ and the associated weather systems.

2.2.1.7 Global Tele-connections

Tele-connections are the climate variability links between non-contiguous geographic regions. Kenya weather characteristics are tele-connected with many anomalies in the general circulation outside the region. The large-scale system are the El-nino/Southern Oscillation (ENSO), the

Quasi-Biennial Oscillation (QBO) and intra-seasonal waves, and many others. In tele-connection research, effects of SSTs on changing air temperatures and air pressures over the Pacific (responsible for its cyclonic activities) are as a result of the ENSO (El Niño-Southern Oscillation), an example of a single large-scale coupled ocean-atmosphere phenomenon. The Southern Oscillation (SO) is measured as an index known as Southern Oscillation Index (SOI). The differences or fluctuations in air pressure between Darwin (northern Australia) and Tahiti (central Pacific) is measured.

During negative SOI (called low phase) air pressure is high over Darwin and low over Tahiti and East Pacific, bringing about a westerly flow (west to east), which is, a reversal of the easterlies. The resulting accumulation of warmer SSTs in Central and East Pacific results to El Niño. During positive SOI (high phase) air pressure is high over the Central Pacific (Tahiti) and low over Darwin, leading to strengthening of the easterlies, promoting La Niña.

Another system often associated with many climate anomalies is the Quasi-Biennial Oscillation (QBO). It has an average period of 23-33 months (Landsberg, 1963). He discovered a downward progression of warming with time which he attributed to small-scale eddy fluxes in the tropical latitudes. Evidence of the presence of the QBO in the variability climate over Eastern Africa has been realised by Ogallo(1992) Ogallo et al (1994), Nyenzi (1992), and Tyson (1984, 1993), amongst many others.

Intra-seasonal waves (30-60 days wave) are also very significant in climate system of Kenya. They are strong over eastern and southern Africa but non-existent over central Africa (Anyamba, 1990). Yasunari (1980) and other authors have reported an observed meridional propagation of the wave. This shows marked spatial and temporal variability in its period, with two distinct peaks centred around 20 to30 days and 40 to50 days respectively.It was observed by Anyamba (1992) that there appears to be some amplification of both peaks during ENSO events when the behavior of the two peaks is similar. Cadet and Daniel (1988) amongst others have attempted to use the intra-seasonal {40-50 day) wave in long range forecasting in those areas where it has regular and significant influence.

Other systems that have been associated with Tropical weather include unique regional systems associated with topography, large water bodies, and other thermally induced systems. More also Congo air mass, and the dry Sahelian Hammattans affect tropical weather.

CHAPTER THREE

3.0 Data and Methodology

This chapter will discuss the data and the methodology used in the research.

3.1 Data

The data that were used in this study were the daily maximum and minimum temperature records which were obtained from Kenya Meteorological Department (KMD). Monthly time series was derived for trend using the daily minimum and maximum temperature records These record were used to study space-time characteristics of extreme temperatures over study region. The data was quality controlled before being subjected to analysis to ensure homogeneity in the temperature records.

3.2 Data Control

Quality control is essential in order to detect any discontinuities in the data that may have occurred from non-natural factors like changes in observational schedules and methods, instrumental changes, shifting of station sites, urbanization, and other human processes (WMO, 1966, Basalirwa, 1979). Heterogeneity makes records not purely comparable over long periods and between different stations. Therefore homogeneity test was conducted for maximum and minimum temperature data before it was used for the study. The following methods can be used for data quality control;

(i) Correlation and Regression Methods
(ii) Wald-Walfowitz one sample runs test
(iii)Mass curves (Relative homogeneity test and Absolute homogeneity test) and
(iv) Maronna and Yohai Method.

In this research mass curves will be were for homogeneity test.

Mass Curves

In this method cumulative records or deviations from the mean will be plotted against time for mass curves and residential mass curves respectively. A strictly homogeneous record would be indicated by a straight line whilst heterogeneity would be shown by significant deviations of some of the plotted from the straight line.

Two approaches have been recommended by the WMO (1966), specifically for temperature record. These methods and others based on the concept of mass and residual mass curves are briefly discussed below.

Relative Homogeneity Test

Temporal "differences between the series being tested for homogeneity and time series which are known to be homogeneous, are first computed". The resulting temporal differences series are then plotted together on linear graph paper. If any time series contains "sizeable" errors, they are revealed as "spikes" on the same dates at least for most of the time series. This method is used to determine inter-compatibility in different time series.

Alternatively, the actual temperature series for each station are plotted together after smoothing using five term, or any other appropriate successive (or moving) averages. This method is not clear as the difference method.

Absolute Homogeneity Test

This involves comparing the difference between the series under test with only other homogeneous series. The latter series will be suitably derived average of the series for the individual surrounding stations. This way, evidence of relative heterogeneity be translated directly into definitive information about the heterogeneity in the test series.

To be able to derive the average series, different factors must be considered Mitchell 1961) namely, the density of reporting stations; the length of the record being investigated; the relative incidence of stations relocations; the climate uniformity over the area; etc (WMO, 1986)

Use of double mass curve is an example of absolute homogeneity test. In this method several stations situated within the same climatic zone and whose record is known to be homogeneous, are chosen. A plot of corresponding cumulative data of the station whose homogeneity is being tested and the homogeneous record is made. A straight line indicates homogeneity, otherwise the record is declared heterogeneous

Heterogeneous record may be adjusted using the slopes of the graphs of the curves, WMO (1966, 1986) and Ogallo (1981, 1987).

3.3 Estimation of Missing Data

Various methods have been recommended for estimation of missing records in meteorological time series by WMO (1986). They include the following methods; isopleth method, remote sensing technique and correlation method.

3.3.1 Arithmetic Mean Ratio Method

This is a simple method based on correlation. Under this method, the ratio of the long-term averages for two correlated locations is used to estimate the missing record using equations of the form

$X_t=X/Y*Y_t$ ……………………………………………eqn 1

Where X and Y are the long-term averages of X_t and Y_t respectively.
X_t is the series with missing data and Y_t a related series with no data gaps. The method assumes that due to high correlation between the pair of points (variables), the ratio of the long-term averages will be reflected at any time scale. This may however, not be true over locations with unique local/regional climate anomalies.

The advantage of this method is that the significance of the estimated records can be tested using standard statistical tests. A disadvantage of this method is that different locations may have unique characteristics that may not be easily accounted for by the simple mathematical functions derived. Another disadvantage is that the calibration of those models based on spatial correlation requires a good network, which is often lacking and each model may be applicable only for a particular time scales.
In this study arithmetic mean method will be used for estimation of minimum and maximum temperature records.

3.4 Data Analysis

The temporal characteristics of extreme temperatures that will be investigated include trend in maximum and minimum and, trend in temperature range.

3.4.1 Trend Analysis

Trend is the long run behavior of the time series. It shows whether the series is stationary or non-stationary. Eitherstatistical and graphical methods may be used to analyse trend in a time series as discussed in the following sections.

3.4.1.1 Graphical Methods

Graphical methods include the plotting of the time series on a linear graph paper. Several smoothing functions may be used to smooth the time series. In the smoothed time series the trend at any point is represented by a weighted average of the observed values near the point. Regression analysis is usually used to give the best mathematical equation or the observed trend. The most commonly used smoothing method has been the use of Binomial coefficient (WMO, 1966, Tyson, 1975, Rodhe and Virjir, 1976, Ogallo, 1977, 1977, 1980, and others).
The disadvantage of the graphical method for trend analysis is that they are highly subjective as they are dependent very much on individual visual judgments. Some data sets are also lost by

some smoothing techniques, and fluctuations that were not in the original series introduced by smoothing techniques (WMO, 1996; Kendall, 1961).

3.4.1.2 Statistical Methods for Trend Determination

Statistical methods include; the analysis of Variance (ANOVA), Mann-Kendall rank and Spearman rank statistic. A brief description of these methods is given in the following section.

3.4.1.2.1 Analysis of Variance Technique

One of the simplest ways of using ANOVA to look for climatic trends is for the period of the study to be divided into subgroups of at least 30 years record each and the averages of subgroups found. The sub-group means are then compared and contrasted using the students t-test or any other suitable test of significance, with respect to the frequency distribution of the time series (WMO, 1966,Parthasarathy and Dhar, 1973;Jones, 1975; Granger, 1976; Ogallo, 1980). The key disadvantage of this method is that it requires a very large data sample due to the normal period recommended by WMO (1967) is 30 years for each subgroup. Most climatic records are scarsely long.

3.4.1.2.2 Mann-Kendall Rank Statistics, τ

This is among the most popular methods for testing for trend against randomness. It uses the relative values of all terms in the X_i, under analysis. The series Xi is replaced by ki, in that every Xi is assigned a number ni, where, $1< n_i< N$ and n_i is the number of observations preceding X_i with magnitudes greater than that of X_i.

The statistic τ, can then be computed from the following formula:-

$$\tau = 4\left\{\frac{\sum_{t=1}^{N-1} ni}{N(N-1)}\right\} - 1$$

Where N is the total number of observations.

If the distribution is nearly Gaussian normal for all N greater than 10, and has an expected value of zero and variance approximately equal to (4N+10)/[9N(N-1), then τ can be used to assess the significance of trend by comparing with the statistics τ_g, where

$$T_g = t_g\sqrt{\frac{(4N-10)}{9N(N-1)}}$$

And t_g is the ordinate corresponding to the desired probality of the standard normal distribution for a two-tailed test. For routine application, the 95% probability point of tg (t_g=1.96) is recommended (WMO, 1966)

3.4.1.2.2 Spearman Rank Correlation Method

$$Y_s = 1 - 6\left\{\frac{\sum_{t=1}^{N} (di)^2}{N(N^2-1)}\right\}$$

$$T_g = Y_s\sqrt{\frac{N-2}{1 - Y_s^2}}$$

CHAPTER FOUR

This chapter is devoted to presenting the results and discussion.

4.0 Results and Discussion

The objectives of the study were to assess temporal characteristics of surface air temperature in Kenya, in order to identify any organized trends in the temperature records.

To achieve the objectives, various analyses were performed on the data including trend analysis on extreme temperatures and examining the trends of temperature range over Kenya.

4.1 Missing Data

The data that were missing were estimated using correlation methods as were described in 3.3.1. The estimated records were subjected to quality-control tests before they were used in any analysis. The quality-control of the estimated records will be presented in the next section. It should be however noted that only a maximum of 10%of the total data at any station was estimated.

4.2 Data Quality Control

Typical samples of the results obtained from the quality-control tests are shown in Figures below. The mass curves were almost linear, signifying that the temperature records were not heterogeneous. The minimum/maximum temperature records were hence declared of high quality, hence appropriate for climatologically analysis.

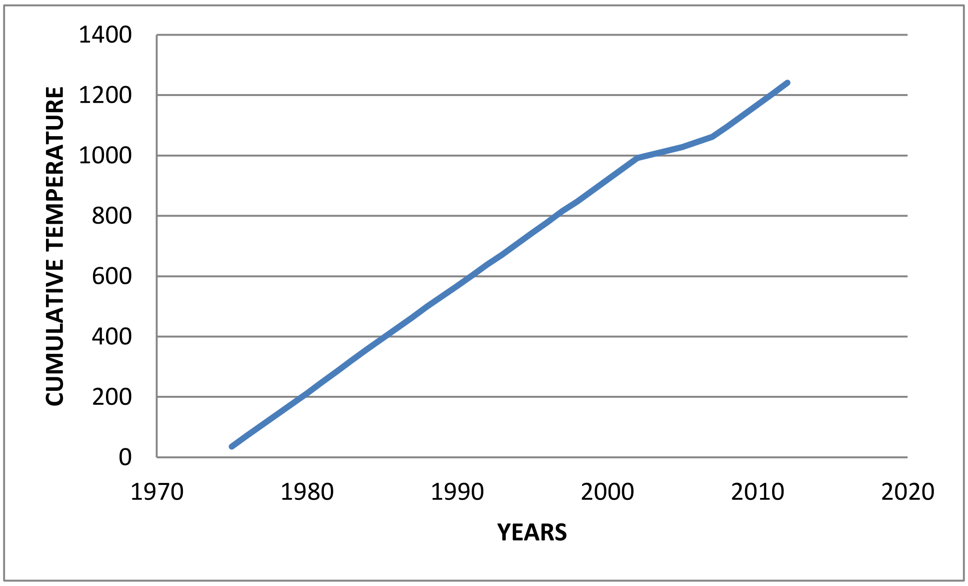

Figure4. 1: Mass Curve for Garissa in January

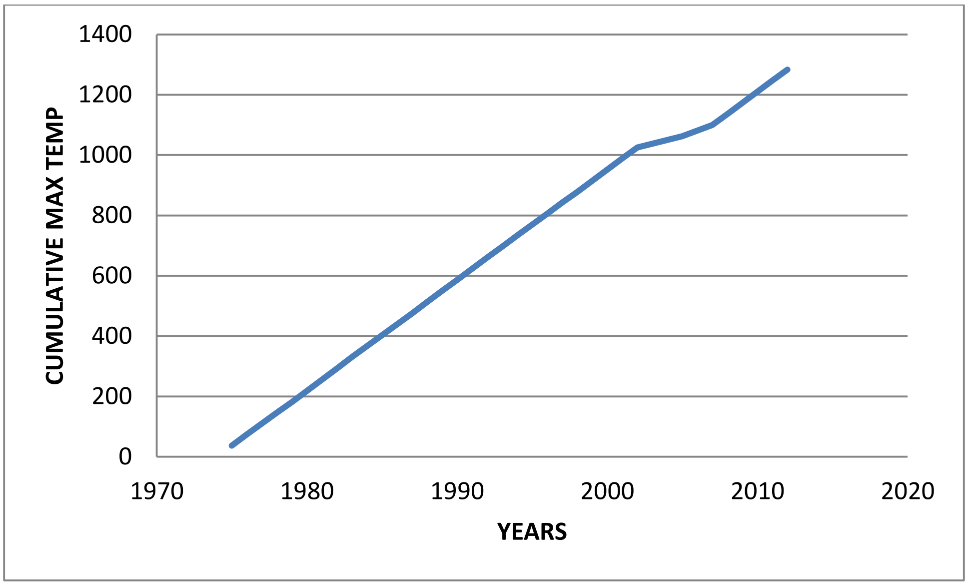

Figure 4.2: Mass Curve for Garissa

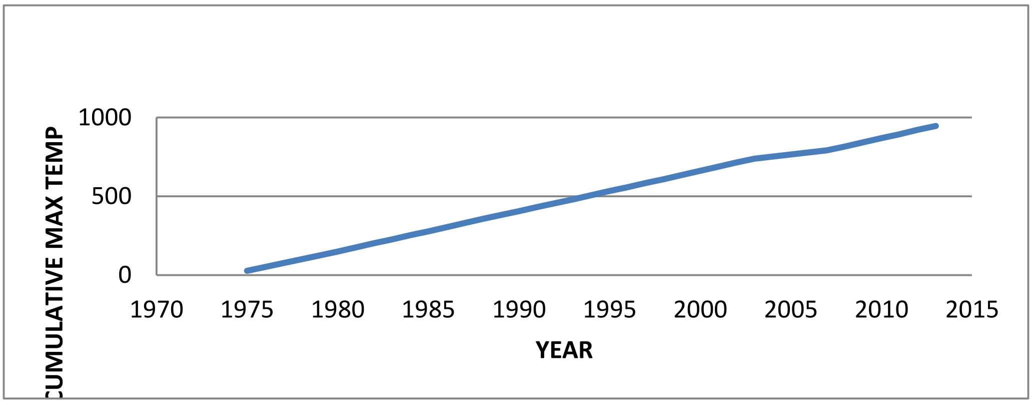

Figure 2.3: Nyeri January Mass Curve

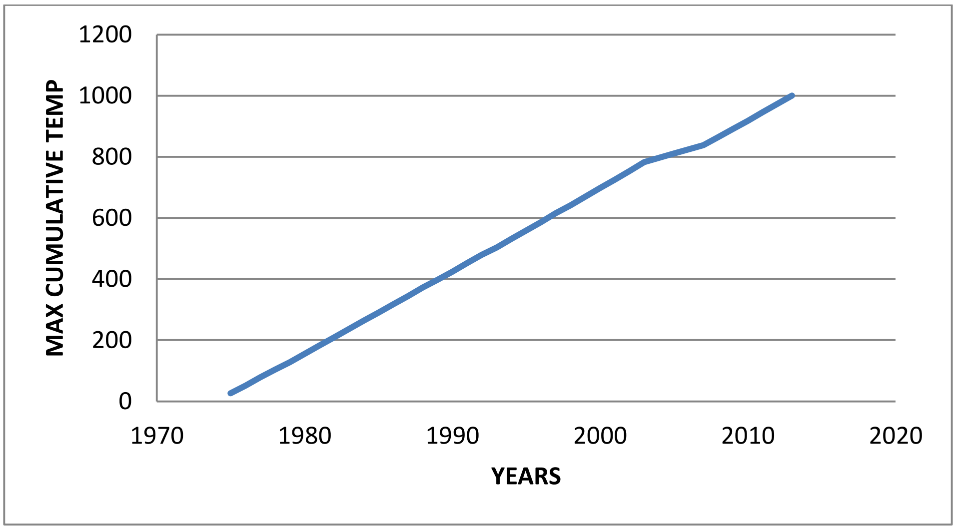

Figure 4.4: Nyeri Feb Mass Curve

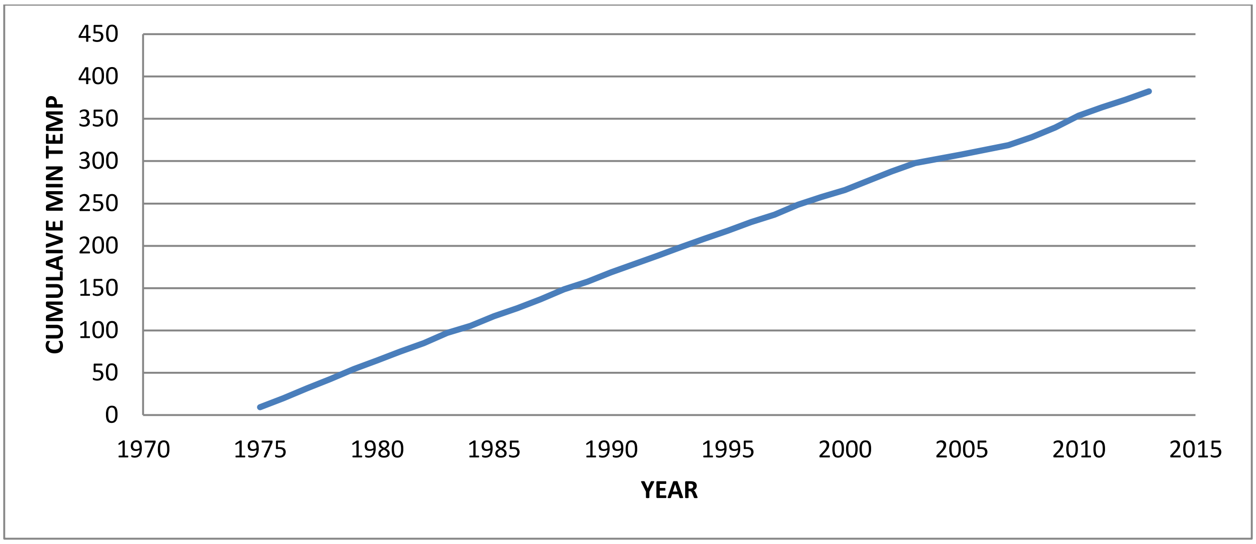

Figure 4.5: Nyeri February Mass Curves

4.3 Trend Analysis Results

Typical examples of the results of graphical analysis of trend are shown in figures below. These results show significant decadal variations in the patterns of the minimum and maximum with global scale warming signals of the 1980's clearly discernible at most locations. Significant geographical and seasonal differences were however observed in the minimum and maximum temperature trends. Most of these trends were positive for example, minimum and maximum temperature for Moi International airport,Dagoretti, Kakamega, Nyeri and Garissa.

Coastal and island locations, and some other locations have shown significant decreasing minimum temperature. The 1980's experienced the lowest minimum temperature value at these locations. Examples include

It is apparent from these time series therefore, that whilst some areas have experienced warming trends in recent years, cooling trends were also observed at some locations whilst at others no significant temperature changes could be delineated. Similar observations have been made by the IPCC (1990a, 1992,1992b). 1970,and 1980's decades were dominated by severe droughts (dry spells) over most parts of Kenya. One of the features of the observed minimum and maximum temperature patterns were however the recurrences of extremely low/high temperature values.

The diurnal temperature range Garissa and Dagoretti was negative (decreasing) . However the diurnal temperature range for Nyeri, MIA and Kakamega was positive.

The trend for diurnal temperature range is generally positive.

Mombasa and Kisumu have experienced temperature trends opposite temperature trends to those of the mainland. Such stations have local moisture source and are therefore not often affected by the many droughts that significantly affected the observed minimum and maximum temperature than the rest of the study region.

Urbanization has been cited as the main cause of warming at local scales, especially where the minimum temperatures are rising whilst those of minimum temperature values are constant or falling (Karl et al, 1991, and Kukla and Karl, 1992. Karl et el 1998) found that urbanization decreases the daily maximum seasons temperature. Apart from winter the temperature range decreases in all seasons.

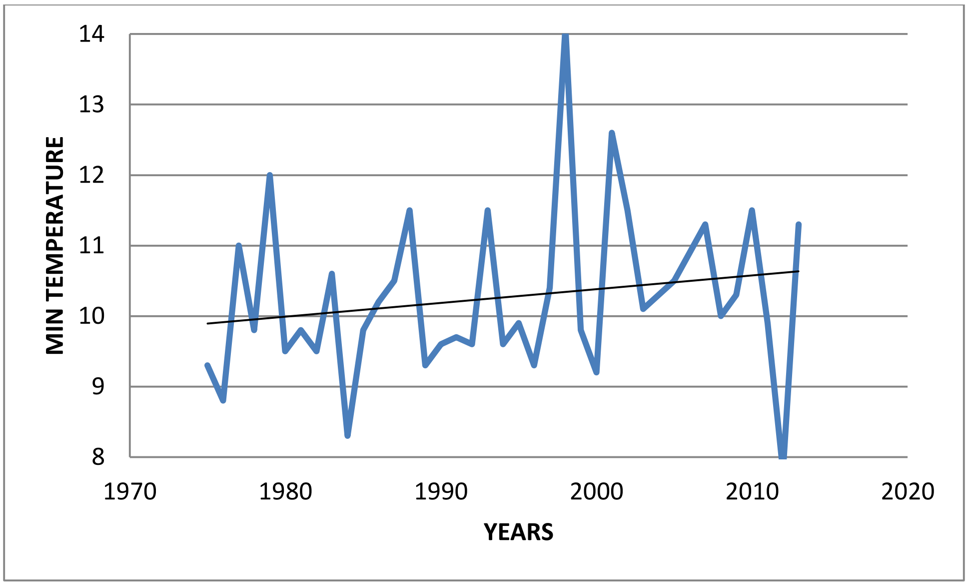

Figure 4.6: Trend Analysis for Nyeri in January

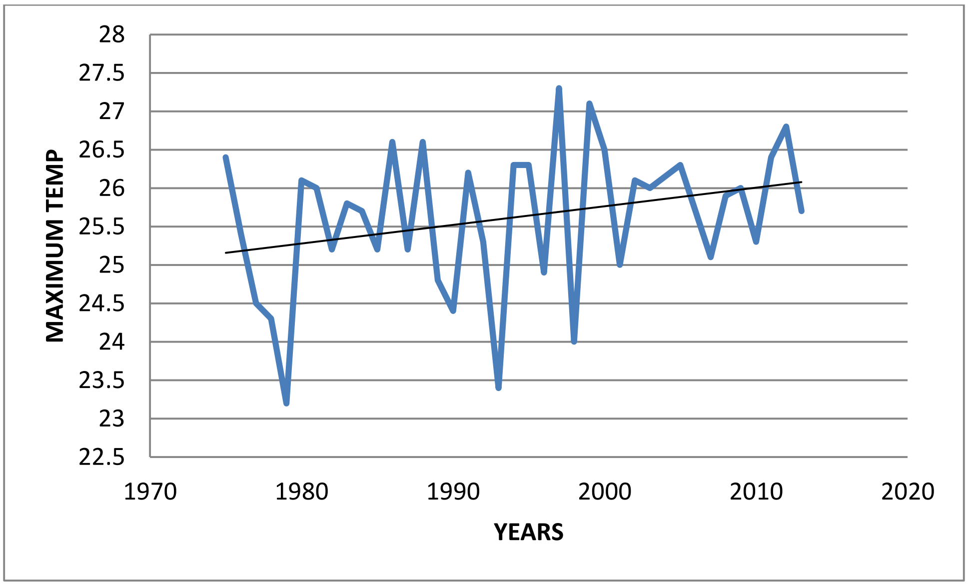

Figure 4.7: Trend Analysis for Nyeri in January

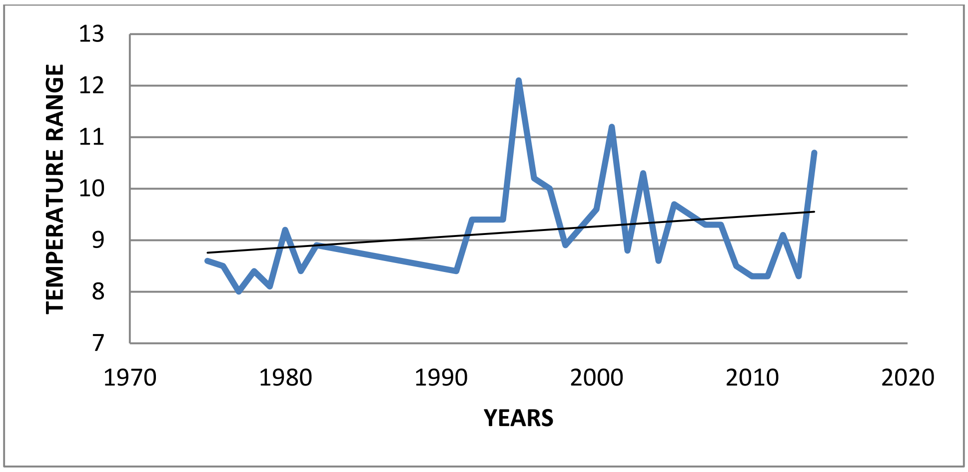

Figure4.8: MIA January Temperature Range Trend

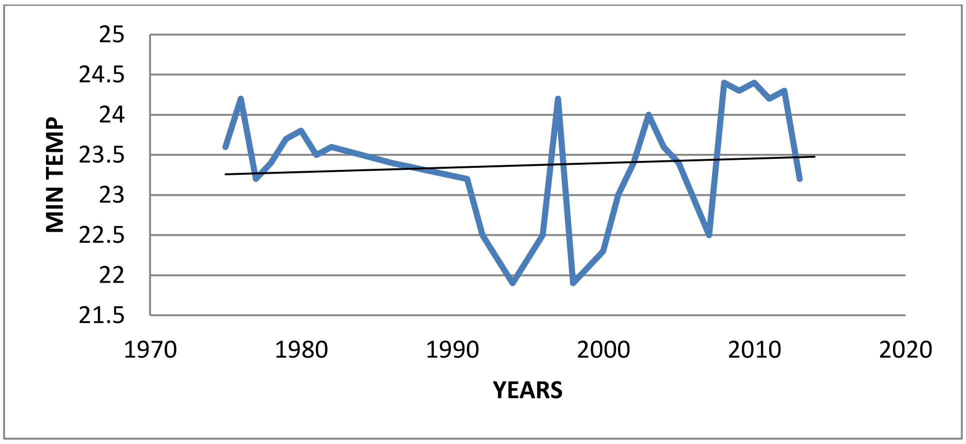

Figure 4.9:Trend Analysis for MIA in February

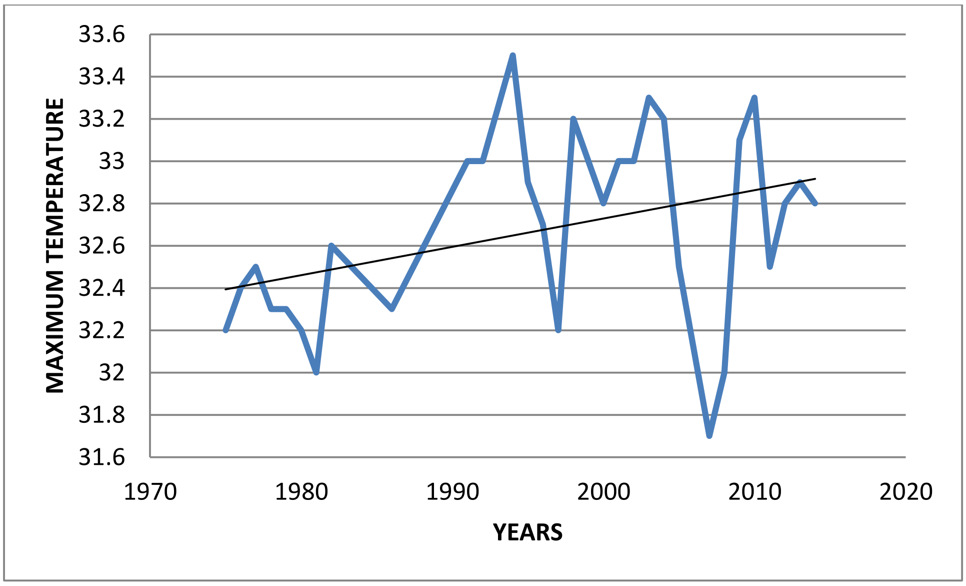

Figure 4.10: Trend Analysis for MIA in February

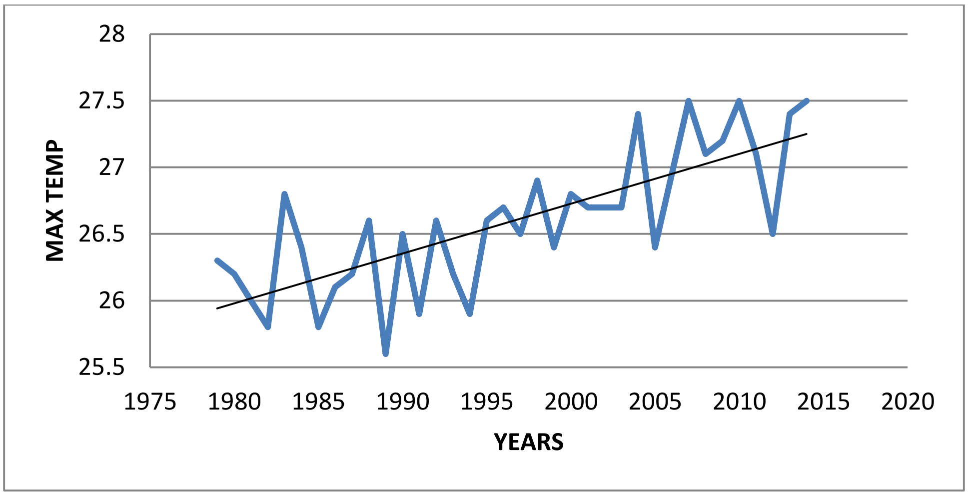

Figure 4.11: Trend Analysis for Kakamega in May

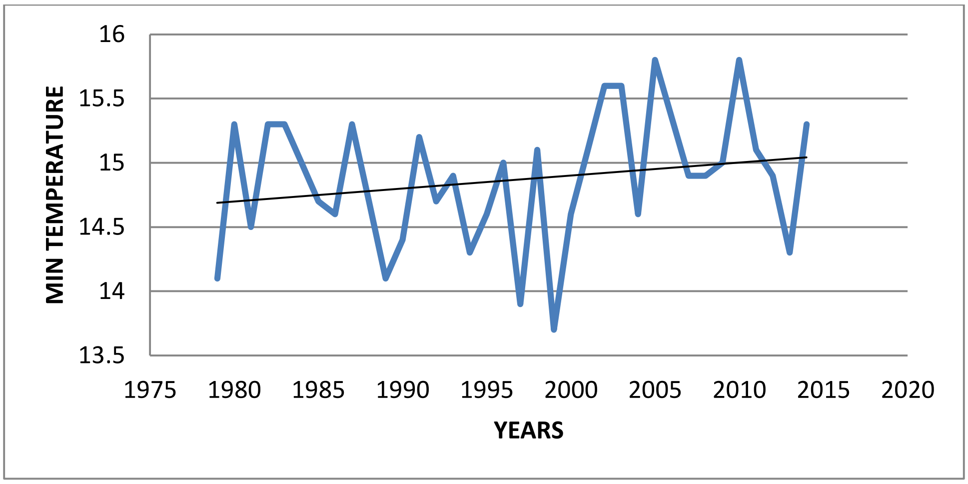

Figure 4.12: Kakamega May Minimum Temperature Trend

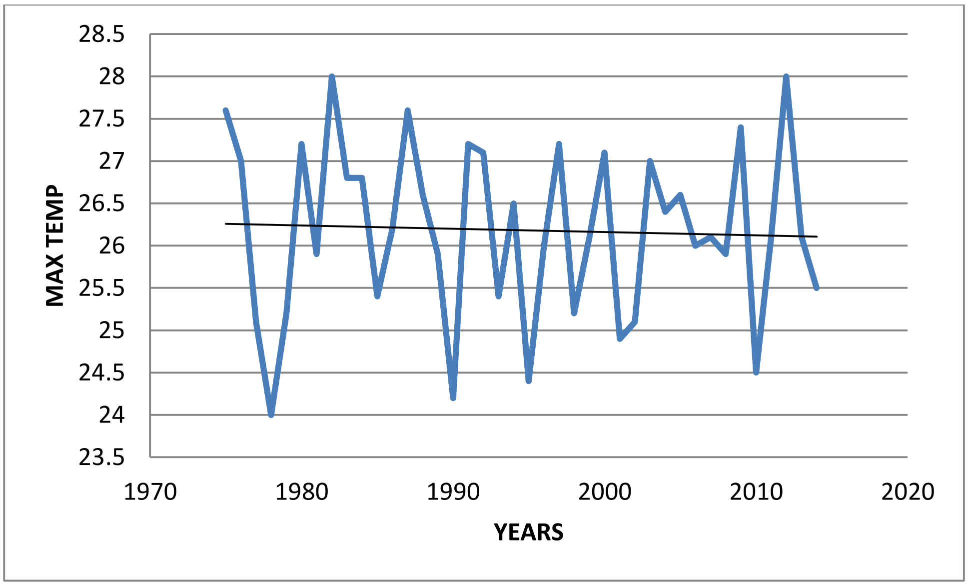

Figure 4.13: Dagoretti March Max Temp Trend

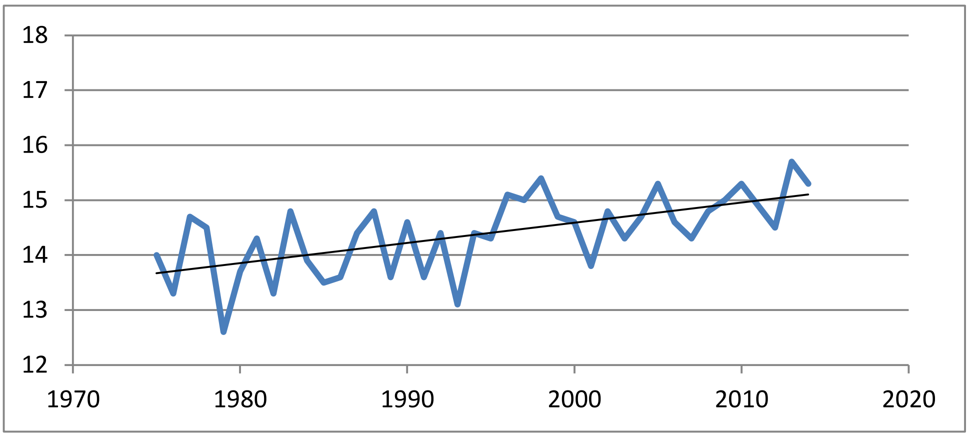

Figure 4.14: Dagoretti March Min Temp Trend

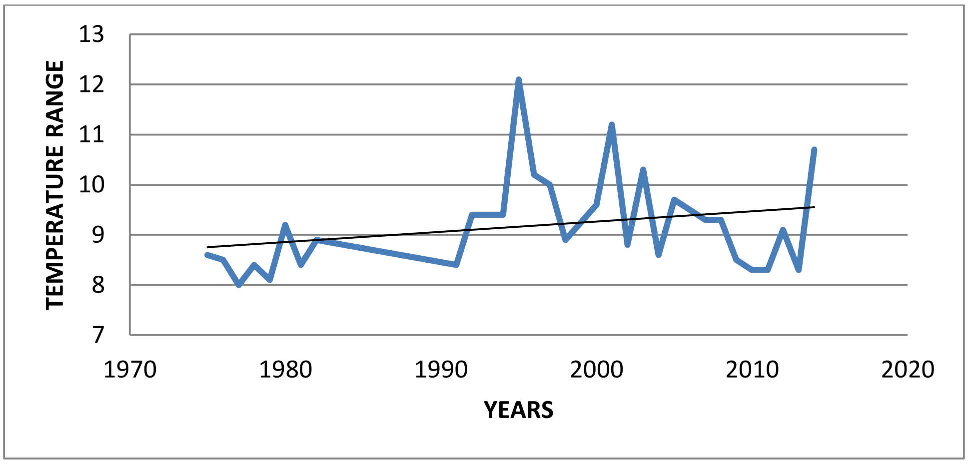

Figure 4.15: Dagoretti March Temp Range Trend

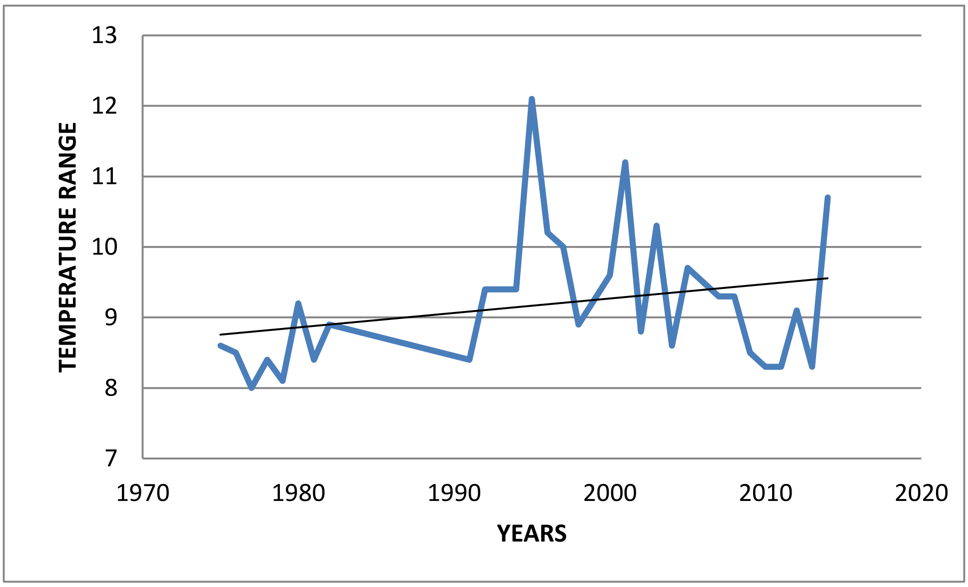

Figure 4.16: Dagoretti April Temp Range Trend

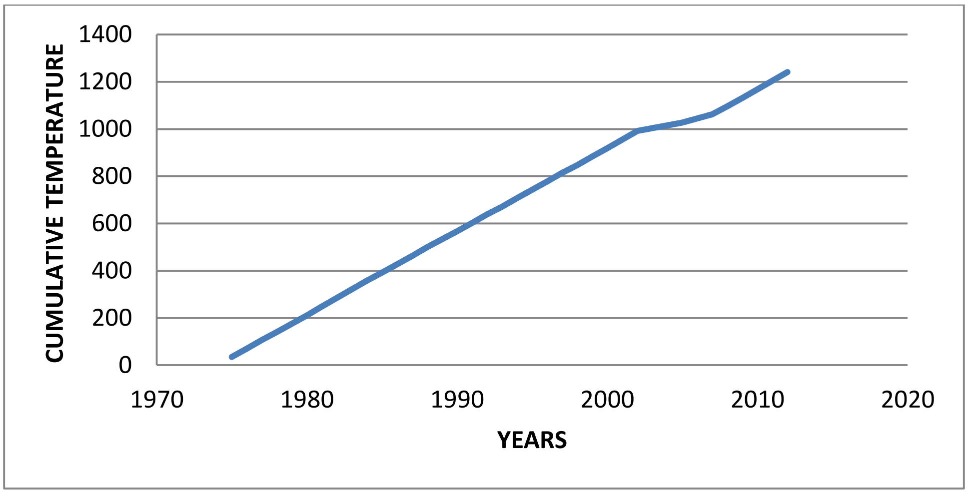

Figure 4.17: Kitale Jan Maximum Temp Mass Curve

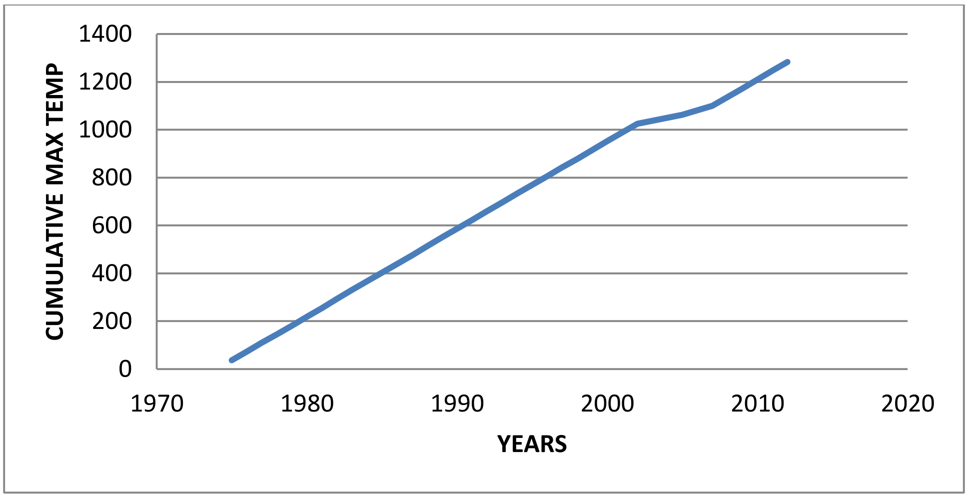

Figure 4.18: Kitale Jan Minimum Temp Mass Curve

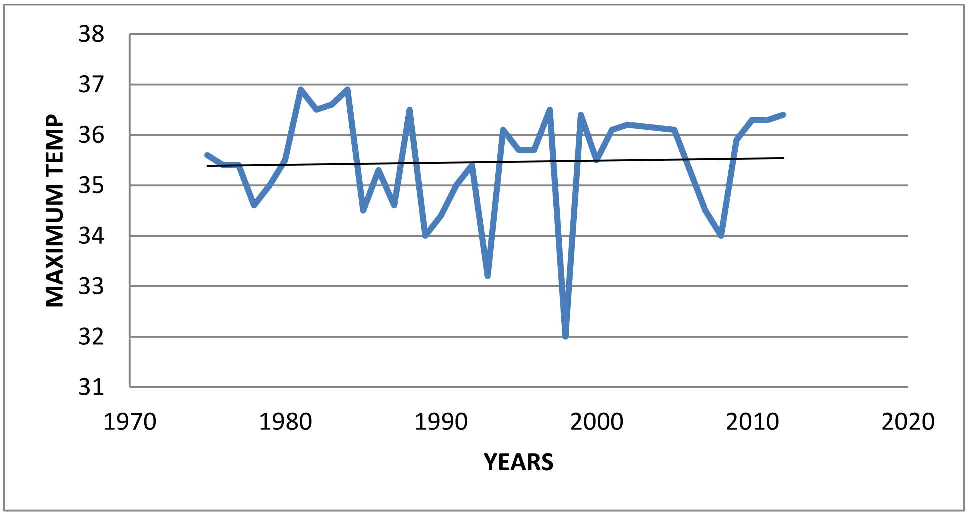

Figure 4.19: Garissa Jan Max Temp Trend

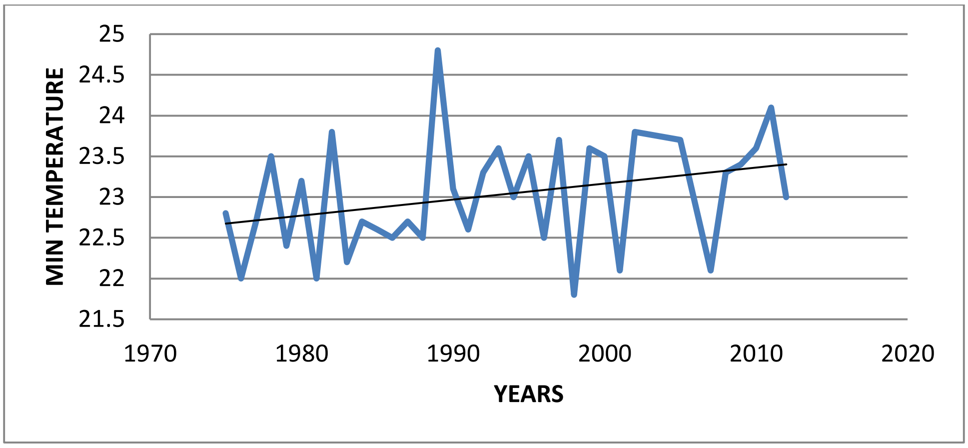

Figure 4.20: Garissa Jan Min Temp Trend

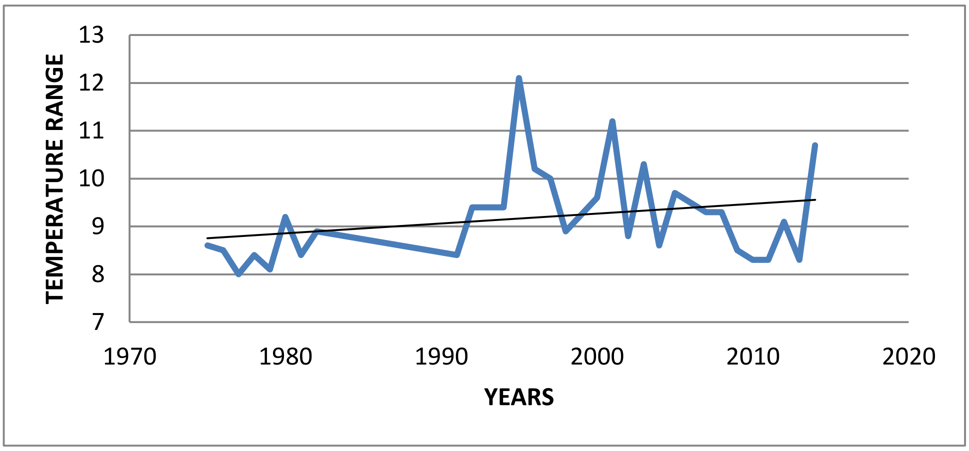

Figure 4.21 : Garissa Jan Min Temp Trend

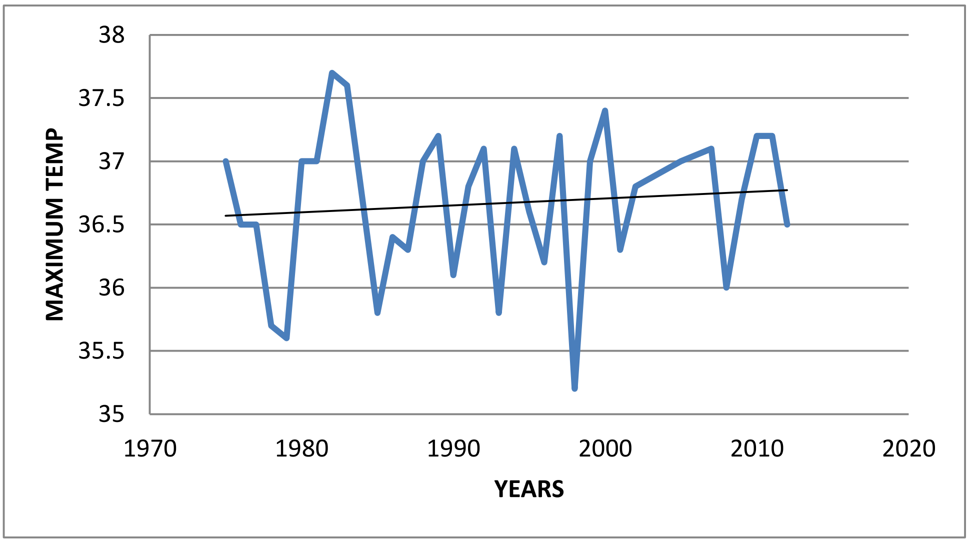

Figure4.22: Garissa Feb Max Temp Trend

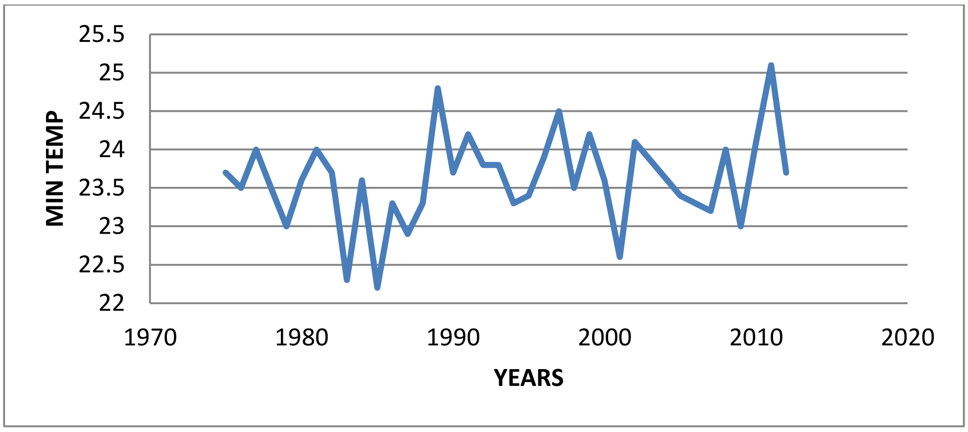

Figure 4.23: Garissa Feb Min Temp Trend

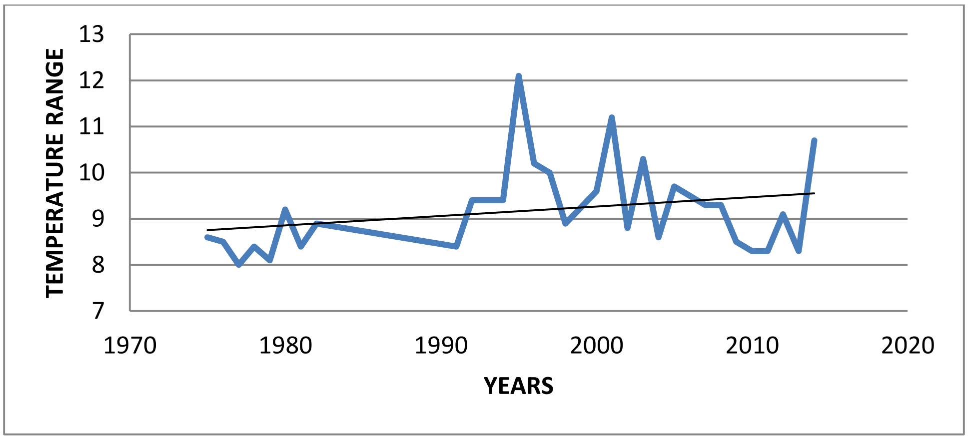

Figure 4.24: Garissa Feb Temperature range Trend

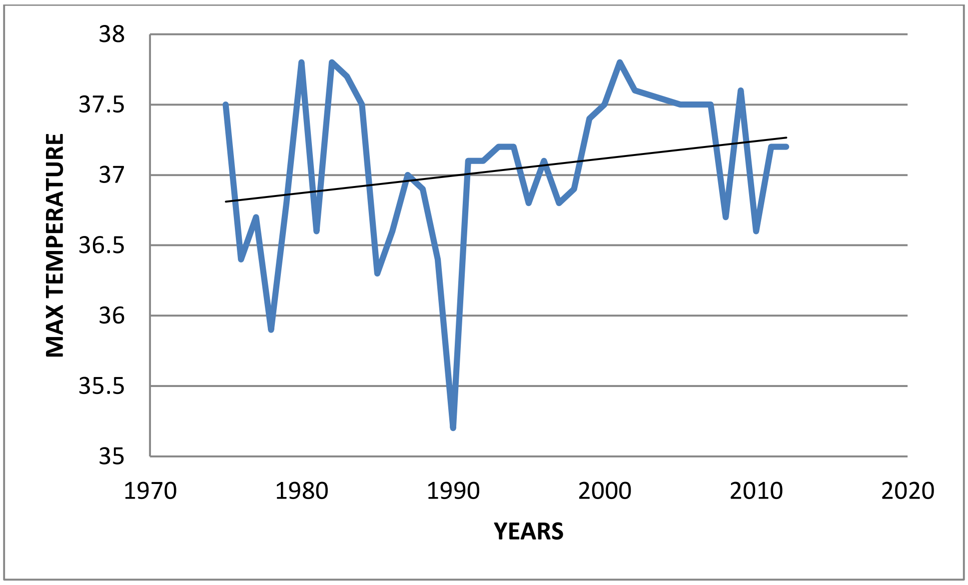

Figure 4.25: Garissa March Max Temp Trend

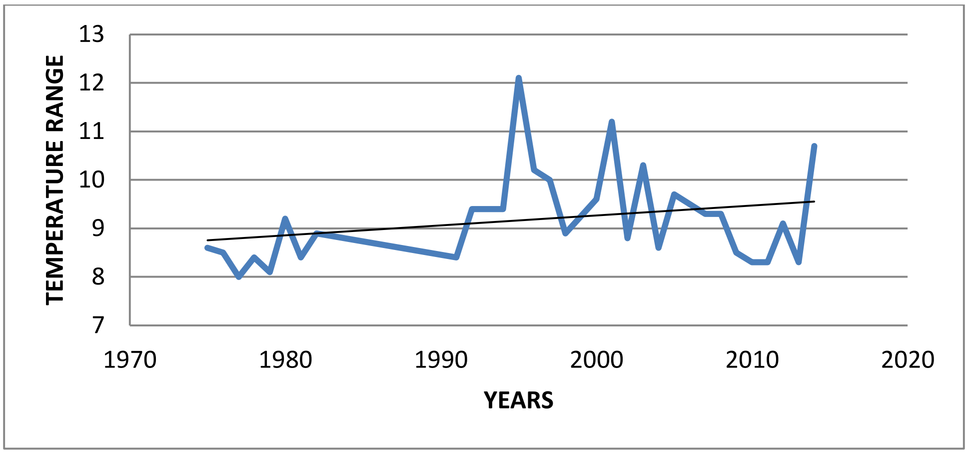

Figure 4.26: Garissa March Temperature range trend

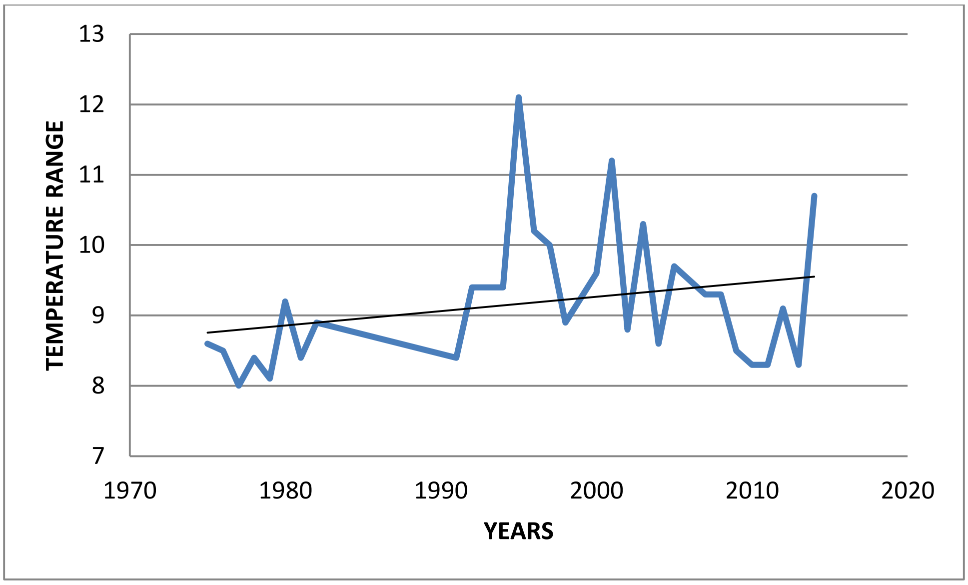

Figure 4.27: Garissa April Temperature range trend

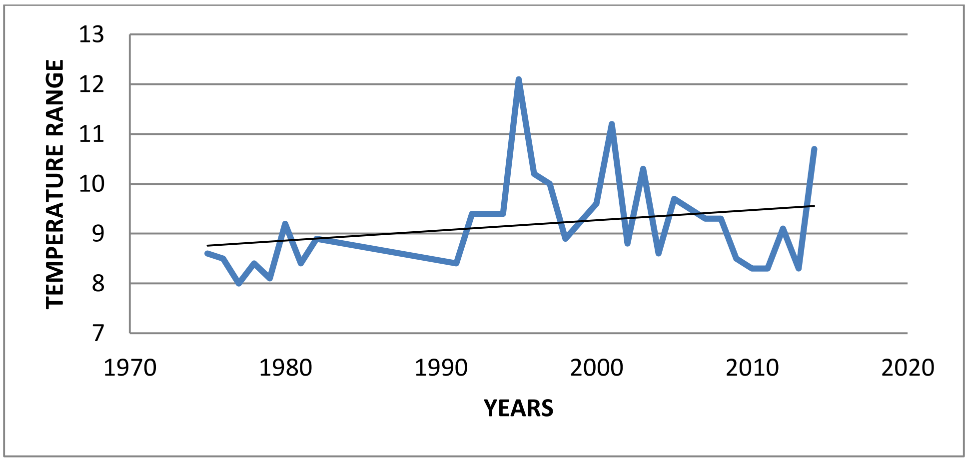

Figure 4.28: Garissa May Temperature range trend

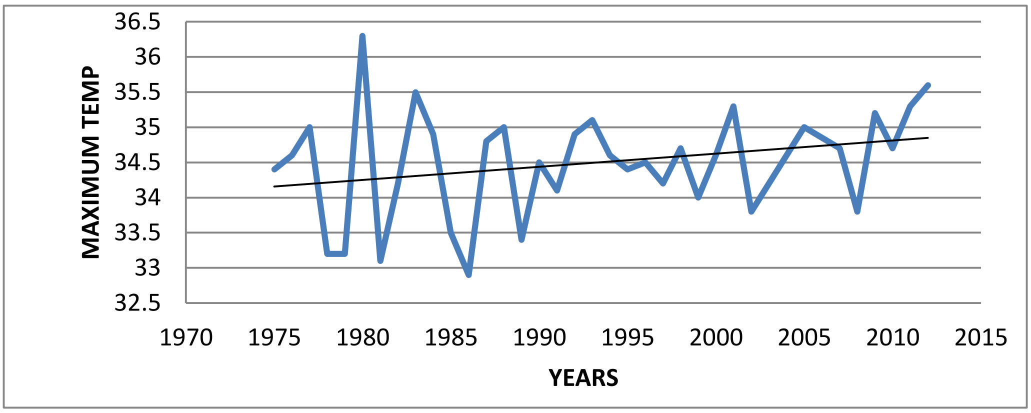

Figure4.29: Garissa May Max Temperature trend

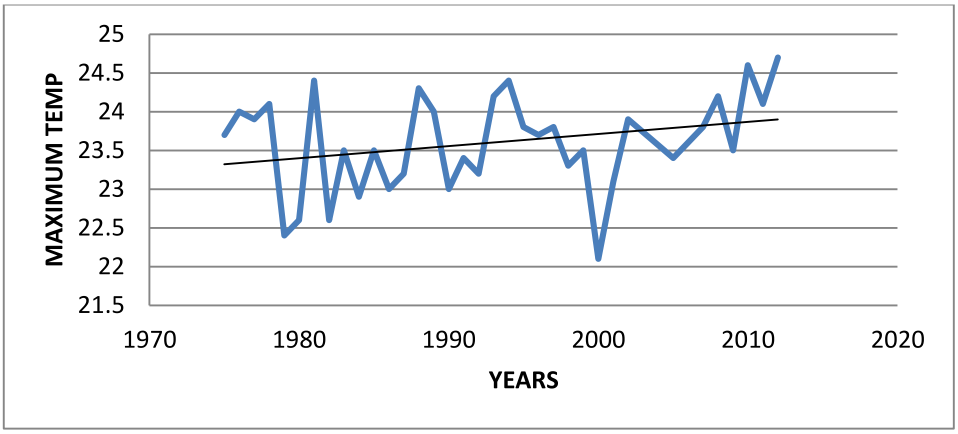

Figure 4.30: Garissa May Minimum Temp Trend

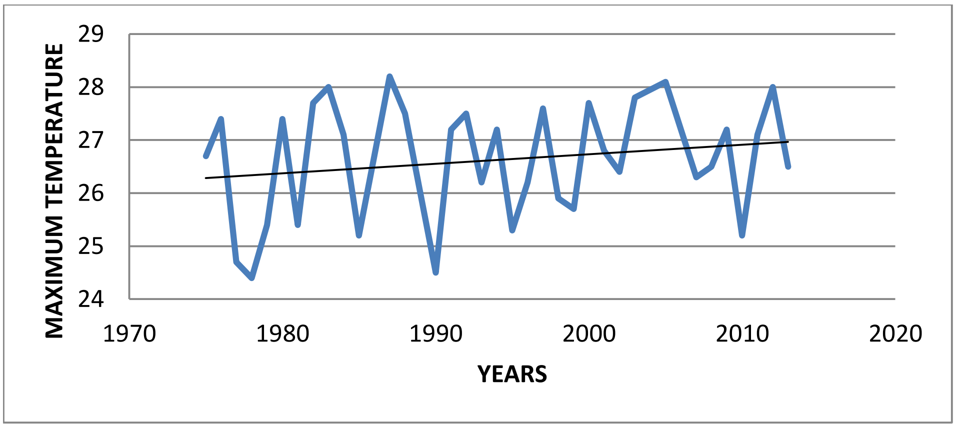

Figure 4.31: Nyeri March Max Temp Trend

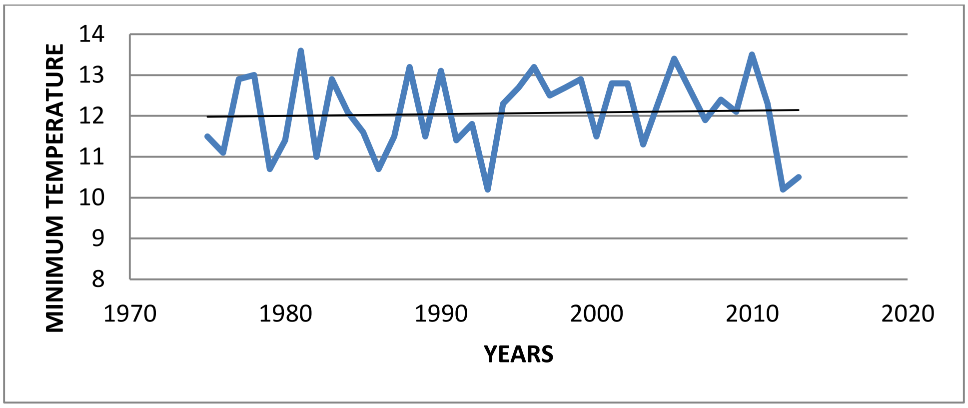

Figure 4.32: Nyeri March Min Temp Trend

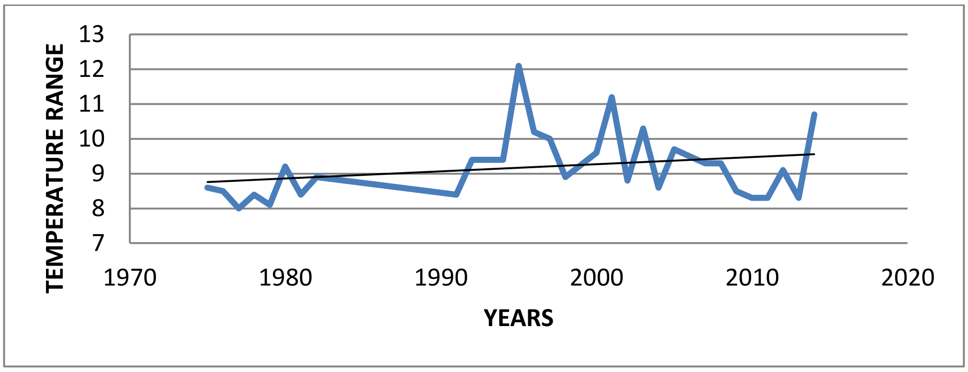

Figure 4.33: Nyeri March Temperature Range Trend

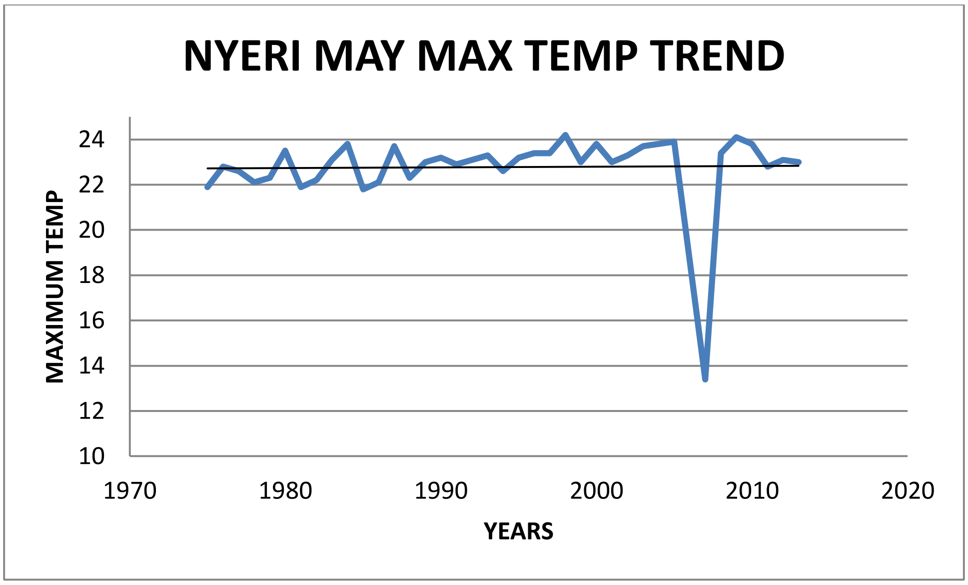

Figure 4.34: Nyeri May Max Temp Trend

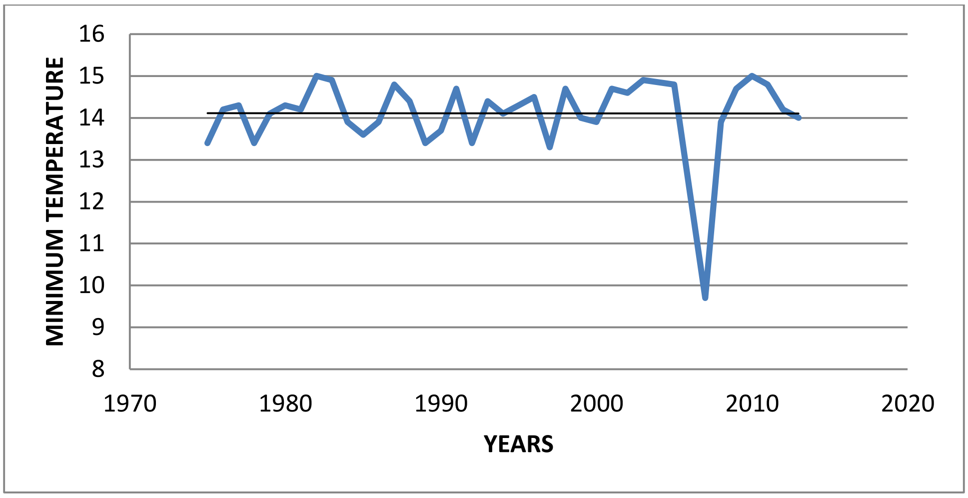

Figure 4.35: Nyeri May Min Temp Trend

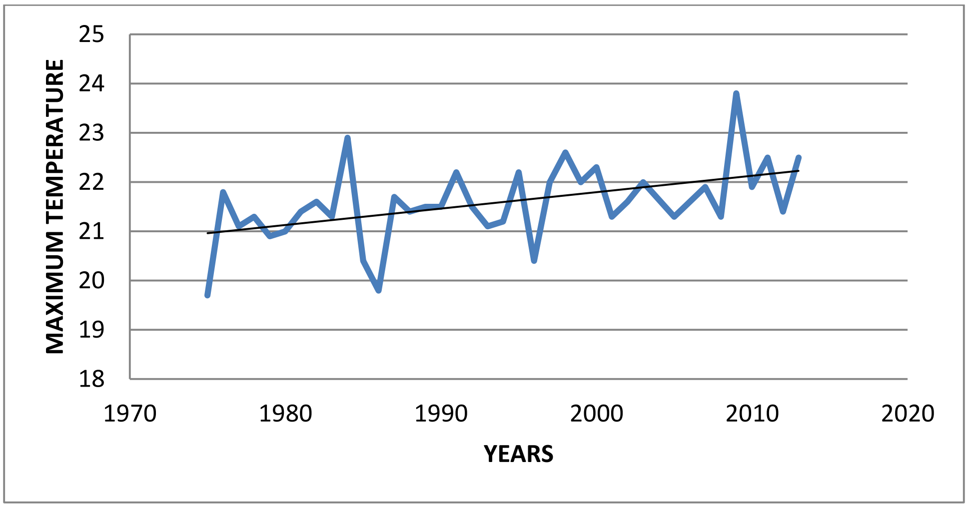

Figure 4.36: Nyeri June Max Temp Trend

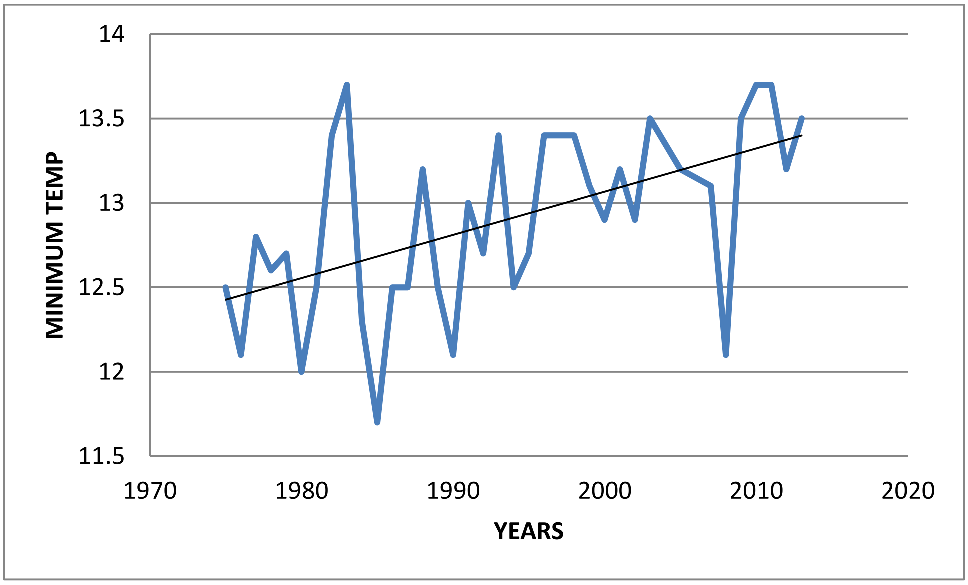

Figure 4.37: Nyeri June Min Temp Trend

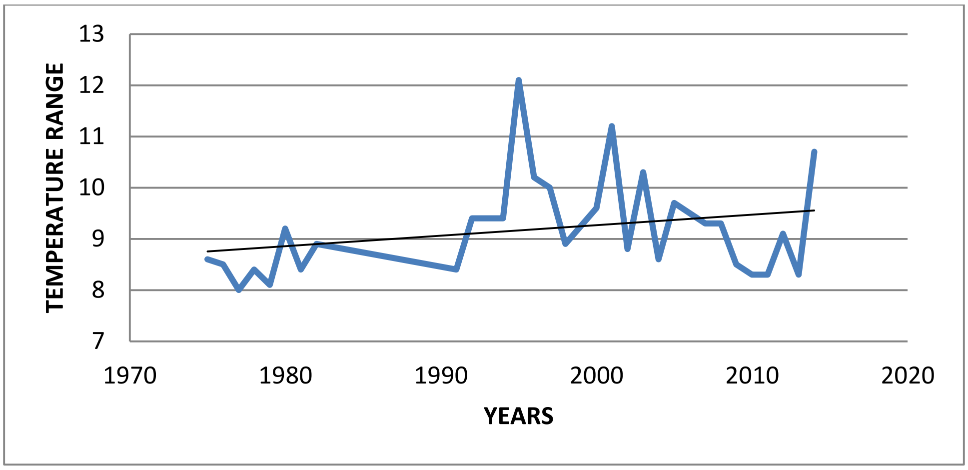

Figure 4.38: Nyeri June Temperature Range

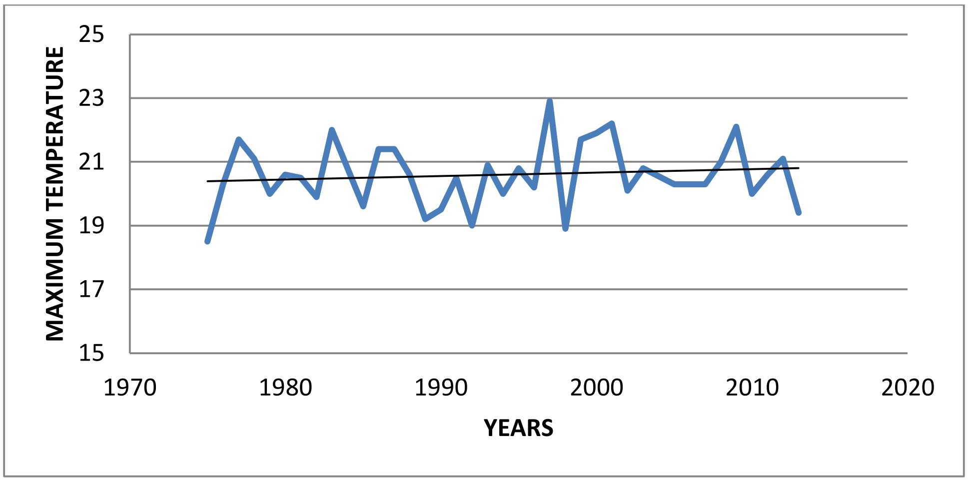

Figure 4.39: Nyeri August Maximum Trend

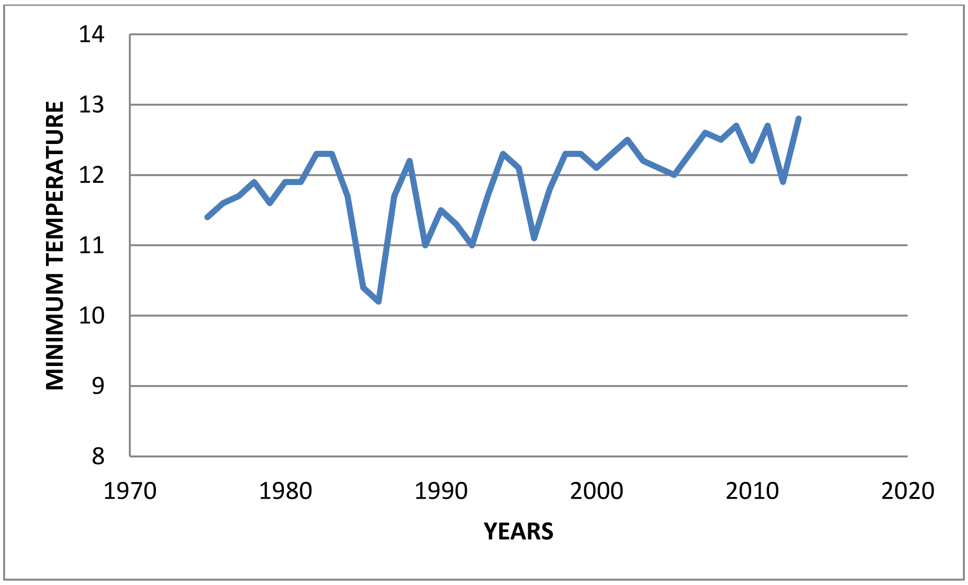

Figure 4.40: Nyeri August Maximum Trend

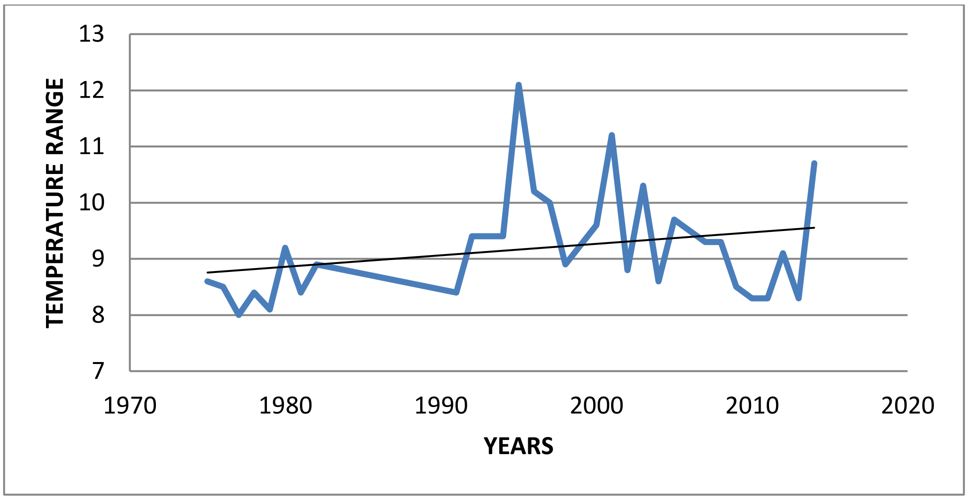

Figure 4.41: Nyeri August Temperature Range Trend

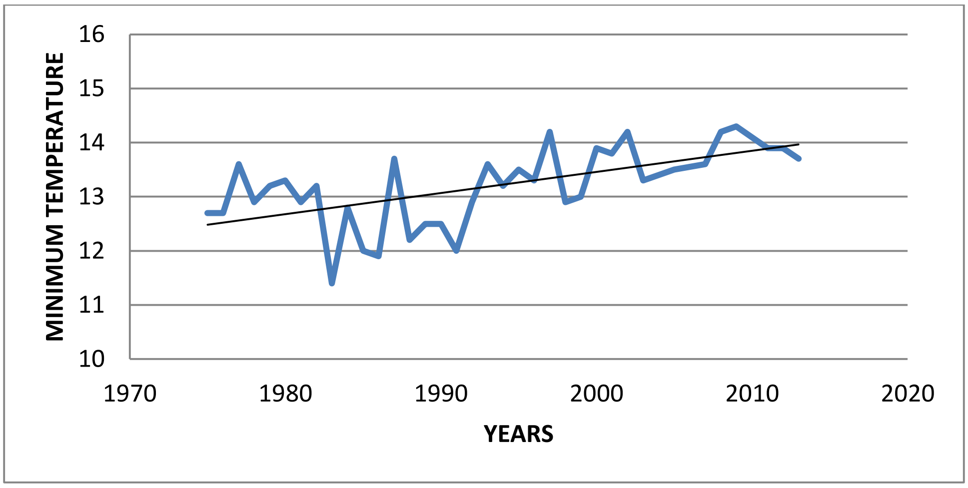

Figure 4.42: Nyeri October Min Trend

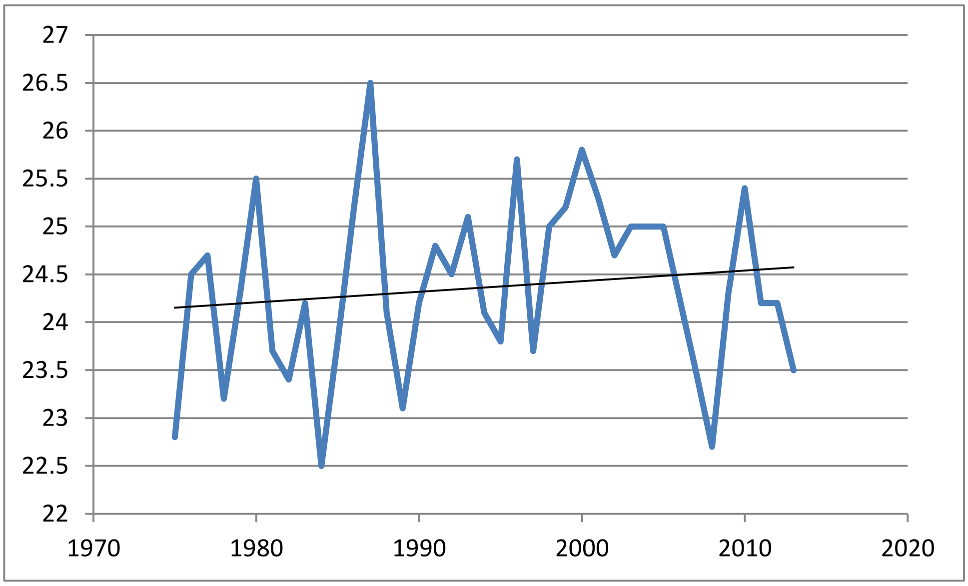

Figure 4.43: Nyeri October Max Temp Trend

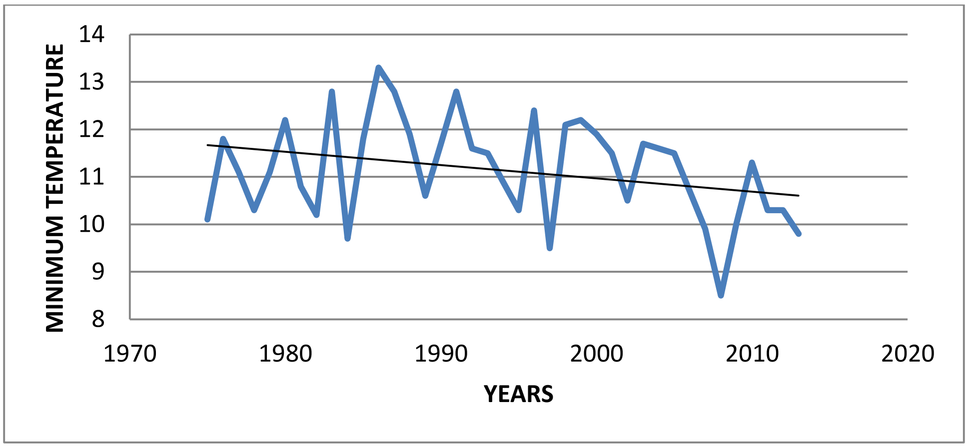

Figure 3.44: Nyeri October Min Trend

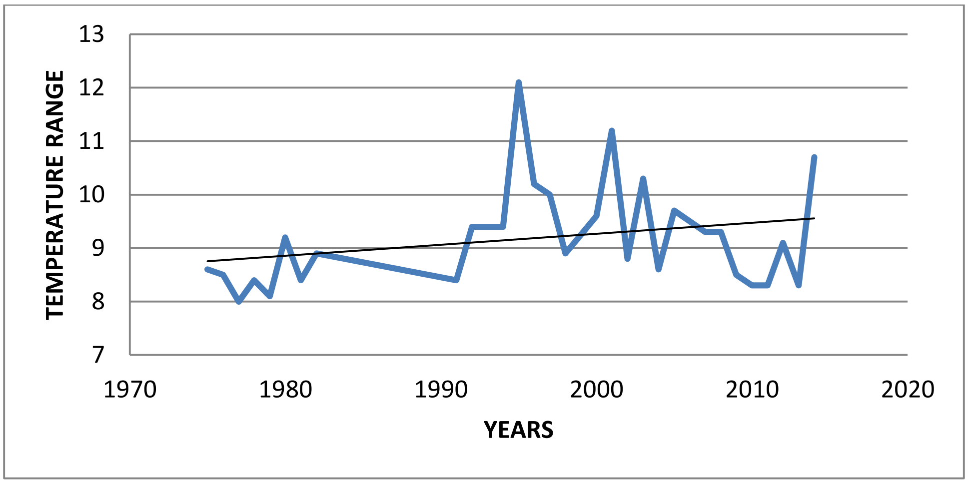

Figure 4.45: Nyeri October Temp Range Trend

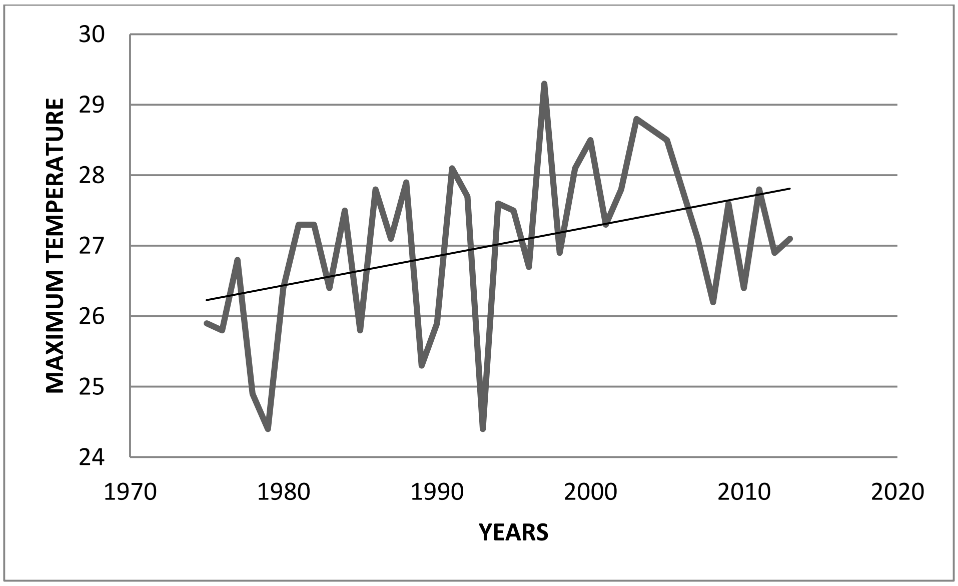

Figure 4.46:Nyeri Feb Trend Analysis

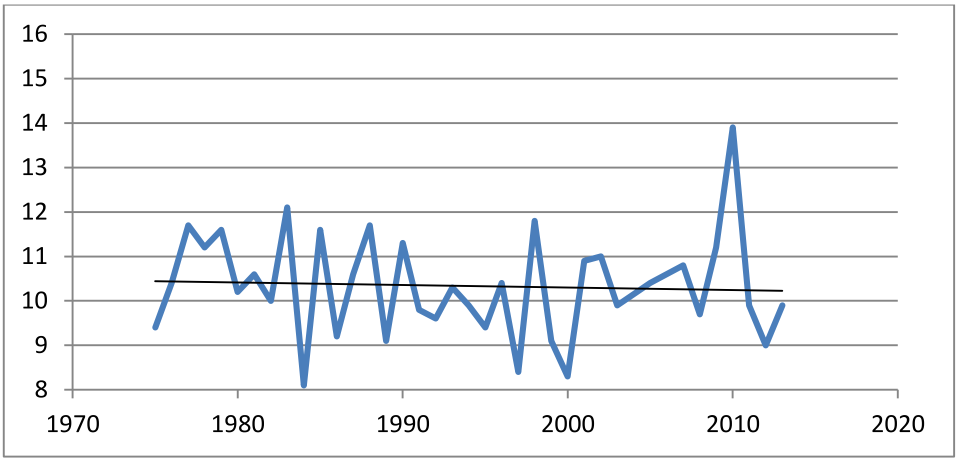

Figure 4.47: Nyeri Feb Min Temp Trend

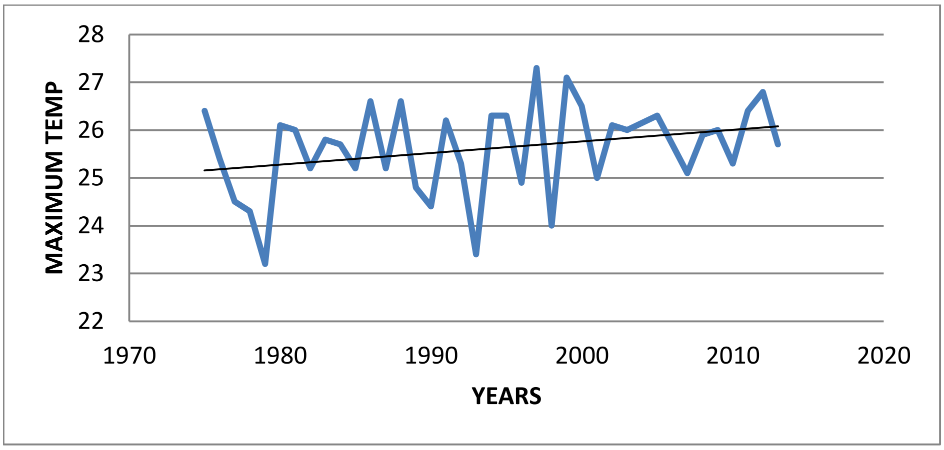

Figure 4.48 : Trend Analysis for Nyeri In Jan

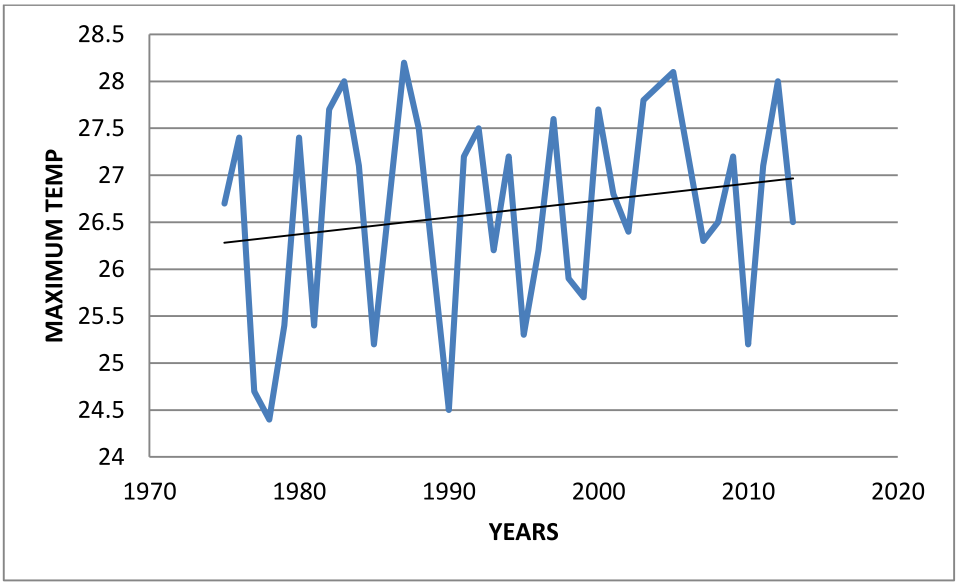

Figure 4.49: Nyeri March Max Temp Trend

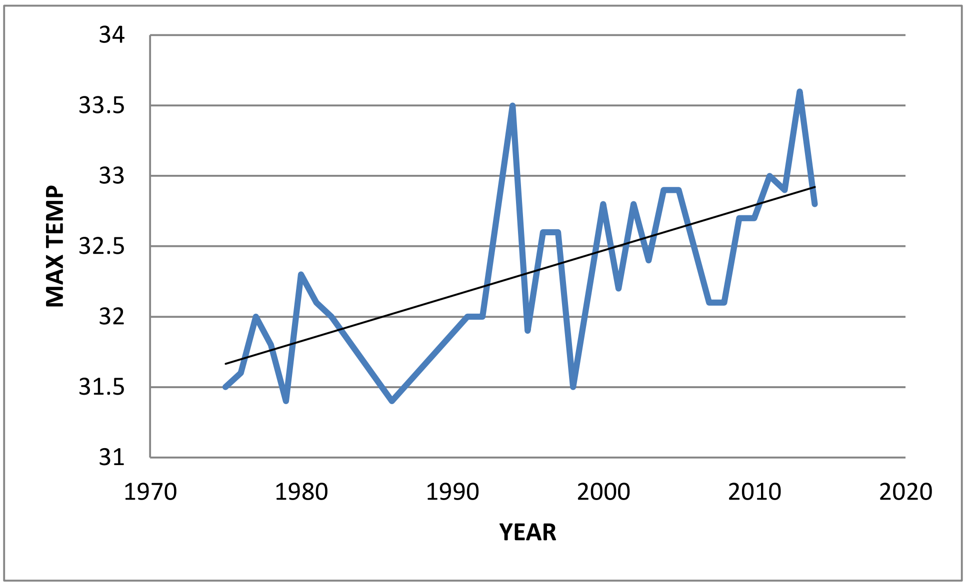

Figure 4.50: Mia Jan Max Temp Trend

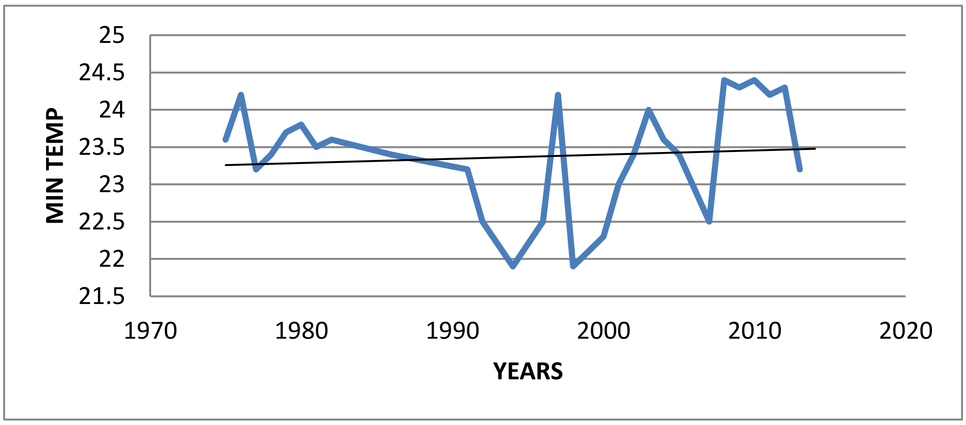

Figure 4.51 : Mia Feb Min Temp Trend

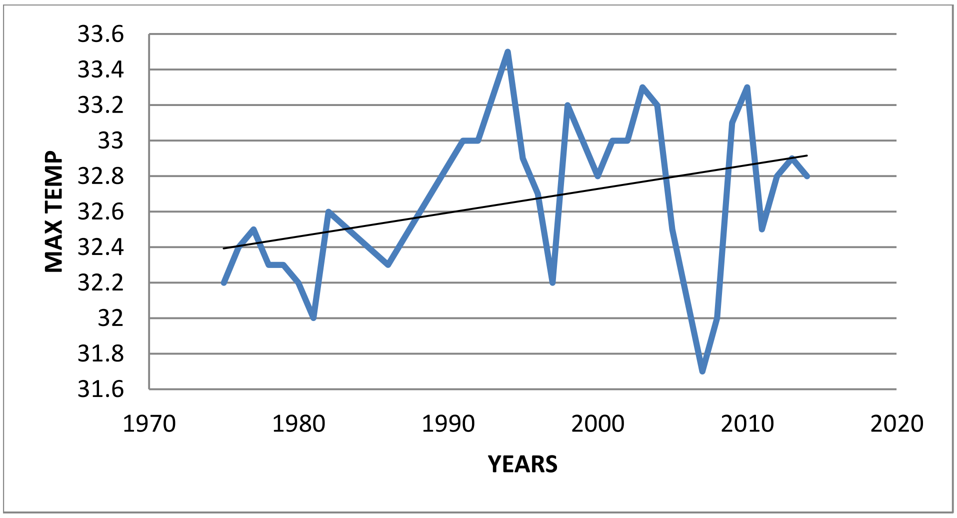

Figure 4.52: Mia Feb Max Temp Trend

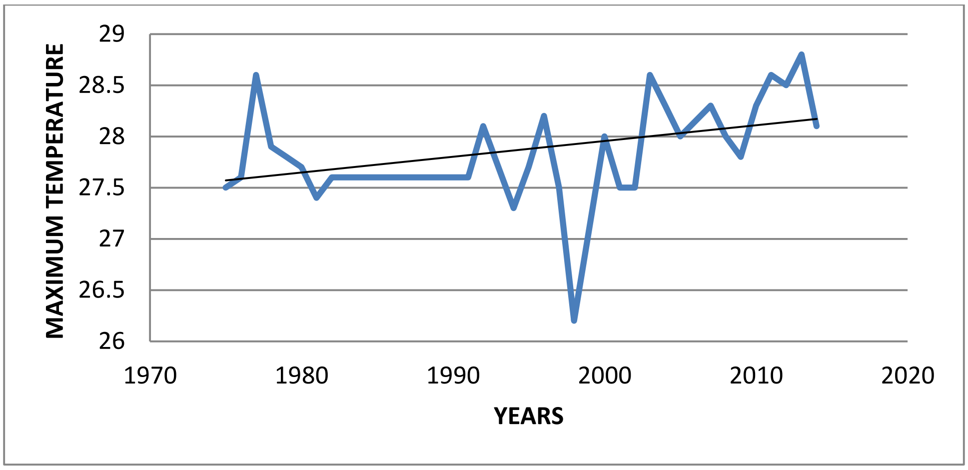

Figure 4.53 :Mia July Max Temp Trend

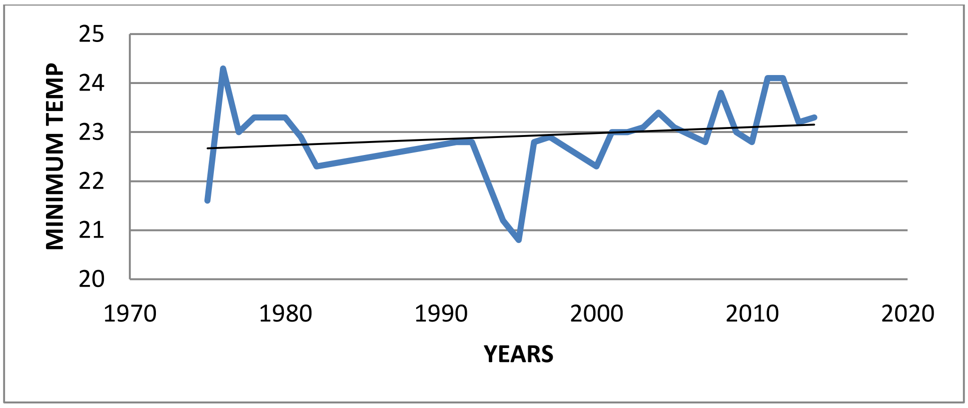

Figure 4.54:MIA Nov Min Temp Trend

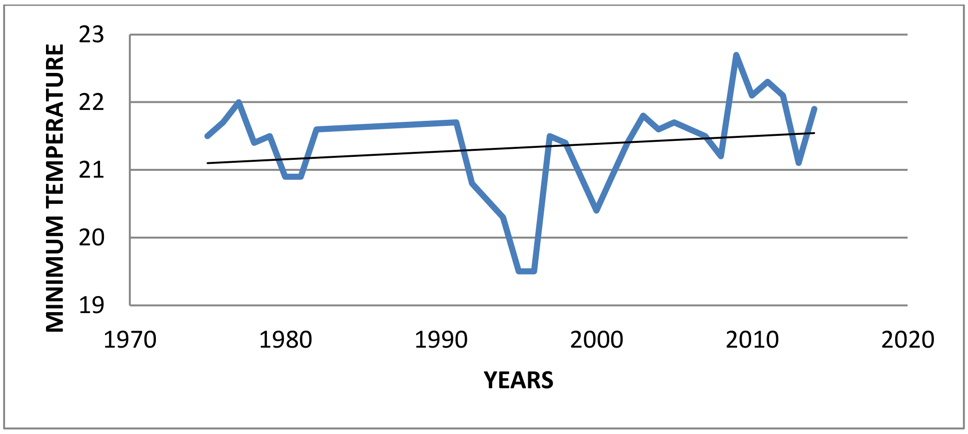

Figure 4.55: Mia June Min Temp Trend

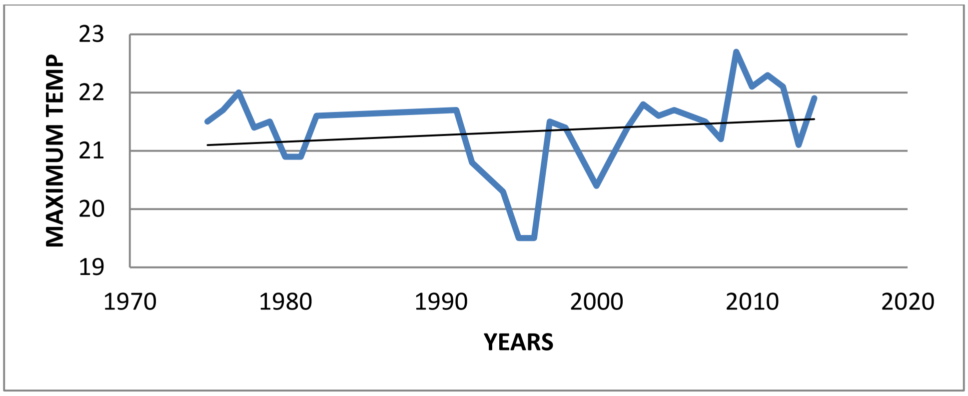

Figure 4.56:MIA June Max Temp Trend:

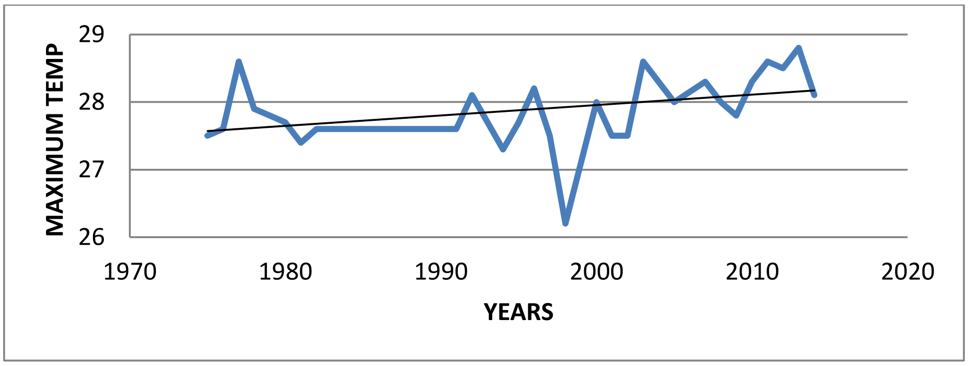

Figure 4.57 : MIA July Max Temp Trend

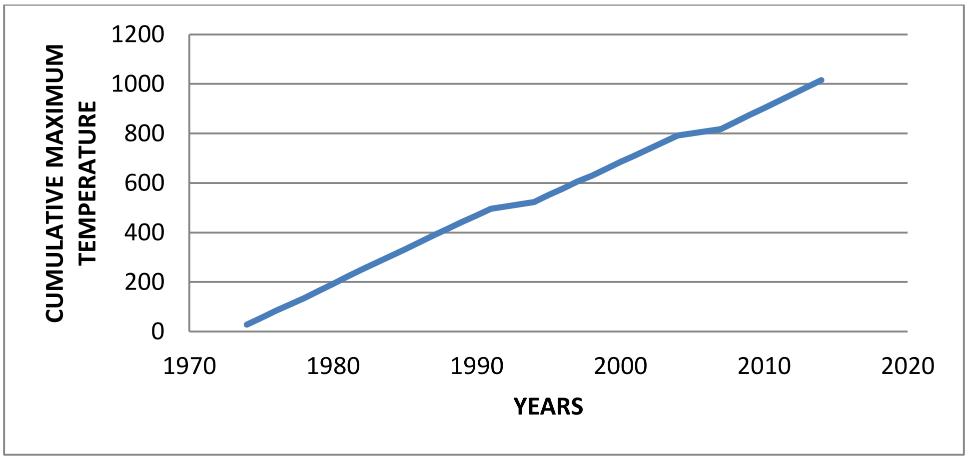

Figure 4.58 : MIA JULY MAX TEMP TREND

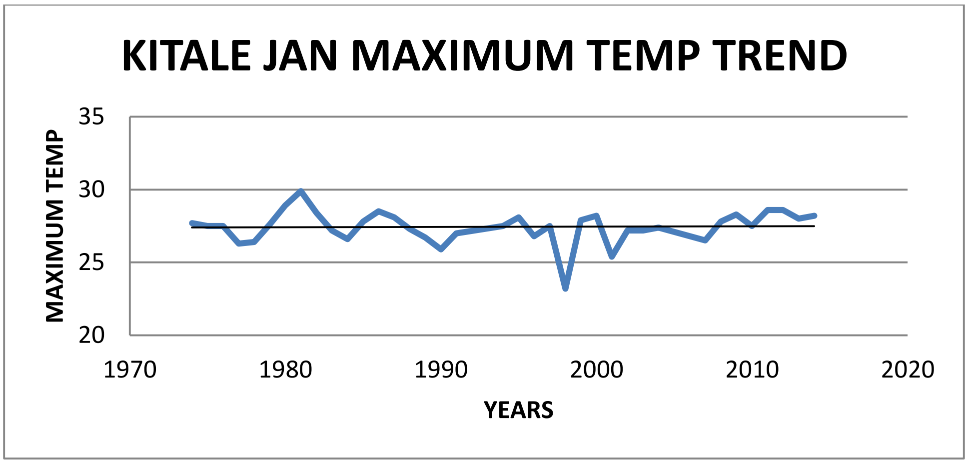

Figure 4.59 : Kitale Jan Maximum Temp Trend

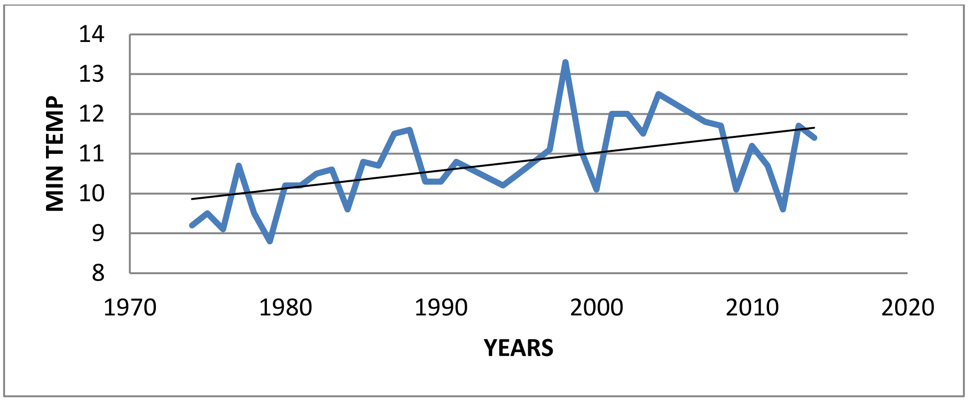

Figure 4.60 : Kitale Jan Min Temp Trend

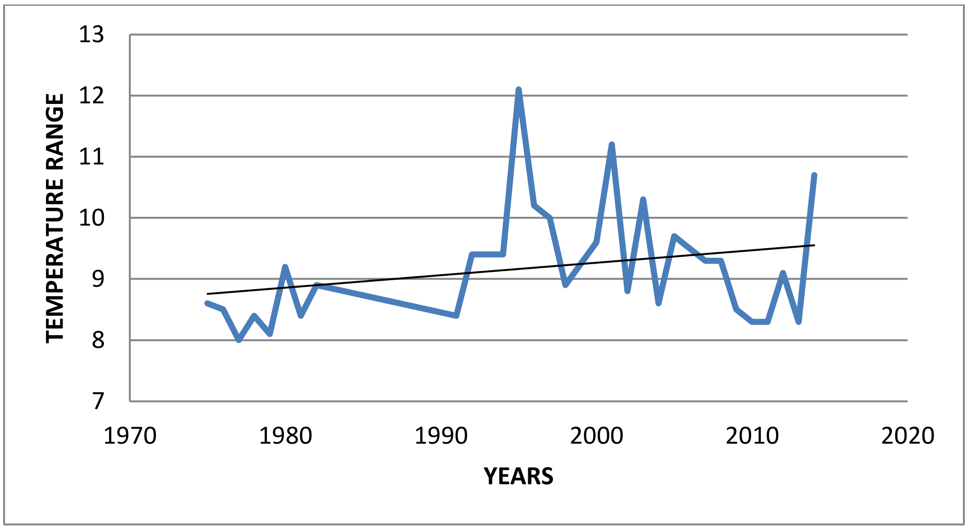

Figure 4.61 : Kitale Jan Temp Range Trend

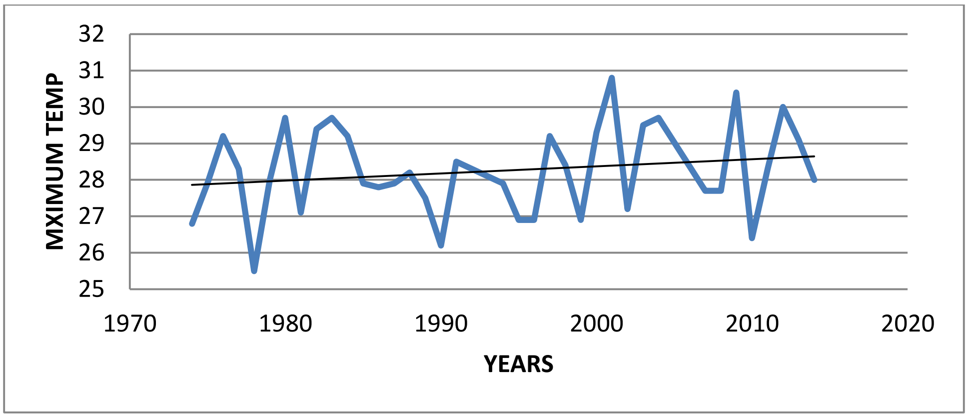

Figure 4.62: Kitale March Max Temp Trend

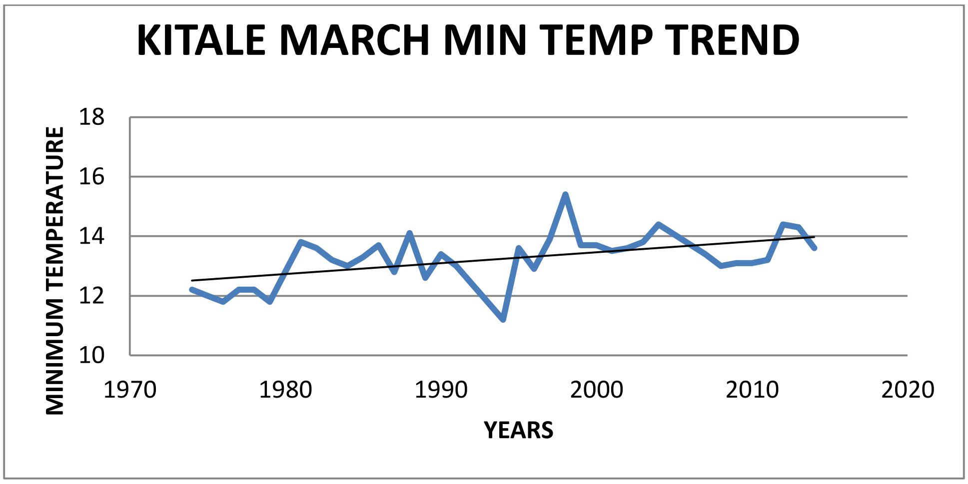

Figure 4.63 : Kitale March Min Temp Trend

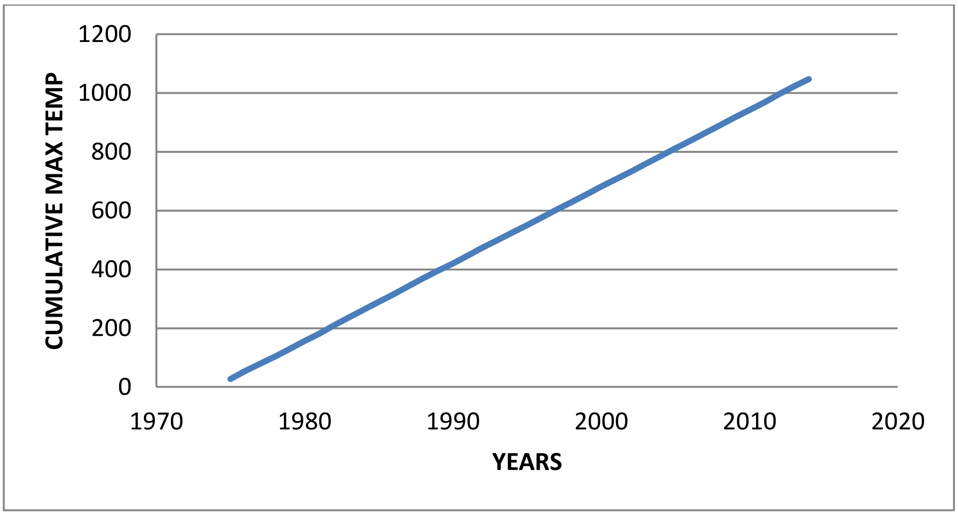

Figure 4.64: Dagoretti March Mass Curve

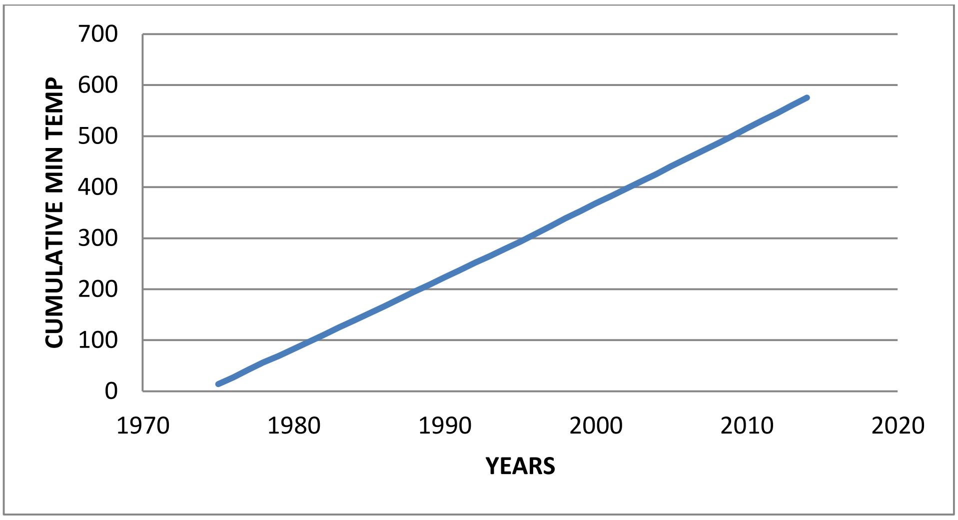

Figure 4.65: Dagoretti March Min Mass Curve

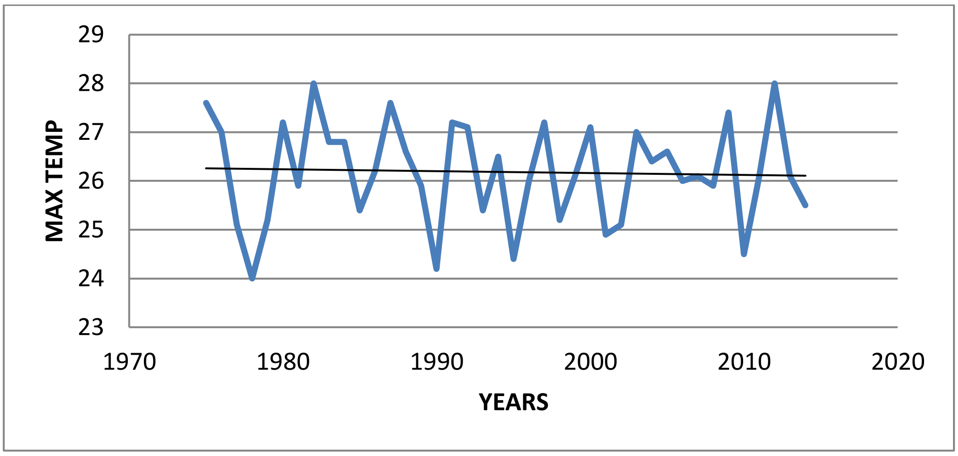

Figure 4.66 :Dagoretti March Max Temp Trend

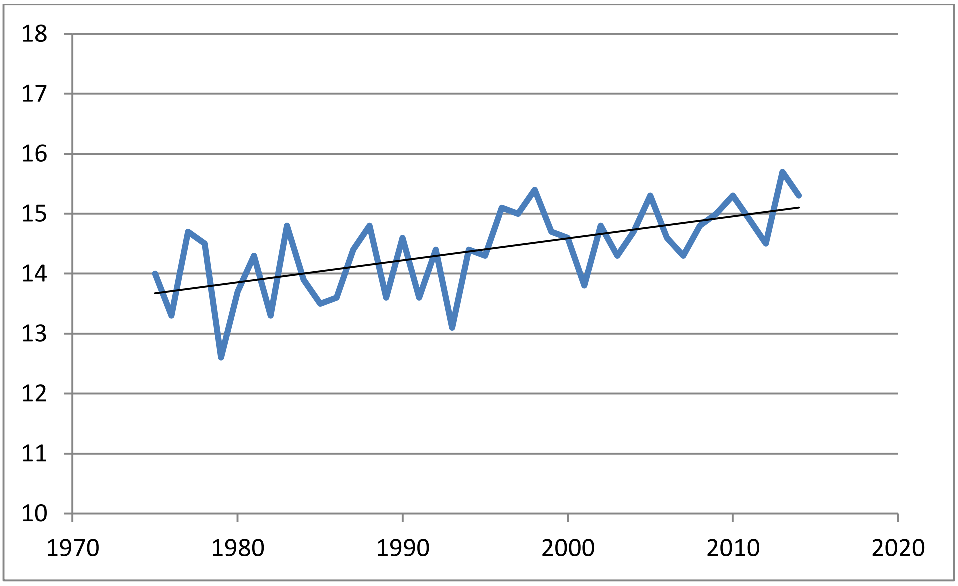

Figure 4.67: DAGOREETTI MARCH MIN Temp TREND

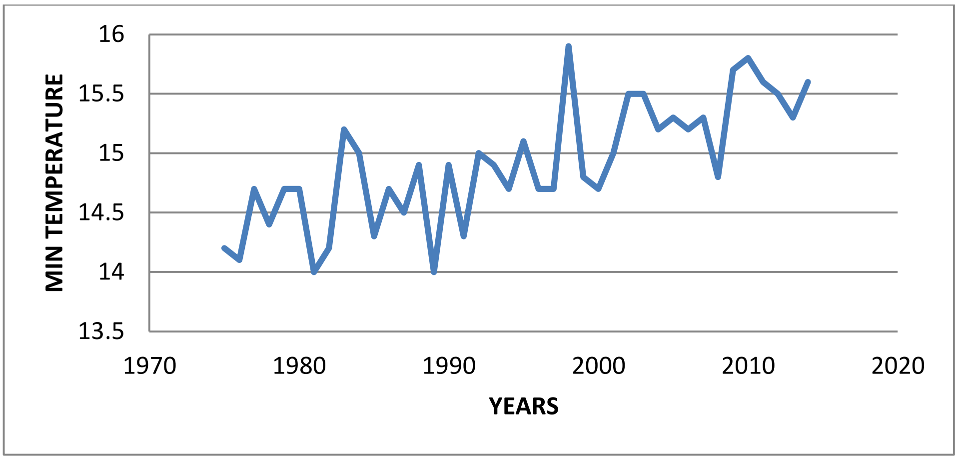

Figure 4.68: DAGORETTI APRIL MIN TEMP TREND

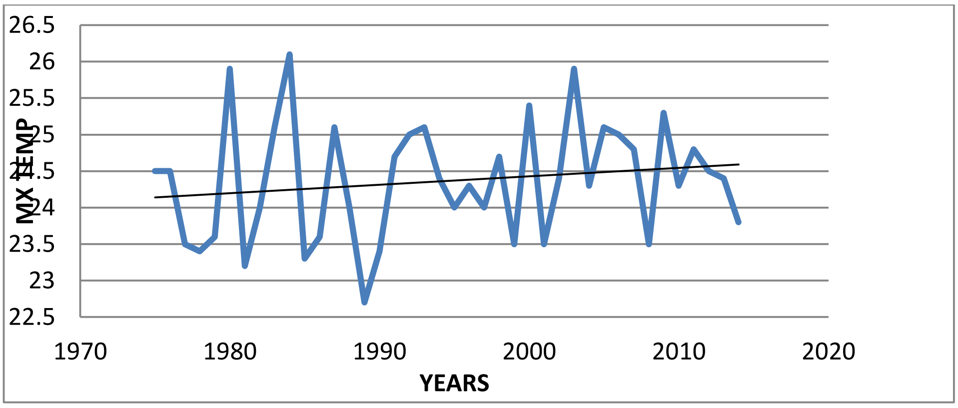

Figure 4.69: Dagoretti April Max Temp Trend

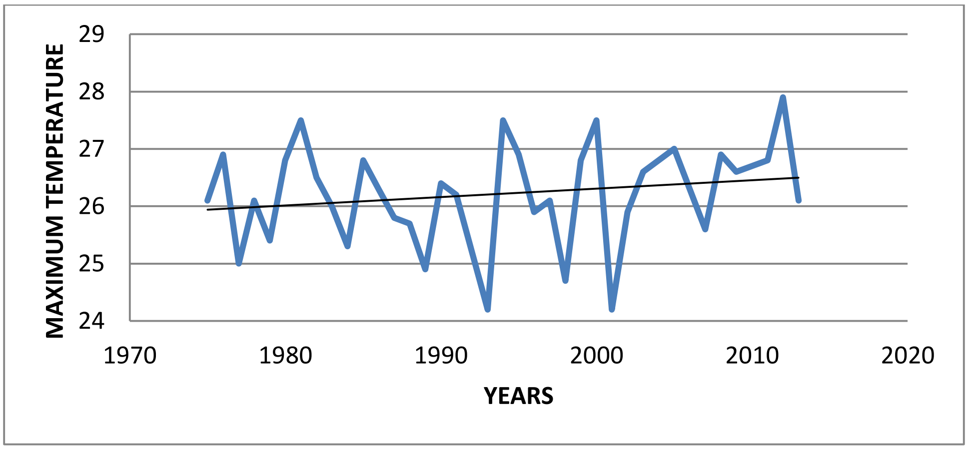

Figure 4.70 Kisii Jan Maximum Temp Trend

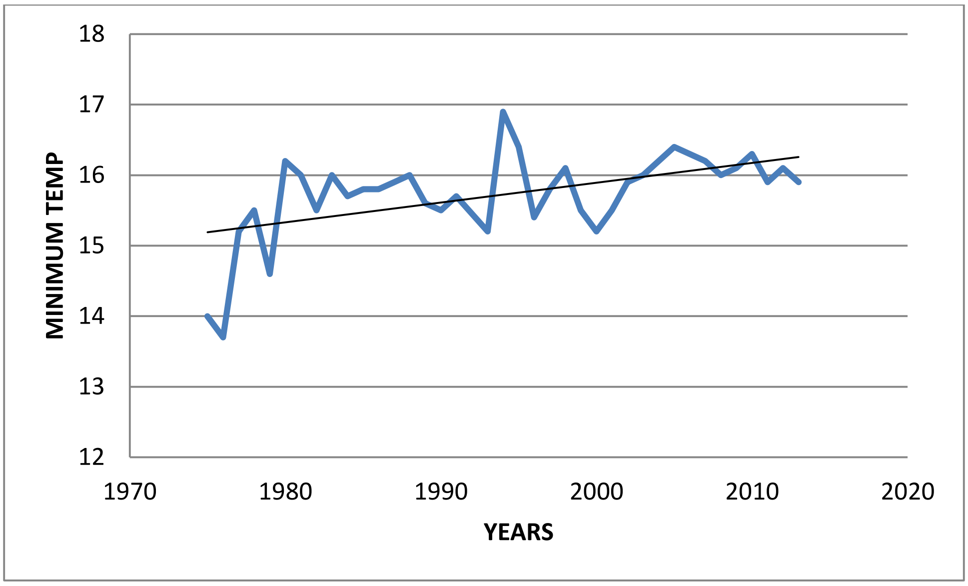

Figure 4.71:KISII JAN Min TEMP TREND:

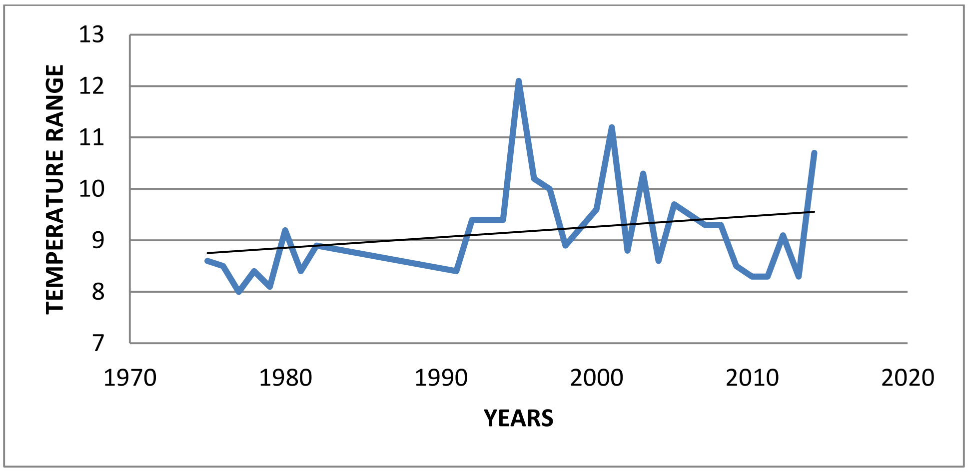

Figure 4.72: KISII JAN TEMP TREND

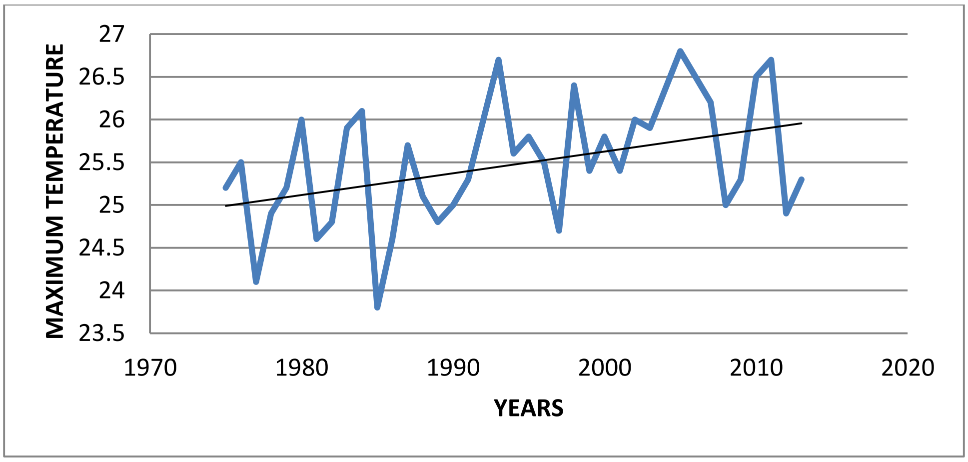

Figure 4.73 :Kisii April Max Temp Trend

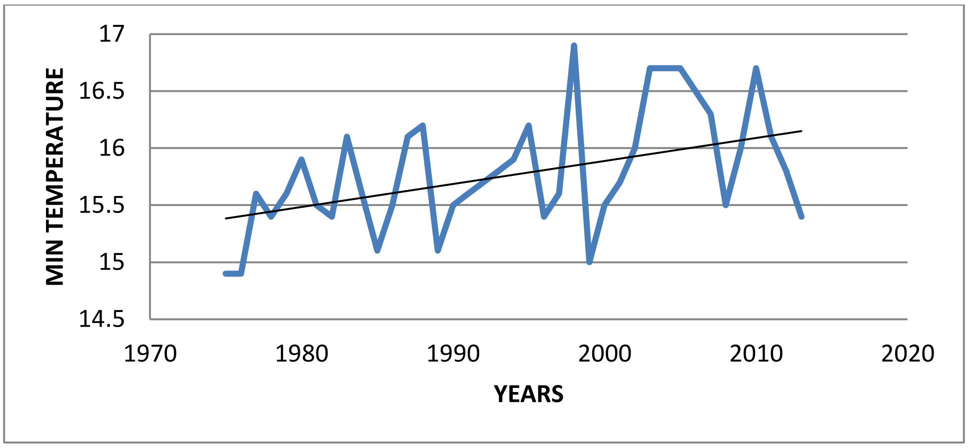

Figure 4.74: Kisii April Minimum Temp Trend

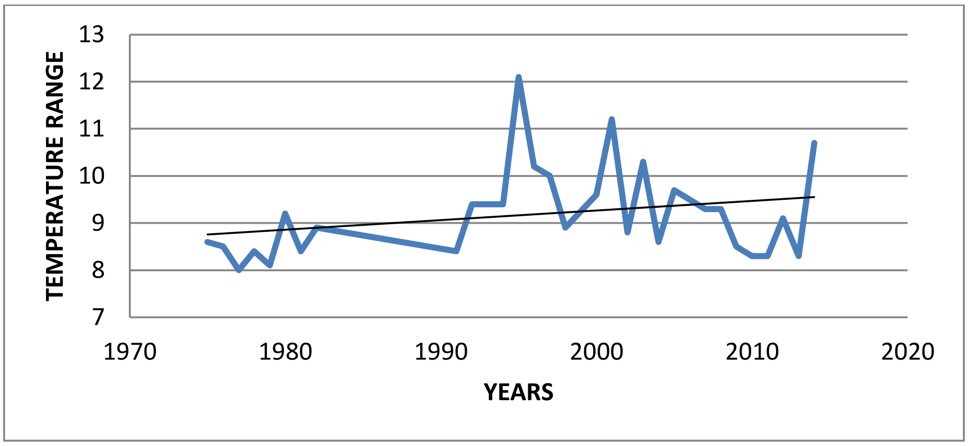

Figure 4.75: Kisii April Minimum Temp Trend

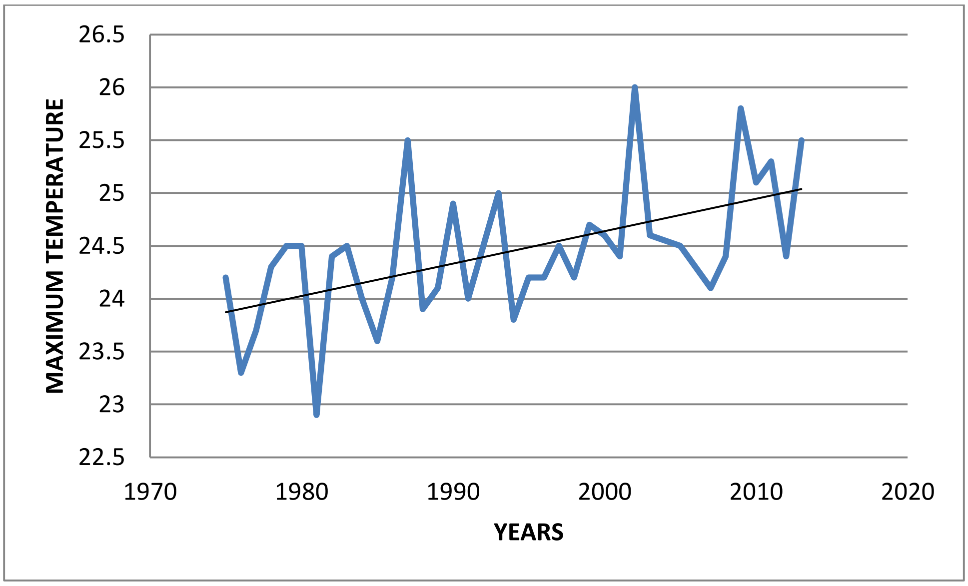

Figure 4.76:Kisii July Maximum Temp Trend

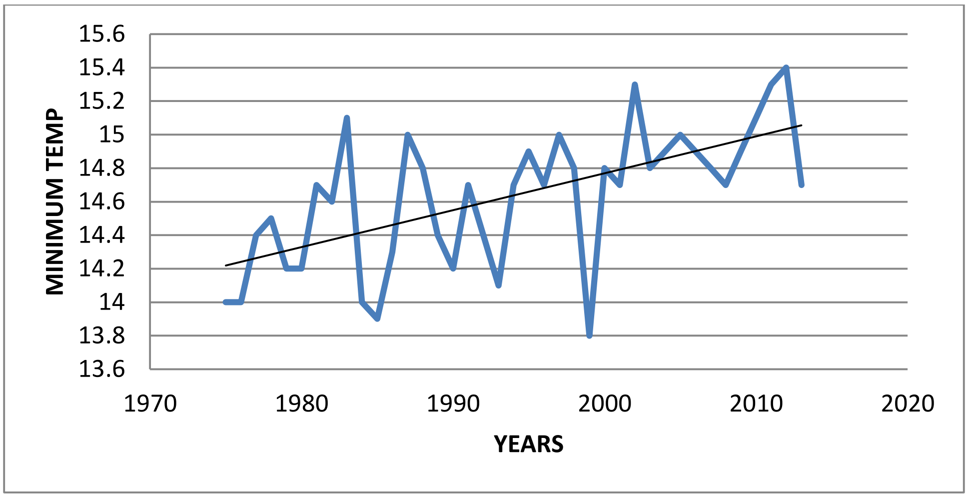

Figure 4.77: Kisii July Min Temp Trend

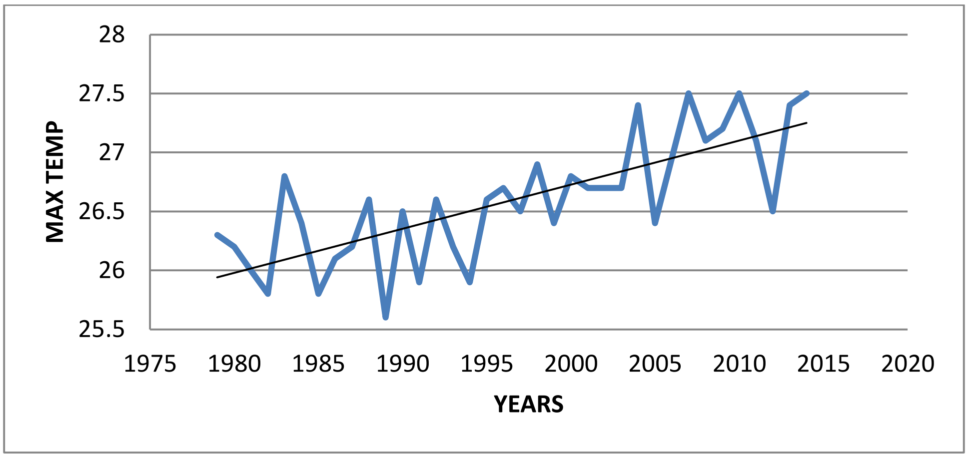

Figure 4.78: Kakamega May Max Temp Trend

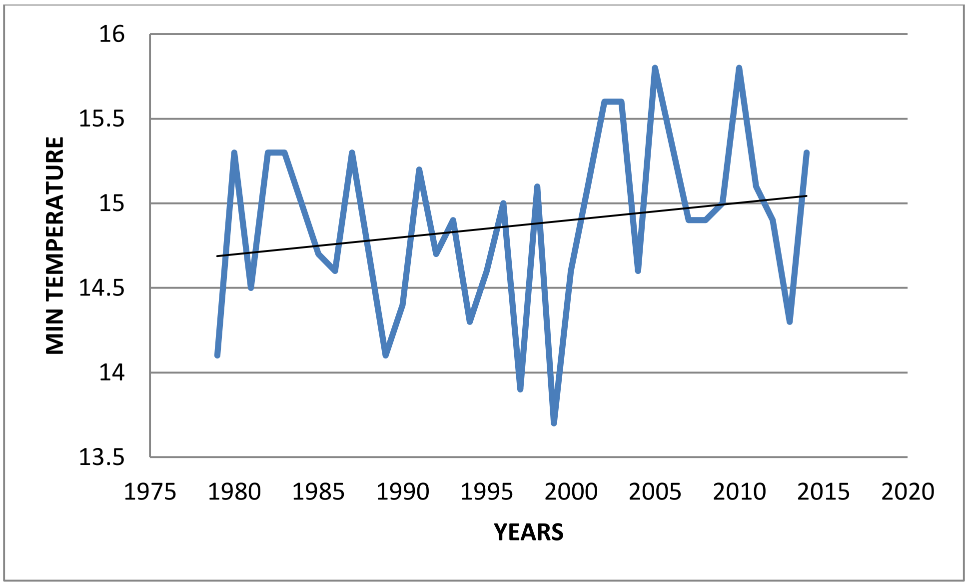

Figure 4.79:Kakamega May Min Temp Trend

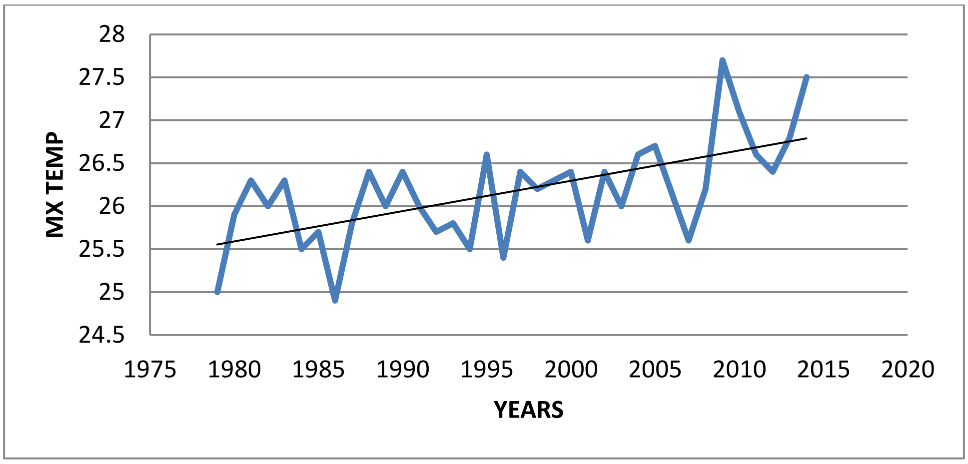

Figure 4.80: Kakamega June Max Temp Trend

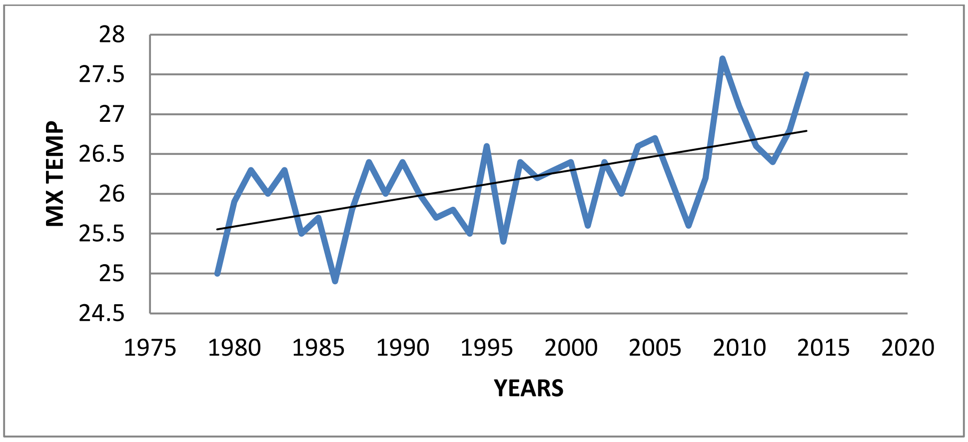

Figure 4.81:Kakamega June Max Temp Trend

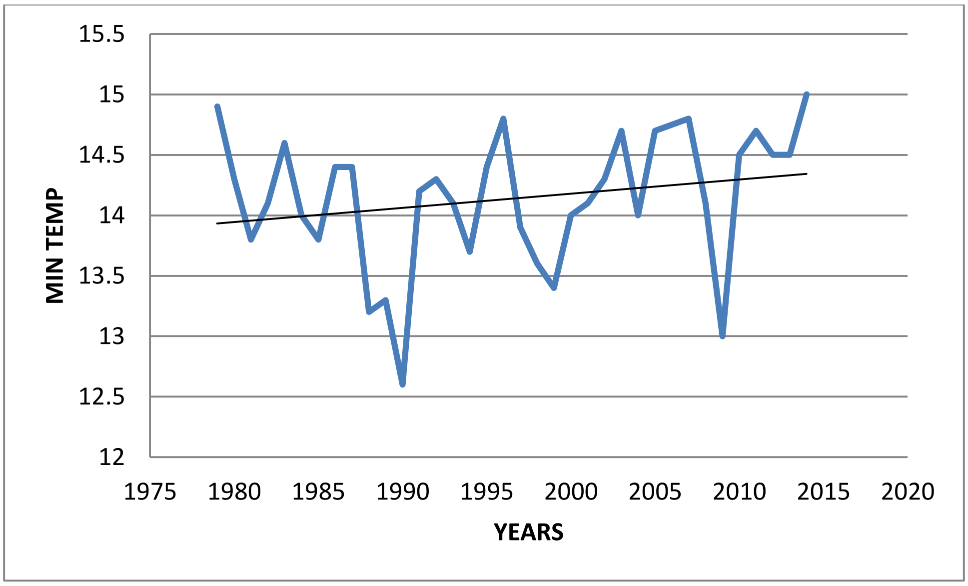

Figure 4.82:Kakamega June Min Temp Trend

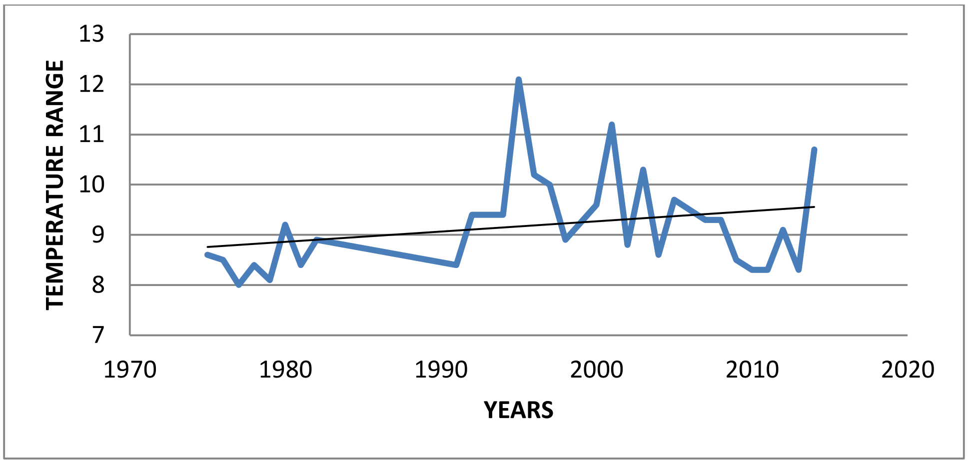

Figure 4.83 : Kakamega June Temperature range Trend

Conclusion

This study showed that minimum and maximum temperature records which were used in the study were of high quality.

The inter-annual patterns of the minimum and maximum temperature records showed distinct decadal variability signals. The decades of the 1970's and 1980's were relatively cold at most locations whilst those of the 1990's to 2010's were generally warm. The 2010's decade was seen to be the warmest in the record.

Most locations within Kenya showed decreasing trends in temperature range which is an essential indicator of warming. These results agree with the observations by Karl et al (1991), Kukla and Karl (1992), and Kinuthia et al (1991).

Significantly increasing trend of mean minimum temperature results to the decrease of mean DTR.

Most coastal and lake locations still showed positive maximum and minimum temperature trend.

Recommendations

As stated earlier some locations in Kenya experienced minimum/maximum temperature warming/cooling over recent years. Further work should be done to ascertain the extent and cause of this warming/ cooling. It will be necessary also to investigate in more details the nature and the cause of the observed inter-decadal temperature variability. Further analysis will also be necessary to establish the exact relationship between the observed minimum and maximum temperature characteristics and human activities like urbanization, and the effect of the large-scale circulation like QBO and ENSO in order, to refine to refine such a relationship at the local levels. This will help establish which of these systems is causing warming/ cooling at particular locations. It is only then that proper mitigation steps can be taken.

More study can be carried on the effect of warming of temperature on living organism.

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